CNES
CENTRE NATIONAL D'ÉTUDES SPATIALES

PROGRESS IN THE PHASE 0: DORIS ON BOARD GALILEO

IDS ANALYSIS WORKING GROUP

November 29, 2023

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Overview

Satellite Navigation/Space Geodesy: Onboard and ground-based single-satellite Precise Orbit Determination (POD) accuracy

Constellation: DORIS beacons positioning performances for the International Terrestrial Reference Frame (ITRF)

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SATELLITE NAVIGATION / SPACE GEODESY

ONBOARD AND GROUND-BASED SINGLE-SATELLITE POD ACCURACY

Goals

Satellite Navigation:

Assess the POD performance of a single GNSS satellite in Medium Earth Orbit (MEO) using a reduced ground network of DORIS beacons such as the Galileo Sensor Stations (GSS) by simulations.

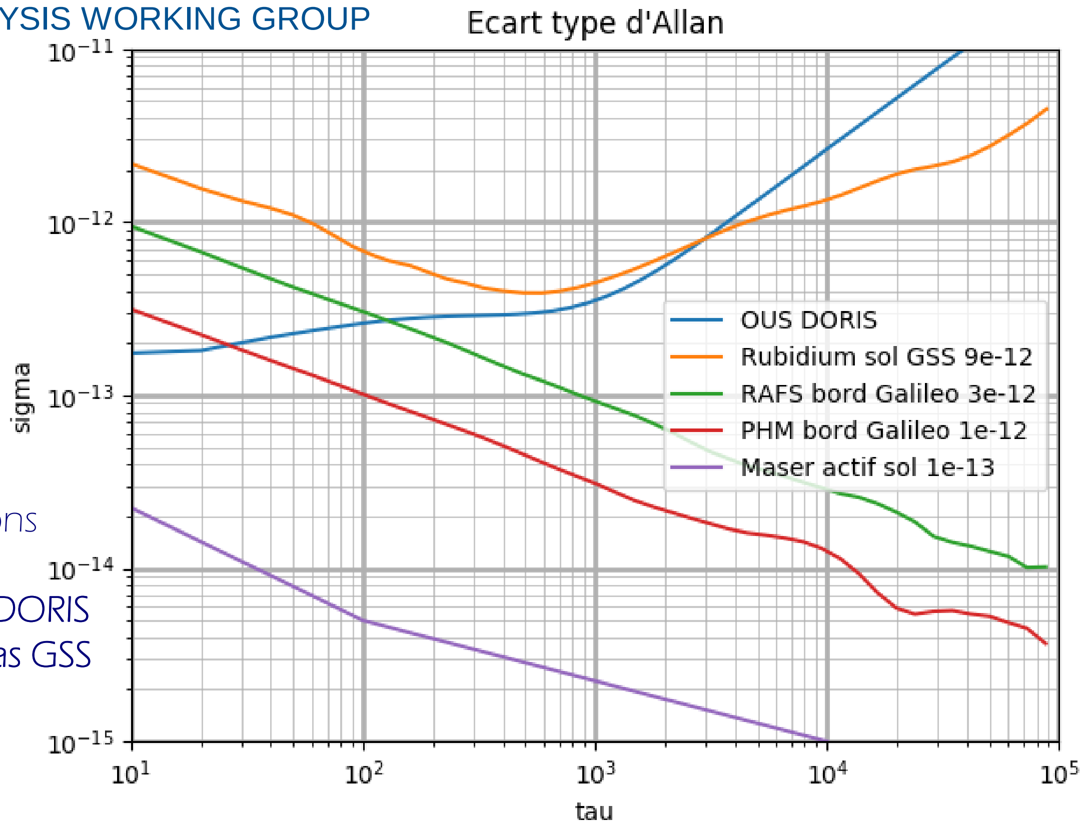
Target: 10-100 cm RMS onboard POD so that DORIS/DIODE could serve as a back-up for the GALILEO Satellite Navigation system. Need of knowledge for the onboard clock to be defined.

Space Geodesy:

Assess the POD performance of a single GNSS satellite in Medium Earth Orbit (MEO) using the full ground network of the current DORIS beacons by simulations.

Target: 1-10 cm RMS ground-based POD so that the DORIS tracking system would align with the performances achieved at the International GNSS Service (IGS).

Different clock solutions



On board:

- Current: Passive maser (PHM = Passive Hydrogen Maser), with RAFS (Rubidium Atomic Frequency Standard) as a back-up.
- Future?

On ground for Satellite Navigation:

- Current: Galileo Sensor Stations (GSS) ground network of ~15 stations equipped with Rubidium clocks (stability of ~9 10^{-12}/sqrt(tau)).
-Future: Active maser. Not feasible to equip the ~60 beacons of the DORIS ground network (300 k€ each) but possible for a sub-network such as GSS (soon >10 DORIS sites will have this ability).

