Genesis Science Workshop

3rd -4th April 2025

Matera, Italy

DORIS Session

Working Group 4

DORIS WG4 Status

Guilhem Moreaux
2025/04/04

WG4 DORIS

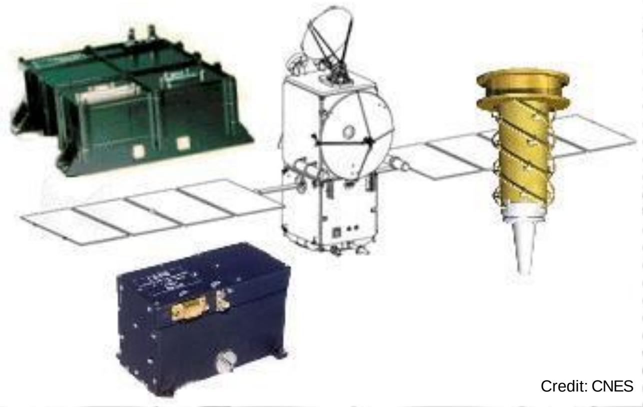
- **First visio meeting on 2024/11/29.**
- **20 members including CNES people in charge of the delivery of the DORIS receiver.**
- **Work Packages**
  - DORIS network
  - DORIS receiver/Genesis clock
  - DORIS data/metadata
  - DORIS simulations
  - DORIS POD
  - DORIS contribution to TRF

The Genesis DORIS Receiver

- **Given the tight schedule of the mission, the approach is to provide a recurrent DORIS instrument, derived from the latest DGXX-S generation on board of LEO altimetric Sentinel-3 and Sentinel-6 satellites.**

- **On Genesis, the clock will be outside the DORIS box and will be provided by ESA/OHB.**

- **The DGXX-S receivers were designed:**
  - **for an altitude between 700 and 1400km.**
  - **to track up to 7 beacons simultaneously.**
  - **to be equipped with a Rakon internal USO.**



Credit: CNES

More details on the CNES DORIS receiver project will be given by François.

