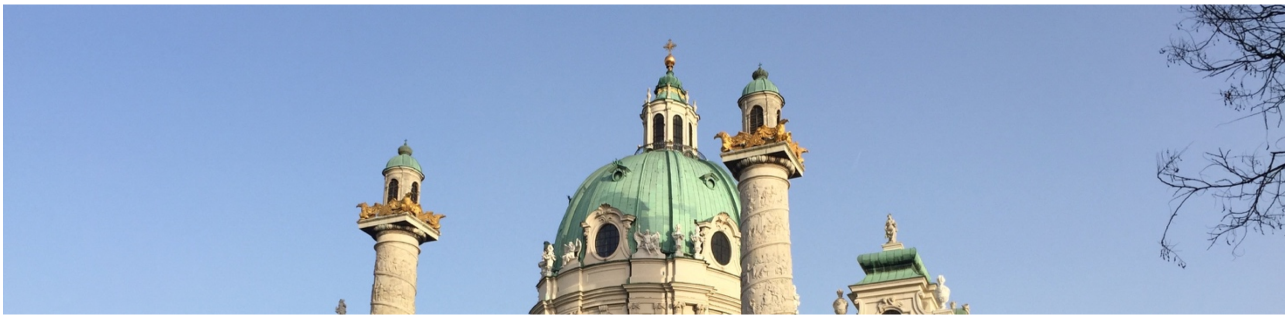

Minutes from the 2018 EGU ILRS ASC Meeting

Thursday, April 12, 2018, TU Wien, Vienna, 9:00 – 17:00

Operational products: status reports and future plans

All ACs & CCs presented brief reports on key issues:

ASI:

- Standard products
    - NSGF restarted in December 2017 to submit the routine products using ITRF2014. The problem of the high scatter in the LD has been solved and it is now included in the combination
    - DGFI orbits show high RMS of the residuals with respect to the combined orbit, more evident for ETALON
    - ESA solved its issue with the ITRF scale in February 2018
    - The daily JCET solutions have a much lower 3D WRMS of the coordinate residuals with respect to the other ACs and to the JCET weekly time series. Similar issue in the scale to ITRF2014 because it is close to zero and in the scale factor used at ASI to make the combination solution which is higher than before and higher than the one used for the weekly solutions.
- Systematic error estimates
    - DGFI time series missing
    - Preliminary check on the single AC time series and plots of the range bias for a few stations.

BKG:

- New colleague joined the group
- Systematic error PP
- Processing of 2000-2017 for EGU2018: discrepancy found with EOPC04_14. High correlation between the range biases from Lageos1/2 except for a couple of sites.
    - NOTE added on 2018.05.04:

I see that BKG reports discrepancies with EOP C04 14 and the minutes doesn't mention any comment/explanation. This is (was) a known issue. There was a communication on that subject from Christian Bizouard a few months ago (see the "January 2018" heading in http://hpiers.obspm.fr/iers/eop/eopc04/updateC04.txt), following a "bug report" that I issued in Dec 2017.
I've been using a patched version of the long term file since. Until recently, Christian was waiting for an official "go" from his central bureau to have this patch made official. Apparently, he got it in Vienna.
I thought that that information was known from everyone at ILRS. At least Florent knew it when he attended the ILRS ASC meeting in Vienna.

Franck

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DGFI:

- Horst retired but still available on a voluntary basis. Still under decision within DGFI if they will continue to perform all of the tasks that Horst contributed to (QCB, QC bias reports, etc.).
- Horst programs still running for the operational service. Working on a revised version of the DOGS-OC and DOGS-CS s/w. By the end of May the operational products will be delivered with the new s/w.
- Increase of the orbit RMS probably due to the solar radiation errors
- DGFI is able to contribute to the next ASC pilot projects: low degree SH of the gravity field, inclusion of LARES, expansion to more targets used in the current operational products
- SLR constellation solution with up to 11 satellites. Paper under revision for publication
- SLR simulation to find a realistic future scenario for the SLR data performance and network geometry

ESA:

- Systematic error PP: a clear bias was visible in the ESA solution. The problem was found in the application of the Mendes-Pavlis tropospheric model with an option only valid for altimeter data, not valid for SLR (eliminated the application of the wet component correction).
- Status of the AC: reprocessing for ITRF2014 used to improve the processing scheme.
- Open issues: work needed to handle stations with multiple wavelengths, estimation of gravity field to be validated
- Other activities:
    - GPS, GLONASS, QZSS, GALILEO orbit validation with SLR (smaller residuals with application of the box-wing model),
    - Comparison of orbit residuals and clock bias,
    - Combination at the observation level of GNSS and SLR: biases in good agreement. Activities resumed after a lack of interest in 2010

GFZ:

- New colleague joined the team
- Operational products and time series for the Systematic error PP: no issue
- Status of the re-analysis for ITRF: ready to include LARES, test to be done for the high frequency EOP modeling
- Plan to test DTRF2014 and JTRF2014

GRGS: Activities will be resumed soon… The time series will be submitted to the CCs for benchmarking

NSGF:

- CoM modeling: For Etalon, test CoM removes almost 1 cm. The picture for LAGEOS is more mixed, the new CoM doesn’t explain all the biases. The values are not final, some model assumption to be checked. LARES to be done shortly
- Site log and CRD issues: no field to supply information about amplifiers, ranging policy, detection rate, system identifier should be linked to system configuration

SHAO:

- SLR quick processing. Improvement of the WRMS of the POD solution when estimating the ZTD parameters, as done for the GNSS data ***(NB: this was not proven though, the “improvement” is most likely due to the addition of numerous new parameters in the solution)***.
- Combination activities of the ILRS AC time series continues

IAA RAS:

- Increasing activities in the LLR analysis: description of the analysis modeling and strategy. The results are presented in terms of statistics of the residuals for each station acquiring data and sigma of the estimated parameters.
- Future work for ILRS: ITRF2014 reanalysis, High frequency EOP models checked with LLR (IAA RAS ready to join the IERS pilot project). More investigation on the residuals that are higher than expected since the NP precision is at the millimeter level.
- Web application, free to use: http://iaaras.ru/en/dept/ephemeris/online http://iaaras.ru/en/dept/ephemeris/llr-pointing and http://iaaras.ru/en/dept/ephemeris/llr-oc

JCET:

- Operational products routinely delivered
- Quarantined sites: 4 sites undergoing validation, 2 engineering sites that have yet not submitted data. San Fernando is going down, to be replaced soon by new Spanish SLR system
- SSEM Project:
    - Results available online on the JCET website. Live use of the website to show how it works.
    - Site selection for the project: some stations have sporadic data and there is no need to include them in the bias analysis (or even the general analysis for ITRF development).
    - Preliminary results for some stations: Yarragadee (good agreement among the ACs), Herstmonceux (ESA systematic have 1 cm difference from the other ACs). The single AC mean values over the entire period agree generally quite well, except in a few cases, with a small sigma associated.
    - Identification of breaks will include the discussion with the station management for additional events at the stations while most of them have been identified with the work done by 2014.
- Next ITRF will be ITRF2020 (i.e. all of the 2020 data should be included). The reanalysis will start at the end of next summer. The CC estimate 6-8 months needed to combine the solutions.
- Expand the list of targets for the operational products for higher quality EOP in a shorter timeframe. A short Pilot Project will be proposed towards the end of 2018.

Re-analysis (weekly series) with ITRF2014 (i.e. the updated SLRF2014 version) plan:

<u>CoM model update status:</u> see NSGF report

<u>Presentation by Randy Ricklefs (done by ECP) on upcoming CPF and CRD Formats' update process</u>

- package of material related to this topic emailed prior to our ASC meeting: more configuration information, a few header fields changed
- ASC will be mostly affected by CRD format changes. We will need to go through a test-period "learning" how to ingest the new format in our processing chain followed by a brief validation of each AC's products based on the new CRD files.
- The stations will be asked to produce the CRD v2 starting from October 2018 and all analysts should be able to use the new CRD at the beginning of 2019.
- Revised CRD and CPF sample code will be available on the ILRS website in the next months.

Station Systematic Error Monitoring Project—The Operational Phase

- The estimated biases will be applied for the operational products. It is under discussion the possibility to estimate the biases in the operational products together with the other parameters, using tight a priori sigmas to allow small updates of the a priori bias values.
- Systematic error on Etalon: all the ACs are asked to redo the series including Etalon 1 & 2 with a combined bias estimation. The solutions must be submitted by the **end of May 2018**.
- In the "operational" delivery schedule we only need to deliver **ONCE per week** the analyzed weekly arc with the freely adjusted systematics;
- This service will most probably come online by October-November 2018.
- See JCET report

Planning the next Pilot Project and launch date:

(a) Pilot Project: Inclusion of LARES as a 5th satellite in our operational product development. All ACs are requested to process the year 2017 with a 5 satellites data set (L1 & L2, E1 & E2, and LARES). No estimation of biases. Time series to be submitted by the **end of June 2018**.

(b) Pilot Project: estimation of low-degree SH of the gravity field solving for a 6x6 gravity field. All ACs are requested to process the year 2017 with 5 satellites data set (as in (a) above). This Pilot Project will follow the previous one and the submission is expected by the **end of September 2018**, depending on the outcome of the previous PP (a). The parameters will be included in the SINEX file.

(c) Expansion of the targets: see JCET report

(d) Revisit NT Atm. Loading & Gravity implementation: internal PP postponed. The ILRS submission to ITRF2020 will not include the loading.

The Journal of Geodesy Special Issue on Laser Ranging—JOGSILR (Status)

Only 11 manuscripts received up to now. The submission has been extended to end of May 2018. The papers are reviewed as soon as they are submitted and we have one manuscript accepted already.

Next meeting:

Sunday, November 4, 2018, 08:30 – 17:00, at Mt. Stromlo station complex, as part of the 21st IWLR in Canberra.

APPENDIX

I. SUMMARY of ACTION ITEMS:

AI No.	Responsible Entity	Action Item Description
1	JCET	Reconcile the SLRF2014-product scale with that of the SLRF2008 series
2	GRGS	Restart your operational product line and deliver the test time-series for validation to the two ILRS CCs
3	ESA	Implement the new format for multi-wavelength bias labels (SOLN field)
4	ALL ACs	If interested in contributing to the *GGOS/IERS Pilot Project to test various High Frequency EOP models*, contact epavlis@umbc.edu
5	ALL ACs	Deliver complete reanalysis of the full SLR data set since 1993 using SLRF2014 and allowing for all-systematics adjustment including a combined bias for the two ETALONs, by the end of May 2018.
6	ALL ACs	Deliver a test series including all weekly SINEXs of 2017 reanalyzed with the inclusion of LARES data and the estimation of a 6x6 set of gravitational harmonics.

II. Consolidated Laser Ranging Data Format (CRD) Version 2.00

Consolidated Laser Ranging Data Format (CRD)
Version 2.00

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

28 February 2018

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 – 10 January 2017
   - See Appendix D.

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 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 are fixed format and similar in content to those of the CPF files. The configuration and data records are 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 canall appear within one file. Also note that multiple colors can appear in one file.

Advantages of this format over the former ILRS formats 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.

Configuration descriptions are addressed in a more explicit, logical and extensible manner than the current format.

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.

Extensibility to the eXtensible Markup Language (XML) is provided in the design.

Fields in the Configuration sections 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 fields in the new format should be set to “-1” to indicate “no information”. Character fields without information should be filled with “na” for “Not Available”.

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. Finally, 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. Appendix D describes the changes in version 2 (this version) of the CRD format.

1. Header Records

These records are **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 (BIH) 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., "Eurolas", "NASA", "WPLTN" or "ILRS")

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.

Currently, 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 was necessary to include the possibility of new values (10-99) that did 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 to 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 is optional. It must be “NA” if no network is specified.

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 “-1” 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

-1=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 could 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.

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) Header

The session/pass header describes information relating to the period over which the data is collected. For normal satellite targets, this is generally each pass, but can be associated with pass segments. For geostationary satellites and distant targets, it must be related to time 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 the place to indicate what type of data records follow – this will enforce providing of data records in blocks of consistent data 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.