On Ground for Satellite Geodesy:

- Current: standard DORIS USO, because neither DORIS USO controlled by Cesium clocks (Time Beacon ~1.2 10^{-11}/sqrt(tau)) nor Passive maser (70 k€ each) is no longer available today for sale.
- Future: TMG clocks controlled by GNSS and DORIS USO.

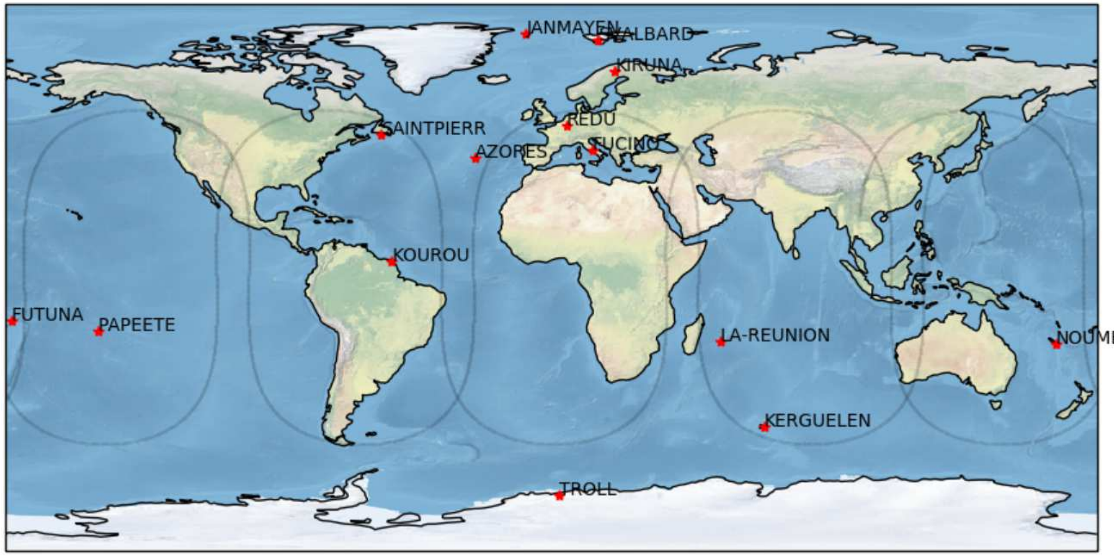
Hypothesis for Satellite Navigation

3-day simulation period for the GAL08 satellite in the GNSS constellation

Simulations sampling measurements at 100s are equivalent to simulations sampling at 10s

Distribution of the 14 stations with respect to the ground track and geometry aspect to be studied further:

Simulation	Estimated Parameters
Hmaser clock on board: passive, ADEV $10^{-12}/\mathrm{sqrt}(\tau)$ ground: active, ADEV $10^{-13}/\mathrm{sqrt}(\tau)$ Measurement noise 3 mm Network of 14 Galileo Sensor Stations DORIS measurement sampling 100 s Tropo. model GPT2/VMF1	Frequency bias adjusted per station/pass Tropo. model GPT2/VMF1 + tropo. parameters adjusted every 2h per station (to be close to a realistic parameterization)
	Empirical 1/rev in along track and cross track directions solved for over the entire period to absorb dynamic errors causing orbital period responses Acceleration bias in the cross track direction (Y satellite reference frame) to absorb thermal effects of radiators



