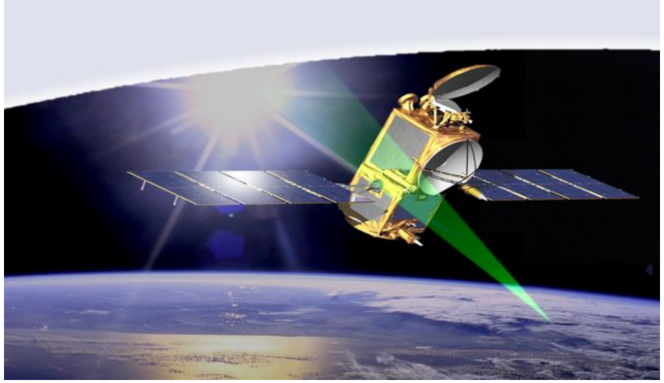
Comparison between DORIS oscillators on Jason satellites in term of radiation sensitivity

Alexandre Belli[1,2], *Pierre Exertier*[1], Hugues Capdeville[3]

[1] : Géoazur/CNRS 250 Rue Albert Einstein 06560 Valbonne, France
[2] : Université Franche Comté, UTINAM, France
[3] : Collecte Localisation Satellites, 11 rue Hermès, 31520 Ramonville Saint-Agne, France



IDS Workshop, October, 31 2016, La Rochelle France

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 ~ $df/f_0=10^{-12}$) measurement over 10sec (linearity over 1200 sec ?)

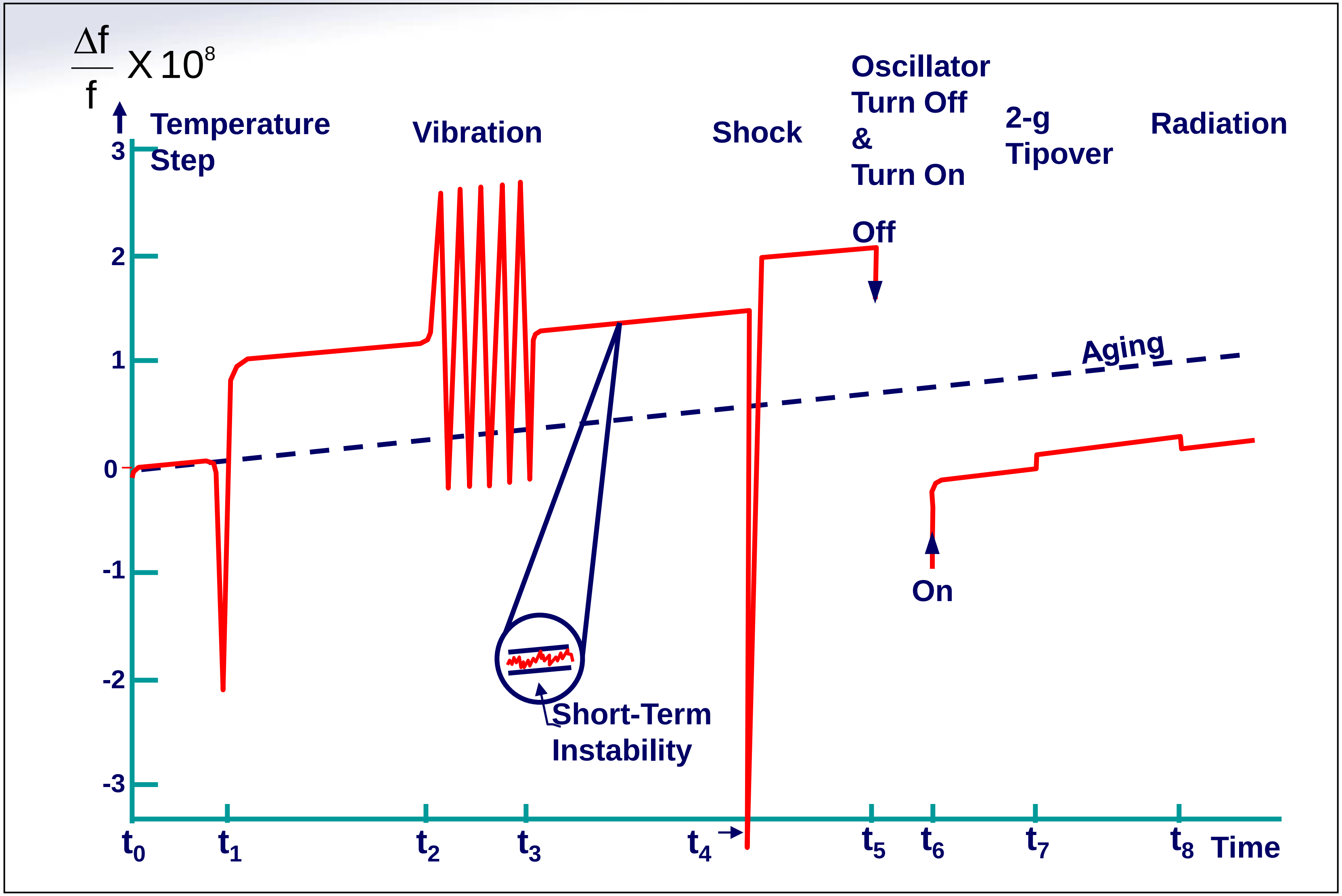
-> historical significance of this technology:
ITRF ref. frame solutions, precise orbit determination, on-board navigation, Earth observing satellites (altimetry)

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



Vig, J.R.

DORIS USO (*a priori*)

Effects	Frequency Bias 10↑−12	Time Period	Sources	T2L2 / DORIS
Noise	0.35	10 s à 100 s	*Auriol & Tourain 2010*	DORIS
Global drift	< 10.0 / day	Long term	*Guillemot et al. 2009*	DORIS & T2L2
Temperature	-0.65 /°C	Orbit (113 min) to 60 days	*Galliou et al. 2007*	T2L2 (short term) DORIS & T2L2 (Long term)
Radiations	6.7 / rad	~20 min to long term	*Lefèvre et al. 2009*	T2L2 (short term) DORIS & T2L2 (Long term)
Relativity	0.1-0.2	Orbit (113 min)	*Petit & Wolf 1994*	T2L2
Total Drift	< 22.0 / day	Long term		DORIS & T2L2

