Preprocessing of Doris phase data for Doppler solutions and low elevation measurements

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Objective

Improvement of the preprocessing for low elevation measurements (5 degrees)

Remark : an elimination based on Doppler residuals is probably not a good approach
because it interrupts the continuity of the phase
(like having 2 ambiguities to adjust instead of 1)

The measurement elimination must produce the best possible phase continuity

→

avoid unnecessary interruptions
(for example a too conservative elimination based on Doppler measurement noise)

improve the processing for high elevation measurements
currently eliminated with the flag ' low Doppler measurements'

reconstruct if possible some cycle slips occuring at high elevation
(observed on Jason 2, see '*Jason-2 DORIS phase measurement processing, JASR 2010*')

Examples and formulation

Example : mean frequency estimation

estimation of the mean frequency for a pass, taking into account the phase noise only

(unmodelled USO error : implies more complex correlations between the measurements)

phase variations over 10 s

phase measurement noise σ_x

$$y_{k+1} = x_{k+1} - x_k$$

Mean frequency estimation over a pass, with Doris standard processing (using phase variations) :

$$f = \frac{1}{n}\sum_{1}^{n} y_k$$

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$$f = \frac{1}{n}\sum_{1}^{n} y_k = \frac{x_n - x_0}{n}$$

error on f : $\frac{\sqrt{2}}{n}\sigma_x$

→ Effect of the elimination of one y_k measurement ?

Example : mean frequency estimation, Doppler measurement elimination

$$f = \frac{1}{n}\sum_{1}^{n} y_k = \frac{x_n - x_0}{n}$$

error on f : $\frac{\sqrt{2}}{n}\sigma_x$

If a Doppler measurement is eliminated (except for the ends of the interval) the estimation error is worse (40% error increase for one elimination):

$$f = \frac{1}{n-1}\sum_{1,k\neq k_0}^{n} y_k = \frac{x_n - x_{k_0} + x_{k_0-1} - x_0}{n-1}$$

error on f : $\frac{2}{n-1}\sigma_x$

→ If there is no cycle slip, it is better to have the complete continuity even if the measurement noise is important

1 cycle slip : 14.7 cm (2 GHz), 74.7 cm (400 MHz)
15.3 cm , 3.0 cm (iono-free combination)

→ Possible combined Doris cycle slips ?

Cycle slips and iono-free variations

f1	f2	(m)
0	**1**	**-0.030**
0	2	-0.060
0	3	-0.091
0	4	-0.121
0	5	-0.151
0	6	-0.181

f1	f2	(m)
1	-1	0.183
1	**0**	**0.153**
1	1	0.123
1	2	0.093
1	3	0.063
1	4	0.032
1	**5**	**0.002**
1	6	-0.028
1	7	-0.058
1	8	-0.088
1	9	-0.118
1	10	-0.149
1	11	-0.179

f1	f2	(m)
2	4	0.186
2	5	0.155
2	6	0.125
2	7	0.095
2	8	0.065
2	9	0.035
2	**10**	**0.005**
2	11	-0.026
2	12	-0.056
2	13	-0.086
2	14	-0.116
2	15	-0.146
2	16	-0.177

f1 cycle slip
(case of high elevation measurements)

red values : below 15 cm (f1 cycle slip)

Lot of combinations are producing small variations on the iono-free combination
this is due to the frequency ratio, very close to 5 (543/107)

Cycle slip characteristics

Not possible to handle correctly simultaneous cycle slips on the iono-free combination

hypothesis : no simultaneous cycle slip on frequency 2 (400 MHz)

Remaining error (for 2 GHz) on the iono-free combination --> 15.3 cm for 1 cy
--> 3.8 cm for 0.25 cy
--> 2.6 cm for 0.17 cy
(below the 1 cycle at 400 MHz)

This is robust to orbit errors
(1m --> 0.001 m/s --> 1 cm over 10 s, there is still a big margin to observe the cycle slip)

<u>Set of measurements assumed without cycle slip are constructed using the iono-free combination</u>

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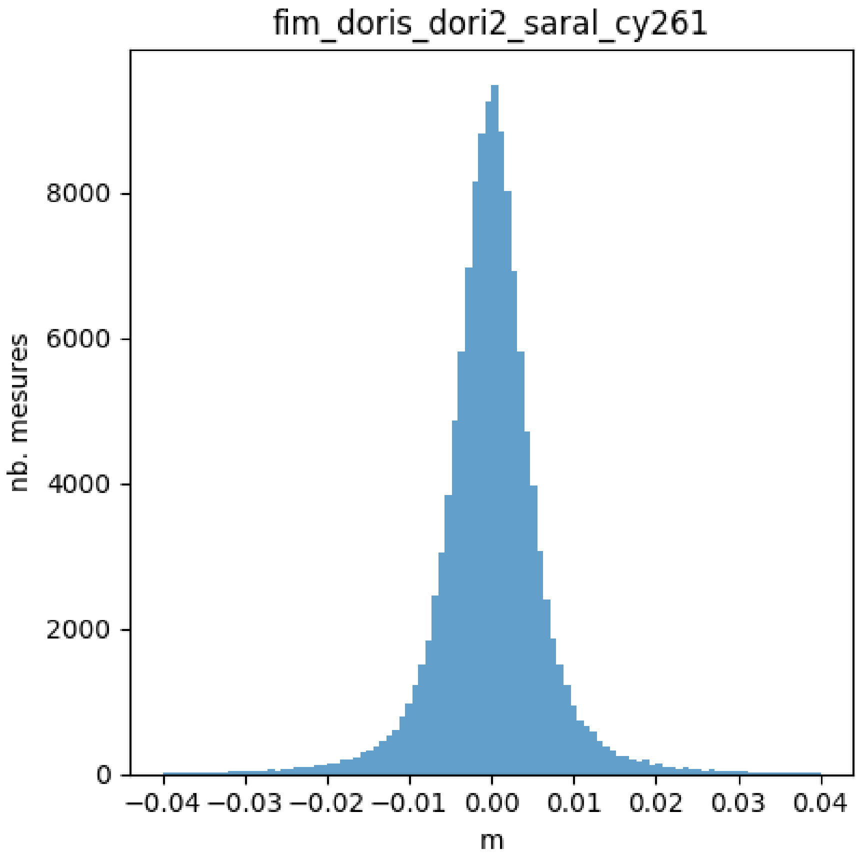
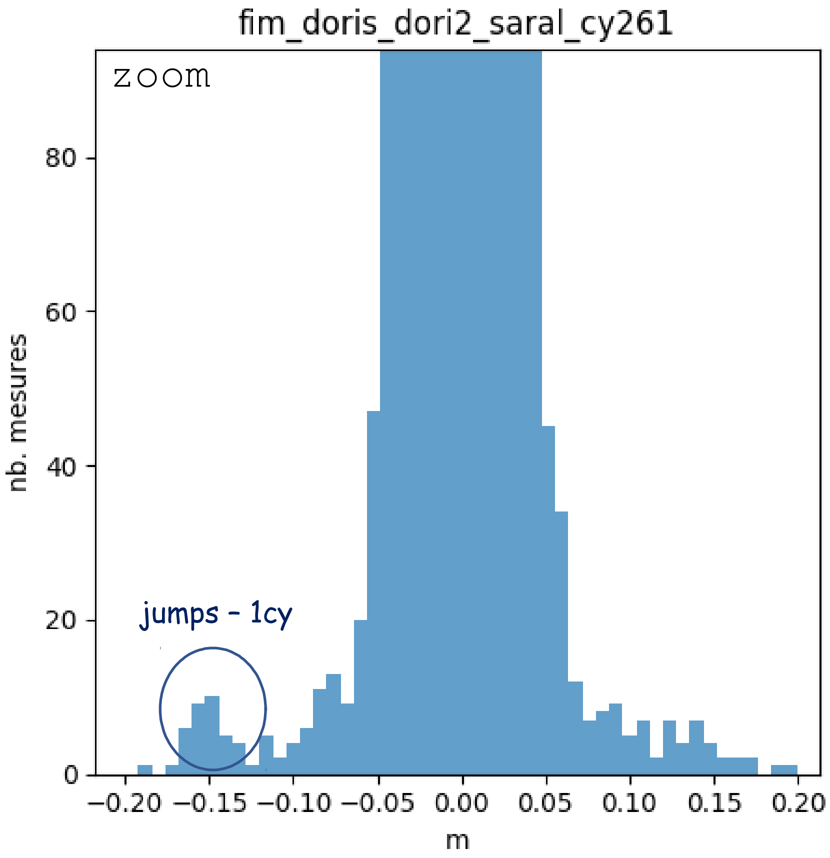
```
low  Doppler : variation [0.75,1.25 cy]     --> correction -1 cy 2 GHz
               variation [-1.25,-0.75 cy]   --> correction  1 cy 2 GHz
anywhere     : variation more than 0.17 cy --> interruption

elevation above 5 degrees
more than 10 consecutive phase measurements
```