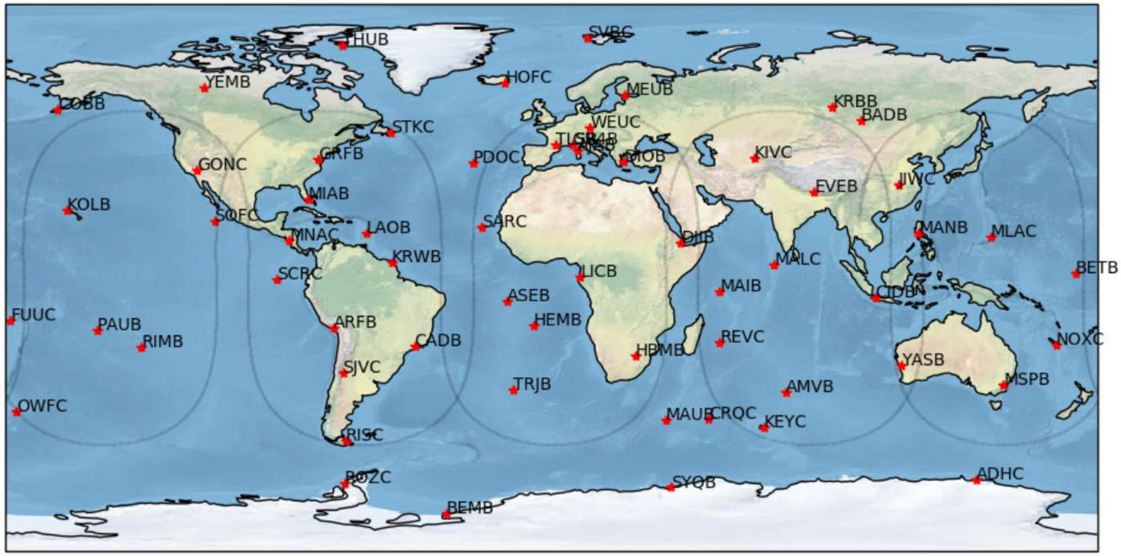
Hypothesis for Space Geodesy

3-day simulation period for the GAL08 satellite in the GNSS constellation

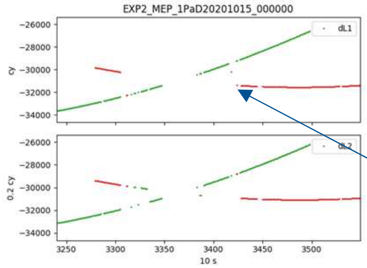
Simulations sampling measurements at 100s are equivalent to simulations sampling at 10s

Distribution of the 60 stations with respect to the ground track and geometry aspect to be studied further:

Simulation	Estimated Parameters
Onboard Hmaser clock ADEV $10^{-12}/\mathrm{sqrt}(\tau)$ Ground clock Current DORIS USO Hmaser ADEV 1.E-12/sqrt(τ) Measurement noise 3mm 60 stations of the current DORIS network DORIS measurement sampling 100 s Tropo. model GPT2/VMF1	Frequency bias/drift adjusted per station/pass, associated with DORIS USO modelling Tropo. model GPT2/VMF1 + tropo. parameters adjusted every 2h per station (to be close to a realistic parameterization)
	Empirical 1/rev in along track and cross track directions solved for over the entire period to absorb dynamic errors causing orbital period responses Acceleration bias in the cross track direction (Y satellite reference frame) to absorb thermal effects of radiators