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***]**

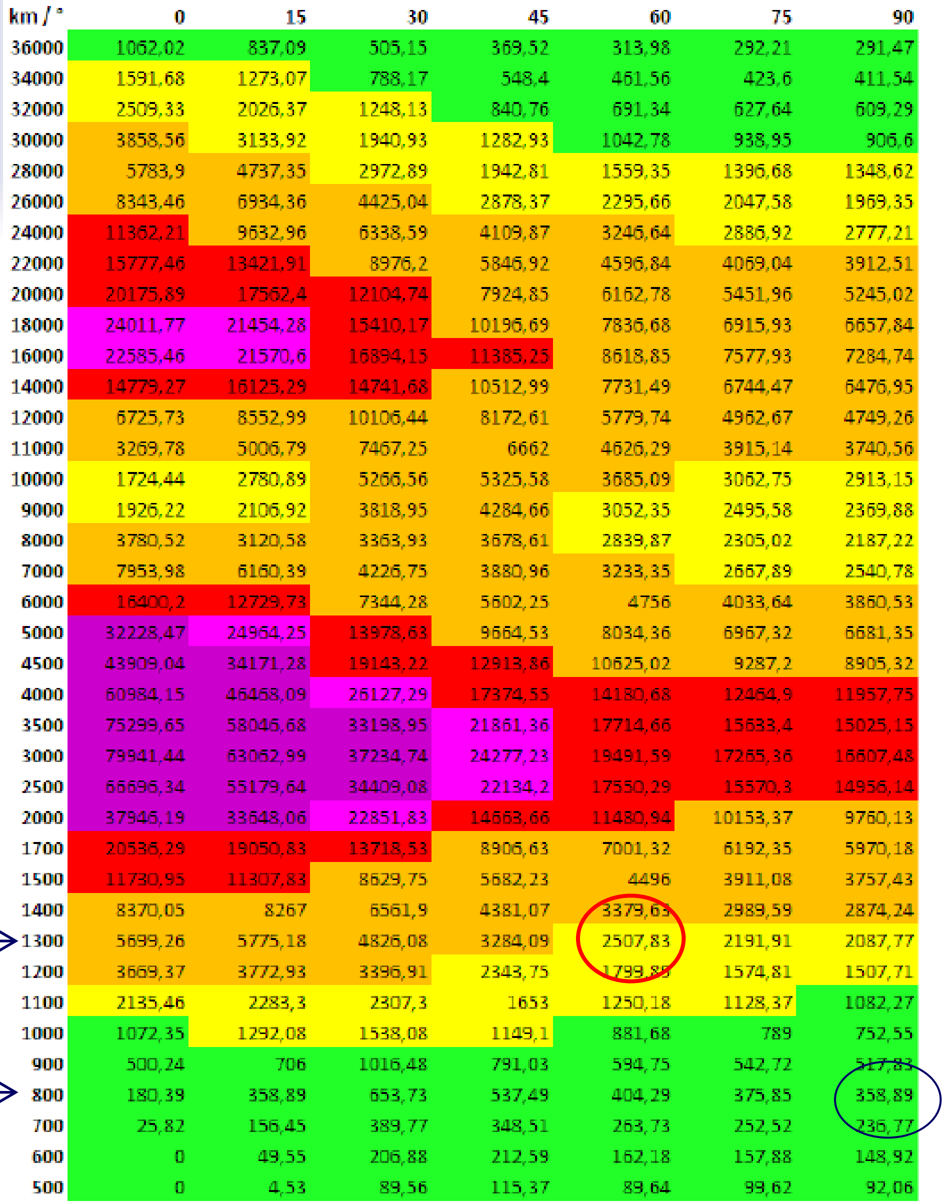
Radiation environment and its effects on devices: SAC-C/D satellites (<800km) and Jason-2 (ICARE-NG, >1300km) [*Boscher,Bourdarie,Lorfevre***]**

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

- plaform (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)

Engineering table, in rad/yr



km / °	0	15	30	45	60	75	90
36000	1062,02	837,09	505,15	369,52	313,98	292,21	291,47
34000	1591,68	1273,07	788,17	548,4	461,56	423,6	411,54
32000	2509,33	2026,37	1248,13	840,76	691,34	627,64	609,29
30000	3858,56	3133,92	1940,93	1282,93	1042,78	938,95	906,6
28000	5783,9	4737,35	2972,89	1942,81	1559,35	1396,68	1348,62
26000	8343,46	6934,36	4425,04	2878,37	2295,66	2047,58	1969,35
24000	11362,21	9632,96	6338,59	4109,87	3246,64	2886,92	2777,21
22000	15777,46	13421,91	8976,2	5846,92	4596,84	4069,04	3912,51
20000	20175,89	17562,4	12104,74	7924,85	6162,78	5451,96	5245,02
18000	24011,77	21454,28	15410,17	10196,69	7836,68	6915,93	6657,84
16000	22585,46	21570,6	16894,15	11385,25	8618,85	7577,93	7284,74
14000	14779,27	16125,29	14741,68	10512,99	7731,49	6744,47	6476,95
12000	6725,73	8552,99	10106,44	8172,61	5779,74	4962,67	4749,26
11000	3269,78	5006,79	7467,25	6662	4626,29	3915,14	3740,56
10000	1724,44	2780,89	5266,56	5325,58	3685,09	3062,75	2913,15
9000	1926,22	2106,92	3818,95	4284,66	3052,35	2495,58	2369,88
8000	3780,52	3120,58	3363,93	3678,61	2839,87	2305,02	2187,22
7000	7953,98	6160,39	4226,75	3880,96	3233,35	2667,89	2540,78
6000	16400,2	12729,73	7344,28	5602,25	4756	4033,64	3860,53
5000	32228,47	24964,25	13978,63	9664,53	8034,36	6967,32	6681,35
4500	43909,04	34171,28	19143,22	12913,86	10625,02	9287,2	8905,32
4000	60984,15	46468,09	26127,29	17374,55	14180,68	12464,9	11957,75
3500	75299,65	58046,68	33198,95	21861,36	17714,66	15633,4	15025,15
3000	79941,44	63062,99	37234,74	24277,23	19491,59	17265,36	16607,48
2500	66696,34	55179,64	34409,08	22134,2	17550,29	15570,3	14956,14
2000	37946,19	33648,06	22851,83	14663,66	11480,94	10153,37	9760,13
1700	20536,29	19050,83	13718,53	8906,63	7001,32	6192,35	5970,18
1500	11730,95	11307,83	8629,75	5682,23	4496	3911,08	3757,43
1400	8370,05	8267	6561,9	4381,07	3379,63	2989,59	2874,24
1300	5699,26	5775,18	4826,08	3284,09	2507,83	2191,91	2087,77
1200	3669,37	3772,93	3396,91	2343,75	1799,85	1574,81	1507,71
1100	2135,46	2283,3	2307,3	1653	1250,18	1128,37	1082,27
1000	1072,35	1292,08	1538,08	1149,1	881,68	789	752,55
900	500,24	706	1016,48	791,03	594,75	542,72	517,83
800	180,39	358,89	653,73	537,49	404,29	375,85	358,89
700	25,82	156,45	389,77	348,51	263,73	252,52	236,77
600	0	49,55	206,88	212,59	162,18	157,88	148,92
500	0	4,53	89,56	115,37	89,64	99,62	92,06

