Earth Observation OPS commanding

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Purpose of this TN is to address the end-to-end handling of the OPS (Orbit Position Schedule) commanding, used in various ESA Earth Observation missions, and characterize the possible errors in terms of command geo-localisation accuracy.

It is possible to avoid ANY geo-localisation error if the implementation is coherent end-to-end, which involves checking the way on-ground mission planning and on-board TC scheduling are designed.

1 OPS ANGLE

1.1 Definition

Traditionally satellite/payload commands on-board are scheduled by time (e.g. UTC), the times are calculated in advance on ground by mission planning systems using orbital prediction, with the result that: the more in the future the event, the more uncertainty in time (and therefore in location).

Following availability of GPS on-board, the new ESA Earth Observation missions foresee now an on-board schedule execution based on location (termed OPS) which aims to precise execution of operation on specific ground location (e.g. measurements, calibration, downlink, etc) without the need for ground to have a very precise orbital prediction and/or frequent update of the on-board command queue.

The location for OPS is not specified by surface lat and long (e.g. WGS84) but by means of the angle defined in the inertial orbital plane (named sometimes *orbit true latitude*) between a reference plane and the desired location on orbit for the command execution. Because the execution is related to a ground target on Earth's surface the angle to be defined is the one between the instantaneous Earth equatorial plane and the desired position in orbit; in this way the same angle (same command) will correspond to the same ground location (for the same orbit in the repeat cycle) and in any case to same geographical latitude of the sub-satellite point. We express this by saying that OPS commands have to be referred to an Earth Fixed (EF) frame of reference (and therefore to the real equatorial plane of the Earth). Use of EF is therefore the recommended natural, no-error definition, plane for OPS commanding.

There are, however, other XY planes in different frames of reference (see Fig. 1 below) that can be used instead of EF as the origin of the angle: the ***True Of Date*** which is the same as EF but neglecting *polar* motion (and *Earth rotation*) and the ***Geocentric Mean of J2000*** (GM2000) which is the same as EF but neglecting *precession, nutation and polar motion (*and *Earth rotation).* The relationship between the various frames of reference is illustrated in Fig. 2 below.

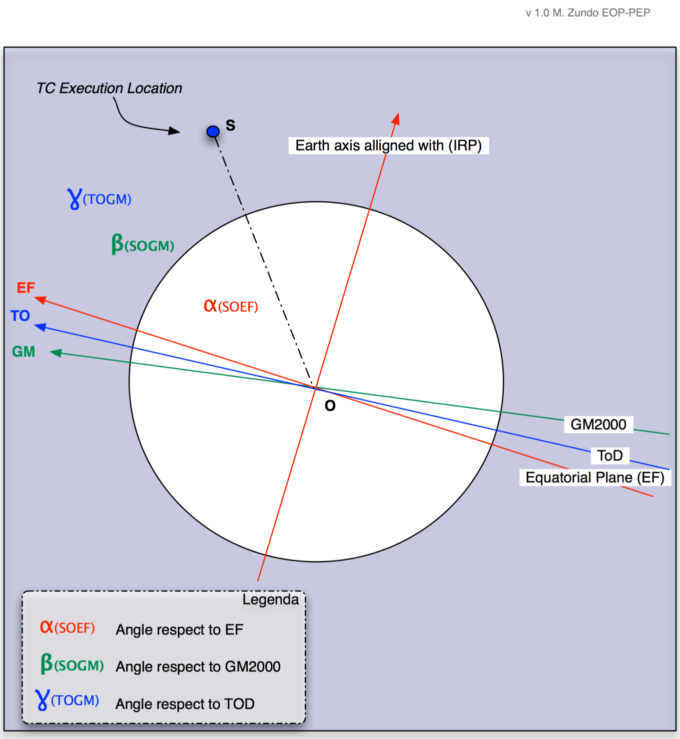

Fig. 1 OPS angle geometry shown in the GM2000 orbital plane.