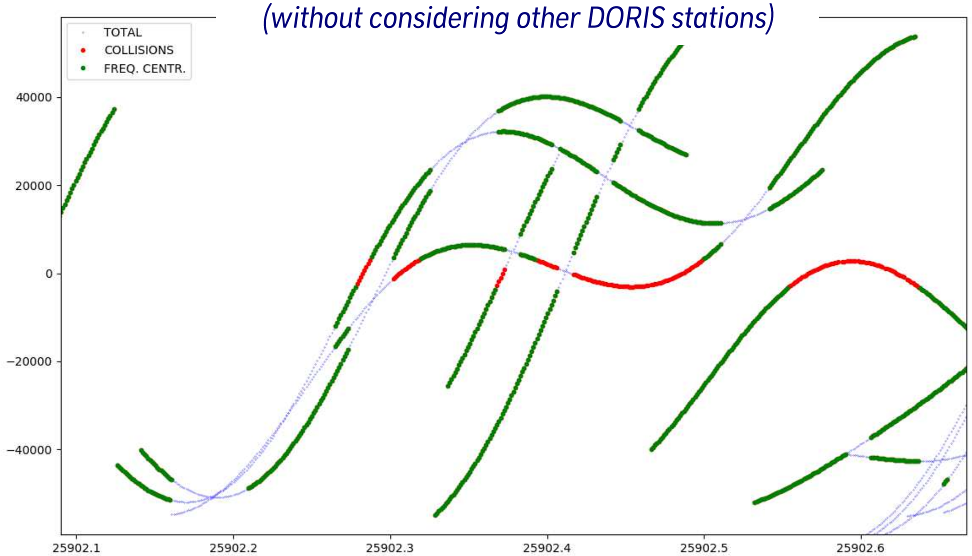


Hypothesis for the DORIS receiver

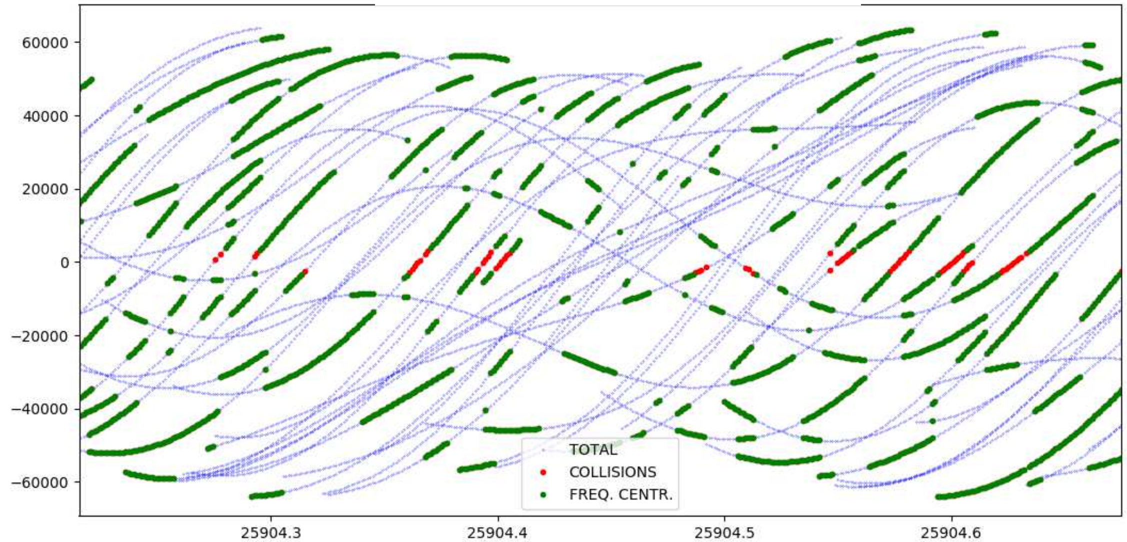


Doppler collision threshold	Zero Doppler threshold
3000 cycles x λ_{2Ghz} x (sampling / 10s)	2065 cycles x λ_{2Ghz} x (sampling / 10s)
local observation on simulated data in the DORIS lab	*current setting for ZOOM processing*

Valid measurements, GSS network
(without considering other DORIS stations)



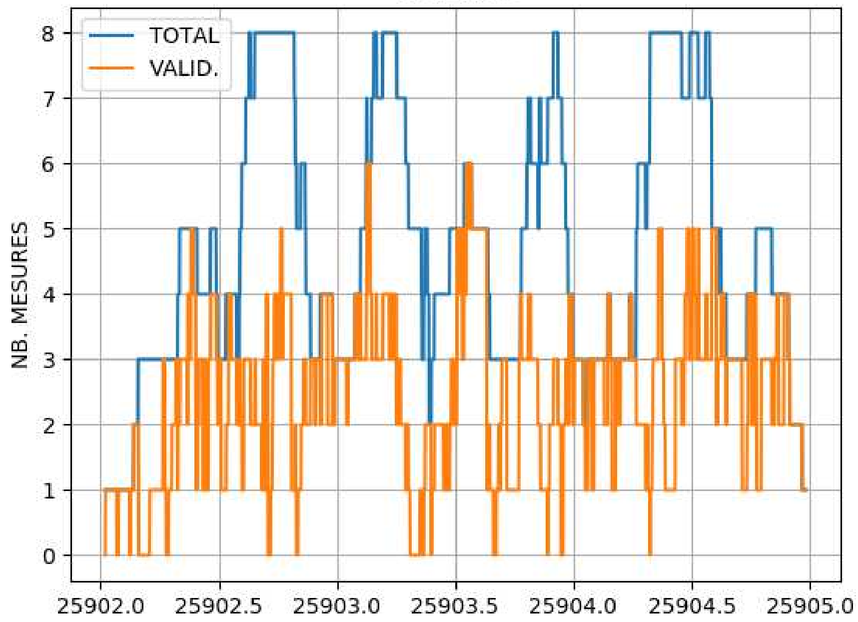
Valid measurements, DORIS network



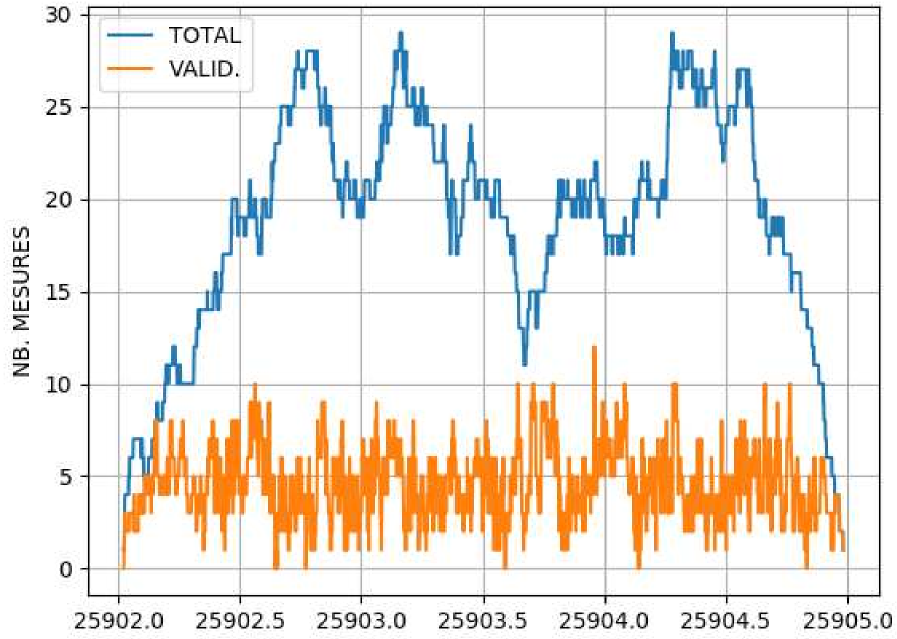
The considered thresholds need to be consolidated
Invalidations on Doppler collisions fragment the passes (observability problems)