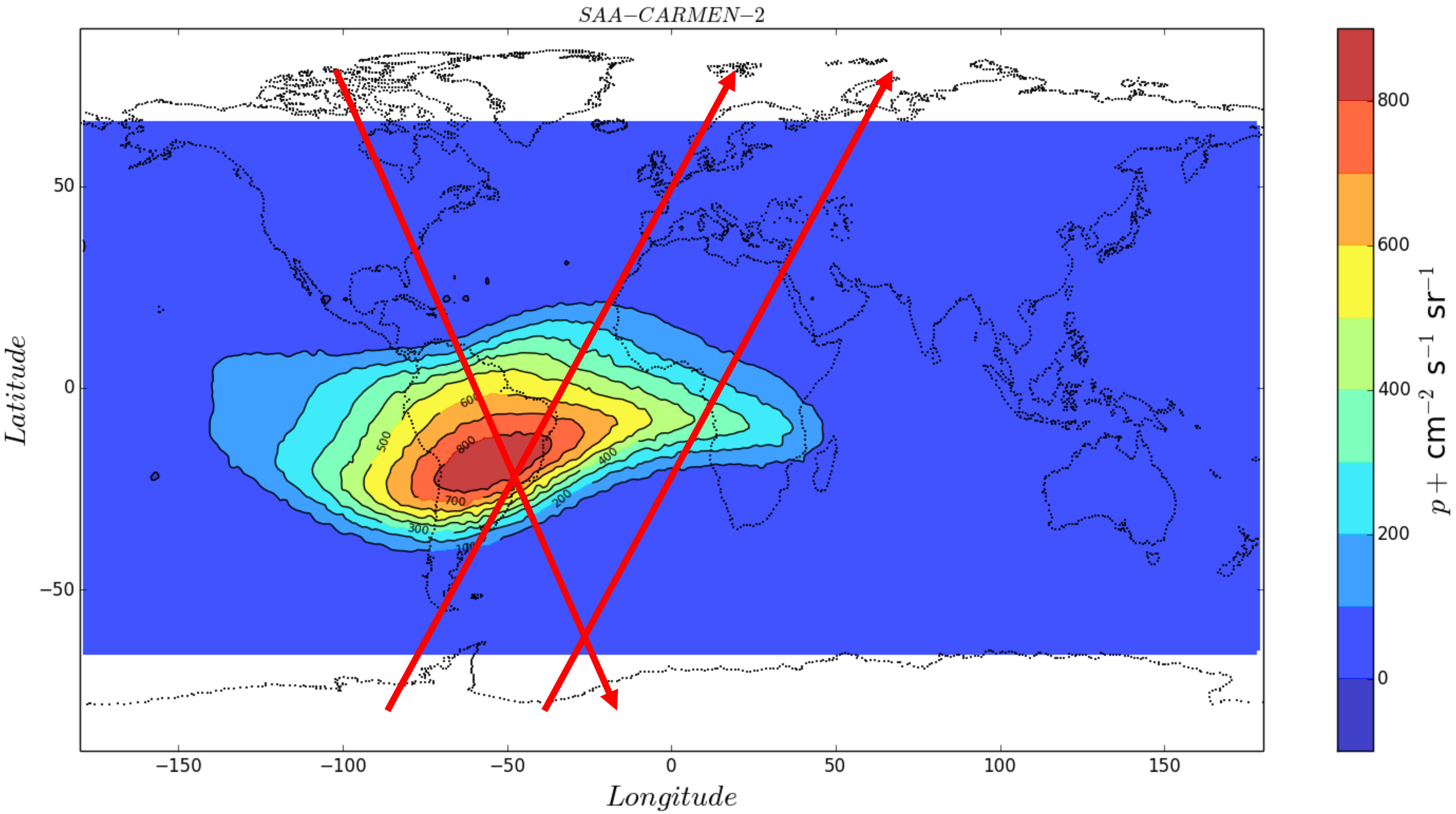
Jason → 1300

SPOT → 800

🟩 < 1 krad / year
🟨 1-3 krad / year
🟧 3-10 krad / year
🟥 10-20 krad / year
🟪 20-30 krad / year
🟪 > 30 krad / year

[CNES, Auriol,Escoffet et al.]

Space environment (SAA): Carmen-2 /J2



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**

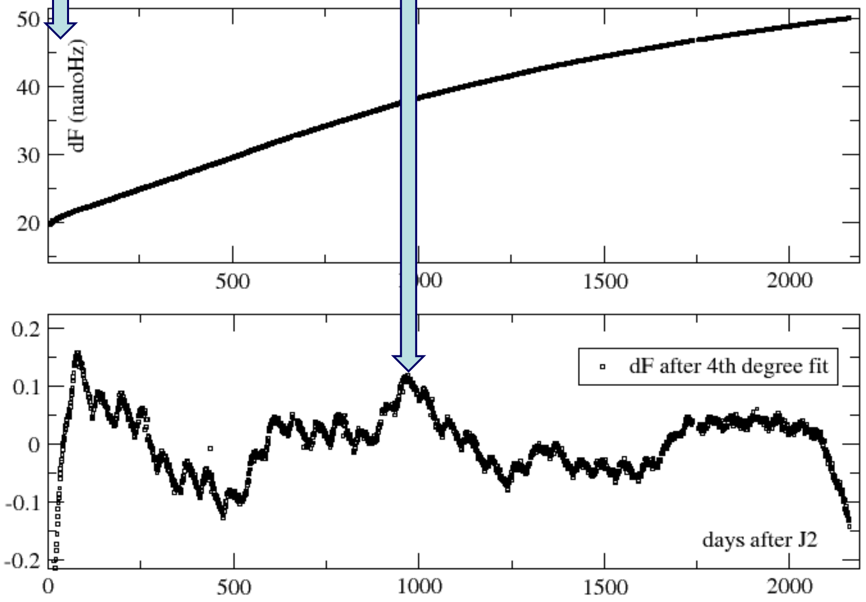
	USO : df /f_0
MOE / POE	1-1.2 10^{-12} (~ 0.3 mm/s)
DIODE	id. (on board)
T2L2	3. 10^{-13} at 1000 sec

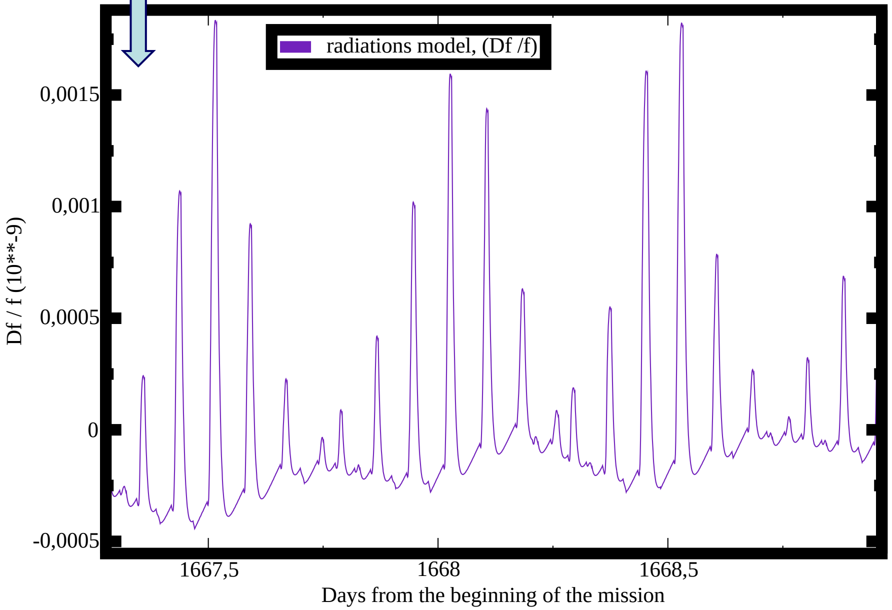
DORIS USO

Long term : > several months/years -> global drift

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

Short term : 0.01-1 day orbital period





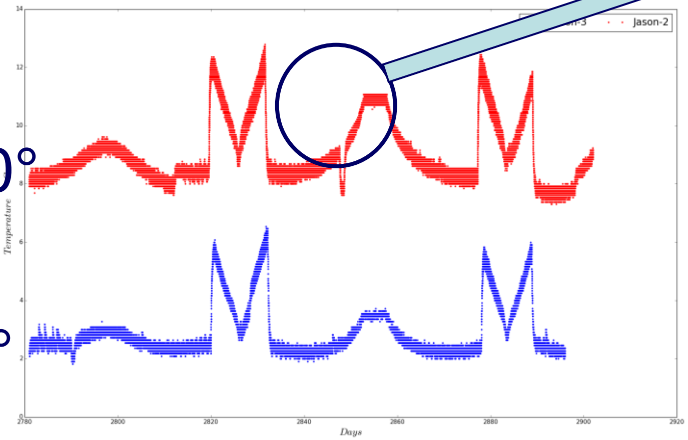
DORIS USO (temperature)