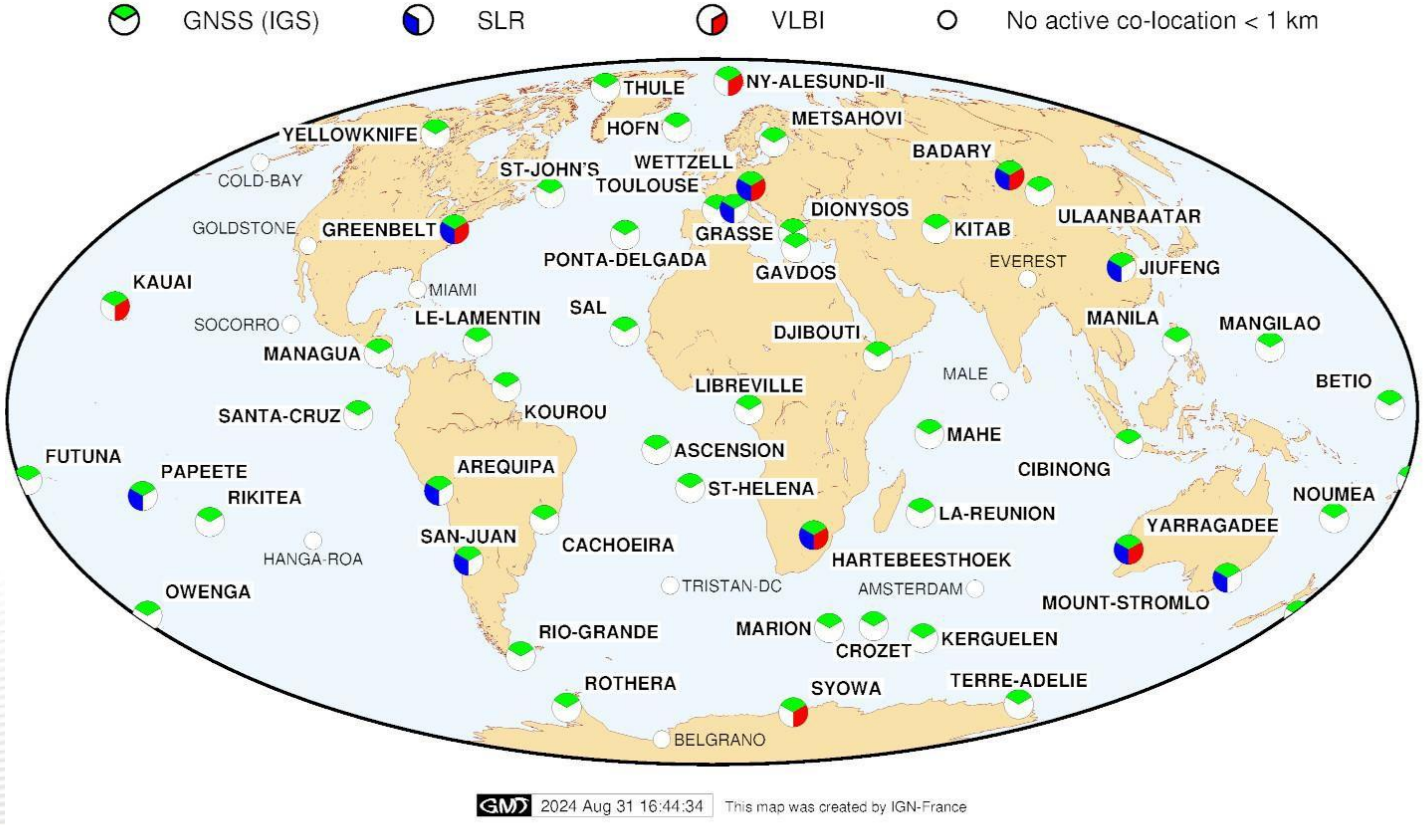
6000 km altitude of Genesis

- ➔ **Longer passes (4000sec vs 1200sec)**
  - ➔ **May require new modelization depending on the USO characteristics.**
- ➔ **Up to 20 stations in visibility**
  - ➔ **Selection strategy of 7 beacons**
- ➔ **Doppler Collisions**
  - ➔ **See John's presentation.**
- ➔ **South Atlantic Anomaly Effect?**
  - ➔ **See Petr's presentation.**
- ➔ **Visibility between each LEO satellite and GENESIS**
  - ➔ **Benefits for the estimation of parameters such as the tropospheric delay?**

Challenges / Open Issues

- **What about the VLBI-DORIS RF compatibility onboard of Genesis?**

- **May we ask for, when possible, connecting the ground colocated instruments to the same clock?**



Challenges / Open Issues

- **Strategies to look at the systematic effects?**
- **Will all the Genesis DORIS data and metadata freely available from the DORIS DCs (CDDIS & IGN)?**
- **Which orbit for the processing of the DORIS Genesis observations?**
  - **From DORIS only**
  - **Multi-techniques (ESA, IAG…)**
- **Which type of IDS solution including Genesis is expected as output of WG4?**
  - **Usual weekly DORIS station positions & EOPs? Normal equation (with position of the DORIS instrument)?**
  - **Single satellite/multi-satellite?**

Radiation Effects on onboard USO

Petr Štěpánek

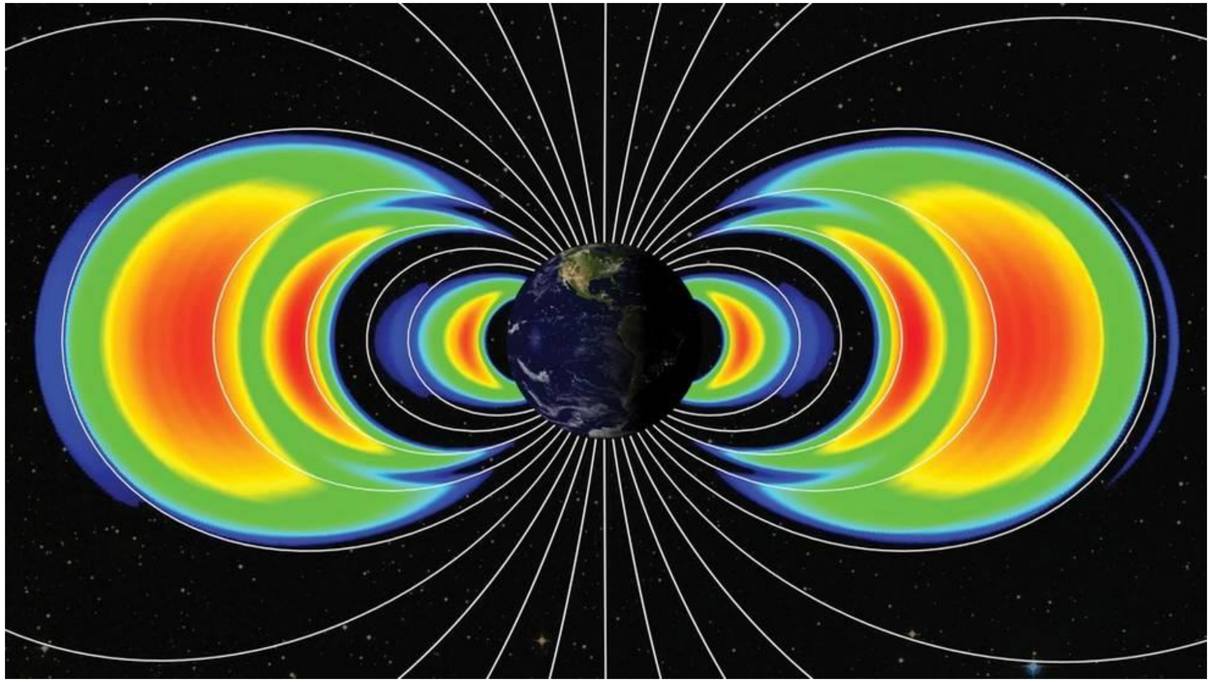
Research Institute of Geodesy, Topography and Cartography, Zdiby, Czechia