Hypothesis for the DORIS receiver

Visibilities, GSS network



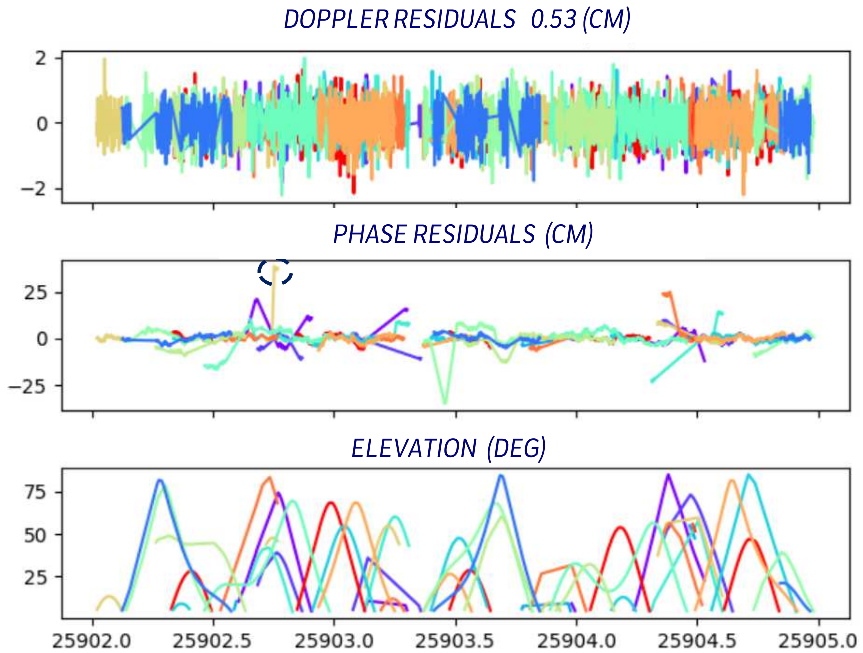
Visibilities, DORIS network

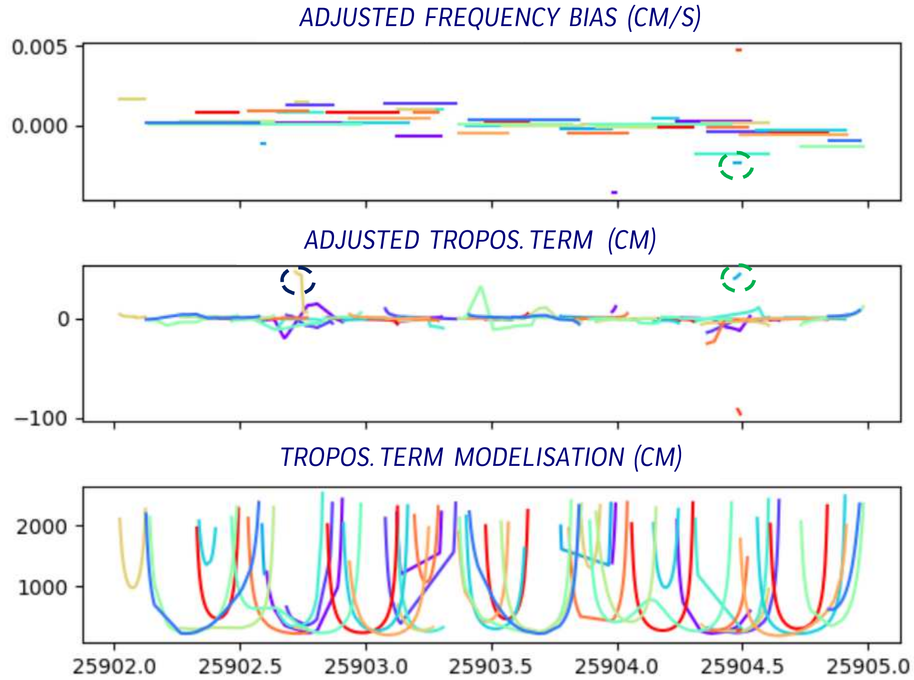


Start and end of period with progressive visibility induced by the ZOOM passage definition process, optimum performance in the central period 25902.5 → 25904.5

Results for Satellite Navigation

10 samples of clocks are made, results for one of them:

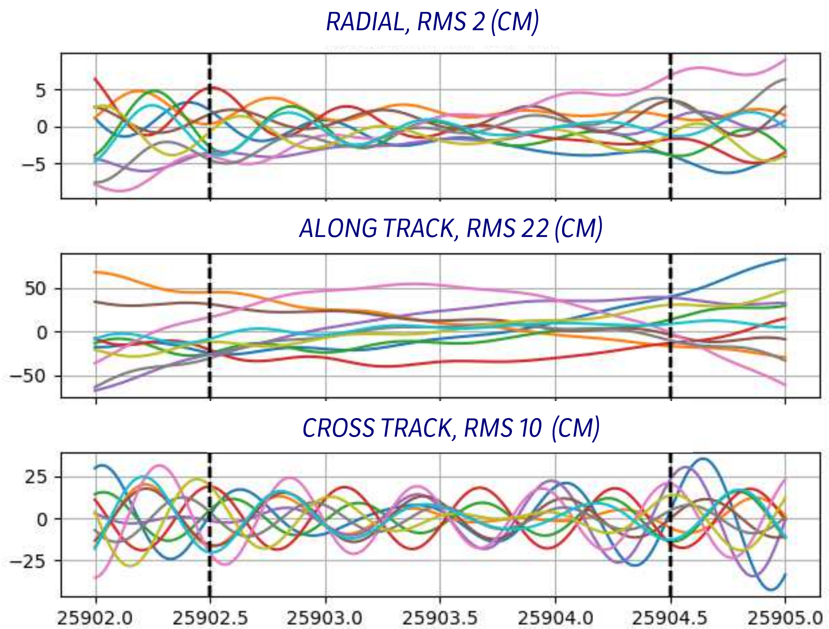




The poor fit of some parameters {frequency biases, ZTD} is induced by the lack of observability linked to the lack of measurements to separate the two parameters (c.f. on the plots)

Results for Satellite Navigation

Comparisons of orbit solutions (10 samples of clocks and measurement noises) with the reference orbit



RMS 3D of 14 cm

Case	RMS 3D	RMS RADIAL	RMS TANG.	RMS NORMAL
All observations	9	2	14	7
Doppler collision invalidation	14	2	22	10
Doppler collision invalidation, w/o measurement noise	14	2	22	11

RMS in cm

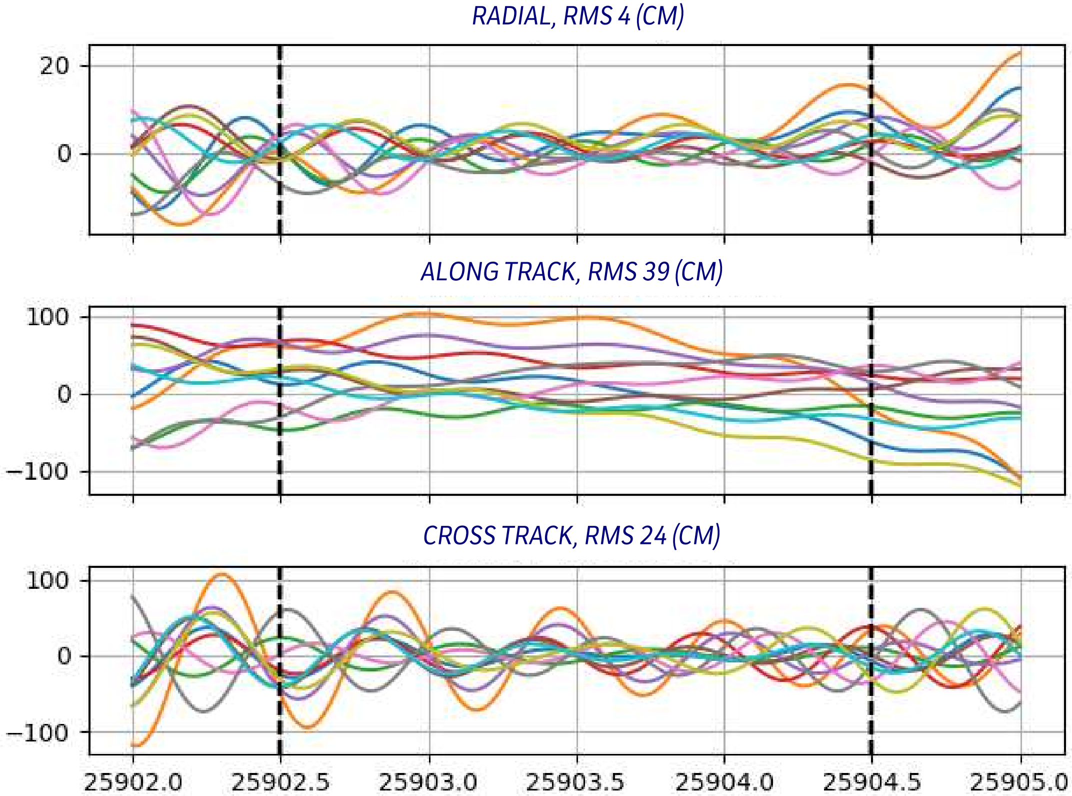
On these 10 simulations, the 3D performance is 9-14 cm, depending on Doppler collision assumptions. Extrapolation performance analysis to be carried out.