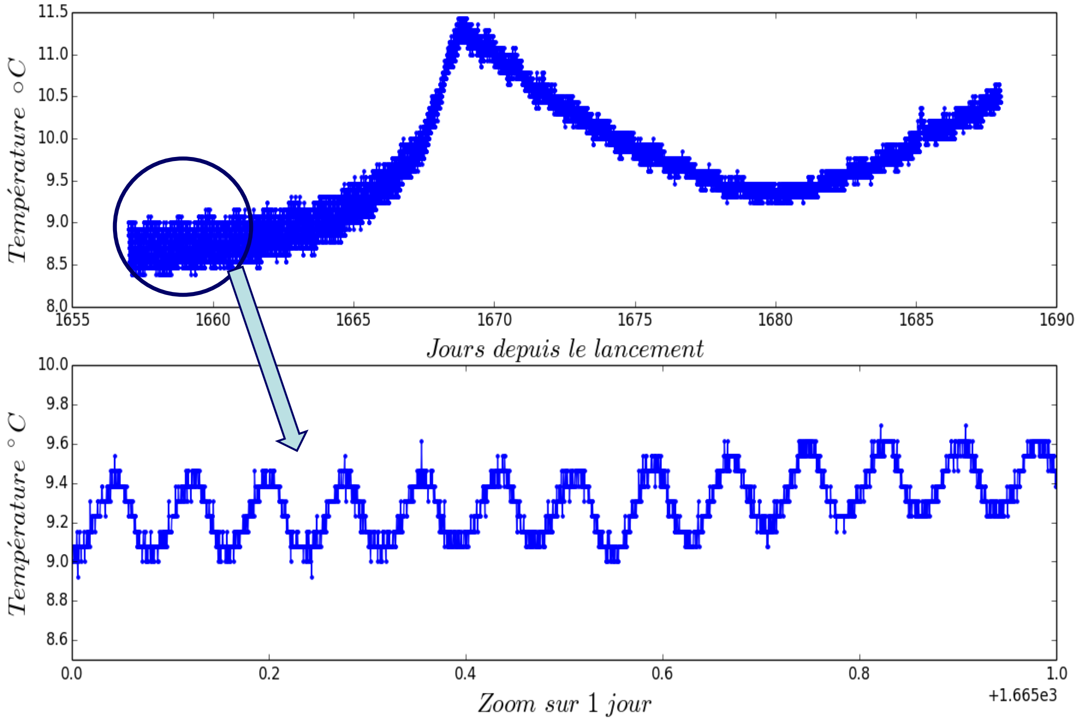
$$\delta f / f_0 = a\,T + b\,T^2 + c\,T^3$$

Jason-2 & -3

J2:10°

J3:3°



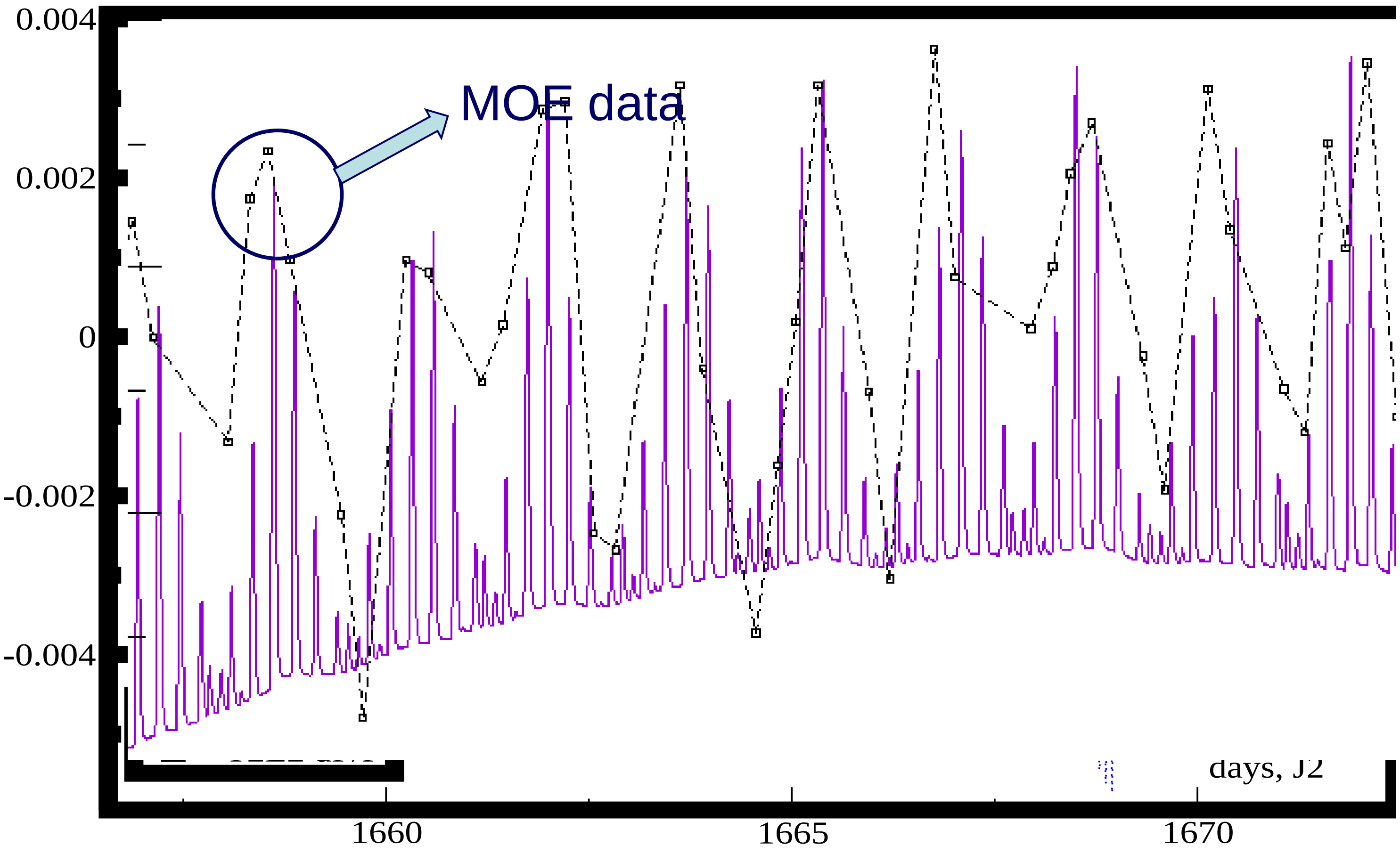


dT: 2° => dF: -2.510^{-12}

DORIS USO (/Jason-2 modelling)