DORIS USO

- **Ultra Stable Uscillator (USO)**
- **Integral part of the DORIS receiver (onboard)**
- **Sensitive to thermal variations, accelerations, humidity, radiations, and magnetic fields**
- **Frequency stability at the level of 10^{-13}**
- **Challenge: high radiation levels in the South Atlantic Anomaly region**

Van Allen radiation belts

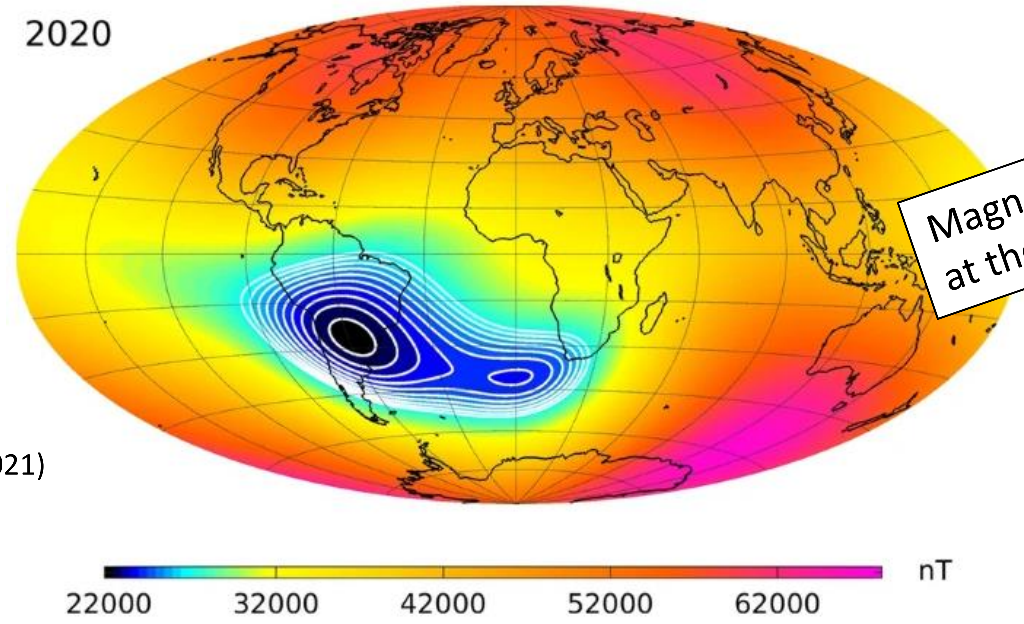
- Zone of energetic charged particles
- Solar wind particles trapped by the Earth magnetosphere
- Altitude range: 640 – 58.000 km
- Inner belt – below 12.000 km, contains both electrons and protons
- Outer belt – dominated by electrons



Source: https://spacecenter.org/what-are-the-van-allen-radiation-belts/

South Atlantic Anomaly – the origin of the phenomenon

- **Earth magnetic filed is non – homogenous and asymmetric relative to the Earth surface**
- **Weakest magnetic field: in the South Atlantic region**
- **The Inner Van Allen Belt is then closer to the Earth surface in this region**
- **Particles Density is by several orders of magnitude higher than in the rest of LEO orbit**