Results for Space Geodesy

USO DORIS beacon clocks

Comparisons of orbit solutions (10 samples of clocks and measurement noises) with the reference orbit

RMS 3D of 27 cm

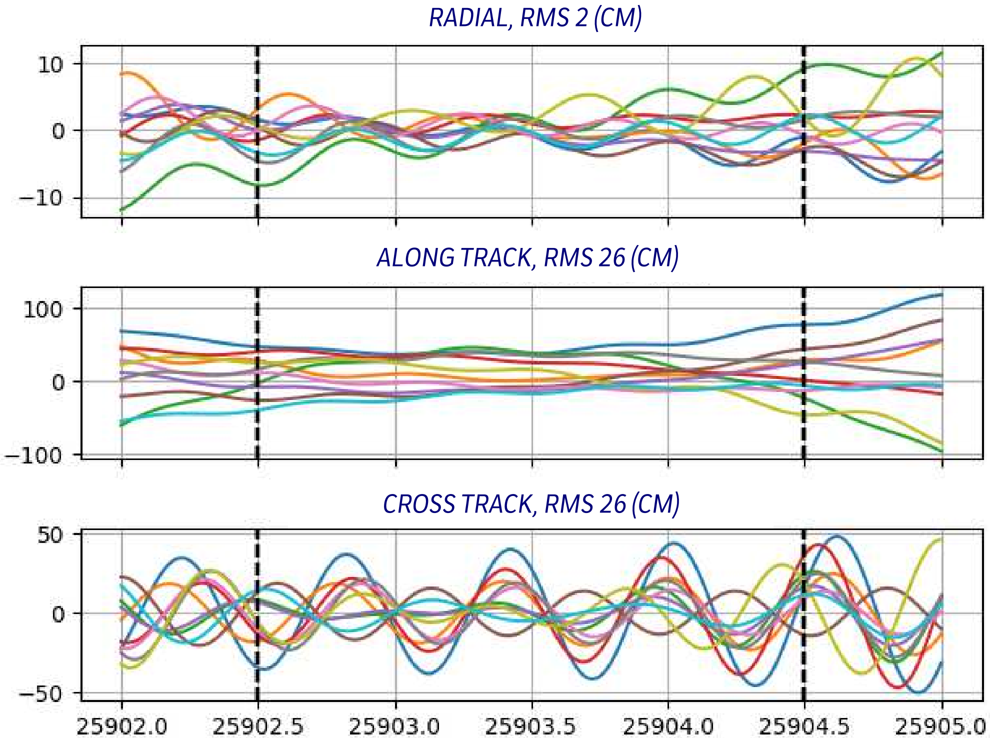


On these 10 simulations, the 3D performance is 27 cm, which is not satisfactory.

Results for Space Geodesy

Passive Hmaser beacon clocks

Comparisons of orbit solutions (10 samples of clocks and measurement noises) with the reference orbit



RMS 3D of 17 cm

Case Hmaser	RMS 3D	RMS RADIAL	RMS TANG.	RMS NORMAL
All observations	8	1	11	8
Doppler collision invalidation	17	2	26	15

RMS in cm

On these 10 simulations, the 3D performance is 8-17 cm depending on the Doppler collision hypotheses.

Doppler collisions and frequency shift

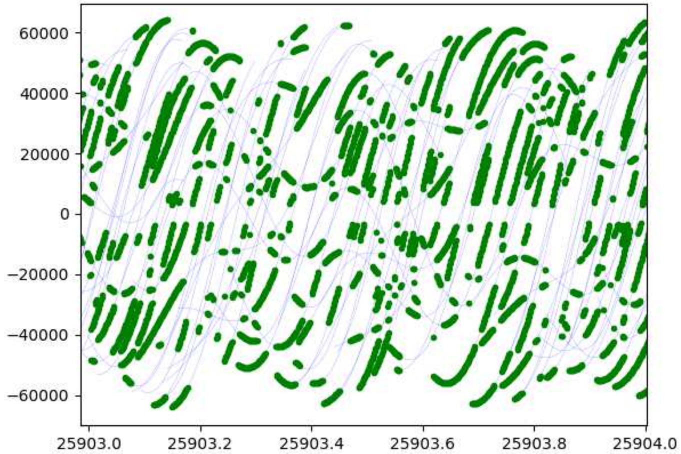
A few DORIS beacons already have their frequency shifted using a factor K to avoid Doppler collisions (e.g., WETZELL)

-> Generalization of this strategy to reduce Doppler collisions in MEO?

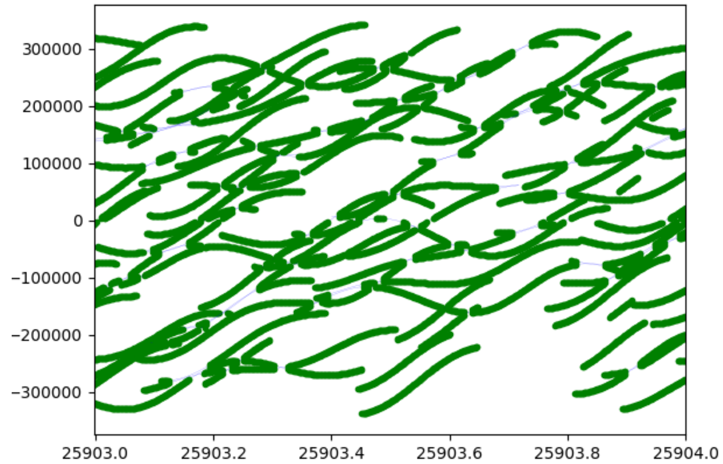
Hypothesis :

60 stations distributed in 19 sub-networks, where each sub-network is given a frequency shift value (K = {-27,-24,..., 27 }).

without frequency shift



with frequency shift



Initial nb. edited measurements	without frequency shift	with frequency shift
48 400	11 600	38 900

Impact on LEO receivers to be evaluated.