$\delta f / f_0$ *(total)*
10-day model

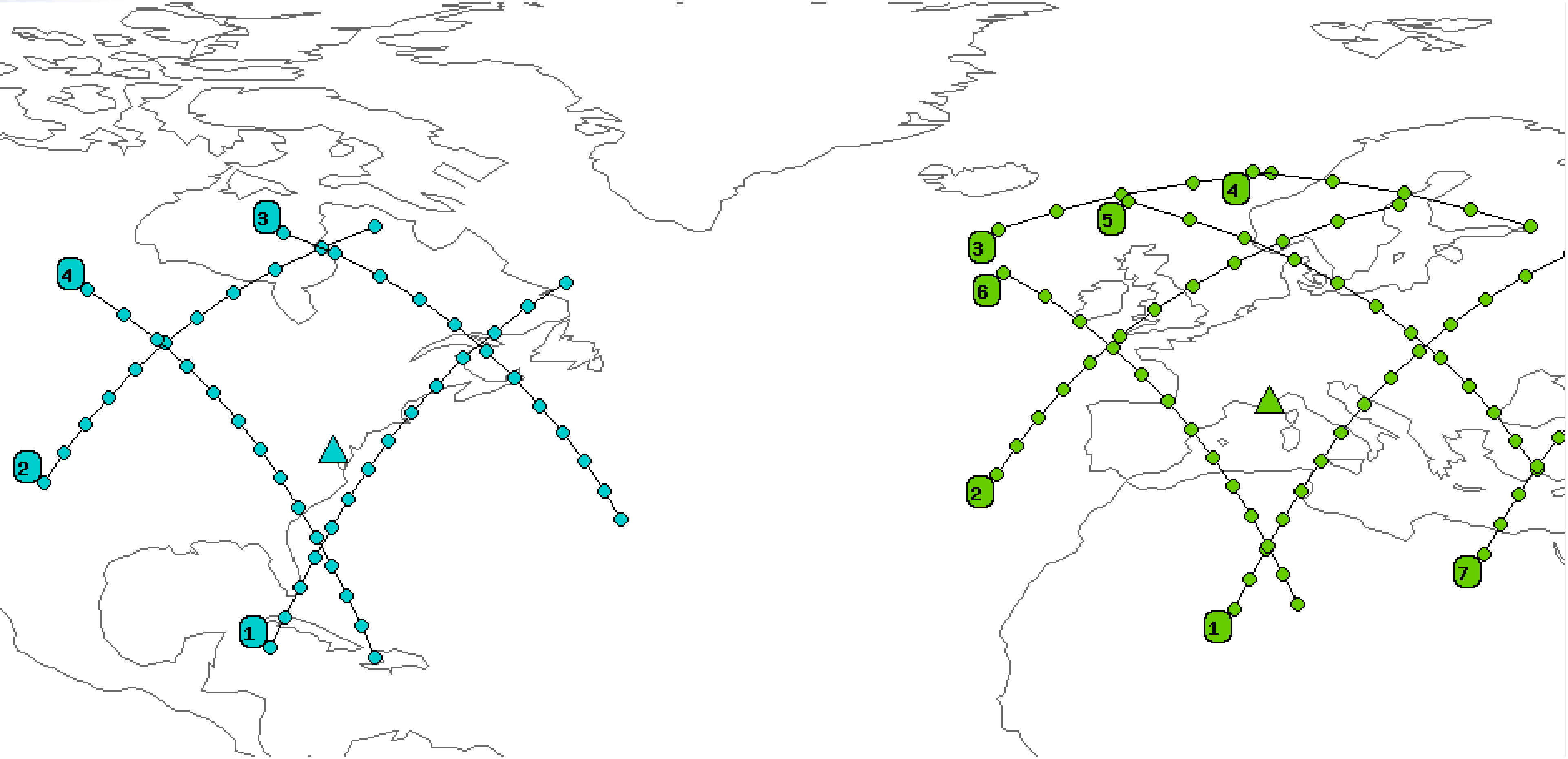
Belli et al.