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 "-1" 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 “-1”.

1.5. Prediction Record

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 “H2” record; or - TLE epoch day/fractional day from line 1
A3	Prediction provider: - CPF provider from “H1” record; - TLE does not include this field, but it should be available
I5	Sequence number: - CPF ephemeris sequence and sub-daily sequence numbers from H1; 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

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 **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.**

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, and the "60" Compatibility Record. The "60" record is not required if records C1-C3 are included, although it may be useful until the format is fully implemented. Record "C4" is always required for transponder data.

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)

Repeat as required.

2.1.2. Notes

The use of configuration records replaces the current Station Configuration Indicator (SCI) and Station CHange indicator (SCH) (but not the station site log) files. To access information currently contained in the SCH file, one should use the date and time as a key and extract the information from station site log files, which should be maintained to provide such data. The SCI file is totally replaced by the records in the current file.

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, there should be multiple system configuration headers in the file. These should appear after all the associated component configuration records have been defined.

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 (arcsec)
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

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)

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

A20	Processing Software Version(s)

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" for primary; “1” for secondary)
A4	Meteorological Configuration ID (unique within the file)
A20	Pressure Sensor Manufacturer and Model (no spaces)
A10	Pressure Sensor Serial Number
A20	Temperature Sensor Manufacturer and Model (no spaces)
A10	Temperature Sensor Serial Number
A20	Humidity Sensor Manufacturer and Model (no spaces)
A10	Humidity Sensor Serial Number
A10	Other Type
A20	Other Manufacturer and Model (no spaces)
A10	Other Serial Number

2.7.2. Notes:

Show each sensor whose data is included in the CRD data file. The same instrument can be named for 1, 2, or all 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.
Example:
C6 0 mets Paroscientific-Met4 123456 Paroscientific-Met4 123456 Paroscientific-Met4 123456 NA NA NA

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 **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.

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

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. The filter flag is used to record whether the station processing indicates that a return is signal or noise.

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 "-1" 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.

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). The file can contain as many calibration records as required, but there must be at least one station calibration record in the file. 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).

3.7.1. 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.

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 (= -1 if no information)

I8 Number of data points used (= -1 if no information)

F7.3 One-way target distance (meters, nominal) (= -1 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)

I1 Calibration Type Indicator

- 0=not used or undefined
- 1=nominal (from once off assessment)
- 2=external calibrations
- 3=internal calibrations
- 4=burst calibrations
- 5=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

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.

It is expected that one calibration record is included for a normal point data block, but this record can be used to also provide single shot measurements for averaged blocks (“normal points”) of internal calibrations for example.

3.8. 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.

3.8.1. 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

3.8.2. 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.

3.9. 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.

3.9.1. 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 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).

3.9.2. Notes

None.

3.10. 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.

3.10.1. Format:

A2(1-2) Record Type (= "9X", X = 0…9)

3-80 User defined format

3.10.2. Notes

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

3.11. 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.

3.11.1. Format:

A2(1-2) Record Type (= "00")

A80 Free format ASCII comments (terminated by an end-of-line character)

3.11.2. Notes

To ensure line lengths do not become excessive, a limit of 80 characters is set. Lines exceeding this limit may 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 (Rarely used)**	**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
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	n/r	√

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

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 being 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 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 part 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) Where 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 0 0
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       -1       -1 0.000 -913.0 0.0 56.0 -1.000 -1.000 -1.0 3 3 0
10 55435.6429746     0.047926839980 std1 2 0 0 0 0 0
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 0 0
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 -1.000 -1.000 -1.0 0.0 0 0.0
20 55504.9728030  801.80 282.10   39 1
40 55504.9728030 0 std1       -1       -1 0.000 -913.0 0.0 56.0 -1.000 -1.000 -1.0 3 3 0
11 55988.9809589 0.044893190432 std1 2  120     19      83.0 -1.000 -1.000 -1.0 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 -1.000 -1.000 -1.0 0.0 0 0.0
11 56223.2817254 0.044605221903 std1 2  120     25      87.0 -1.000 -1.000 -1.0 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 -1.000 -1.000 -1.0 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 -1.000 -1.000 -1.0 0.0 0 0.0
11 56565.2288146 0.045288773098 std1 2  120     25      92.0 -1.000 -1.000 -1.0 0.0 0 0.0
11 56680.8785419 0.045804632570 std1 2  120     10      55.0 -1.000 -1.000 -1.0 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 0 0
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 0 0
30 55482.4631214 299.4370  39.8100 0 0 0 0.0000000 0.0000000
...
10 56589.0390552     0.045383653062 std1 2 0 0 0 0 0
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 0 0
30 56623.4538362   8.8120  47.4510 0 0 0 0.0000000 0.0000000
10 56657.6685552     0.045690091816 std1 2 0 0 0 0 0
30 56657.6685552  10.8230  46.9570 0 0 0 0.0000000 0.0000000
10 56699.7866762     0.045901952309 std1 2 0 0 0 0 0
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       -1        -1 0.000 113069.0 0.0 138.0 -1.000 -1.000 -1.0 2 2 0
11 27343.5080895 0.051405458691 std2 2  120     28      79.0 -1.000 -1.000 -1.0 0.0 0 0.0
11 27372.6080888 0.050895050517 std2 2  120     30      76.0 -1.000 -1.000 -1.0 0.0 0 0.0
11 27373.1080893 0.050886342010 std1 2  120     17     158.0 -1.000 -1.000 -1.0 0.0 0 0.0
11 28003.8080894 0.042252027043 std1 2  120     19     170.0 -1.000 -1.000 -1.0 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 -1.000 -1.000 -1.0 0.0 0 0.0
11 28402.1080897 0.040251470202 std1 2  120      6     183.0 -1.000 -1.000 -1.0 0.0 0 0.0
11 28406.5080897 0.040247878310 std2 2  120     45      78.0 -1.000 -1.000 -1.0 0.0 0 0.0
11 28620.0080896 0.040574433849 std1 2  120     18     163.0 -1.000 -1.000 -1.0 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 -1.000 -1.000 -1.0 0.0 0 0.0
11 29151.2080895 0.045287136931 std2 2  120      7      65.0 -1.000 -1.000 -1.0 0.0 0 0.0
11 29156.7080892 0.045360524908 std1 2  120      7     134.0 -1.000 -1.000 -1.0 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 -1.000 -1.000 -1.0 0.0 0 0.0
11 29237.7080892 0.046488750878 std2 2  120     50      78.0 -1.000 -1.000 -1.0 0.0 0 0.0
11 29326.8080894 0.047825380133 std1 2  120     49     152.0 -1.000 -1.000 -1.0 0.0 0 0.0
11 29334.2080895 0.047940570614 std2 2  120     73      85.0 -1.000 -1.000 -1.0 0.0 0 0.0
11 29461.4080892 0.050011219353 std2 2  120     29      76.0 -1.000 -1.000 -1.0 0.0 0 0.0
11 29477.2080896 0.050279566397 std1 2  120     25     187.0 -1.000 -1.000 -1.0 0.0 0 0.0
11 29544.4080897 0.051445695153 std1 2  120     19     164.0 -1.000 -1.000 -1.0 0.0 0 0.0
11 29549.5080897 0.051535764981 std2 2  120     14      87.0 -1.000 -1.000 -1.0 0.0 0 0.0
50 std1 165.0 -1.000 -1.000 -1.0 0
50 std2 78.0 -1.000 -1.000 -1.0 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
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 NA NA NA
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 -1 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 -1 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
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
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
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 -1 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
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 0 0
30 2734.998 326.2469 35.2830 0 1 1 0.0000000 0.0000000
10 2738.899248614531 0.013359440021 std 2 1 0 0 0 0
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 0 0
30 2762.002 324.9939 39.3585 0 1 1 0.0000000 0.0000000
...
21 3309.000 2 80 fog 20 -1 3 10
30 3309.224 164.3231 22.4342 0 1 1
10 3309.224609210523 0.016974823000 std 2 1 0 0 0 0
```

```
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 the configuration and data sections.

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 -1.00 1
c2 0 mcp_with_amp mcp_and_avantek_amp 532.000 -1.00 3800.0 0.0 unknown -1.0 0.00 -1.0 0.0 none
c3 0 mt1 TAC TAC MLRS_CMOS_TMRB_TD811 na 439.45
40 34823.000 0 std 398 190 -1.000 402.3 0.0 131.1 0.168 -0.130 494.4 3 3 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 -1.00    1
c2 0 mcp mcp    532.000  -1.0 3800.0   0.0 unknown  -1.0  0.00  -1.0  0.00 none
c3 0 mt1 TAC TAC MLRS_CMOS_TMRB_TD811 na  439.4
40 34823.000000 0 std      398      190  -1.000      402.3      0.0  131.1   0.168  -0.130  494.4 3 3 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
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 18014.400         0   ES      -1      -1  122.977  105420.9     0.0  35.4   0.2   2.9   0.0 2 2 0
40 20355.840         0   ES      -1      -1  122.977  105426.9     0.0  35.4   0.1   2.7   0.0 2 2 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
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)
directory: crd_rw_c

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) 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.

7) 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 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.

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 could (can?) indicate quality of calibration results.
- Skew, kurtosis, and peak-mean are also included here.

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
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.
µs	microseconds
UTC	Coordinated Universal Time, formerly known as Greenwich Mean Time (GMT).
XML	eXtensible Markup Language.

Appendix C: Limits for CRD Fields

Record Type	Record Name	Field Name	CRD Format Specification	New Spec	Error Type	Questions/Comments	Cells in yellow are fields where we are seeking input
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	[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	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 – indicates the time scale reference	[0,1,…]	[0,…99]	Error	Currently recognized values are 3,4,7 Any need to discuss the process of	

						accepting others?
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 SOD number must be from the same station		
H2	Station Header	Other H2 Check		SOD & CDP 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 the official target name list	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	Error	
H3	Target Header	SIC		Target SIC must be found on official target SIC	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	Do the satellite name, SIC, COSPAR, and NORAD ID all need to match? Is one most/least important?
H3	Target Header	NORAD ID		NORAD ID must fit to satellite	Error	

				name		
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	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	Error	
H3	Target Header	Other H3 Check		If Target Type ==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]	[0,1,2,3 (time transfer), 4 (visual)]	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 full rate 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	-1 Accepted	[-1, 1950, …,2100]	Error	
H4	Session (Pass) Header	Ending Month	-1 Accepted	[-1, 1,…,12]	Error	
H4	Session (Pass) Header	Ending Day	-1 Accepted	[-1, 1,…,31]	Error	
H4	Session (Pass)	Ending Hour	-1 Accepted	[-1, 0,…23]	Error	

	Header					
H4	Session (Pass) Header	Ending Minute	-1 Accepted	[-1, 0,…,59]	Error	
H4	Session (Pass) Header	Ending Second	-1 Accepted	[-1, 0,…,59]	Error	
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	Error	
H4	Session (Pass) Header	Other H4 Check		Ending date must be valid	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		
H4	Session (Pass) Header	Other H4 Check		(if end year != -1)		
H4	Session (Pass) Header	Other H4 Check		Duration must be less than one day (MJD or unix or whatever)		
H8	End of Session Footer	H8	“H8” or “h8”	“H8” or “h8”	Error	
H8	End of Session	Other H8 Check		Must contain H8	Error	