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Conclusions

With optimistic simulations, i.e :

- same dynamic models and measurements between simulations and orbit determinations
- addition of measurement/clock noise
- raw orbit determination parameterization

Case	RMS 3D (cm) All observations	RMS 3D (cm) Doppler collision invalidation
Space Geodesy DORIS USO		27
Space Geodesy TMG	8	17
Satellite Navigation (LSE)	9	14

Doppler collision assumptions to be consolidated (threshold, mitigation strategy)

Results for a given ground track, if necessary to be extended to other ground tracks

Constellation mode resolution to be addressed in the ITRF study

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CONSTELLATION

DORIS BEACONS POSITIONING PERFORMANCES FOR THE ITRF

Background to the previous ITRF CLS study

Working (simplifying) assumptions:

1. Galileo-GNSS downlink phase measurements are of homogeneous quality with future Galileo-DORIS uplink Doppler measurements.

2. Galileo satellites (all or part) will be equipped with a DORIS receiver receiving signals (all or part) from a set of stations based on the reduced CNES/IGN REGINA* network (limited to ~35 Galileo stations vs. ~60 stations for the real DORIS network).

3. Floating phase processing (ambiguities not fixed).

4. Daily solutions of orbits/station positions and Earth Orientation parameters from Galileo measurements over the year 2020.

*REGINA: REseau GNSS pour l'IGS et la NAvigation made up of GNSS stations generally co-located with DORIS stations.

Conclusions from the previous CLS study

Preliminary results to be compared with the results of the next study:

1. ~ 20 stations max. seen simultaneously with this network of ~35 Galileo stations versus potentially more with ~60 DORIS stations?
   => In fact, not far from 30 stations (according to the latest simulations), so ideally we'd need a 30-channel receiver!

2. Coordinate/orbit degradation below the 11-channel threshold with the Regina network.

3. Floating phase results are very similar to fixed ambiguity solutions.

4. Need to equip the entire Galileo constellation with a DORIS receiver with typical daily IGS processing.

Next CLS study

Description of the main points to be analyzed:

1. Validate the positive points highlighted by the previous simulation with the actual number of DORIS stations (~60 and therefore potentially needing more channels than 11?).

2. Take into account the characteristics/systematisms of DORIS Doppler measurements (different from the Galileo phase measurements used for the initial simulation):
   - Potential limitation of station measurements above 15° elevation (on-board antenna design constraint).
   - Study the impact of Doppler collisions as observed without a mitigation strategy.
   - Reflection on the clock models to be adjusted for Galileo satellites and DORIS beacons according to common visibilities.

3. Simulate ITRF performances in three typical scenarios (based on real GNSS measurements):
   - Galileo constellation partially equipped with a DORIS instrument (compensated by reflection on the clock models to be adjusted for Galileo satellites and DORIS stations, lengthening of orbit arcs, etc.).
   - Complete Galileo constellation (standard IGS processing where clocks are adjusted at each measurement date).
   - Addition of the contribution of current LEOs (simulation?) to the two previous configurations: consistency with LEO solutions and contribution of their combination to ITRF parameters.

Optional: Evaluate the benefit of no longer estimating the wet zenith tropospheric delay* on a current DORIS-based ITRF resolution and a DORIS-based approach with Galileo, depending on the level of precision of knowledge of this parameter.

* Assumption of a radiometer at the foot of each DORIS beacon, using the DORIS uplink system to redistribute radiometric information to the Galileo system (adjustment of co-located reference orbits/stations for future ITRF solutions).

BACKUP

Distribution of the DORIS network with shifted frequencies

This table shows the distribution of 60 DORIS beacons in 19 sub-networks and associated K factor (shift frequency)

K FACTOR	BEACONS
-27	FUUC CADB CRQC KRBB
-24	OWFC COBB MAIB
-21	KOLB BEMB PDOC BADB
-18	PAUB SARC REVC
-15	RIMB HOFC ASEB CIDB
-12	GONC TRJB KIVC
-9	YEMB HEMB JIWC
-6	SOFC TLSB KEYC
-3	SCRC GR4B YASB
0	MNAC AJAB MANB ADHC
3	MIAB LICB MLAC
6	GRFB MALC MSPB
9	ARFB THUB AMVB NOXC
12	SJVC SVBC BETB
15	ROZC WEUC
18	RISC DIOB
21	LAOB MEUB HBMB
24	STKC MAUB EVEB
27	KRWB SYQB DJIB