Source: Adler (2021)

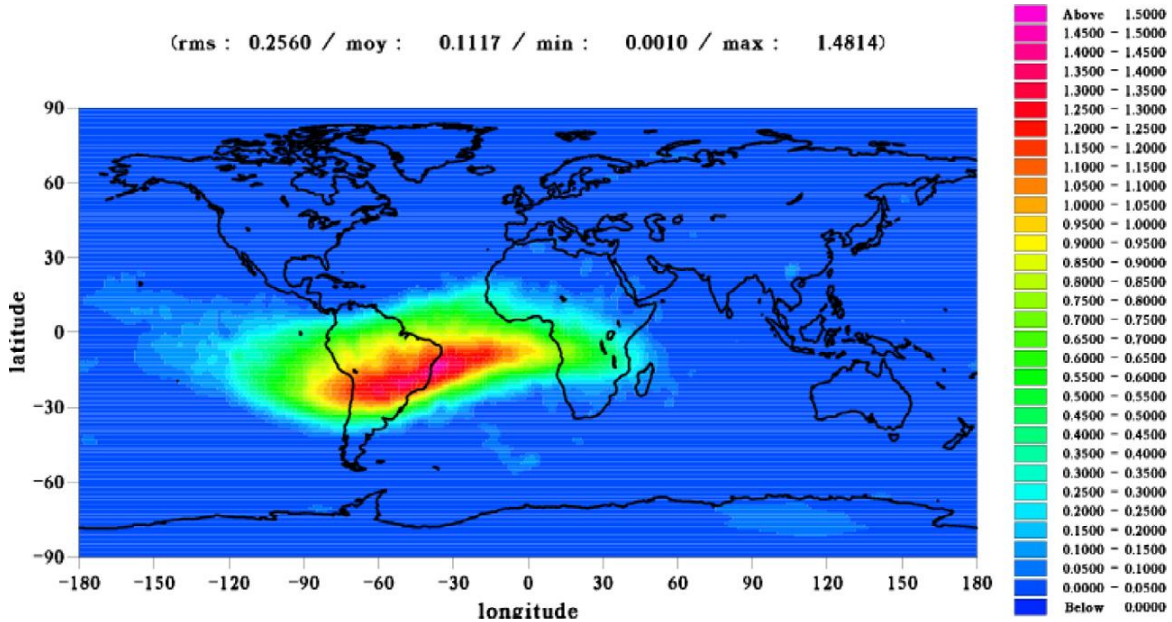
South Atlantic Anomaly – effect on satellites

- Spacecraft with altitude of several hundreds km or 1000+ km flying through a high radiation area
- High radiation is not a DORIS specific problem
  - Lost spacecraft (e.g. Japanese JAXA X-ray)
  - International Space Station - extra shielding
  - Hubble Telescope – switch off
  - Space Shuttle – crash of laptops

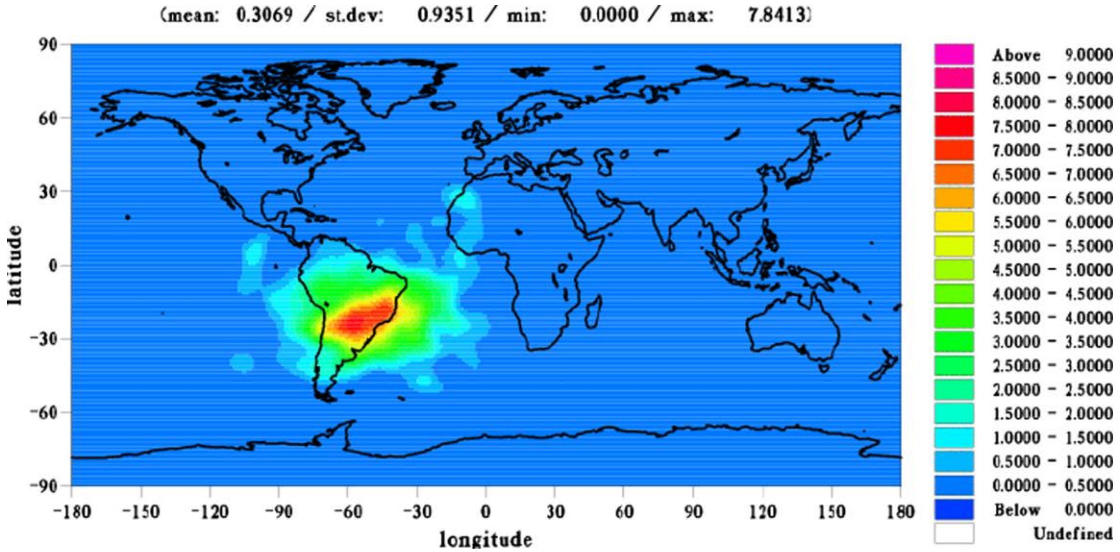
- DORIS – instability of the onboard USO (Ultra Stable Oscillator)
  - Sensitivity and effect is satellite specific
  - Jason-1 USO was the most affected
  - Despite some improvements, the resistant USO has not yet been developed (commercially available chip-scale atomic clocks do not meet a requirement of relative short-term frequency stability at the level 10^{-13})
  - Necessity to apply additional SAA mitigation strategies