	Footer			before H9		
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 the 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)		Suggest Check: maintain a list of standard wavelengths and check that the value is within +/- 1% of something on the list. Proposed list: 355, 423, 532, 694, 847, 1064, 1550	Error	How much leeway from the specified list is appropriate?
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	Other C0 Check		The record length must be at least 4	Error	

				characters		
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)		Suggest Check: maintain a list of standard wavelengths and check that the value is within +/- 1% of something on the list. Proposed list: 355, 423, 532, 694, 847, 1064, 1550	Error	How much leeway from the specified list is appropriate?
C1	Laser Configuration	Nominal Fire Rate (Hz)		[-1,0,1,…10000] or not in [> 0] (n.a. -1)	Warning	
C1	Laser Configuration	Pulse Energy (mJ)		[-1,0,1,…1000] or not in [> 0] (n.a. -1)	Warning	
C1	Laser Configuration	Pulse Width (FWHM in ps)		[-1,0,1,…10000] or not in [> 0] (n.a. -1)	Warning	
C1	Laser Configuration	Beam Divergence (arcsec)		[-1,0,1,…40] or not in [> 0] (n.a. -1)	Warning	
C1	Laser Configuration	Number of pulses in outgoing semi-train		[-1,0,1,…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	Detector Type				

	Configuration					
C2	Detector Configuration	Applicable wavelength (nm)		Suggest Check: maintain a list of standard wavelengths and check that the value is within +/- 1% of something on the list. Proposed list: 355, 423, 532, 694, 847, 1064, 1550	Error	How much leeway from the specified list is appropriate?
C2	Detector Configuration	Quantum efficiency at applicable wavelength (%)		[-1,…,100]	Warning	
C2	Detector Configuration	Applied voltage (V)		[-1.e4,…,1e4]	Warning	
C2	Detector Configuration	Dark Count (kHz)		[-1,…,1e3]	Warning	
C2	Detector Configuration	Output pulse type				
C2	Detector Configuration	Output pulse width (ps)		[-1,…,1e6]	Warning	
C2	Detector Configuration	Spectral Filter (nm)		[-1,…,1e2]	Warning	
C2	Detector Configuration	% Transmission of Spectral Filter		[-1,…,100]	Warning	
C2	Detector Configuration	Spatial Filter (arcsec)		[-1,…,1e2]	Warning	
C2	Detector Configuration	External Signal processing				
C2	Detector Configuration	Other		The record length must contain 14 fields	Error	
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)		[-1,-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 ID match C0 record Component D configuration ID	Warning	
C4	Transponder (Clock)	Estimated Station UTC offset (nanosec)		[-5e8,…5e8]	Warning	What might appropriate values be?
C4	Transponder (Clock)	Estimated Station Oscillator Drift		Numerical Test	Error	What might appropriate values be?
C4	Transponder (Clock)	Estimated Transponder UTC offset		Numerical Test	Error	What might appropriate values be?
C4	Transponder (Clock)	Estimated Transponder Oscillator Drift		Numerical Test	Error	What might appropriate values be?
C4	Transponder (Clock)	Transponder Clock Reference Time		Numerical Test	Error	What might appropriate values be?
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	
10	Range (Full rate)	10	"10"	"10"	Error	
10	Range (Full rate)	Seconds of day		[0,…,86400]	Error	Appropriate upper bound? E.g. 2 x 86400 = 172800
10	Range (Full rate)	Time-of-flight in seconds		[-1,…10000]	Error	
10	Range (Full rate)	System configuration ID		System configuration ID must be in C0-record	Error	
10	Range (Full	Epoch event	[0,1,2,3,4,5,6]	[0,1,2,3,4,5,6]	Warning	

	rate)					
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		[-1, 0,...,99999]	Warning	
10	Range (Full rate)	Other 10 Check		The record length must contain 9 fields	Error	
11	Range (Normal Point)	11	"11"	"11"	Error	
11	Range (Normal Point)	Seconds of day		[0,…,86400]	Error	Appropriate upper bound? E.g. 2 x 86400 = 172800
11	Range (Normal Point)			Must be in same revolution	Error	
11	Range (Normal Point)	Time-of-flight in seconds		[-1,…,10000]	Error	
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,…3600]	Warning	Is 1hr a relevant threshhold?
11	Range (Normal Point)	Number of raw ranges		[0,1,…]	Warning	
11	Range (Normal Point)	Bin RMS from mean of raw accepted time-of-flight values minus the trend function (ps)		[0,1,…1.e5] (test to see what extremes are good for the data and use those values)	Warning	What might appropriate values be?
11	Range (Normal Point)	Bin skew from mean of raw accepted time-of-flight values minus the trend function		(test to see what extremes are good for the data and use those values) Invite other reviewers to suggest a threshold.	Warning	What might appropriate values be?
11	Range (Normal Point)	Bin kurtosis from mean of raw accepted time-of-flight values		(test to see what extremes are good for the data and use those	Warning	What might appropriate values be?

		minus the trend function		values)		
11	Range (Normal Point)	Bin peak – mean (ps)		[-1.e5,..,1.e5]	Warning	What might appropriate values be?
11	Range (Normal Point)	Return rate		[-1,0,1,…,100]	Warning	
11	Range (Normal Point)	Detector channel	[0, 1,…]	[0,1,…, 99]	Error	
11	Range (Normal Point)	Other 11 Check		The record length must contain 13 fields	Error	
12	Range Supplement	12	"12"	"12"	Error	
12	Range Supplement	Seconds of day		[0,…,86400]	Error	Appropriate upper bound? E.g. 2 x 86400 = 172800
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		[-1,0,..,2e5]	Warning	What might appropriate values be?
12	Range Supplement	Target center of mass correction		[-1,0,...,]	Warning	What might appropriate values be?
12	Range Supplement	Neutral density filter value		[-1,0,…,100]	Warning	What might appropriate values be?
12	Range Supplement	Time bias applied		[-10,...,10]	Warning	What might appropriate values be?
12	Range Supplement	Other 12 Check		The record length must contain 7 fields	Error	
20	Meteorological	20	"20"	"20"	Error	
20	Meteorological	Seconds of day		[0,…,86400]	Error	Appropriate upper bound? E.g. 2 x 86400 = 172800
20	Meteorological	Surface pressure		[600,…,1100]	Error	
20	Meteorological	Surface temperature (K)		[200,…,340]	Error	
20	Meteorological	Relative humidity (%)		[0,…,100]	Error	
20	Meteorological	Origin of values	[0,1]	[-1 ,0,1]	[0,1]	

20	Meteorological	Other 20 Check		The record length must contain 6 fields	Error	
20	Meteorological			There must be at least one meteorological record	Error	
21	Meteorological Supp	21	“21”	“21”	Error	
21	Meteorological Supp	Seconds of day		[0,…,86400]	Error	Appropriate upper bound? E.g. 2 x 86400 = 172800
21	Meteorological Supp	Wind Speed (m/s)		[-1,…,100]	Warning	
21	Meteorological Supp	Wind Direction (deg az, north=0)		[-1, -180, … , 360]	Warning	
21	Meteorological Supp	Precipitation type				
21	Meteorological Supp	Visibility (km)		[-1,…,100]	Warning	
21	Meteorological Supp	Sky Clarity (zenith extinction coefficient)		[-1,…,100]	Warning	
21	Meteorological Supp	Atmospheric seeing (arcsec)		[-1,…,100]	Warning	
21	Meteorological Supp	Cloud cover (%)		[-1,…,100]	Warning	
21	Meteorological Supp	Other 21 Check		The record length must contain 9 fields	Error	
30	Pointing Angles	30	“30”	“30”	Error	
30	Pointing Angles	Seconds of day		[0,…,86400]	Error	Appropriate upper bound? E.g. 2 x 86400 = 172800
30	Pointing Angles	Azimuth in degrees		[-1, -180, … , 360]	Warning	
30	Pointing Angles	Elevation in degrees		[-1,…,180]	Warning	
30	Pointing Angles	Direction Flag	[0,1,2]	[-1,…,2]	Warning	
30	Pointing Angles	Angle origin indicator	[0,1,2,3]	[0,…,3]	Warning	
30	Pointing Angles	Refraction correction	[0,1]	[0,1]	Warning	
30	Pointing Angles	Other 30 Check		The record length must contain 7 fields	Error	
40	Calibration	40	“40”	“40”	Error	

40	Calibration	Seconds of day		[0,…,86400]	Error	Appropriate upper bound? E.g. 2 x 86400 = 172800
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	[-1,0,1,…]	[-1,…,1.e8]	Warning	
40	Calibration	Number of data points used	[-1,0,1,…]	[-1,…,1.e8]	Warning	
40	Calibration	One-way target distance (m)	[-1,0,1,…]	[-1,0.0,…1.e4]	Warning	
40	Calibration	Calibration System Delay (ps)		[-1.e4,…,1.e8]	Error	What might appropriate values be?
40	Calibration	Calibration Delay Shift (ps)		[-1.e5,…,1.e5]	Error	What might appropriate values be?
40	Calibration	RMS of raw system delay	[-1,…,2.e5]	[-1,…,2.e5]	Error	What might appropriate values be?
40	Calibration	Skew of raw system delay values from the mean		(test to see what extremes are good for the data and use those values)	Warning	What might appropriate values be?
40	Calibration	Kurtosis of raw system delay values from the mean		(test to see what extremes are good for the data and use those values)	Warning	What might appropriate values be?
40	Calibration	System delay peak – mean		[-1.e5,..,1.e5]	Warning	What might appropriate values be?
40	Calibration	Calibration Type Indicator	[0,1,2,3,4,5]	[0,1,2,3,4,5]	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]	Error	
40	Calibration	Other 40 Check		The record length must contain 16 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		[0,…,2.e4]	Warning	What might appropriate values be?
50	Session (Pass) Statistics	Session skewness from the mean of raw accepted time-of-flight values minus the trend function		(test to see what extremes are good for the data and use those values)	Warning	What might appropriate values be?
50	Session (Pass) Statistics	Session Kurtosis from the mean of raw accepted time-of-flight values minus the trend function		(test to see what extremes are good for the data and use those values)	Warning	What might appropriate values be?
50	Session (Pass) Statistics	Session peak – mean		[-1.e5,..,1.e5]	Warning	What might appropriate values be?
50	Session (Pass) Statistics	Data quality assessment indictor	[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

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

2. **CPF changes**
   1. The European Laser Transfer (ELT) mission required a change to the "H4" header record to include the epoch of the transponder oscillator drift.
   2. 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.
   3. 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.
   4. 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.
   5. 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.
   6. 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.
   7. NOTE: Read and observe the new method of handling leap seconds instituted in 2016, in which there is no tracking through the leap second.
   8. NOTE: Various prediction centers handle start time and 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.
   9. 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**
   1. 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.
   2. 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.).

3. 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.
4. 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.)
5. Shot records (“10”) now include the fire energy; the return energy is already recorded.
    1. These 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.
6. 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.
7. 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.
8. 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.
9. 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. Another piece of meteorological equipment can be included as well. This record should correspond to the meteorological equipment listed in the ILRS Site Log.
10. 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.
11. 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.
12. The Compatibility record (“70”) is obsolete and should no longer be sent.
13. 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

14. 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.

4. CPF and CRD

1. Added “Satellite Catalog Number” to NORAD ID field name, since they are interchangeable.
2. 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.
3. 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:

1. 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.
2. Milestones and associated dates will be provided in other communications.

CRD update implementation plans:

1. 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 formats.

    6. Station software: Mainly processing and normal point code.
    7. OCs, Data Centers, analysts, and debris tracking SC must accept original and new versions.
2. Milestones and associated dates will be provided in other communications.

6. Implications for Producers and Users

1. 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.
2. 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.
3. 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.
4. 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.
5. Prediction file record (H5) should be included, but should not generate error messages from the OCs for some time.
6. 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.

III. Consolidated Laser Ranging Prediction Format Version 2.00

Consolidated Laser Ranging Prediction Format
Version 2.00

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

28 February 2018

Revision History
0.2 1.10 – 10 January 2018

- Clarified documentation on certain fields.
- Added epoch of the transponder oscillator drift to "H4" record.
- Sub-daily sequence number can now be: 1-9 and a-z.
- Split Target ID into Target reflector type and Target location.
- Updated leap-second handling.
- Rewrote manual to remove most references to TIV/IRV format.
- For more detail, see Appendix G.