Raw residuals histogram (Saral)

No elimination
Phase variation residuals





Reconstruction : Saral cy 261, 2GHz cycls slips at low Doppler

```
 reconstruction   64  :      -0.966 cy, variation      747.4 cy
 reconstruction   78  :      -1.097 cy, variation     -490.8 cy
 reconstruction  184  :      -1.130 cy, variation     -275.2 cy
 reconstruction  293  :      -1.156 cy, variation      300.2 cy
 reconstruction  319  :      -1.066 cy, variation       74.4 cy
 reconstruction  349  :      -0.948 cy, variation     -785.3 cy
……
 reconstruction 1962  :       0.876 cy, variation     -241.2 cy
 reconstruction 2076  :      -0.984 cy, variation       86.6 cy
 reconstruction 2084  :      -0.911 cy, variation     -877.3 cy
 reconstruction 2230  :      -0.848 cy, variation      300.8 cy
 reconstruction 2286  :      -0.884 cy, variation      857.9 cy
 reconstruction 2318  :      -1.097 cy, variation      348.6 cy
 reconstruction 2372  :      -0.993 cy, variation     -766.5 cy
 reconstruction 2383  :      -0.909 cy, variation      851.9 cy
 reconstruction 2491  :      -1.106 cy, variation     -713.8 cy
 reconstruction 2496  :      -0.933 cy, variation      633.8 cy
 reconstruction 2567  :      -0.877 cy, variation      527.7 cy
nombre de reconstructions fréquence centrale :   43
```

The jumps occur at low elevations : 43 here for a 9 days arc
(Cryosat, 2 to 3 jumps per day)

Almost always -1 cycle at 2GHz.

Intermediate values of the residuals (Saral)

High residuals (phase variations) : few cases, easy to detect and remove

statistics for cycle 261 Saral,
all measurements
low Doppler measurements reconstructed

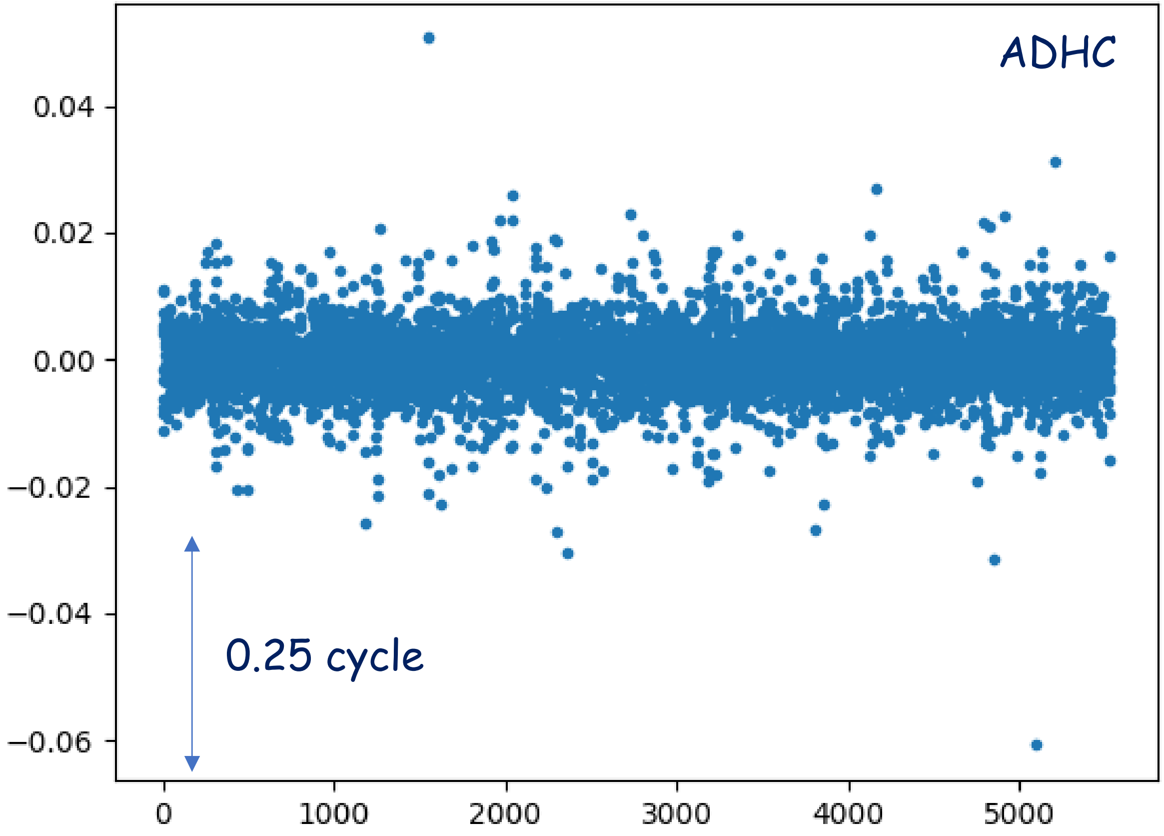
residual (m)	<0.1	<1	<10	<100	<1000
nb. tot. mes.	128588	128652	128666	128753	128768
nb. mes.		64	14	87	15