DORIS satellites dose exposure

DORIS derived relative dose exposure Jason-1



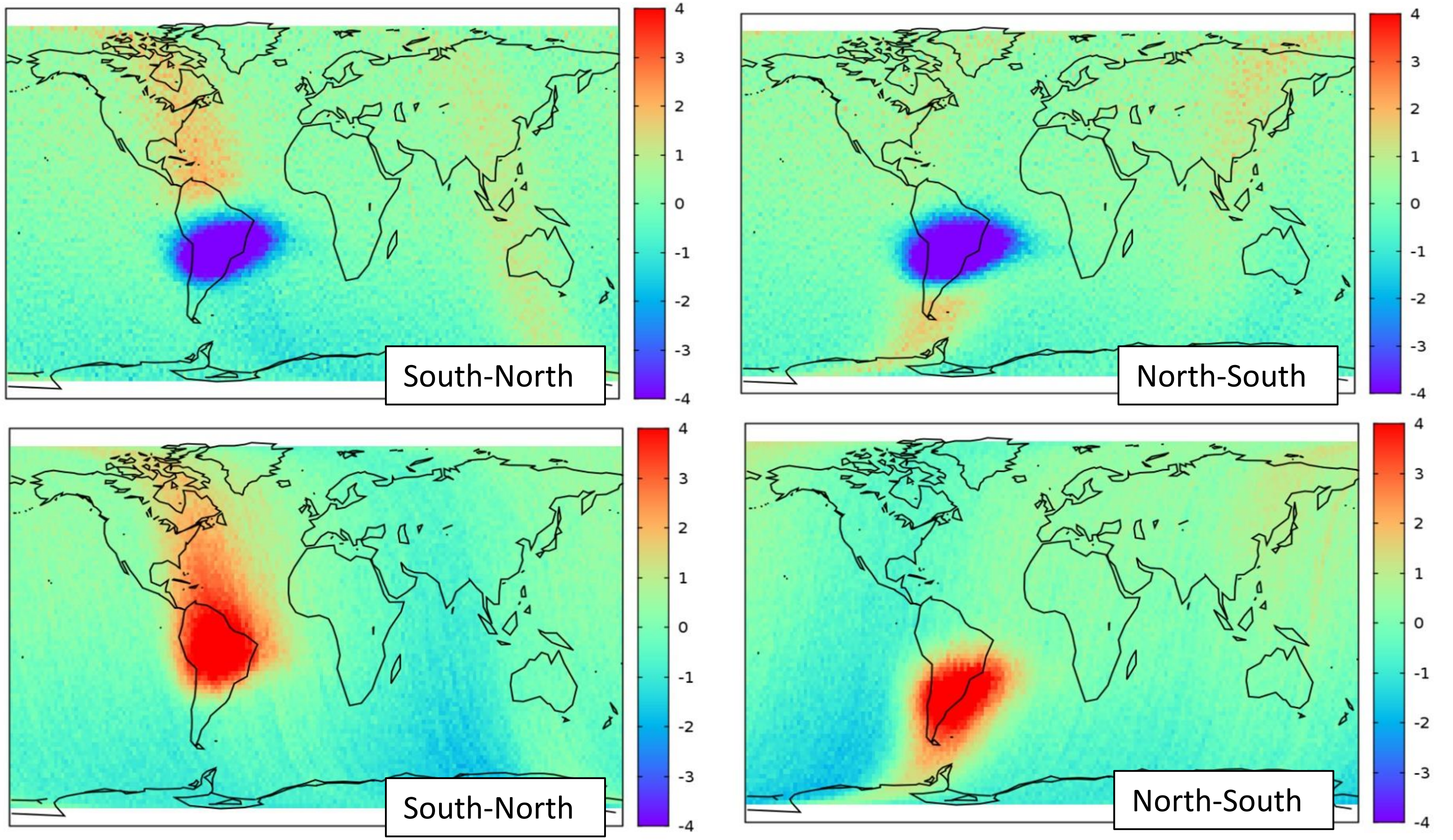
DORIS derived relative dose exposure SPOT-5