Introduction
In 2006, due to requirements for more accurate predictions and a need to provide predictions for different target types, the existing Tuned Inter-range Vector (TIV) and lunar formats were replaced by the Consolidated Prediction Format (CPF), which was flexible enough to handle earth satellites, lunar retro-reflector arrays, lunar satellites, and various transponders. Transponders were being developed for the first time, and would have needed yet another prediction format, if it were not for the CPFs. In addition, time biases and other corrections could be built into the predictions without requiring separate files. Instead of using an integrator to handle a single state vector per day, the CPF files with many records per day are interpolated with a high order (9th) polynomial.

Format Features

1. **No Euclidean Space Assumptions**
   The range to the environs of the moon and beyond cannot be simply calculated from the square-root of the sum of the squares of the reflector's topocentric X, Y, and Z coordinates. The movement of the Earth and moon during the approximately 2.5 second round trip is large enough that the range must be computed as the sum of the iteratively determined lengths of the outbound and inbound legs. Because of the distances and masses involved, there is also a non-negligible relativistic correction. The difference between the true range and the Euclidean distance gives a range error for the moon of a few to hundreds of microseconds. Omitting the relativistic correction causes a range error of about 50 nsec. Stellar aberration effects on pointing need to be considered since the aberration is a second or two of arc at the

moon, 30 or more arc-seconds for Mars and asteroids, and possibly more for any close-in spacecraft in transit.

The orbits of the moon and other major solar system objects are computed in the solar system barycentric reference frame, so they cannot be integrated easily on site in the way artificial Earth satellites can. However, one can readily interpolate tables of geocentric coordinates for these objects and other laser targets. The tabular format also benefits lower Earth satellite ranging by removing the need to tune the predictions to a particular integrator. In addition, other non-integrable functions, such as drag and orbital maneuvers, can be included with a tabular format.

2. **Multiple records**
The tabular format includes x, y, z and a corresponding time for each ephemeris entry. This and other specialized information are spread over several records for a day, the number and type depend on the altitude and the target class. The time between adjacent entries will normally be constant and will be small enough to meet any reasonable precision requirements using the supplied interpolation software. The time is large enough to avoid excessive file size. Typical values are 1 minute for low Earth satellites, 15 minutes at the moon, and hours or longer for the planets. See the section **Interpolator Definition** below for more information.

Record pairs like position10, directions 1 and 2, and corrections 30, directions 1 and 2 should be treated as a single-time set of predictions. For a transponder or any other target for which the time between entries is less than the round-trip light time, records 10, directions 1 and 2, etc. must be grouped so that the fire and receive legs follow each other in the file. In other words, the records are not in strict time order. See the transponder example in Appendix B or the records below.

```
10 1 53098  84449.02096     -125015785900.315 -238593151366.328  113777817699.433
10 2 53099      0.00000     -157578821821.085 -218511517400.466  113800334257.752
20 1         -4900.351123        27002.440493       -11504.716991
20 2         -1033.856498        27424.269894       -11503.554375
30 1     14960874.918060    -6906109.317657     1955191.986389   19356.3
30 2    -13838706.981995     8961558.044586    -1956244.853897   19361.8
```

3. **Variable entry spacing**
To accommodate high eccentricity satellites, variable entry spacing is a possibility that is permitted in the format and the sample interpolator.

4. **Line-length limits and method of transmission**
There are no length limits (within reason). No mode of distribution is assumed, so email, ftp, and scp should be usable.

5. **Free format read, fixed format write**
Due to the large dynamic range in the target positions and velocities, the non-header data should be read in free format. The prediction providers should write with a fixed format so that all fields line up for a given satellite. Doing so will allow easy visual

reading of the files for debugging. White space (at least one space) is required between fields to clearly separate them.

The format in Appendix A shows the width and the significant digits for each field. **The width and the format represent typical width for planning purposes. Change as needed.**

6. True body fixed system of date and Earth rotation parameters

The coordinate system used in the CPF format is usually presented in the true-body-fixed of date system. (We also use the term International Terrestrial Reference Frame – ITRF). In this reference system, Earth's pole positions have been included in the predicted positions. Since fresh Earth orientation parameters (EOP's) are now easily available to the prediction suppliers and since the predictions are usually supplied daily via the Internet, there is no need to apply the EOP information on site, or to back out values that may have been used in the predictions. Earth orientation information will only be supplied in the case of predictions that are presented in the inertial (space-fixed) reference system.

7. Multiple days per file

The CPF prediction file for a particular satellite contains several days worth of data. Seven days of predictions is standard, though some providers' predictions may be shorter. Multi-day files help the stations interpolate over day boundaries, which could otherwise cause problems. Multi-day files also allow ranging in case something prevents daily CPF downloads. Header records appear only once per file.

8. Integration past end of file

It should be possible for the site to integrate the last state vector in a prediction file for some time into the future. (Targets on or orbiting the moon and planets cannot be handled in this way.)

9. Elimination of drag and maneuver messages

Since the drag information can be built into the tabular state vectors, there is no need for separate drag messages. Drag could not be easily incorporated into tuned IRVs.

Maneuvers can be built into the CPF files. In these cases, maneuver messages are only needed to warn stations of the event. It has turned out that it is often not possible to accurately predict the trans- and post-maneuver satellite positions. In these cases the maneuver messages are still valuable, as are special post maneuver CPFs.

10. Compression

Common compression software such as compress, gnu zip, and others can be used to reduce the size of CPF files to be distributed. Thus far, the files have been of a manageable size and have not required compression even with email distribution.

11. File naming conventions

The following file naming convention is required for the new prediction format:

target_cpf_yymmdd_nnnvv.src
where the fields are as follows:

- target:
  - the official satellite name (See table in Appendix C and the up-to-date list at https://ilrs.cddis.eosdis.nasa.gov/missions/satellite_names.html.)
  - no special characters ("-", "_", "#", etc) or spaces are allowed
  - variable length with a maximum length of 10 characters
- yymmdd:
  - start year, month, and day of the CPF from the CPF H2 record
- nnn:
  - ephemeris version number. This is the day of year from the production date in the CPF H1 record. (Originally, 500 was added to distinguish CPFs from TIVs in time bias and other messages.) This field is three digits in length with zero leading fill.
- vv:
  - version number within the day. This is two digits with zero leading fill, starting with '01', and increasing to '99'.
- src:
  - prediction provider code, 3 characters long.

Format Field Comments

1. Target IDs and Names

SIC (Satellite ID Code), COSPAR (aka ILRS ID), and NORAD IDs (aka Satellite Catalog Number) and satellite/target name are included in the prediction headers as a convenient cross reference.

- Satellite/target names should be taken from the standard list at https://ilrs.cddis.eosdis.nasa.gov/missions/satellite_names.htm.
- The SIC is assigned by the ILRS for laser tracking targets.
- The ILRS ID can be derived from the official COSPAR number, as detailed on the ILRS web site and below.

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's ILRS Satellite ID is **7603901**

2. **Center of mass to reflector offset**
   The position vectors of spherical satellites always refer to the satellite's center of mass. An optional record H5 can indicate the range correction from the center of mass to the reflector reference radius. If H5 is present, the stations can correct the interpolated two-way range from the center of mass to the reflectors by subtracting twice this correction.

   Position vectors of non-spherical, attitude-controlled satellites can be given for either the center of mass (center of mass correction flag in header record H2 set to '0') or the reflector reference point (correction flag set to '1'). As the stations usually do not know the attitude of the satellites, no action is required in either case.

   As the GNSS satellites (GPS, GLONASS, Galileo, COMPASS) are seen from the Earth's surface within a small angle only, reflector corrections can be given as an approximate radial correction in header record H5 if the given positions are referred to the center of mass.

3. **Estimated accuracy**
   These optional records give an estimate of the expected accuracy (peak-to-peak) at certain points during the day. The estimates will be based on the experience of the prediction provider. The intention is to use this information to suggest or automatically set a station's range gate. They will be especially valuable to automated stations so that excessive time is not spent in searching for an optimal range gate and tracking settings.

4. **Leap second**
   Application of leap seconds has always been a source of some confusion. In the new format, each ephemeris record contains a leap second value. In prediction files spanning the date of a leap second, those records after the leap second will have this flag set to the number of leap seconds (always '1' so far, but standards allow for -1). In other words, a 3-day file starting the day before a leap second is introduced will have the leap second flag set to '0' for the first 24 hour segment and '1' in the last 48 hours.

   Even though the flag is non-zero, the leap second is not applied to the CPF times or positions. The station software needs to detect the leap second flag and apply the time argument to the interpolator appropriately.

   Prediction files can still have the leap second flag set to non-zero for several days after the leap second has been introduced.

Once the leap second flag returns to '0' after introduction of the leap second, stations still running on the old time system have to take into account the leap second.

Normally, the leap second field will be set to '0'.

As of the leap second on December 31, 2016, the ILRS has adopted the “coffee break” technique to deal with the leap second discontinuity. A crew ranges with the CPFs without the leap second until near the time of the leap second. They can then “take a coffee break” until some time after the leap second has passed. Then the crew uses the next day's CPFs which include the leap second. The leap second flag is ignored.

5. **Position and velocity fields**
   For artificial Earth satellites, these fields do not include light time iteration corrections. These 10-0 (record type 10, direction flag = 0) records contain the position vector corresponding to the same (common) epoch at the geocenter and satellite. For any CPF computed using a solar system ephemeris (e.g. DE-421), the 10-1 and 10-2 records are used and are the result of light time iteration. For this case, the vector spans fire time at the geocenter to bounce time at the target (record 10-1) and from bounce time to return time at the geocenter (record 10-2).

   The corresponding elements in the outgoing and incoming position fields will have opposite signs. The same is true for the velocities.

6. **Correction fields**
   As noted above, several complications arise in predicting ranges and pointing angles for solar system targets. They are essentially relativity and aberration. The aberration can be broken into light-time aberration, which applies to all targets (including earth satellites), and stellar aberration, which applies to those targets (such as the moon and planets) computed from solar system ephemerides. Near-Earth artificial satellites are usually computed in the geocentric reference system and do not require the so-called stellar aberration.

   Light time aberration is already applied implicitly in the state vectors, so it affects both range and pointing angles. Stellar aberration corrections (for the moon and other solar system bodies) are applied in computing the topocentric pointing angles. The relativistic corrections are computed separately and applied to the ranges. See Seidelmann, ESAA, pp 127-130.

   The in-bound and out-bound relativistic corrections are due to geodesic curvature. The time-scale correction converts a solar system barycentric range into an elapsed time, which can be observed at a station. This correction can be 200 m for a round trip range to Mars and is necessary because the position vectors are computed in the solar system barycentric frame using a solar system ephemeris. The geodesic correction is included in the format while the time-scale correction is site-dependent and is computed in the sample on-site code. See Seidelmann.

If there are outgoing and incoming correction records, the corresponding aberration and relativity fields will have opposite signs. If there is only one correction record, it will be the '30' record with direction = '1', and the software must sense this and set the incoming aberration values as negative of the outgoing ones. For pointing angle computations, the aberration values are added to the corresponding velocity values, and the result is converted to topocentric coordinates. (Aberration must not be added to the position as part of the range computation!)

The relativistic corrections are both positive, scalar values. They are added to the range based on the vector distances calculated from the outgoing and incoming positions. Again, if there is only one correction record, the relativistic correction will need to be doubled for the round trip range. An additional 0.27 nsec can be added to the round-trip range as an Earth-moon geodesic curvature correction. The resulting range with relativistic corrections is then scaled from proper to coordinate time.

7. Lunar fields

Lunar predictions may include lunar features for offset pointing. These features do not have SIC or COSPAR IDs since they are not ranging targets. These objects are given bogus IDs, perhaps negative numbers. A list of targets, names, and IDs will be supplied as needed by the prediction provider.

The libration vector (Euler angles ϕ,θ,ψ) and Greenwich apparent solar time are available in the "rotation angles" record, type 60, for the center of the moon file (SIC = 0099). This allows a station to compute pointing angles to any arbitrary lunar surface feature whose selenocentric coordinates they supply. Stations without arc-second level pointing accuracy may need this as a basis for offset pointing to the reflectors. Ranges computed in this way are not ("will not be" or "are not"?) accurate enough for ranging (some station-dependent corrections have been left out).

