### Time Systems

Four time systems are of primary interest for the IAS geometric algorithms: International Atomic Time (Temps Atomique International [TAI]), Universal Time—Coordinated (UTC), Universal Time—Corrected for polar motion (UT1), and Spacecraft Time (the readout of the spacecraft clock, derived from GPS time). Spacecraft Time is the time system used for the spacecraft time codes found in the Level 0R ancillary data (including image time codes). UTC is the standard reference for civil timekeeping. UTC is adjusted periodically by whole leap seconds to keep it within 0.9 seconds of UT1. UT1 is based on the actual rotation of the Earth and is needed to provide the transformation from stellar-referenced inertial coordinates (ECI) to terrestrial-referenced Earth-fixed coordinates (ECEF). TAI provides a uniform, continuous time stream that is not interrupted by leap seconds or other periodic adjustments. It provides a consistent reference for resolving ambiguities arising from the insertion of leap seconds into UTC, which can lead to consecutive seconds with the same UTC time. Spacecraft time is based on GPS time, which is, itself, a fixed offset from TAI. The Explanatory Supplement to the Astronomical Almanac, mentioned previously, describes these and a variety of other time systems and their relationships. The following text describes the significance of each of these time systems, with respect to the IAS geometric algorithms.

1. Spacecraft Time

In accordance with the Landsat Data Continuity Mission Spacecraft to Ground Interface Control Document (70-P58230P, Rev C), the L8/9 spacecraft clock reports time as TAI seconds since the spacecraft (J2000) epoch, defined as follows:

January 1, 2000, 11:59:27.816 TAI

which is the same as the following:

January 1, 2000, 11:58:55.816 UTC.

Epoch J2000 occurred at January 1, 2000 12:00:00 Barycentric Dynamical Time (TDB). At the time of the J2000 epoch, Terrestrial Dynamical Time (TDT) differed from TDB by approximately 73 microseconds (ref. Explanatory Supplement to the Astronomical Almanac). This small difference is ignored in the definition above, and the epoch is effectively taken to be January 1, 2000, 12:00:00 TDT. Since TDT is defined to be TAI + 32.184 seconds, we have 11:59:27.816 TAI + 32.184 sec = 12:00:00 TDT. Furthermore, at the time of the J2000 epoch, TAI and UTC differed by 32 accumulated leap seconds, so 11:58:55.816 UTC + 32.000 sec = 11:59:27.816 TAI. Note from the above that the relationship between spacecraft time and TAI is fixed, but the relationship between spacecraft time and UTC changes over time, with the offset increasing by one second each time a new leap second is declared. Note that as of the date of this document, five additional leap seconds have been declared (in January 2006, January 2009, July 2012, June 2015, and January 2017).

The L8/9 flight software maintains the accuracy of the spacecraft clock, using time data from the on-board GPS receiver(s). The spacecraft clock is then used to time tag the spacecraft ancillary data and to provide a timing reference for the OLI and TIRS instruments. Spacecraft time is used to define the times at which the flight software generates filtered attitude and ephemeris estimates based on the input GPS, star tracker, and SIRU data. These estimates are included in the spacecraft ancillary data stream for use by ground processing. Also included in the ancillary data are the raw SIRU measurements. Individual SIRU observations are time tagged using a clock/counter internal to the SIRU itself, but the SIRU ancillary data also includes SIRU time synch events that make it possible to relate the SIRU clock to spacecraft time.

The spacecraft clock also provides time synchronization signals to the OLI and TIRS instruments once per second. Both instruments use this one-pulse-per-second signal to regulate their internal clocks, thereby registering the image time codes to spacecraft time. Note that any instrument clock rate errors will manifest as (small) step discontinuities in the image time codes, which correspond to the 1 PPS updates. The resulting time code irregularities are corrected when the OLI and TIRS geometric models are created, as described below in the OLI LOS Model Creation algorithm and the TIRS LOS Model Creation algorithm.

1. UTC

As mentioned above, UTC is maintained within 0.9 seconds of UT1 by the occasional insertion of leap seconds. A table of leap seconds relating UTC to TAI is maintained in the L8/9 CPF to support the spacecraft time to UTC conversion. To convert spacecraft time to UTC, the number of additional leap seconds declared since the spacecraft epoch are subtracted from the reported spacecraft seconds since epoch and the result is added to the UTC representation of the epoch presented above. Leap second information is available from the International Earth Rotation Service (IERS) in their Bulletin C publications.

1. UT1

UT1 represents time with respect to the actual rotation of the Earth, and is used by the IAS algorithms, which transform inertial ECI coordinates or lines of sight to Earth-fixed ECEF coordinates. Failure to account for the difference between UT1 and UTC in these algorithms can lead to ground position errors as large as 400 meters at the equator (assuming the maximum 0.9-second UT1-UTC difference). The UT1-UTC correction typically varies at the rate of approximately 2 milliseconds per day, corresponding to an Earth rotation error of about 1 meter. Thus, UT1-UTC corrections should be interpolated or predicted to the actual image acquisition time to avoid introducing errors of this magnitude. The UT1-UTC offset, along with the polar wander Earth orientation parameters, can be obtained from IERS Bulletin B (for retrospective data) and Bulletin A (for predicted data). The L8/9 CPF also includes tables of the UT1-UTC and polar wander Earth orientation parameters.

1. TAI

Although the IAS algorithms do not operate directly in TAI, it underlies the definition of spacecraft time, as noted above. As such, it can be helpful to use TAI as a standard reference that can be related to UTC, using the CPF leap second file, and to spacecraft time, via the constant offset, to assist IAS operations staff in anomaly resolution.