Capdeville et al., 2016

Profiting from unique Sentinel architecture

- GNSS receiver clocks driven by the DORIS USO
- DORIS – only polynomial clock model
- GNSS – epochwise clock model
- USO frequency can be estimated from GNSS observation and then introduced to DORIS processing



Sentinel-3A

Sentinel-3B

Štěpánek et al., 2020

Inner Van Allen belt and SAA

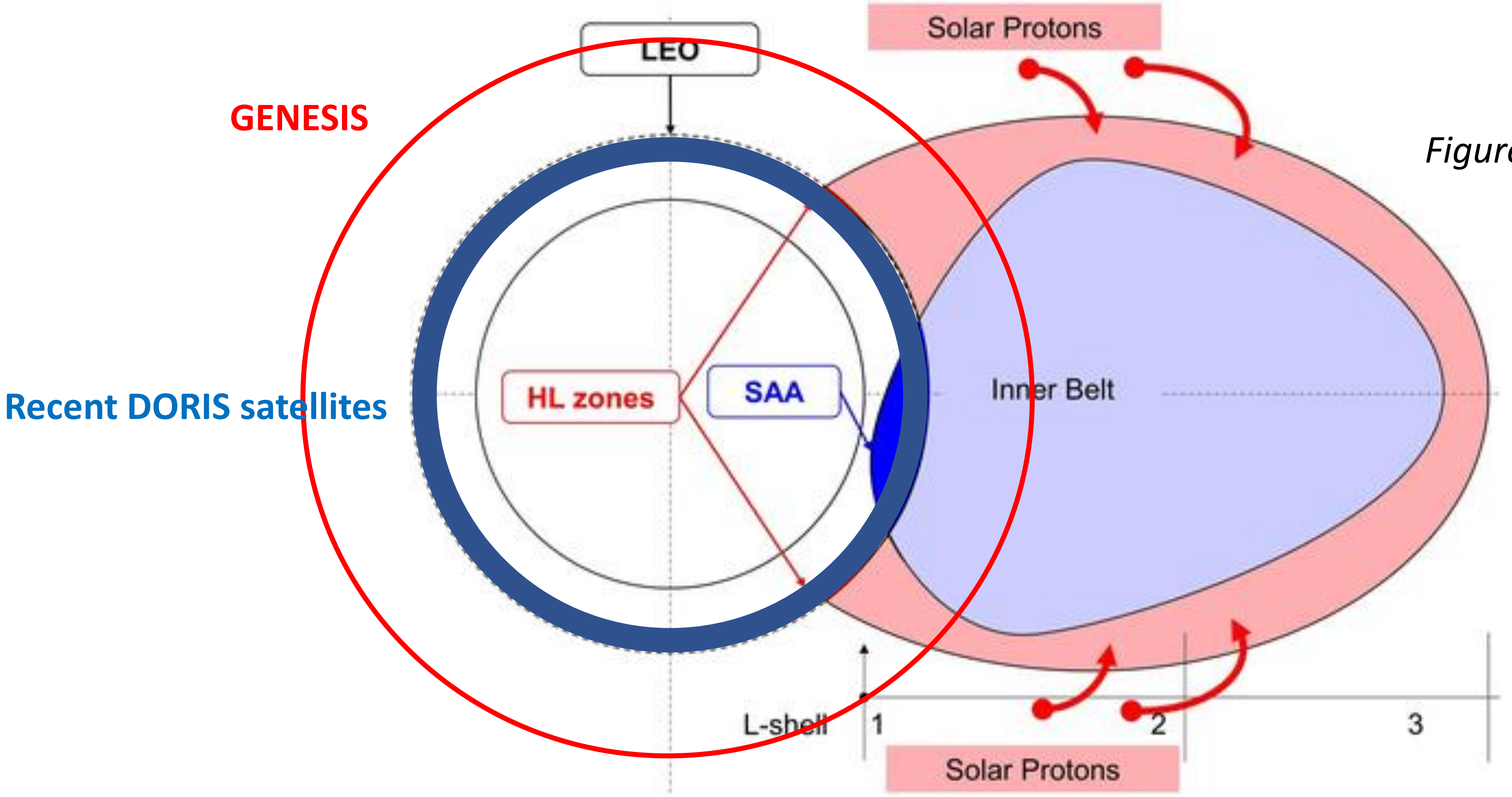


Figure by Girgis at al., 2023

particles radiation – DORIS satellites and Genesis

	Orbit altitude	oscillator	Sharing clocks/oscillator	High energy particles radiation
Recent DORIS satellites	700-1300 km	DORIS USO, Integrated in DORIS receiver	only Sentinel-3A,3B, 6A with GNSS receiver	SAA area
Genesis	6000 km	Outside DORIS receiver	With GNSS receiver and VLBI transmitter	Van Allen Belt

Summary and Conclusions

- DORIS requires an oscillator with a typical short-term relative frequency stability of 10^{-13}
- Recent DORIS receiver oscillators (USOs) are sensitive to high-energy particle radiation
- DORIS at Genesis can benefit from sharing the oscillator/clocks with GNSS, similar to the approach used for Sentinel satellites.
- Unlike past and current DORIS satellites in LEO, Genesis operates in MEO
- Genesis will traverse the inner Van Allen radiation belt. The radiation area is larger than for LEO orbits
- Comparing radiation intensity between DORIS LEO orbits and the Genesis orbit is complex due to differences in particle types, energy levels, and variations caused by the solar cycle and geomagnetic storms. Consultation with plasma physicists or other experts may be necessary.
- Ensuring adequate protection for the Genesis oscillator/clocks against radiation is an important consideration