To determine the pointing angles using the lunar Euler angles, the center of moon to the center of Earth vector is translated to the laser station coordinates using light time iteration. The aberration corrections are then added to this vector. The new aberrated body-fixed coordinates are then rotated through the negative of the Greenwich apparent sidereal time (GAST). A libration vector is then created from the rotation vector of (ϕ,θ,ψ) (X X Newhall, private correspondence; see sample code) and pre-multiplied by the station coordinate vector (X, Y, Z) (change to (X, Y, Z) to be consistent with those in later text and appendixes ?). The result is added to the rotated, aberrated coordinates. The resulting vector is in the inertial coordinates of the lunar feature. This vector is then rotated back through the GAST to give the body fixed coordinates of date for pointing to the lunar feature. These coordinates can then be converted to RA/Dec, then to HA/Dec, and, finally, to azimuth/elevation. If the lunar positions and velocities are supplied in inertial coordinates (reference frame = 1), the first rotation, through -GAST, is unneeded.

8. Transponder fields

Transponders can be either synchronous or asynchronous. Synchronous transponders fire when a laser pulse is received from a ground station. The delay between receiving and transmitting the return pulse must be accounted for in both the prediction and data flow. Asynchronous transponders fire continuously for some period of time, as does the ground station. Both the spacecraft and the ground station record transmit and receive time based on their own local clock, which must be tied with an offset and rate to a master clock.

Transponders need various time, frequency and range rate fields in the format. With the exception of the oscillator relativity correction, these are slowly changing with time, so they can be included in the data header records. (Alternatively, some quantities could be distributed in separate files.) These fields are as follows:

- Pulse Repetition Frequency (PRF) - 1×10^{-5} to 1×10^{6} Hz
  - Asynchronous transponders only.
- Transponder transmit delay – 1 msec to 10 sec
  - Synchronous transponders: delay between receive and fire
  - Asynchronous transponders: delay between fire command and fire
- Transponder UTC offset - 10 nsec to 1 second
  - Asynchronous transponders only
- Oscillator Frequency Drift - 1 part in 10^{12} -10^{15}/day
  - Asynchronous transponders orbiting a solar system body
  - Corrects for the drift of the satellite's on-board oscillator
  - Transponder clock reference time of oscillator drift is provided in seconds
- Relativity Correction to Satellite Oscillator Time Scale for One-Way Range Rates -- 1 cm/sec to 1.5 m/sec (0.03 nsec/sec to 5 nsec/sec)
  - Asynchronous transponder orbiting a solar system body
  - Corrects for range rate change due to satellite orbiting in a different gravitational field
- Range rate is also needed to an estimated accuracy of 15 cm/sec, but this is computable from positions and/or velocities given a small enough time between vectors (5-10 sec).

As with lunar ranging, it may be necessary to compute pointing angles and range based on the rotation angles of a planet or the moon. While it is convenient and very accurate to use Euler angles for the moon, the universal system adopted by the IAU/IAG/COSPAR Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites uses the right ascension and declination of the body's pole as well as the position of the body's prime meridian (a_0, d_0, and W). See Davies or Seidelmann for more details. These quantities also have a place in the new prediction format as do x, y, and z offsets from the center of the main body (e.g., a planet).

The experience with the only lunar transponder so far, LRO-LR, is that the prediction provider distributed CPFs with records at 15-second intervals for the LRO spacecraft. The extreme precision required for ranging to reflectors is not needed for transponders.

Interpolator Definition

The baseline for interpolation of the CPF predictions is a 10-point (9^{th} order) Lagrange interpolation algorithm, which allows for records with variable time spacing. A sample interpolator was written to accompany the format. The following record spacings are reasonable, using position (X, Y, and Z) only. Note that the MGS (Mars Global Surveyor) interval is identical with the step size of the integration of the satellite's orbit.If the target had been on Mars, the interval would have been much larger.

Satellite	Interval (min)	
	Degree 7 (8 point)	Degree 9 (10 point)
CHAMP (LEO)	2	3
GFO-1	3	4
TOPEX	4	5
LAGEOS	5	10
GPS	15	30
Moon	30	60
MGS at Mars	N/A	0.3

Ranging stations can use one of a variety of interpolation schemes, preferably Lagrange (Splines are strongly discouraged). However, the baseline scheme is use of the 10-point Lagrange interpolation with a maximum error of less than 1 nsec in range, which is due to production and interpolation of the predicted ephemeris. To be conservative, prediction providers should use the intervals above for the 8-point interpolation. Any alternate interpolation scheme must provide 1 nsec agreement using a grid no narrower than the above. Interpolation must always be done in the Cartesian (X, Y, Z) space and not in the range/pointing angles for acceptable accuracy (see Appendix E). The interpolation time must be between the middle 2 points of the interpolation series for maximum accuracy (i.e., between the 5^{th} and 6^{th} points of a 10 point interpolator). See Abramowitz and Stegun for details.

Sample code

Sample station implementation code incorporating the interpolator is available on the ILRS web site (https://ilrs.cddis.eosdis.nasa.gov/data_and_products/formats/cpf.html) in FORTRAN and C. This computer software handles the computation of topocentric ranging predictions rigorously for artificial satellites near or distant, the moon, and other solar system bodies. Targets computed from a geocentric ephemeris and those computed using a solar system barycentric ephemeris (the moon, planets, or satellites of either) must be handled differently, but the software package will call the routines which are necessary based on the target. See Appendix D for more details.

Constants

The speed of light used by both prediction centers and stations should be the IERS Convention 2003 standard of 299792458 m/sec. Site coordinates should be in the International Terrestrial Reference Frame (ITRF). Although JPL's DE-403 and DE-421 ephemerides are not, the differences are not significant for predictions and normal point formation. Lunar reflector coordinates are usually supplied by the creators of the ephemeris and are the result of fitting the ranging data.

Conclusion

The requirements established for the CPF format for improved prediction accuracy and inclusion of exotic targets have been met. This format covers four different target types in one prediction format and sample software set. It opens up opportunities for most stations to range to a wider variety of targets and naturally overcomes several difficulties in previous tracking prediction formats. The format comes at the expense of larger file transfers. It does, however, provide a flexible platform for laser ranging predictions into the foreseeable future.

References

Abramowitz, M. And Stegun, I. A., Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables, National Bureau of Standards, Washington, 1964, p. 878.

Davies, M. E., et al (1991) "Report of the IAU/IAG/COSPAR Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites: 1991," Celestial Mechanics, 53, 377-397.

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Appendix A. Prediction Format Version 2.00

1) Data headers

NOTE: ALL fields MUST be separated by spaces, since these records are read as free format. The field-widths (e.g., I5, f12.5) are suggestions, and should be sized according to the target's needs. The field specifiers are based on FORTRAN. Samples of the C equivalents are A3 → %3s; I2 → %2d; F12.5 → %12.5f.

Header type 1 Basic information - 1 (required)

1-2	A2	Record Type (= "H1")
	A3	"CPF"
	I2	Format Version = **2**
	A3	Ephemeris Source (e.g., "HON", "UTX ")
	I4	Year of ephemeris production
	I2	Month of ephemeris production
	I2	Day of ephemeris production
	I2	Hour of ephemeris production (UTC)
	I3	Ephemeris Sequence number
	I2	Sub-daily Ephemeris Sequence number
	A10	Target name from official ILRS list (e.g. lageos1)
	A10	Notes (e.g., "041202","DE-403") with no spaces

Header type 2 Basic information - 2 (required)

1-2	A2	Record Type (= "H2")
	I8	ILRS Satellite ID (Based on COSPAR ID)
	I4	SIC (Provided by ILRS; set to "-1" for targets without SIC)
	I8	NORAD ID (i.e., Satellite Catalog Number)
	I4	Starting Year
	I2	Starting Month
	I2	Staring Day
	I2	Starting Hour (UTC)
	I2	Starting Minute (UTC)
	I2	Starting Second (UTC)
	I4	Ending Year
	I2	Ending Month
	I2	Ending Day
	I2	Ending Hour (UTC)
	I2	Ending Minute (UTC)
	I2	Ending Second (UTC)
	I5	Time between table entries (UTC seconds)(=0 if variable)
	I1	Compatibility with TIVs = 1 (=> integrable, geocentric ephemeris)
	I1	Target class 0=no retroreflector (includes debris)

1=passive retroreflector
2=(deprecated – do not use)
3=synchronous transponder
4=asynchronous transponder
5=other

I2 Reference frame
0=geocentric true body-fixed (default)
1=geocentric space-fixed (i.e., Inertial) (True-of-Date)
2=geocentric space-fixed (Mean-of-Date J2000)
I1 Rotational angle type
0=Not Applicable
1=Lunar Euler angles: ϕ, θ, and ψ
2=North pole Right Ascension and Declination, and angle to prime meridian (α_0, δ_0, and W)
I1 Center of mass correction
0=None applied. Prediction is for center of mass of target
1=Applied. Prediction is for retro-reflector array
I2 Target location/dynamics
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)

Header type 3 Expected accuracy

1-2	A2	Record Type (="H3")
	I5	Along-track run-off after 0 hours (meters)
	I5	Cross-track run-off after 0 hours (meters)
	I5	Radial run-off after 0 hours (meters)
	I5	Along-track run-off after 6 hours (meters)
	I5	Cross-track run-off after 6 hours (meters)
	I5	Radial run-off after 6 hours (meters)
	I5	Along-track run-off after 24 hours (meters)
	I5	Cross-track run-off after 24 hours (meters)
	I5	Radial run-off after 24 hours (meters)

Header type 4 Transponder information

1-2	A2	Record Type (= "H4")
	F12.5	Pulse Repetition Frequency (PRF) in Hz

F10.4 Transponder transmit delay in microseconds
F11.2 Transponder UTC offset in microseconds
F11.2 Transponder Oscillator Drift in parts in 10^{15}
F20.12 Transponder Clock Reference Time (seconds, scaled or unscaled)

Header type 5 Spherical satellite center of mass correction

1-2	A2	Record Type (= "H5")
	F7.4	Approximate center of mass to reflector offset in meters (always positive)

Header type 9 End of header (Last header record)

1-2	A2	Record Type (= "H9")

2) Ephemeris entry (repeat as needed)

NOTE: ALL fields MUST be separated by spaces, since these records are read as free format. The field-widths (e.g., I5, f12.5) are suggestions, and should be sized according to the target's needs. The field specifiers are based on FORTRAN. Samples of the C equivalents are A3 → %3s; I2 → %2d; F12.5 → %12.5f.

Record type 10 Position

1-2	A2	Record Type (= "10")
	I1	Direction flag* (common epoch = 0; transmit = 1; receive = 2)
	I5	Modified Julian Date (MJD)
	F13.6	Seconds-of-Day (UTC) (Transmit or receive)
	I2	Leap second flag (= 0 or the value of the new leap second)
	F17.3	Geocentric X position in meters
	F17.3	Geocentric Y position in meters
	F17.3	Geocentric Z position in meters

Record type 20 Velocity

1-2	A2	Record Type (= "20")
	I1	Direction flag* (common epoch = 0; transmit = 1; receive = 2)
	F19.6	Geocentric X velocity in meters/second
	F19.6	Geocentric Y velocity in meters/second
	F19.6	Geocentric Z velocity in meters/second

Record type 30 Corrections (All targets computed from a solar system ephemeris)

1-2	A2	Record Type (= "30")
	I1	Direction flag* (common epoch = 0; transmit = 1; receive = 2)
	F18.6	X stellar aberration correction in meters
	F18.6	Y stellar aberration correction in meters
	F18.6	Z stellar aberration correction in meters
	F5.1	Relativistic range correction in nsec (positive number)

Record type 40 Transponder specific (Transponders)

1-2	A1	Record Type (= "40")
	F6.3	Oscillator relativity correction in meters/second

Record type 50 Offset from center of main body (Surface features and satellites)

1-2	A2	Record Type (= "50")
	I1	Direction flag (bounce=0; transmit = 1; receive = 2)
	I5	Modified Julian Date (MJD)
	F13.6	Seconds-of-Day (UTC)
	A10	Name of target (no spaces in middle)
	F17.3	X position offset in meters
	F17.3	Y position offset in meters
	F17.3	Z position offset in meters

Record type 60 Rotation angle of offset (Surface features)
(See Rotation Angle Type in header record 2.)