Example : residuals for ADHC (Saral)

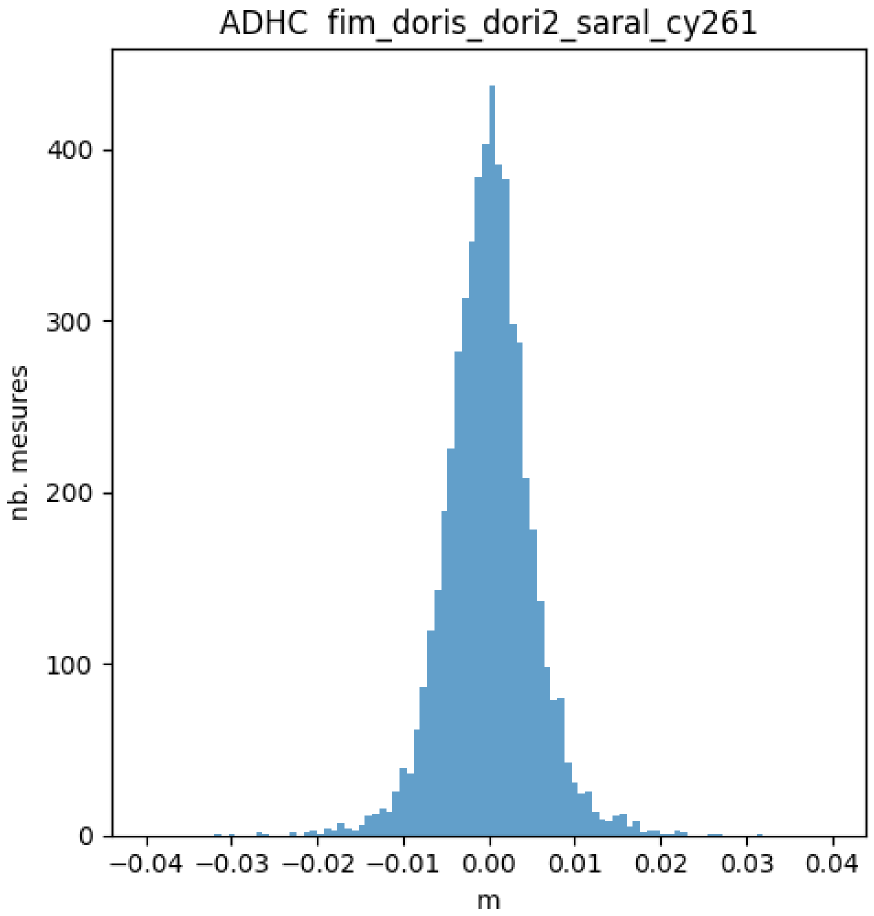
Phase variations over 10 s

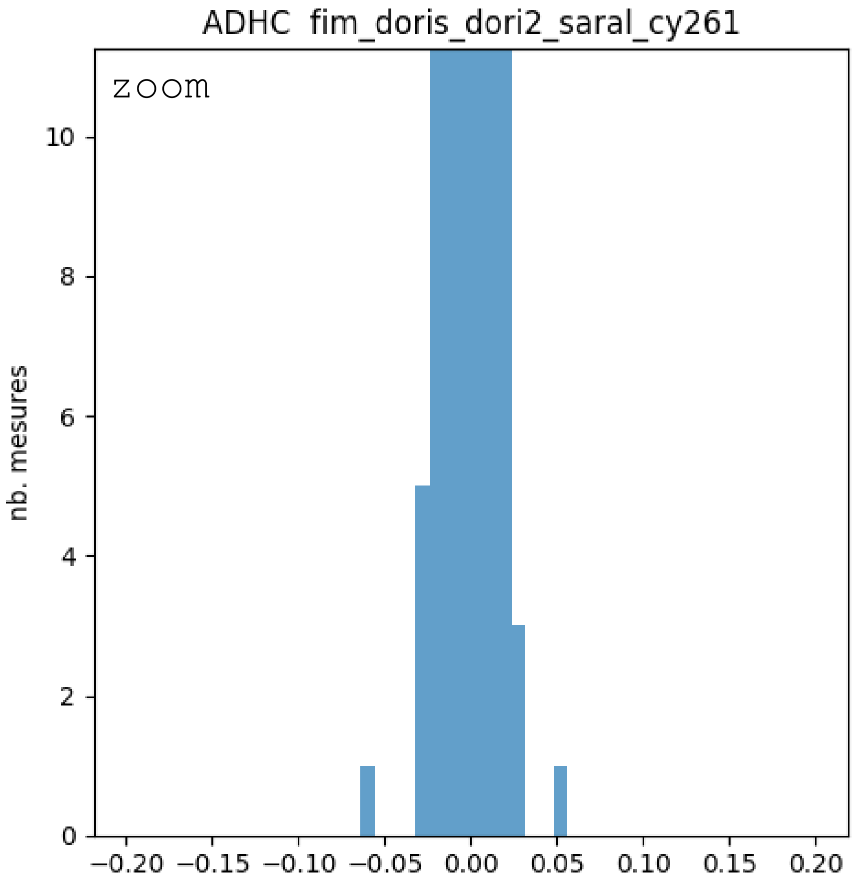
All measurements, threshold 100 m

With 1 m threshold for example
we obtain correct measurements
(all varations are below 0.5 cycle)



Raw residuals histogram ADHC (Saral)

