Comparison between DORIS oscillators on Jason satellites in term of radiation sensitivity

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JASON-2 with T2L2 & CARMEN-2: an opportunity to study radiation effects

DORIS oscillator (USO):
- is the on-board time & frequency reference for a constellation of satellites
- provides the quality of the Doppler effect (0.3 mm/sec \( \sim df/f_0 = 10^{-12} \)) measurement over 10 sec (linearity over 1200 sec ?)

- historical significance of this technology:
  ITRF ref. frame solutions, precise orbit determination, on-board navigation, Earth observing satellites (altimetry)

USOs were improved upon time; Jason-2 (2008) was equipped with a new DGXX model (pre-exposed to radiation)

T2L2 /Jason-2: showed, as a time transfer space instrument (based on laser ranging), a great stability to «read» the oscillator up to a few \( 10^{-13} \)

Carmen-2 /Jason-2: particle flux measurements (p+, e-): 1->300 MeV
Frequency-time-influence behavior

\[ \frac{\Delta f}{f} \times 10^8 \]

Temperature Step  Vibration  Shock  Oscillator Turn Off & Turn On  2-g Tipover  Radiation

Off  On

Short-Term Instability  Aging

Vig, J.R.

IDS Workshop, October, 31 2016, La Rochelle France
### DORIS USO (a priori)

<table>
<thead>
<tr>
<th>Effects</th>
<th>Frequency Bias 10(^{+})–12</th>
<th>Time Period</th>
<th>Sources</th>
<th>T2L2 / DORIS</th>
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<td>Noise</td>
<td>0.35</td>
<td>10 s à 100 s</td>
<td>Auriol &amp; Tourain 2010</td>
<td>DORIS</td>
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<td>Global drift</td>
<td>&lt; 10.0 / day</td>
<td>Long term</td>
<td>Guillemot et al. 2009</td>
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<td>Temperature</td>
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<td>Orbit (113 min) to 60 days</td>
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<td>T2L2 (short term) DORIS &amp; T2L2 (Long term)</td>
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<td>Radiations</td>
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DORIS USO and radiations

USO’s and high energy particle flux ( > 85 MeV with radiation shielding)

Radiation affected:
Jason-1 [Willis, Lemoine & Capdeville], SPOT-5 [Stepanek], and Jason-2 [Belli, Willis]

Radiation environment and its effects on devices: SAC-C/D satellites (<800km) and Jason-2 (ICARE-NG, >1300km) [Boscher, Bourdarie, Lorfevre]

Studies were conducted at ground level: space agencies, laboratories and manufacturers ([Galliou, Cibiel, Bezerra & Lorfevre] identified the relevance of:

- platform (attitude and mass/position of devices), orbit (inclination and altitude)
- SAA area (shape & flux), solar flux and geomagnetic activity
- USO: mass, surface, temperature, absorption, sensitivity (df/rad)
## DORIS USO (radiations)

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<th>30</th>
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</table>

**Engineering table, in rad/yr**

- [Jason SPOT] [CNES, Auriol,Escoffet et al.]

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Proton flux, our CALibration => 206 rad/month

[Lemoine & Capdeville 2006; Lorfevre et al. 2009]
Frequency bias: time periods & effects

Long term: > several months/years
- drift
- aging + radiations

Mean term: 30-90 days
- attitude law (59 days)
- temperature + radiations*

Short term: 0.01-1 day
- orbital period
- temperature + SAA passes

USO: $\frac{df}{f_0}$
- $1-1.2 \times 10^{-12}$ (~ 0.3 mm/s)

MOE / POE
- id. (on board)

DIODE
- $3.1 \times 10^{-13}$ at 1000 sec

T2L2
- $3.1 \times 10^{-13}$ at 1000 sec
Long term: > several months/years  → global drift
Mean term: 30-90 days  → attitude law (59 days)
Short term: 0.01-1 day  orbital period

Days from the beginning of the mission:
-0.0005
0
0.0005
0.001
0.0015

$D_f / f (10^{-9})$

Radiations model, $(D_f / f)$

Mean term: 30-90 days: attitude law (59 days)

Short term: 0.01-1 day: orbital period
\[ \frac{\delta f}{f_0} = a T + b T^2 + c T^3 \]

**Jason-2 & -3**

**J2:10°**

**J3:3°**

\[ dT: 2° \Rightarrow dF: -2.510^{-12} \]
DORIS USO (/Jason-2 modelling)

\[ \delta f / f_0 \text{ (total)} \]
10-day model

Belli et al.

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USO short-term: Time transfer in non-CV

Jason-2 pass over North Atlantic
DORIS USO T2L2 data -> Jason-2

59 days

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Basic assumptions in favor of radiation:
- df is positive during 10d
  - after, a relaxation period
- attitude -> yaw fixed:
  - angles of OY axis relative to the magnetic field
  - decreasing over several years

Temperature is not possible: no aging, df=-dT, signature « M », effect 10 times lower, acceleration, magnetism, vibration, etc. (to small, CNES studies)

DORIS USO: mean term (-> radiations)

df: 2-3. $10^{-11}$ / 10 days
DORIS USO (mean-term modelling)

Mean-term modelling of the frequency response to radiation exposure during the yaw fixed period -> RMS: 0.02 $10^{-11}$
Frequency variations of J3 are >> the ones of J2 in 2016 but not in 2008

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Due to aging process:

USO’s should be compared at the same age!

Rather than at the same period

Even if each USO is going to be used for space geodesy at the same time.
DORIS USO (J3 modelling)

J3 model: same as J2 (temperature, aging and radiation), but the sensitivity df/rad is greater (>2)
dF from MOE ephem.
CONCLUSIONS

We studied the USO frequency response to radiation exposure over short, mean and long terms.

For one energy level (100MeV), we indentified several time dependencies:
short term -> SAA pass,
mean term -> 10d yaw-f,
long term -> memory effect + aging = global drift

Similar behavior of J2 and J3, but 2.5 times greater for J3 (at same age !)
J2 df: ±2.10^{-12} whereas J3 df: ±5.10^{-12}

Futur developments:
Precisely adjust some empirical coeff. for a USO model /Jason-3

Understanding the role of geomagnetic acitivity and solar flux (SAA flux is not constant and the are is moving 0.3°w /yr

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