1-2	A2	Record Type (= "60")
	I5	Modified Julian Date (MJD)
	F13.6	Seconds of Day (UTC)
	F17.12	Rotation angle 1 in degrees (For moon: ϕ)
	F17.12	Rotation angle 2 in degrees (For moon: θ)
	F17.12	Rotation angle 3 in degrees (For moon: ψ)
	F17.12	Greenwich Apparent Sidereal Time in hours

Record type 70 Earth orientation (For space-fixed reference frame,
as needed, typically once a day)

1-2	A2	Record Type (= "70")
	I5	Modified Julian Date (MJD)
	I6	Seconds of Day (UTC)
	F8.5	X pole (arcseconds)
	F8.5	Y pole (arcseconds)
	F10.6	UT1-UTC (seconds)

Record type 99 Ephemeris Trailer (last record in ephemeris)

1-2	A2	Record Type (= "99")

3) Comments

1-2	A2	Record Type (= "00")
3-80	A	Free format comments

* Direction flag has the following meanings (see Appendix C):

- Common epoch (0): instantaneous vector between geocenter and target, without light-time iteration. This epoch is the same as found in the corresponding old TIV format.
- Transmit (1): position vector contains light-time iterated travel time from the geocenter to the target at the transmit epoch.
- Receive (2): position vector contains light-time iterated travel time from the target to the geocenter at the receive epoch. (The sign of each element is opposite to that of the transmit vector.)

Appendix B - Sample Prediction Configurations

Note: the number after the hyphen in the typical configurations below refers to the direction indicator, 1 for outbound, 2 for inbound.

1. Earth-orbiting artificial satellites
A typical record configuration for most satellite is as follows:

H1 H2 H3 H9 10-0 10-0 10-0 ... 99

Mandatory records: H1, H2, H9, 10-0, 99.

Example:
```
H1 CPF 2 AIU 2005 11 16 4 320 1 gps35
H2 9305401 3535 22779 2005 11 15 23 59 47 2005 11 20 23 29 47 900 1 1 0 0 0 1
H9
10 0 53689  86387.000000  0  -13785362.868 -12150743.695  19043830.747
10 0 53690    887.000000  0  -13656536.158 -14288496.731  17628980.237
10 0 53690   1787.000000  0  -13618594.073 -16250413.260  15908160.431
10 0 53690   2687.000000  0  -13647177.924 -18001187.561  13911910.138
10 0 53690   3587.000000  0  -13712868.344 -19511986.614  11675401.577
10 0 53690   4487.000000  0  -13782475.931 -20761369.576   9237779.852
...
99
```

2. Lunar reflectors
For lunar reflectors, a typical sequence of records is as follows. Note that the '30-2' record is not really needed for the moon. The aberration corrections are not needed unless the orbit is computed relative to a solar system ephemeris, as the moon is.

H1 H2 H3 H9 10-1 10-2 30-1 30-2 10-1 10-2 30-1 30-2 10-1 10-2 30-1 30-2 ... 99

Mandatory records: H1, H2, H9, 10-1, 10-2, 30-1, 99.

Example:
```
H1 CPF 2 UTX 2005 11 16 14 320 1 apollo15 jpl_de-403
H2 103 103 0 2005 11 17 0 0 0 2005 11 21 23 45 0 900 0 1 0 0 0 3
H9
10 1 53691     0.0 0      343226579.261       46543054.740      166061912.378
10 2 53691     0.0 0     -343237287.411      -46403753.013     -166044491.398
30 1   -7566.  36724.   5545.  25.5
10 1 53691   900.0 0      345427390.701       24820813.890      166269371.365
10 2 53691   900.0 0     -345429119.195      -24681112.863     -166251952.876
30 1   -5221.  37124.   5504.  25.5
10 1 53691  1800.0 0      346255366.913        3006463.995      166475893.820
10 2 53691  1800.0 0     -346248108.749       -2866942.040     -166458477.824
30 1   -2855.  37375.   5463.  25.5
...
99
```

For the center of the moon, the libration information needs to be carried along.

H1 H2 H3 H9 10-1 10-2 30-1 30-2 60 10-1 10-2 30-1 30-2 60 10-1 10-2 30-1 30-2 60 ... 90

Mandatory records: H1, H2, H9, 10-1, 10-2, 30-1, 60, 99.

Example:

```
H1 CPF 2 UTX 2005 11 16 14 320 1 luncenter jpl_de-403
H2 99 99 0 2005 11 17 0 0 0 2005 11 21 23 45 0 900 0 1 0 1 0 3
H9
10 1 53691     0.0 0      344918986.877       46883148.021      165882903.645
10 2 53691     0.0 0     -344929799.893      -46742993.132     -165865415.671
30 1   -7566.  36724.   5545.  25.5
60 53691     0.0    -0.762524039740    21.927815073381   242.085911540111
3.743252931977
10 1 53691   900.0 0      347138025.698       25052846.263      166090930.914
10 2 53691   900.0 0     -347139804.259      -24912287.206     -166073445.455
30 1   -5221.  37124.   5504.  25.5
60 53691   900.0    -0.762477162557    21.927762020202   242.223125654342
3.993937427448
10 1 53691  1800.0 0      347977335.938        3129493.252      166298018.604
10 2 53691  1800.0 0     -347970072.850       -2989111.915     -166280535.662
30 1   -2855.  37375.   5463.  25.5
60 53691  1800.0    -0.762430689795    21.927708977647   242.360340162630
4.244621923024
...
99
```

For inertial systems:

> H1 H2 H3 H9 10-1 10-2 30-1 30-2 50 60 10-1 10-2 30-1 30-2 50 60 10-1 10-2 30-1 30-2 50 60 ... 99

3. Asynchronous Transponders

A typical record sequence is the following:

> H1 H2 H3 H4 H9 10-1 10-2 30-1 30-2 40 10-1 10-2 30-1 30-2 40 10-1 10-2 30-1 30-2 40... 99

Mandatory records: H1, H2, H4, H9, 10-1, 10-2, 30-1, 30-2, 40, 99.

Example:

```
H1 CPF 2 GSC 2004 03 30 12 90 1 lro
H2 99999999 9999 99999999 2004 04 04 00 00 00 2004 04 04 05 00 00 10 0 4  0 0 0 2
H3 0 0 0 1 0 0 5 1 1
H4 1999.91715 273.1500 2004.93 15.30 478579238.40
H9
10 1 53098  84449.02096     -125015785900.315 -238593151366.328  113777817699.433
10 2 53099      0.00000     -157578821821.085 -218511517400.466  113800334257.752
20 1         -4900.351123        27002.440493       -11504.716991
20 2         -1033.856498        27424.269894       -11503.554375
30 1     14960874.918060    -6906109.317657     1955191.986389   19356.3
30 2    -13838706.981995     8961558.044586    -1956244.853897   19361.8
40  0.1000
10 1 53098  84459.01980     -125189460917.443 -238502228781.030  113777934456.549
10 2 53099     10.00000     -157737908754.342 -218396877560.796  113800451035.803
20 1         -4880.719560        27005.997166       -11504.711036
20 2         -1013.916777        27425.015665       -11503.548412
30 1     14955868.474579    -6917009.332855     1955188.391006   19356.3
30 2    -13832201.994965     8971645.220612    -1956241.253082   19361.8
```

```
40  0.1000
10 1 53098  84469.01863     -125363069927.043 -238411179620.121  113778051444.382
10 2 53099     20.00000     -157896912383.972 -218282121726.361  113800568044.534
20 1         -4861.085417        27009.539567       -11504.705081
20 2          -993.976518        27425.746937       -11503.542448
30 1     14950854.096252    -6927905.739502     1955184.780594   19356.3
30 2    -13825689.658722     8981727.696381    -1956237.637238   19361.9
40  0.1000
...
99
```

4. Synchronous Transponders

A typical record sequence is:

> H1 H2 H3 H4 H9 10-1 10-2 30-1 30-2 10-1 10-2 30-1 30-2 10-1 10-2 30-1 30-2 ... 99

Mandatory records: H1, H2, H4, H9, 10-1, 10-2, 30-1, 30-2, 99.

Example:

```
H1 CPF 2 GSC 2004 03 30 12 90 1 xponder1
H2 99999999 9999 99999999 2004 04 04 00 00 00 2004 04 04 05 00 00 10 0 3 0 0 0 2
H3 0 0 0 1 0 0 5 1 1
H4 0.00000 273.1500 0.00 0.00 0.00
H9
10 1 53098  84449.02096     -125015785900.315 -238593151366.328  113777817699.433
10 2 53099      0.00000     -157578821821.085 -218511517400.466  113800334257.752
20 1         -4900.351123        27002.440493       -11504.716991
20 2         -1033.856498        27424.269894       -11503.554375
30 1     14960874.918060    -6906109.317657     1955191.986389   19356.3
30 2    -13838706.981995     8961558.044586    -1956244.853897   19361.8
10 1 53098  84459.01980     -125189460917.443 -238502228781.030  113777934456.549
10 2 53099     10.00000     -157737908754.342 -218396877560.796  113800451035.803
20 1         -4880.719560        27005.997166       -11504.711036
20 2         -1013.916777        27425.015665       -11503.548412
30 1     14955868.474579    -6917009.332855     1955188.391006   19356.3
30 2    -13832201.994965     8971645.220612    -1956241.253082   19361.8
10 1 53098  84469.01863     -125363069927.043 -238411179620.121  113778051444.382
10 2 53099     20.00000     -157896912383.972 -218282121726.361  113800568044.534
20 1         -4861.085417        27009.539567       -11504.705081
20 2          -993.976518        27425.746937       -11503.542448
30 1     14950854.096252    -6927905.739502     1955184.780594   19356.3
30 2    -13825689.658722     8981727.696381    -1956237.637238   19361.9
...
99
```

Appendix C - How to Create Consolidated Prediction Format Files: A Cookbook

The CPF format provides better prediction accuracy than the previous TIV format for artificial satellites, especially the low Earth orbit (LEO) satellites, as well as a common system that includes lunar retro-reflectors and transponders in lunar orbit and beyond.

This short document summarizes the main requirements for producing CPF files. There is a more complete and extensive document that discusses the philosophy and format details, which can be found at the addresses listed in the **Resources** section.

Satellite Laser Ranging (SLR) Predictions (Earth orbiting satellites)

1) CPF predictions are tabulated satellite state vectors generally in the geocentric Earth-fixed coordinate system of date known as the ITRF (International Terrestrial Reference Frame).

2) The state vectors are generated from predicted orbits based on the best possible force models (gravity field, air drag, solar pressure, ...) and predicted Earth rotation parameters. No tuning is performed.

3) CPF files are generated at least on a daily basis, containing a data span of five days, although some providers supply files with as little as three-days of data. The prediction center should re-issue prediction files for low satellites several times per day, if necessary.

4) When interpolated with a 10-point Lagrange interpolator, the CPF file must reproduce the output of the prediction orbit to ± 0.5 nanoseconds in range. Separations of tabular records for various altitudes of satellites are included below.

5) Fill in all fields of the records that are written. All records are free format (after the 2 digit record identification) with at least 1 space between fields. For a specific target, the fields in the body records should line up, for easy reading by humans.

6) Required records: Headers H1, H2, and H9. Header H3 is optional. Header H4 is for use with transponders only, and header 5 is for use with spherical satellites only. Data record 10 with direction '0' (instantaneous vector between geocenter and satellite at fire time) and 99 are required. None of the rest pertain.