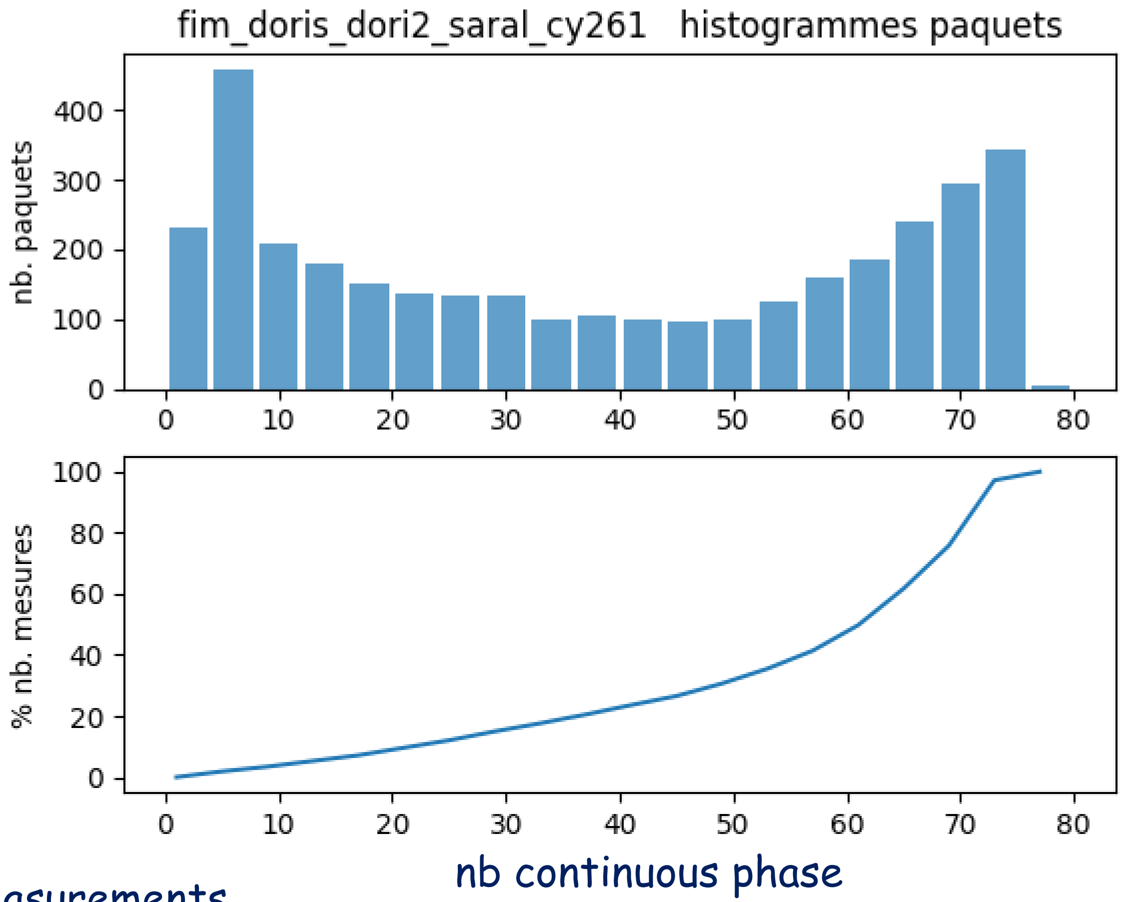




Continuous phase data (Saral, 9 days)

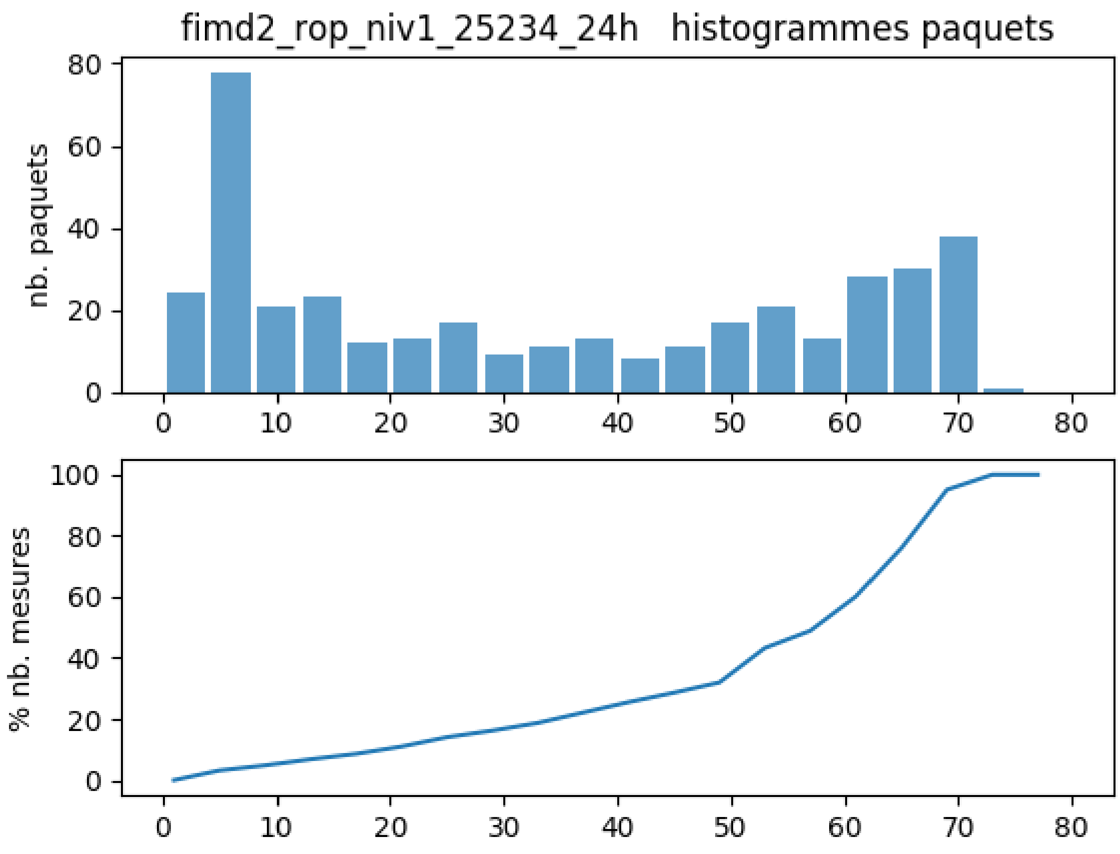
Sets below 10 measurements

- important number of cases
- less than 5 % of the total measurements



Continuous sets with more than 10 measurements

Continuous phase data (Cryosat, 1 day)