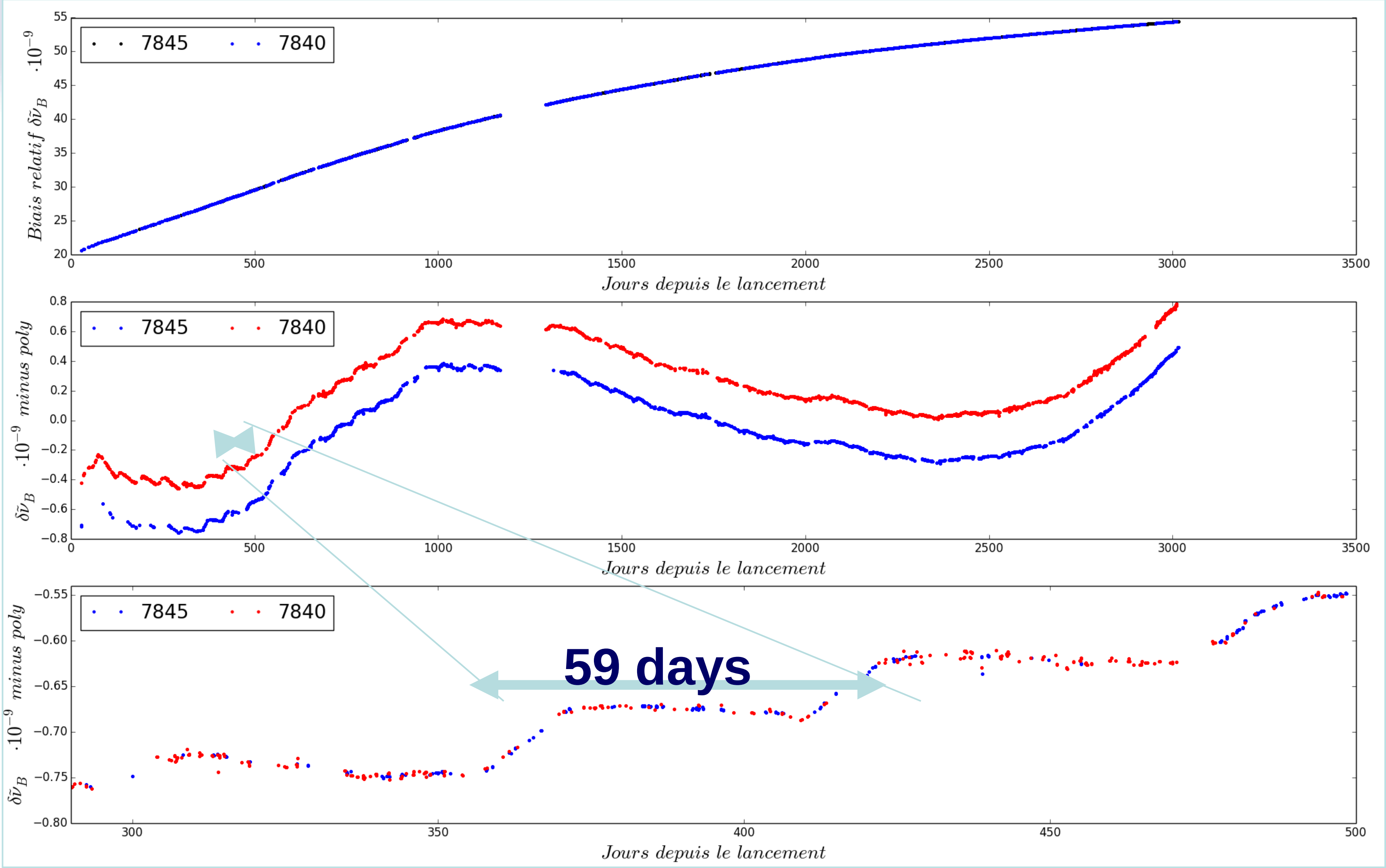
2013

USO short-term: Time transfer in non-CV

Jason-2 pass over North Atlantic



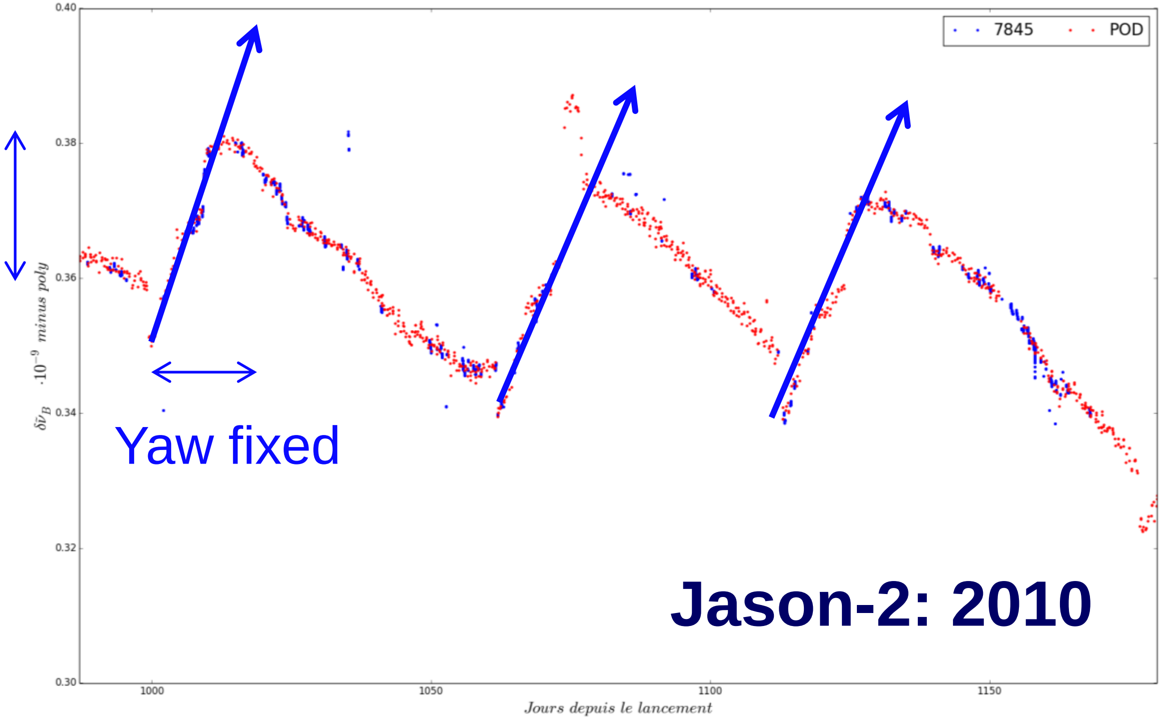
DORIS USO T2L2 data -> Jason-2



IDS Workshop, October, 31 2016, La Rochelle France

DORIS USO: mean term (-> radiations)

df: 2-3. 10^{-11} / 10 days



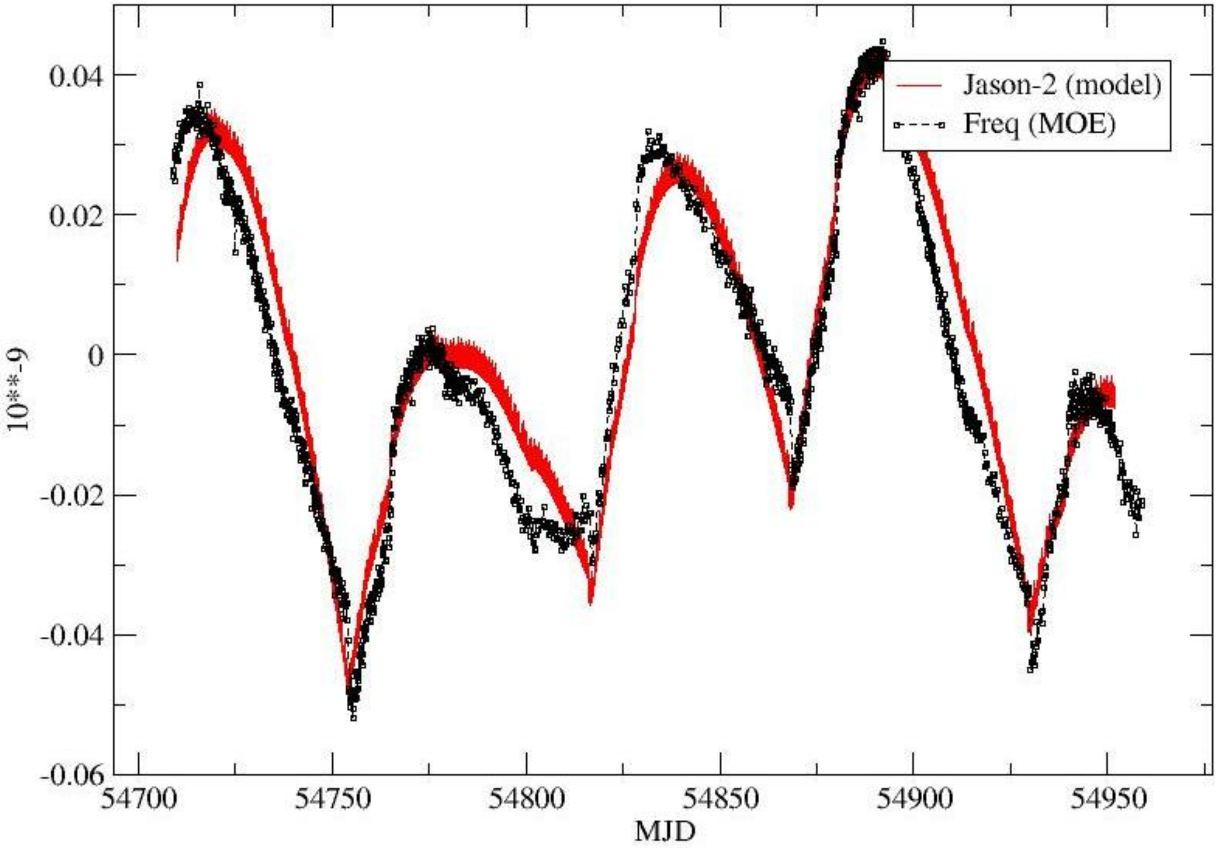
Yaw fixed

Jason-2: 2010

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)