7) The interpolator must always interpolate in the center interval of a 10-point span. Therefore, include at least 5 points prior to the file generation/distribution time to prevent stations from trying to interpolate outside the optimal interval.

8) Each ephemeris record contains a leap second value. In prediction files spanning the date of a leap second, the records after the time of the leap second will have this flag set to the number of leap seconds (always '1' so far, but standards allow for -1). In other words, a 3-day file starting at the day before a leap second is introduced will have the leap second flag set to '0' for the first 24-hour segment and '1' in the last 48 hours.

Even though the flag is non-zero, the leap second is not applied to the CPF times or positions. The station software needs to detect the leap second flag and handle the time argument for the interpolator appropriately.

Prediction files starting at 0 hour immediately after the leap second has been introduced will have the leap second flag set to '0'.

Normally, the leap second flag will be set to '0'.

Note: the leap second flag is currently ignored. Leave it set to '0'. See item 4 in the Format Field Comments above.

9) CPF files should be named in accordance with the following format:
satellite_cpf_yymmdd_nnnvv.src
where:
- satellite:
  - the official satellite name (See table below and the up-to-date list at https://ilrs.cddis.eosdis.nasa.gov/missions/satellite_names.html.)
  - no special characters ("-", "_", "#", etc.) or spaces are allowed
  - variable length, with a maximum length of 10 characters
- yymmdd:
  - Start year, month, and day from the H2 record
- nnn:
  - ephemeris version number. Ephemeris production day of year from the H1 record. This field is three digits with zero leading fill.
- vv:
  - version within the day. Two digits with zero leading fill, starting with '01'.
- src:
  - prediction provider code. Three characters.

10) If predictions are emailed, the subject line should read:
Subject: satname DAILY CPFS center,
e.g., SUBJECT: ICESAT DAILY CPFS UTX .
The file should be mailed as embedded text, not as an attachment.

11) Maneuver messages are no longer needed except to alert operators.

12) CPF files should normally be ftp-ed to EDC or CDDIS for distribution, as detailed in their instructions.

13) There is a sample software program called cpf_chk that can be used to test the CPF files' format. Using this program can save a great deal of time in hand-checking the

prediction files. The code is provided as-is, and any bug fixes or improvements will be gratefully accepted.

14) Format Version Numbers: Only the integer portion should be used. For example, version 2.34 would be entered as '2'. All versions from n.00 to n.99 would be backward compatible.

Predictions for the Moon and other bodies requiring a solar system ephemeris

Follow the same procedures as for "SLR Predictions" with the following differences.

1) The out-bound and in-bound leg vectors (records 10-1 and 10-2) are corrected for light time. In other words, for record 10-1, the vector spans from the geocenter at fire time to target position at bounce time. Similarly, for record 10-2, the vector spans from the target at bounce time to the geocenter at return time.

2) For the moon and transponders, time of prediction is fire time for the outbound leg and return time for in-bound leg. The latter is for reference only. For rotation records (30), the time is bounce time (i.e., firing time + out-bound leg length). Out- and in-bound leg and rotation records remain together in fire time order.

3) The in-bound leg is required for ranging to the moon and beyond or any other orbit that has been computed using a solar system ephemeris.

4) Position, velocity, and aberration vector elements have opposite signs on out-bound and in-bound leg records. Relativistic corrections are always positive and additive. When there is only one corrections record (type 30) for each out-bound/in-bound leg pair, the relativistic correction must be one-way, as it will be added twice.

5) Include the following records:

- Lunar reflectors: H1, H2, H9, 10-1, 10-2, 30-1, 99
- Center of moon: H1, H2, H9, 10-1, 10-2, 30-1, 60, 99
- Asynchronous transponders: H1, H2, H4, H9, 10-1, 10-2, 20-1, 20-2, 30-1, 30-2, 40, 99
- Synchronous transponders: H1, H2, H4, H9, 10-1, 10-2, 30-1, 30-2, 99

Resources

1) Standard Satellite Prediction Spacing

Satellite class	Interval (min)
CHAMP (LEO)	2
GFO-1	3
TOPEX	4

LAGEOS	5
GPS	15
Moon	30

2) Standard Laser Target Names

SLR Targets (not up-to-date):

adeos
adeos2
ajisai
beaconc
champ
diadem1c
diadem1d
envisat
ers1
ers2
etalon1
etalon2
fizeau
geos3
gfo1
gfz1
glonass## (where ## is the 2-digit GLONASS satellite number)
gpb
gps35
gps36
gracea
graceb
icesat
jason1
lageos1
lageos2
larets
lre
meteor3
meteor3m msti
reflector
resurs
starlette
starshine2
starshine3
stella
sunsat
tips
topex
westpac
zeia

LLR Targets:

apollo11
apollo14
apollo15
luna17
luna21
luncenter

An up-to-date list will be maintained at:
https://ilrs.cddis.eosdis.nasa.gov/missions/satellite_names.html

2. Full documentation
https://ilrs.cddis.eosdis.nasa.gov/data_and_products/predictions/index.html

3. Sample Software
Enter https://ilrs.cddis.eosdis.nasa.gov/data_and_products/formats/cpf.html to download the software "tar" file.

4. EDC and CDDIS upload instructions
Contact Carey Noll at carey.noll@nasa.gov or
Christian Schwatke at Christian.Schwatke@tum.de .

5. For reference, CPF files can be found at:
ftp://cddis.gsfc.nasa.gov/pub/slr/cpf_predicts or
ftp://edc.dgfi.tum.de/pub/slr/cpf_predicts/.
or contact Carey Noll (carey.noll@nasa.gov) to be added to the email exploder.

6. CPF email exploder:
Contact Christian Schwatke at Christian.Schwatke@tum.de or check the ILRS web page (https://ilrs.cddis.eosdis.nasa.gov/about/contact_ilrs/ilrspred.html).

Appendix D - Consolidated Prediction Format User's Guide

At the Laser Workshop in Eastbourne in October, 2005, the ILRS Governing Board set the goal of converting all stations from the Tuned Inter-range Vectors (TIVs) to the new Consolidated Predictions Format (CPF) by June 31, 2006. All prediction centers were expected to start providing the CDDIS and EDC with CPF files on a routine basis by the end of 2005. This conversion is the culmination of 5 years of work by the ILRS Prediction Format Study Group. The new format promises to provide better prediction accuracy for artificial satellites, especially LEOs, as well as a common system that will include lunar retro-reflectors and transponders in lunar orbit and beyond.

This short document tries to summarize the main requirements for using CPF files. There is a more complete and extensive document that discusses the philosophy and format details. It can be found at the addresses listed in the **Resources** section.

General comments

1) Sample software is provided at the address given at the end of this document. There are 'C' and FORTRAN versions of the CPF file reading and interpolation software (with test programs and "readme" files), a more advanced program for SLR-type predictions (CPF_INTER), and a more advanced program for lunar and transponder predictions (CPFPRED). In addition, there is a CPF file format checker (cpf_chk) and a file to convert CPF files into untuned TIVs. It is expected that all this code will be supported. Note that bug fixes and improvements will be gratefully accepted. Treat this as an open source project where everyone making changes to the software contributes to the improvement of the final product.

In addition, there is a suite of software to split a CPF file into shorter single pass files for a particular station and produce a schedule file. There is also a directory containing fragments of C++ code for reading and interpolating the CPF files. This software is for demonstration purposes only, and active maintenance is not anticipated.

Test input and output are supplied with all programs.

2) For acceptable precision, interpolate in Cartesian coordinates (body-fixed or inertial) and not in pointing angles and range. There is sample code to read and interpolate the CPF files, so you do not need to "re-invent the wheel."

3) Interpolated time must be between the 5th and 6th points for the 10-point interpolation, or precision will be degraded.

4) Due to rule 3), the interpolator needs 5 extra records at the beginning and the end of a pass to maintain full prediction accuracy. The sample interpolator will produce a warning message and give the best results it can if there are not enough records to center on the time of interpolation.

5) Do not assume that the prediction file starts at 0 hour UTC.

6) It is a good practice to read all fields in as ASCII strings before converting to integers or floating point. With added checks, this will prevent software crashes when mis-formed or blank fields are encountered.

Resources

1. Full documentation

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

2. Sample Software

The software is organized into the following directories:

    common_c cpf_c   cpf_comb_c cpf_llr_c cpf_slr_c cpf_chk_c   cpf_sched
    common_f cpf_f   cpf_comb_f cpf_llr_f cpf_slr_f cpf_eos_cpp include
    cpf2irv_c

There are FORTRAN and C versions of most programs. Directories with names ending in "_c" contain C code, directories with names ending in "_cpp" contain C++ code, and directories with names ending in "_f" contain FORTRAN.

common_c, common_f -
Routines that read and interpolate a CPF file are included.
Also, the directory contains additional routines needed by several of the programs listed below.

cpf_c, cpf_f -
These contain programs and standard input and output to test the basic CPF read and interpolation software found in common_c and common_f.

cpf_slr_c, cpf_slr_f -
Programs in these directories produce range and pointing angles for SLR predictions. Test input and output files are included.

cpf_llr_c, cpf_llr_f -
Programs in these directories produce range and pointing angles for LLR and transponders at the moon and beyond. Test input and output files are included.

cpf_comb_c, cpf_comb_f -
Programs in these directories produce range and pointing angles for SLR, LLR and transponders. Test input and output files

are included. This code combines SLR and LLR code above into one set of routines.

>> NOT YET AVAILABLE <<

cpf_chk_c -

This contains a program to test CPF files for conformity with the format standard. This is mainly designed for prediction centers and their test stations. It can be installed in any station with a feeling of paranoia.

cpf_eos_cpp -

C++ code fragments from EOS. See the Readme.doc file for an explanation.

cpf_sched -

This directory contains a program to split a multi-day CPF file into pass-by-pass files for a particular station. It also contains programs to produce an eye-readable schedule of the passes. Two programs are in FORTRAN and one is in C.

cpf2irv_c -

This software converts a CPF file into a set of untuned IRVs.

include -

Headers for FORTRAN and C programs can be found here.

Note that not all programs and routines are available in all languages. Currently, the only C++ routines are provided as code fragments and not as a full compilable package.

Priority for maintenance will be given to common_c, common_f, cpf_c, cpf_f, cpf_slr_c, cpf_slr_f, cpf_llr_c, cpf_llr_f, and include. The rest will be maintained as resources are available.

To download the sample code, enter https://ilrs.cddis.eosdis.nasa.gov/data_and_products/formats/cpf.html and select "sample code". The appropriate file will be downloaded.

3. CPF files can be found at:

ftp://cddis.gsfc.nasa.gov/pub/slr/cpf_predicts/, or
ftp://edc.dgfi.tum.de/pub/slr/cpf_predicts/

or contact Carey Noll (carey.noll@nasa.gov) to be added to the email exploder.

4.It is recommended that the stations use predictions from the primary providers for each satellite as listed at

https://ilrs.cddis.eosdis.nasa.gov/data_and_products/predictions/prediction_centers.html
Use backup providers when usable predictions are not available from the primary providers.

Appendix E: Common Abbreviations

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
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 opacity of a broad band optical filter.
NORAD	The North American Aerospace Defense Command
ns	nanoseconds
ps	picoseconds
RMS	Root Mean Square. Same as standard deviation.
SLR	Satellite Laser Ranging
SCH	Station Change Indicator
SCI	Station Configuration Indicator
SIC	Satellite Identification Code, a 4 digit satellite descriptor.
SRP	System Reference Point, usually described as the first non-moving point in the telescope light path.
µs	microseconds
UTC	Coordinated Universal Time, formerly known as Greenwich Mean Time (GMT).
XML	eXtensible Markup Language.

MAXIMUM PREDICTIONS GRID SPACINGS

to achieve RSS due to INTERPOLATION ONLY of:
1 ns, and 10 ps, in RANGE
1 second of arc, in AZIMUTH and ELEVATION

J.McK. Luck
Research Fellow
Electro Optic Systems Pty.Ltd.