Continuous sets with more than 10 measurements

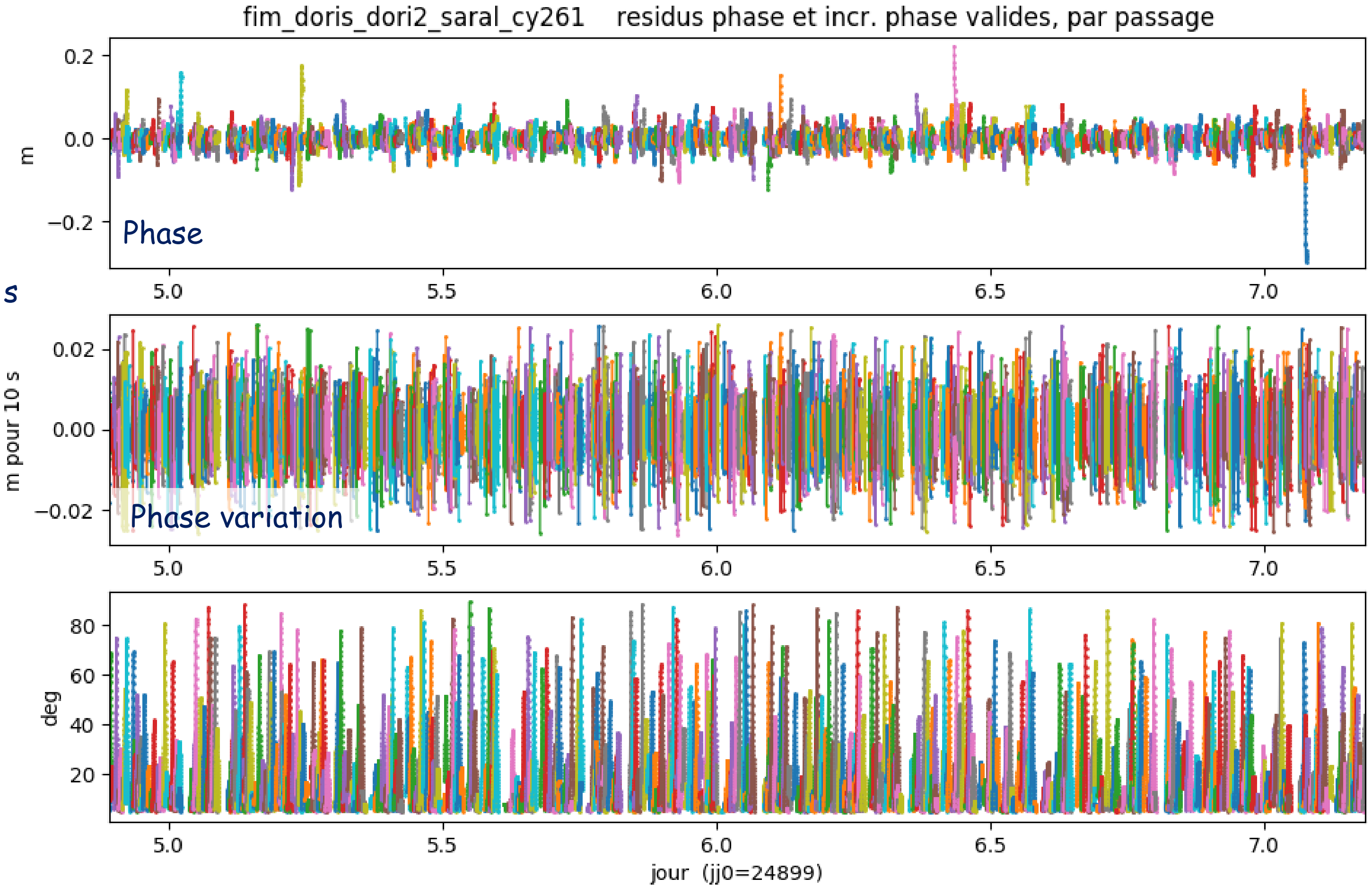
nb continuous phase

Saral residuals (POE)

Threshold 2.6 cm over 10 s

rms phase variation
5.6 mm

Elevation > 5 deg



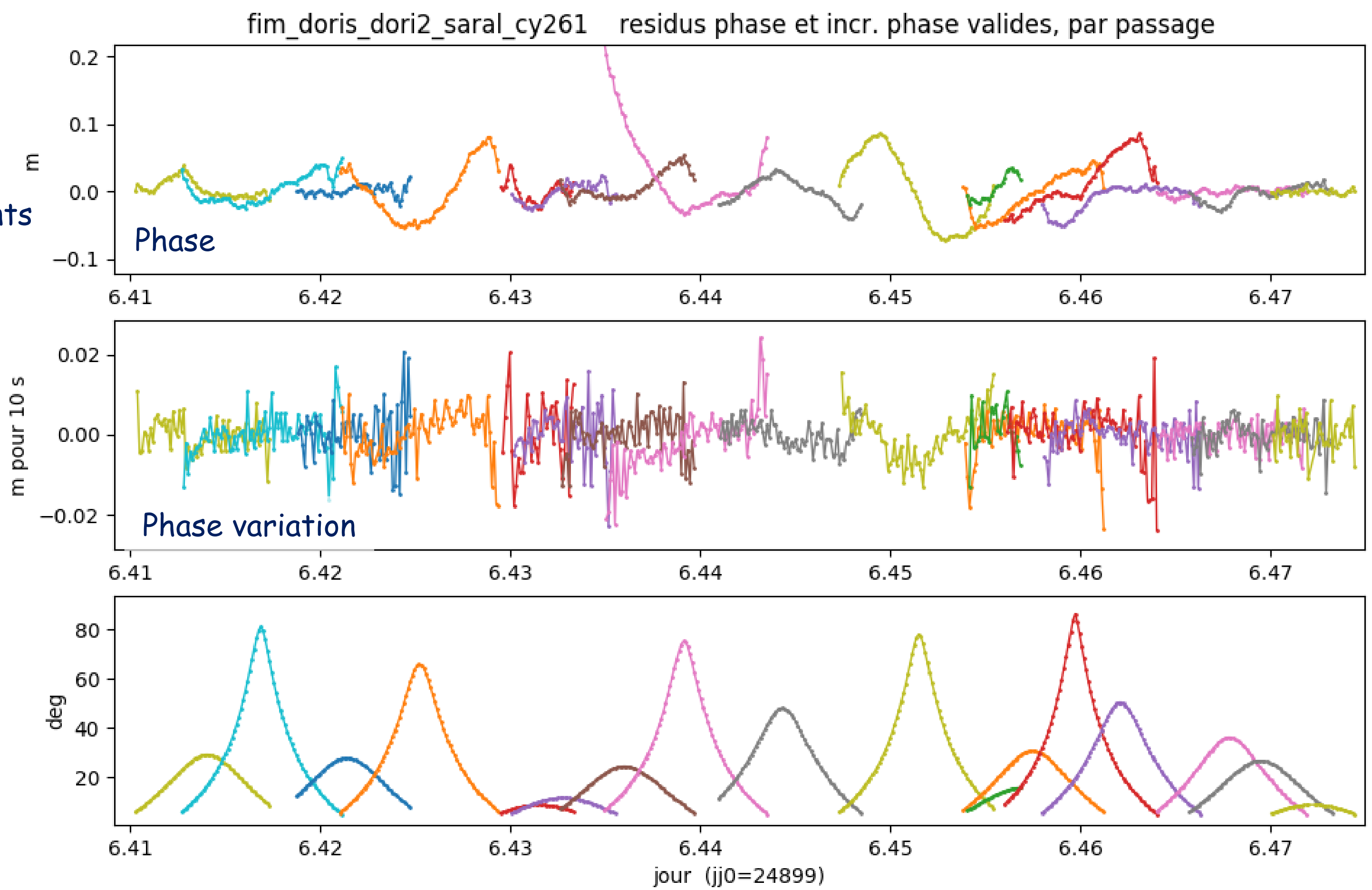
Saral residuals (POE)

Almost all passes have measurements below 5 degrees

All information present in the residuals seems relevant

Remaining signatures

- USO
- troposphere
- multipath
- … ?