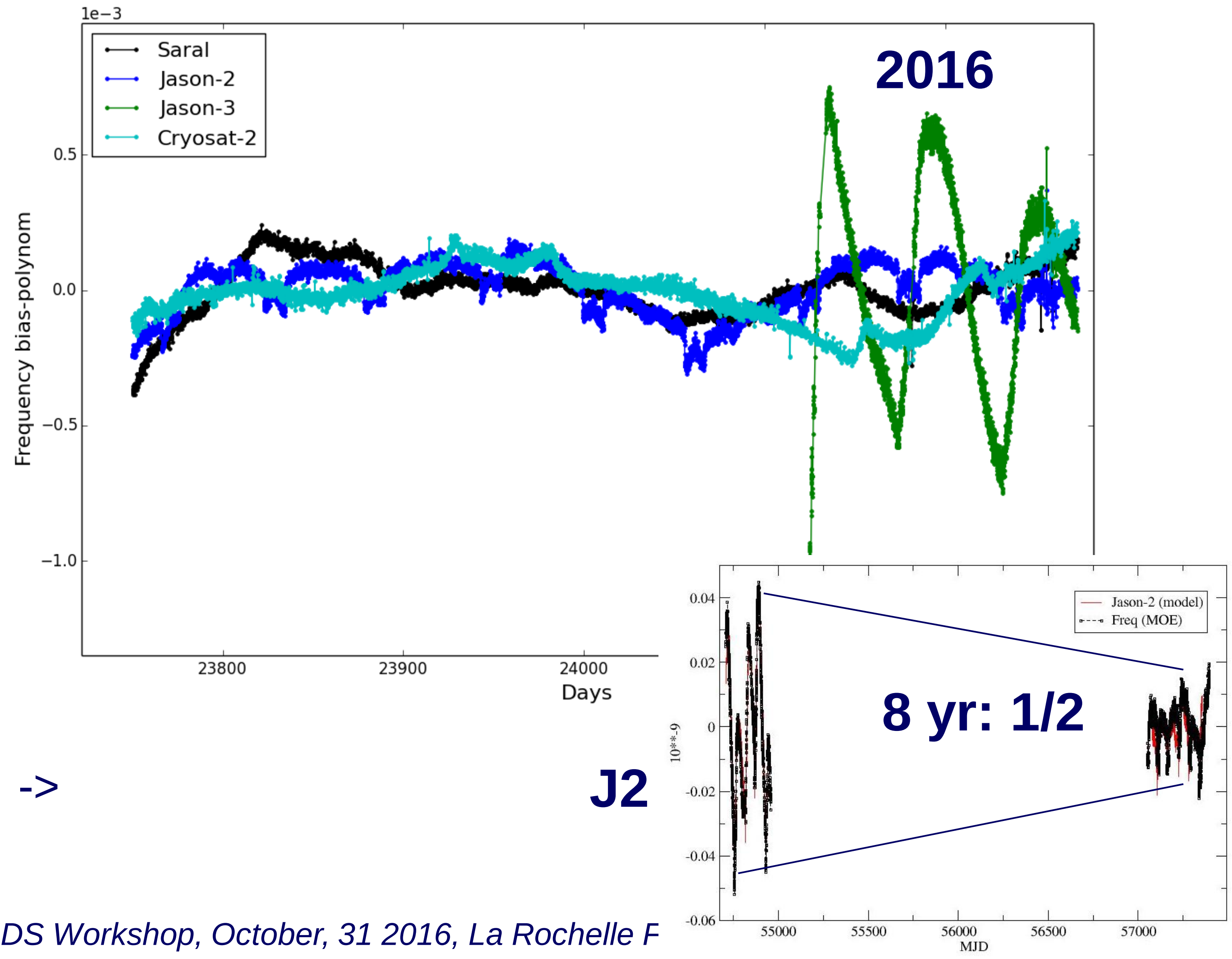
DORIS USO (mean-term modelling)



Mean-term modelling
of the frequency response

to radiation exposure during the yaw fixed period -> RMS: 0.02 10^{-11}

DORIS USO (freq. bias): long term



2016

8 yr: 1/2

J2

Frequency variations of
J3 are >>
the ones of J2
in 2016 but not in 2008

->

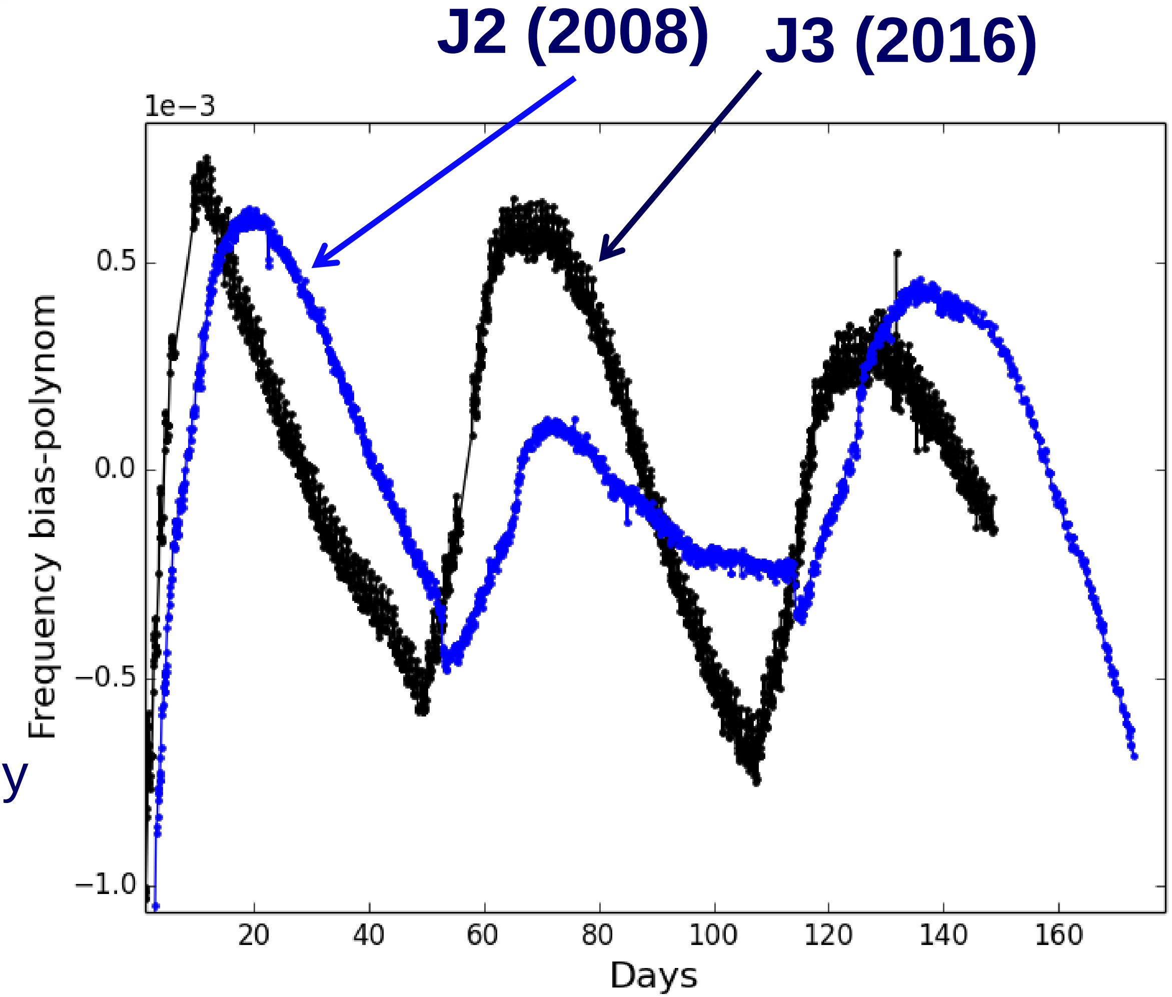
DORIS USO: Jason-2 & Jason-3

Due to aging process:

USO’s should be compared
at the same age !