Table 1: Prediction Intervals giving nominated Interpolation Errors

Satellite	**Maximum Grid Spacings (seconds)** when using 8th-order Lagrange Interpolation				**CPF Recommendation**	
	RANGE		**AZIMUTH**	**ELEVATION**	Deg 7	Deg 9
	1 ns	**10 ps**	**1 arcsec**	**1 arcsec**		
CHAMP	234	127	441	456	120	180
STARLETTE	240	127	466	519	180	240
AJISAI	310	170	617	628	240	300
LAGEOS	501	280	1097	1118	300	600
GPS35	1360	763	2970	3160	900	1800

EXPLANATION

Files of predictions for each satellite chosen were kindly provided by Chris Moore. They were generated in the "Inertial" reference frame (True-of-date) at 1-second intervals, as geocentric Cartesian X,Y,Z coordinates. They are labeled as "I".

The "I" coordinates were then transformed to body-fixed Greenwich coordinates, labeled as "G", by rotating through Greenwich Mean Sidereal Time. These coordinates are those proposed for the ILRS Consolidated Prediction Format (CPF). In this study, UT1-UTC and polar motion were ignored.

The "G" coordinates were then transformed to the relative topocentric Cartesian coordinates (East, North, Up) at the Mount Stromlo SLR station, labeled as "T", by rotating through longitude and latitude.

Finally, the "T" coordinates were transformed to Range, Azimuth and Elevation, labeled as "P" (for Polar), by the usual formulae.

These four data sets were considered to be "truth". They each covered about a day of predictions.

Interpolation errors were examined for a variety of circumstances:

- Grid spacings of 15, 30, 60, 120, 240, 480 or 960 seconds, with tabular points ("nodes") selected from the "true" data;
- Interpolation orders of 4, 6, 8, 10, 12 (degrees are one less than these);
- Interpolating into the I, G, T or P reference frames, at every second. When interpolating using tabular points in the first three systems, the interpolation results were transformed to range, azimuth and elevation.

Each circumstance was characterized by its "RSS", i.e. the square-root of the average square of the deviates "interpolated - truth", over all the 1-second points. The various RSSs were plotted on log-log graphs against grid spacing; and the grid spacings for the nominated values of RSS, shown in Table 1, were then obtained by inverse logarithmic interpolation. The relevant graphs for LAGEOS are shown in Figures 1 and 2.

OUTCOMES

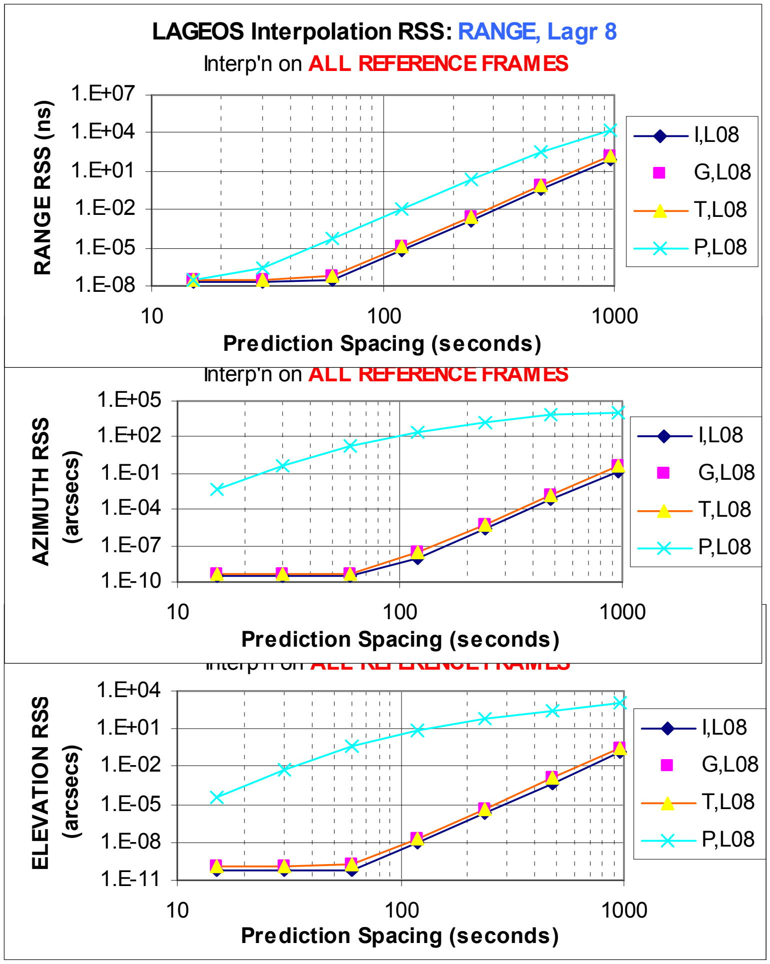
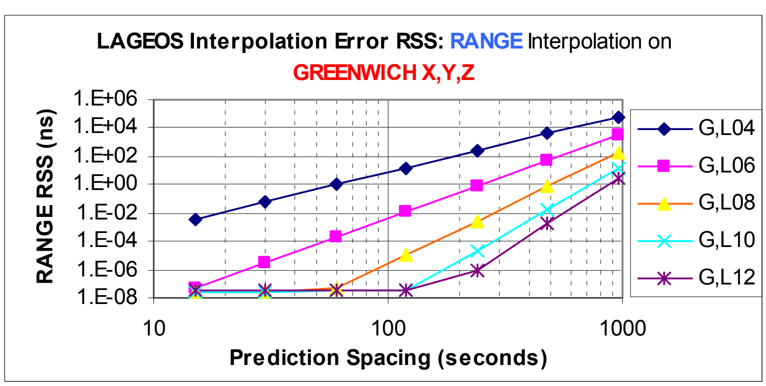


Figure 1: Log-log graphs of Range, Azimuth and Elevation Interpolation Errors using an 8^{th}-order interpolator in Inertial XYZ (I), Greenwich XYZ (G), Topocentric ENU (T) and local Az/El/R (P) systems.

From Figure 1, it is seen that the results are virtually identical when interpolating with an 8^{th}-order interpolator on any of the Cartesian systems (I,G,T), but much worse when interpolating directly in range, azimuth and elevation (P). This general result holds for all satellites tested and for all interpolator orders used, although their graphs are not shown here.

Both sets of figures also show that, after a "floor" due to subtraction of nearly equal large numbers, the log-log relationships are linear, consistent with the theoretical behaviour of interpolation errors. This, too, is a general result.



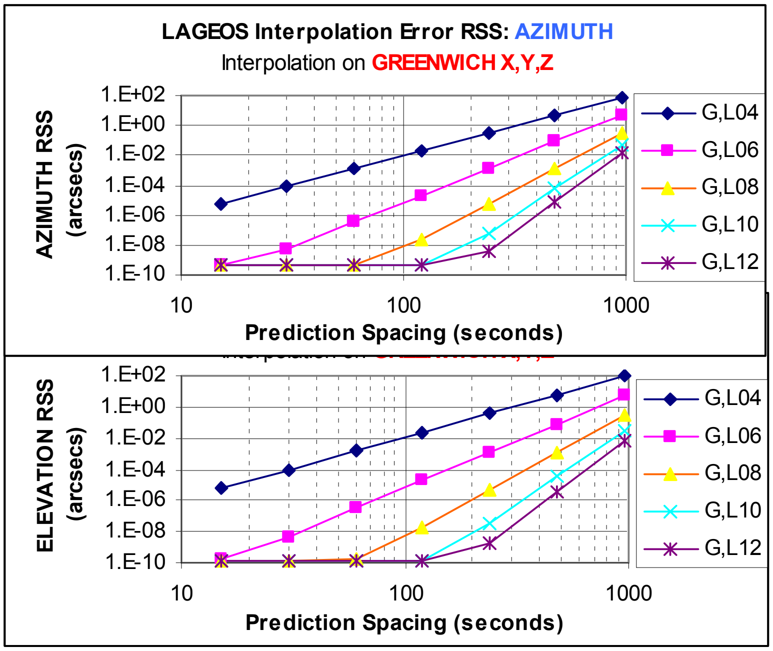


Figure 2: Log-log graphs of Range, Azimuth and Elevation Interpolation Errors using interpolators of order 4, 6, 8, 10 and 12 in the Greenwich XYZ (G) system.

CONCLUSIONS

From the point of view of interpolation error, the grid spacings proposed for the ILRS Consolidated Prediction Format are adequate for producing better than 1 ns accuracy in range, and 1 arcsec accuracy in azimuth and elevation, provided that an 8^{th}-order interpolator (or higher) is used on Cartesian coordinates. They are not adequate for producing ranges with 10 ps accuracy (if anybody would ever want such accuracy in predictions).

They are grossly inadequate for interpolating directly into tables of range, azimuth and elevation!

CAUTIONS

Transforming from an inertial (or quasi-inertial) reference frame to the Greenwich (body-fixed) frame involves application of sidereal time, which in turn requires the Julian Date (JD). Now, a typical satellite range rate is 5 km/sec, or 1 ns (2-way) per 30 µs. If the formula for GMST given, for example, on page B6 of "*The Astronomical Almanac 2005*", is followed blindly at an arbitrary time, about 17 decimal places are required for the JD to reach the 30 µs resolution needed. My Windows-based 32-bit computer only gives about 14 decimal places in FORTRAN double precision, so the rounding error is highly significant - it caused a 30-ns saw-tooth during my experiments. A simple remedy is to calculate GMST for exactly 0h UTC on the required day, reduce it by modulo 86400, then add [UTC + (UT1-UTC)] multiplied by the sidereal conversion factor 1.002737811911354448 ("*IERS Conventions (2003)"*, p.38). Or simply increase the precision of calculations…..

[*Confession*: I have always known about this, but forgot. The reminder came when the interpolation errors on “G” were much larger than on “I”, which was hard to understand since the transformation between them is essentially extremely smooth. There’s no fool like an old fool.]

It was also humbling to have to take several goes at getting the azimuths strictly continuous before their interpolations, because the ATAN2 function only returns values in the range $-\pi < Az < \pi$. Failures showed up as ridiculously large interpolation RSSs, e.g. 10^5 seconds of arc. [The old fool does still remember to do simple, yet comprehensive, sanity checks on all his software…..]

Appendix G: Changes from CRF v. 1 to CRF v. 2

CRD and CPF Format and Manual Updates
28 February 2018

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

2. **CPF changes**
   1. The European Laser Transfer (ELT) mission required a change to the "H4" header record to include the epoch of the transponder oscillator drift.
   2. 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.
   3. 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.
   4. 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.
   5. 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.
   6. 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.
   7. NOTE: Read and observe the new method of handling leap seconds instituted in 2016, in which there is no tracking through the leap second.
   8. NOTE: Various prediction centers handle start time and 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.

9. 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

1. 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.
2. 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.).
3. 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.
4. 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.)
5. Shot records ("10") now include the fire energy; the return energy is already recorded.
    1. These 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.
6. 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.
7. 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.
8. 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.
9. 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. Another piece of meteorological equipment can be included as well. This

record should correspond to the meteorological equipment listed in the ILRS Site Log.

10. 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.
11. 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.
12. The Compatibility record ("70") is obsolete and should no longer be sent.
13. 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

14. 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.

4. CPF and CRD

1. Added “Satellite Catalog Number” to NORAD ID field name, since they are interchangeable.
2. 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.
3. 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:

1. 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.
2. Milestones and associated dates will be provided in other communications.

CRD update implementation plans:

1. 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 formats.
   6. Station software: Mainly processing and normal point code.
   7. OCs, Data Centers, analysts, and debris tracking SC must accept original and new versions.
2. Milestones and associated dates will be provided in other communications.

6. Implications for Producers and Users

1. 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.
2. 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 will be written and added to the sample code if necessary.

3. 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.
4. 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.
5. Prediction file record (H5) should be included, but should not generate error messages from the OCs for some time.
6. 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.

IV. ASC List of Attendees, 2018 EGU Meeting, TU Wien, Vienna, Austria

Thursday, April 12, 09:00 – 17:00

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