Cryosat residuals (MOE)

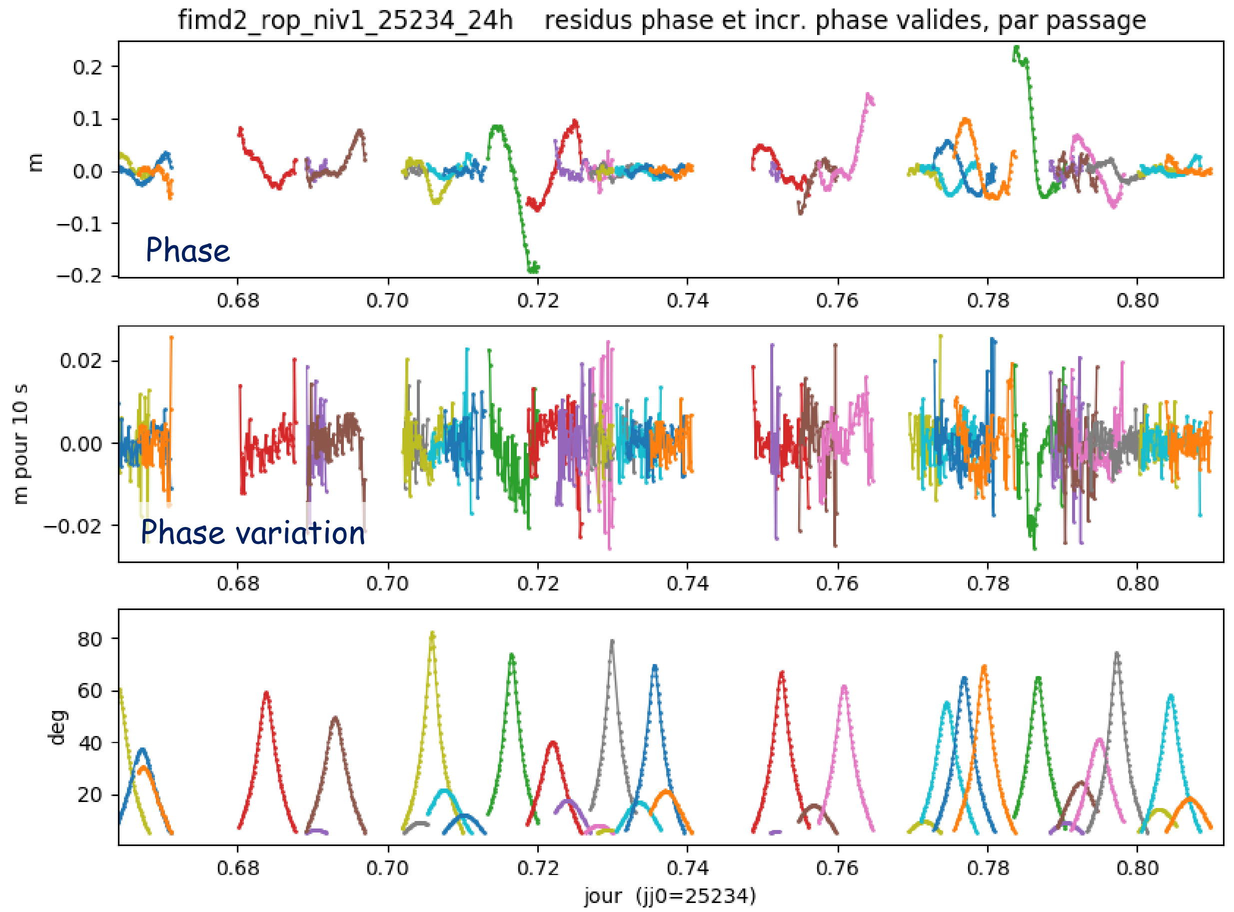
Almost all passes have measurements below 5 degrees

All information present in the residuals seems relevant

Rms phase variation
6 mm

Remaining signatures

- USO
- troposphere
- multipath
- … ?