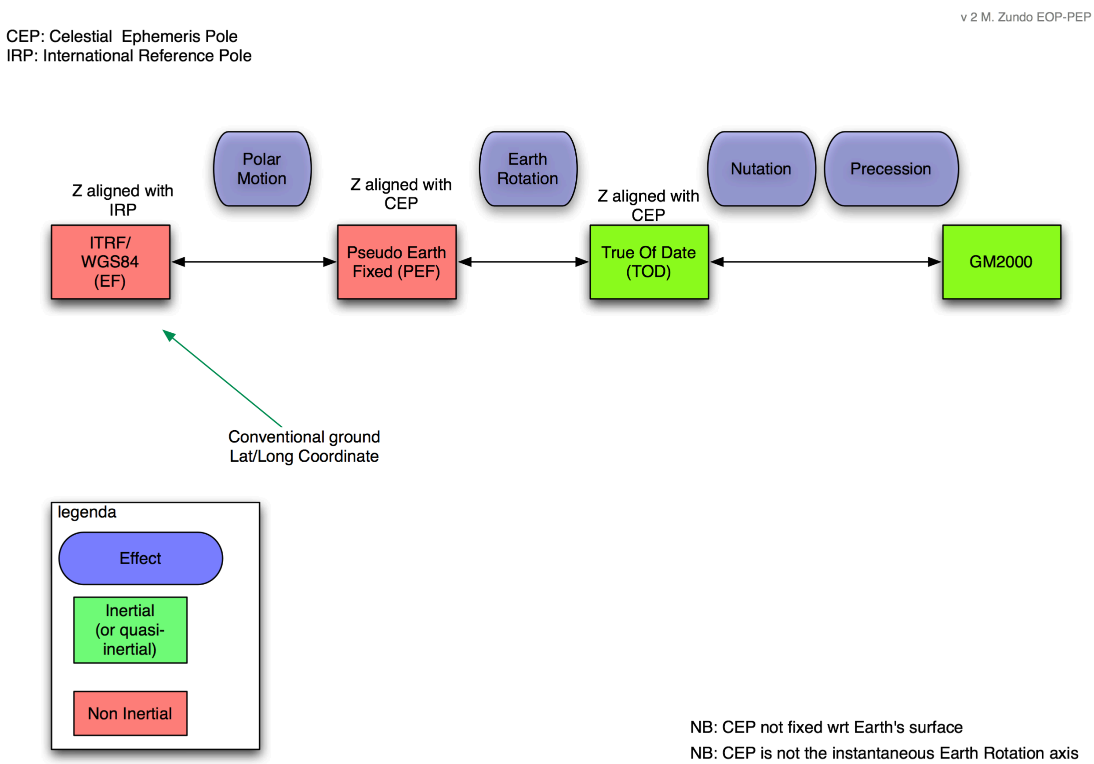

Fig. 2 Relations between Frames of Reference

1.2 Inaccuracies related to various frames of reference

The table below lists, for each frame of reference in which the OPS angle can be defined, the estimated differences in the localisation (and time) of the command execution (assuming perfect orbit = zero dead band).

Reference XY Plane for OPS angle	Ground differences due to XY Plane definition	Time differences due to XY Plane definition
Earth Fixed	0 m	0 s
True Of Date	± 200 m	0.03 s
GM2000	8000 m (in 2010)	1.2 s (2010)

Table 1. OPS angle definition and corresponding errors

2 OPS COMMANDING

2.1 End-to-end accurate implementation

Assuming an OPS angle definition in EF (as it should be), the end-to end typical data flow from calculation on-ground to execution on-board is presented in the Fig. 3 below.