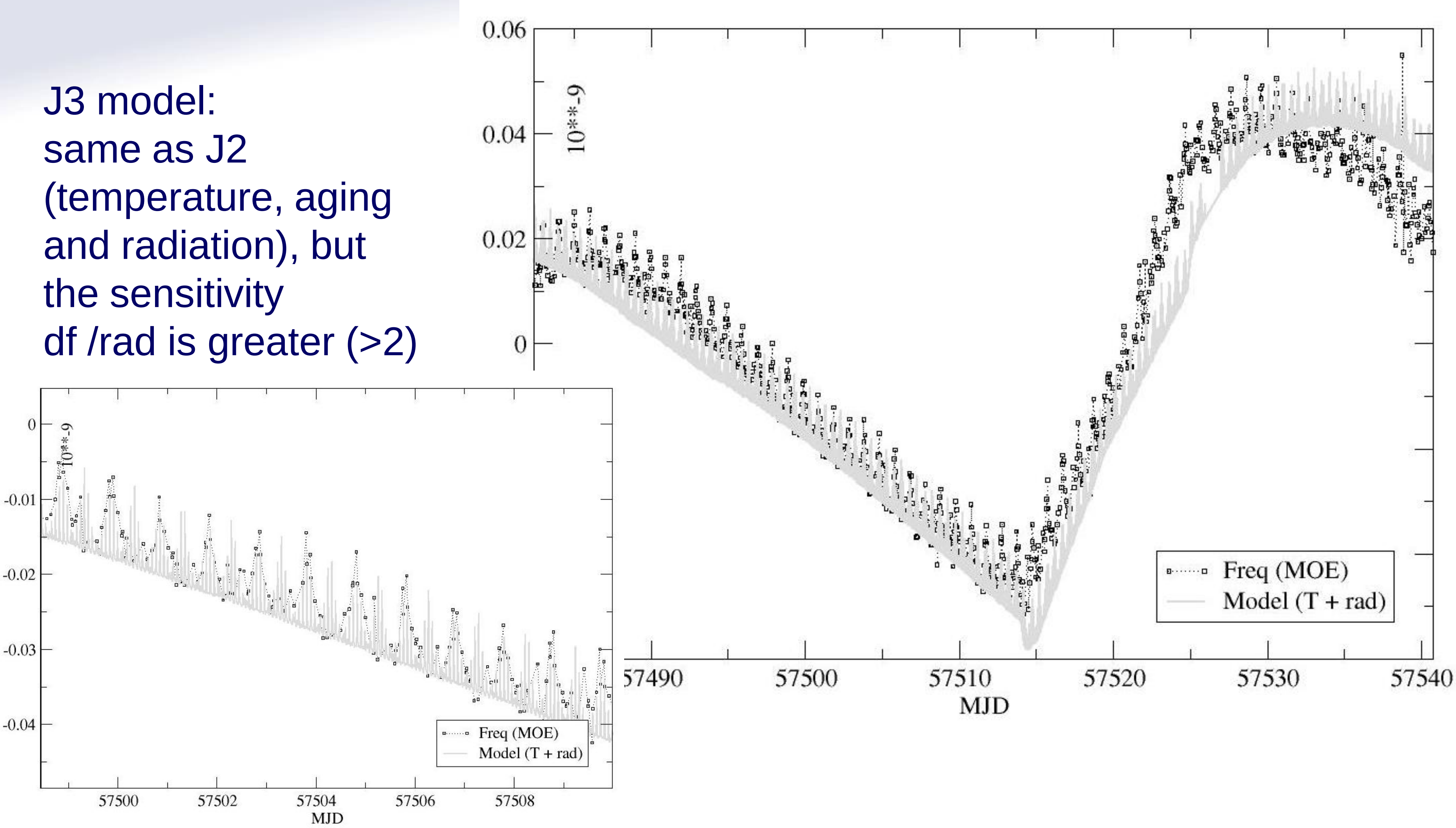
Rather than at the same
period

Even if each USO is going
To be used for space geodesy
At the same time



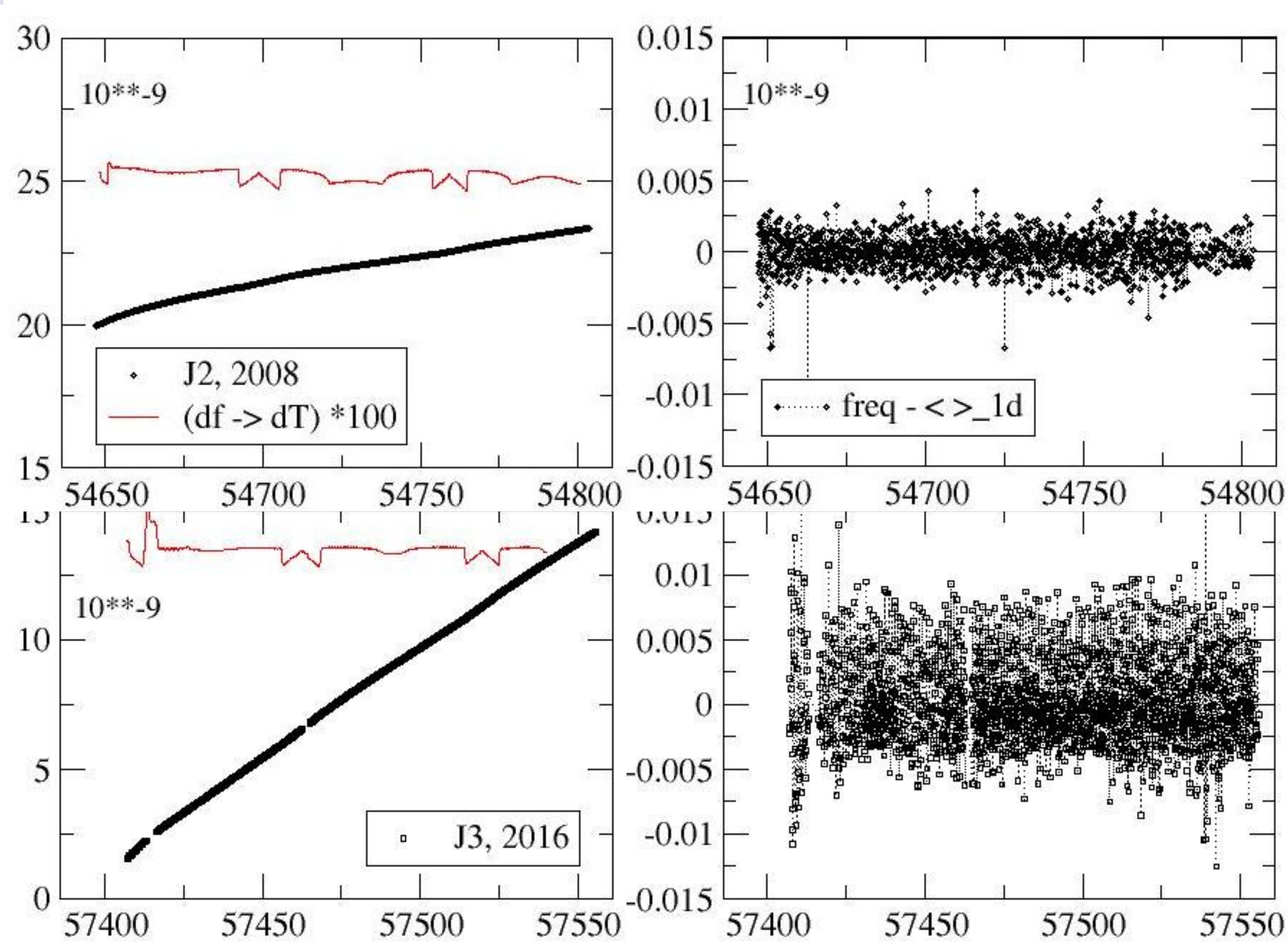
DORIS USO (J3 modelling)

J3 model:
same as J2
(temperature, aging
and radiation), but
the sensitivity
df /rad is greater (>2)



DORIS USO: Jason-2 // Jason-3

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: $\pm 2.10^{-12}$ whereas J3 df: $\pm 5.10^{-12}$

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