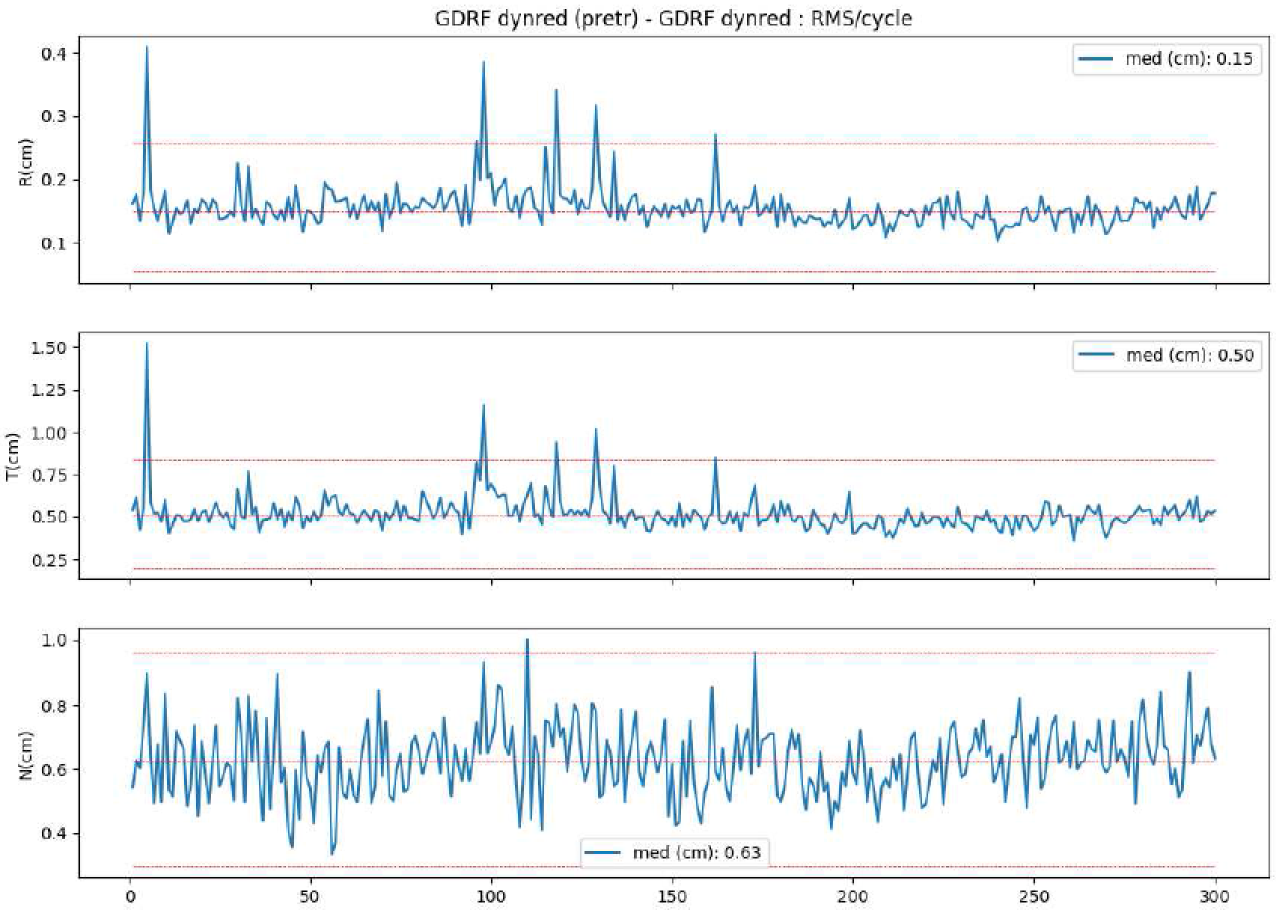


Orbit determination results on Saral and Cryosat

Reprocessing of Saral, orbit comparison

Difference with current solution
1.5 mm rms radial

Some cycles are perturbated
due to manoeuvres

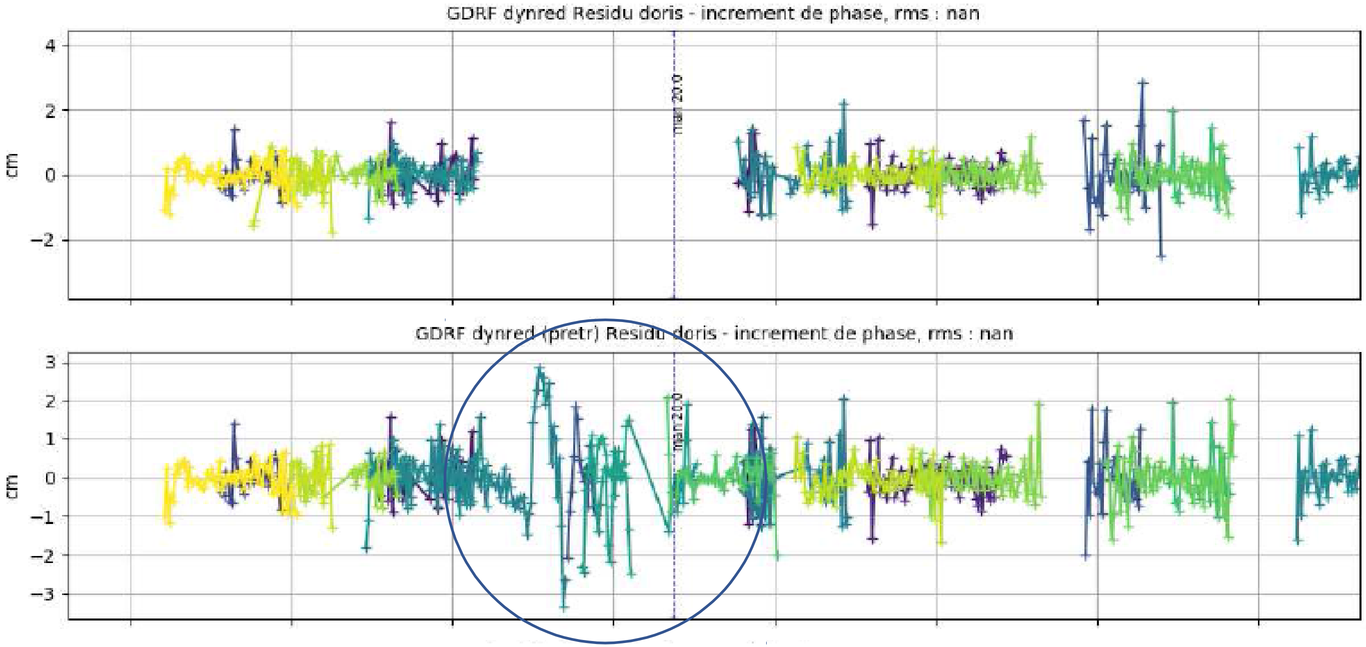


Manoeuvers (Saral)

The new preprocessing is not too sensitive to the dynamic modelling errors

Some passes occur during the manoeuver and the measurements are correct
But the model is not precise enough

These data were eliminated in the standard processing
(rms residuals over a pass)



around the manoeuvre

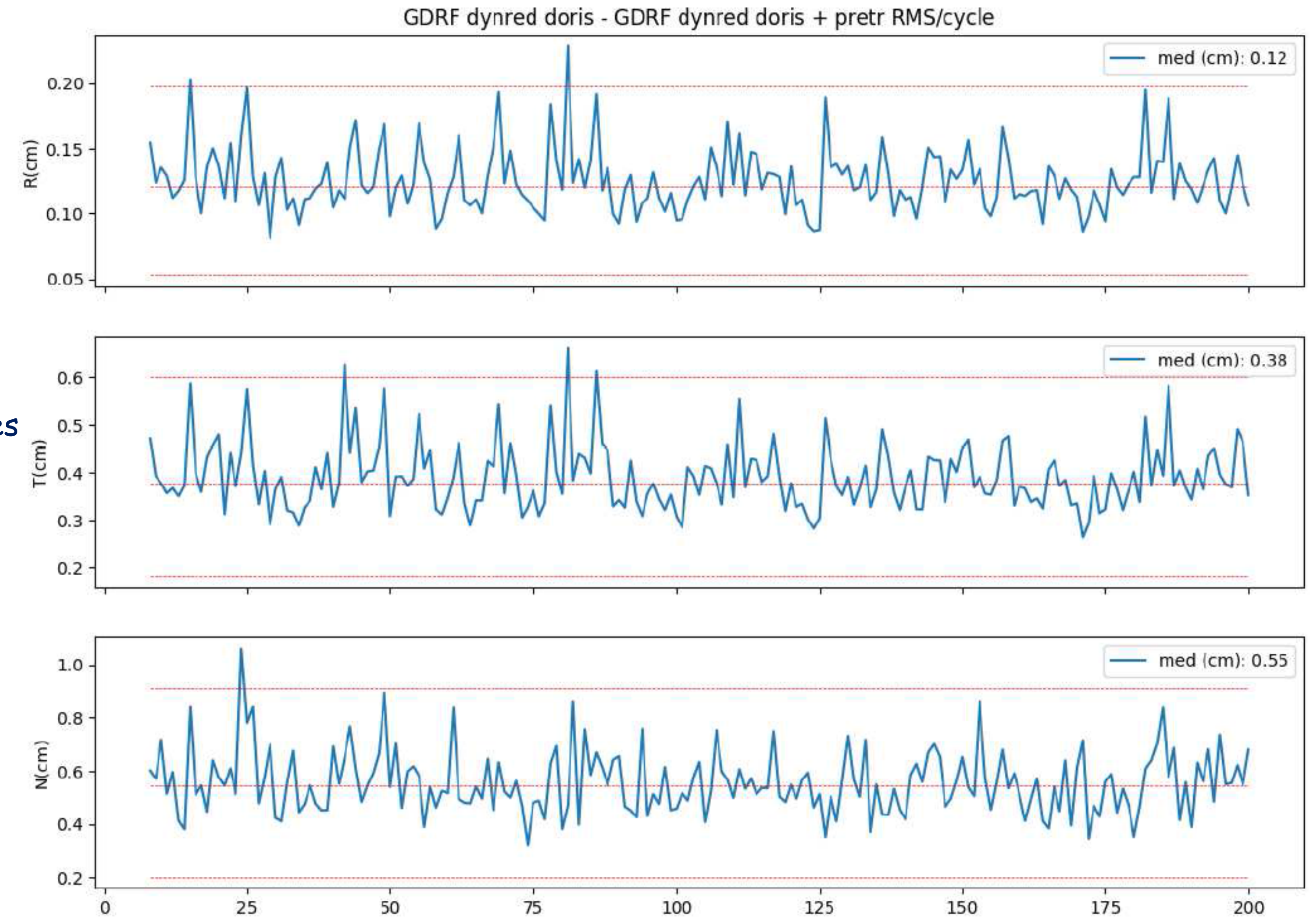
Reprocessing of Cryosat, orbit comparison