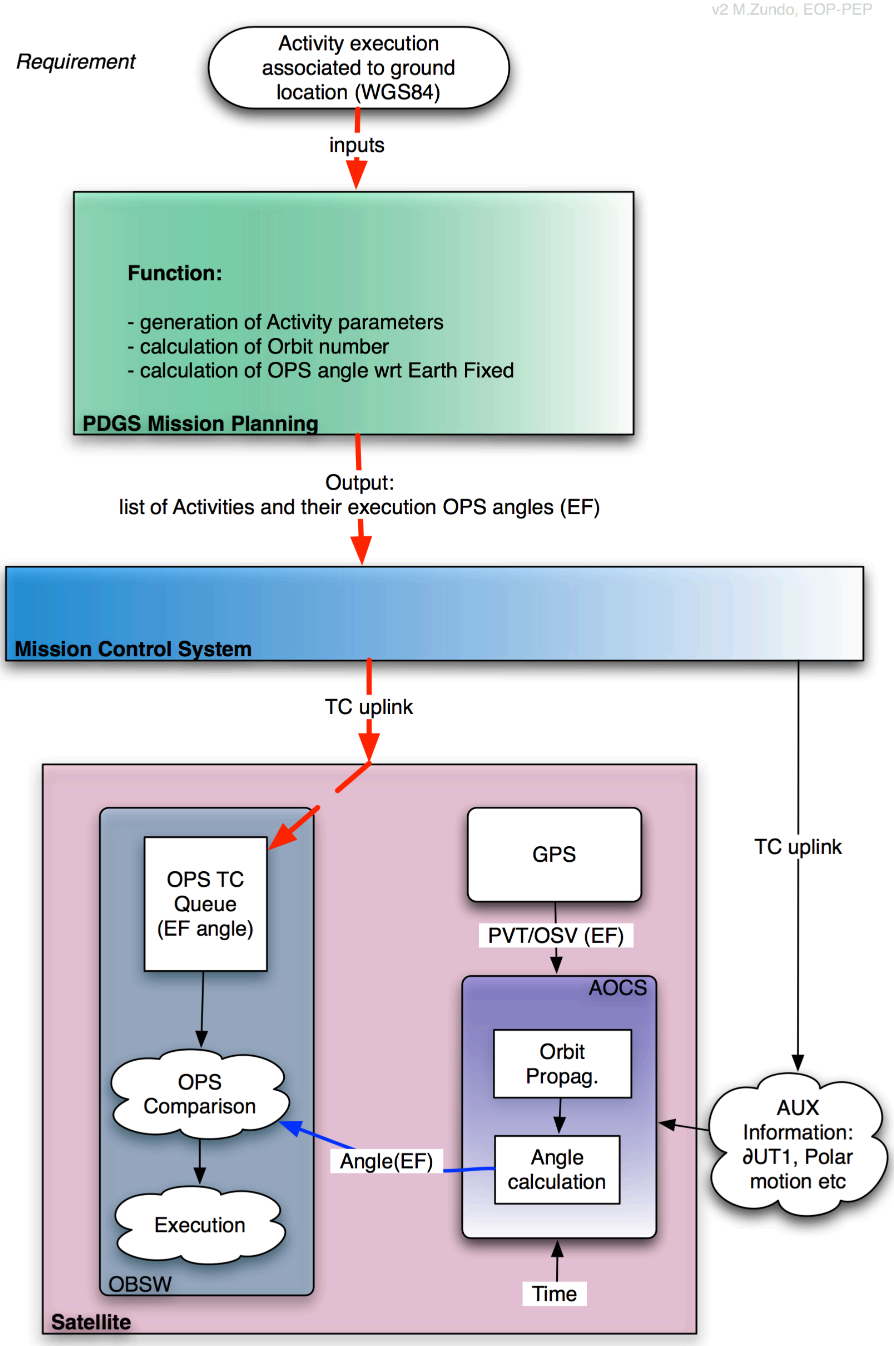

Fig 3. OPS angle end-to-end flow

Note that some missions do not implement an OPS angles comparison on-board but converts OPS angle into times, then compare times, however the same principle regarding accuracy depending on the selected frame (and neglected effect) applies.

The suggested ideal steps are as follows:

1. Ideally, we should plan in PDGS using EF to perfectly match the location of execution of each TC.
2. The OPS timeline is uplinked on-board and OPS angles are expressed in EF frame.
3. GPS orbit position data (OSV) on-board are in EF and are provided to AOCS.
4. The AOCS internally converts the EF OSVs to inertial (GM2000) frame, propagate the orbit, do any necessary filtering and compute the angle in the inertial orbital plane wrt the GM2000 XY plane.
5. The AOCS convert this angle to EF and send them to OBSW
6. The OBSW can do a perfect comparison (or conversion to time) with the pending OPS command in the queue staying in Earth-Fixed

Note: The AOCS propagator and filters normally work in inertial frame (GM2000) since this is the best frame for orbit propagation and attitude control, but can perform conversion to EF frame using precession, nutation and polar motion (and Earth rotation).
Note 2: To achieve very accurate conversion between GM2000 and EF reference frames, regular update on-board of non-deterministic earth parameters is needed (DUT1 and polar motion angles, daily available from the IERS Bulletin A)

Additional sources of inaccuracy in the end-to-end chain could also be:

1. attempts to pre-compensate on-ground (e.g. in the Mission Planning) for the expected behaviour or definition on-board (e.g. compute angle in EF on-ground then compute the expected difference between EF and GM2000 at the time of command execution adding it to the angle before uplink)
   ⇨ to be avoided

2. conversions between the different frames performed *on-ground* which are different from the one performed *on-board* (e.g. different precession, nutation, polar motion parameters as applicable).
   ⇨ to be avoided

3. the reference orbit is not perfectly flown but within a *dead-band*.
   ⇨ cannot be avoided

2.2 Checklist for each mission

In order to estimate how accurate the end-to-end implementation for each mission using OPS commanding is, the following points need to be checked:

1- does the PDGS Mission Planning use the EF equatorial plane to compute the OPS angles ?

2- does the GPS device on-board provide orbit positions to the AOCS in EF ?

3- does the AOCS/OBSW convert the orbit position to GM2000 ? Using up-to-date earth parameters for best accuracy ? If yes, how often are the Earth parameters updated ?

4- does the AOCS/OBSW convert back the propagated orbit position to EF, in order to compute the OPS angles using the EF equatorial plane and the inertial GM2000 orbital plane ?

If any of the answers to those questions is no, inaccuracies will result. It will then be necessary to assess if they are acceptable, or take measures to correct them.