Difference with current solution
1.2 mm rms radial

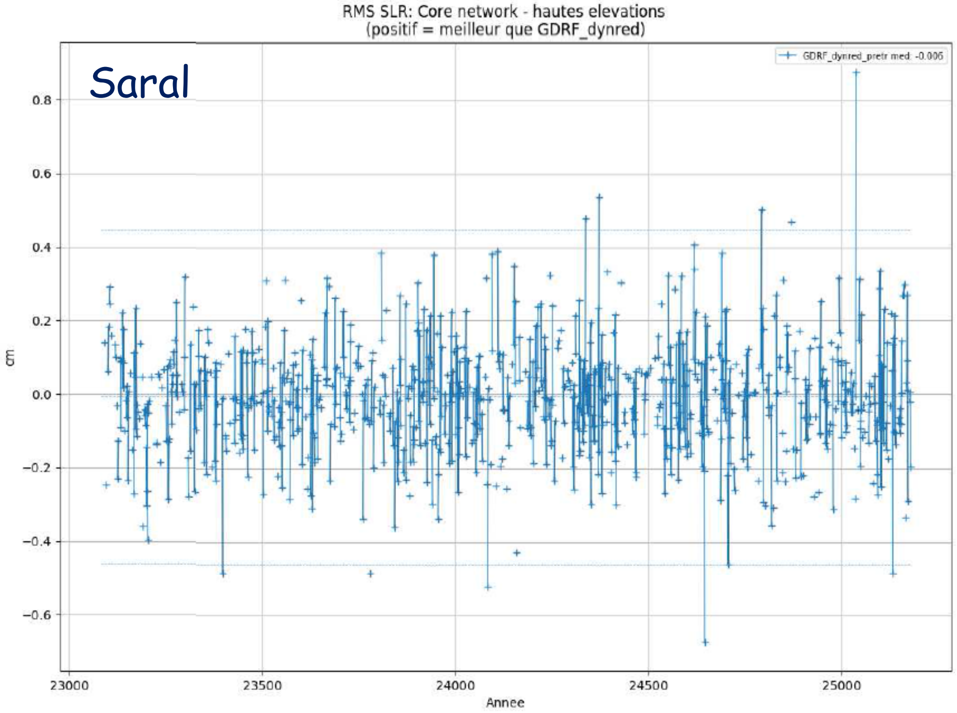
Like Saral, some orbits are perturbated
by isolated passes with important signatures
USO effect, SAA ?

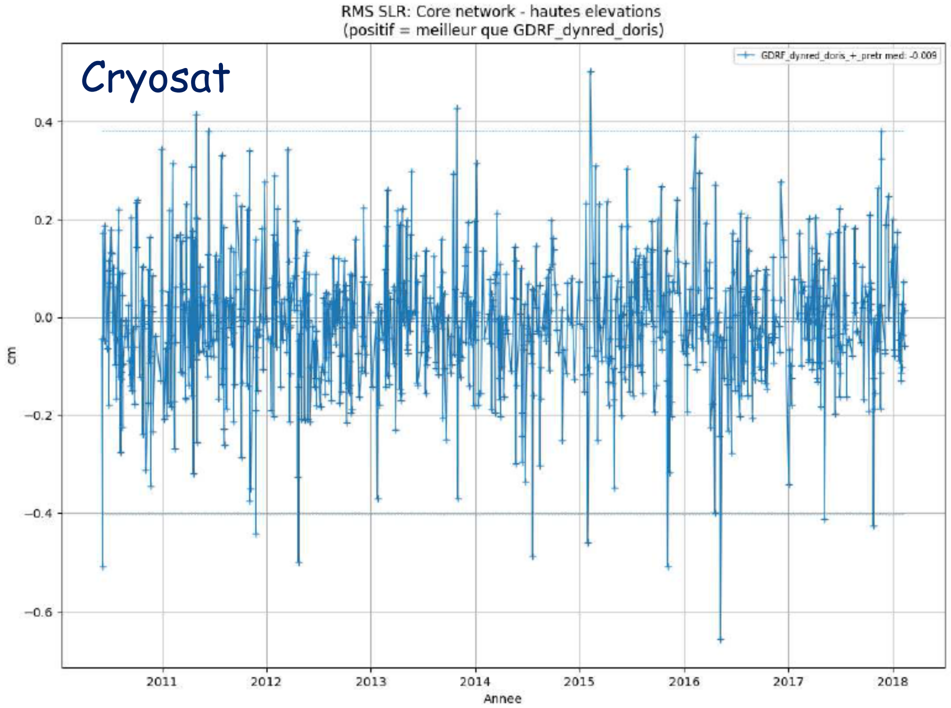
(~1 cm in radial locally)

Some cycles are perturbated
due to manoeuvres



Global results, high elevation SLR residuals





(>0 , better than current gdrf product)

High elevation SLR residuals : similar performance with the new processing

Conclusion

New preprocessing
- low Doppler meaurements are used, cycle slip reconstruction
- 10 consecutive correct phase measurements minimum
- minimal elevation 5 degrees

Achieved radial accuracy : similar to current products
- effets for positioning ?
- pole and geocentre ?
- some passes with important signatures (manoeuvre, USO, attitude, others ?)

Less sensitive to orbit errors (0.25 cycles --> 3.8 cm variation over 10 s)

Combined cycle slips are still an issue

Preparation of future formulations (direct phase processing)
- phase maps (see Hanane presentation)
- USO, SAA studies
- orbits
- ….