References

Adler, D., 2021. The spacecraft-killing anomaly over the South Atlantic, published online, https://astronomy.com/news/2021/02/hidden-spaceflight-danger-the-south-atlantic-anomaly

Capdeville, H.; Štěpánek, P.; Hecker, L.; Lemoine, J.M., 2016. Update of the corrective model for Jason-1 DORIS data in relation to the South Atlantic Anomaly and a corrective model for SPOT-5, Adv. Space Res.

Girgis, K.M.; Hada, T.;Yoshikawa, A.; Mausukiyo, S.; Piarrard, V.; Samwel, S.W., 2023. Geomagnetic Storm Effects on the LEO Proton Flux During Solar Energetic Particle Events, Space weather.

Štěpánek, P.; Bingbing, D.; Filler, V.; Hugentobler, U., 2020. Inclusion of GPS clock estimates for satellites Sentinel-3A/3B in DORIS geodetic solutions, J. Geod.

Thank you for your attention !

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DORIS ON GENESIS

STATUS FROM CNES PROJECT TEAM

SCIENCE TEAM WORKSHOP

MATERA

03-04/04/2025

AGENDA

- Status of DORIS on-board Genesis – formally speaking
- Main challenges
- Topics to be investigated with the WG-4

DORIS ON-BOARD GENESIS

- Contractualisation between ESA & CNES to come soon…
- Main principles of the CNES DORIS package:
  - 1 on-board antenna
  - 1 recurrent DGXX-S receiver
    - **Without internal USO**
    - With cold redundancy (**2 chains**)
  - 1 DIODE navigator (OBSW)
  - EGSE SW update

+

  - Support to DORIS receiver integration & tests
  - Support to DORIS receiver operations
  - **Production of DORIS RINEX files (SSALTO)**

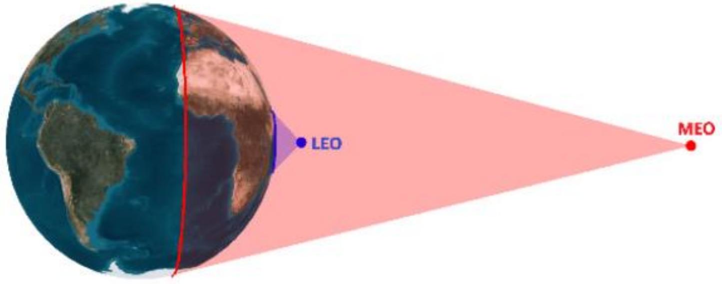
> Design changes and new tests to be avoided

> Loan of electric model to OHB- to support **EFM AIT activities** (instrument & antenna)

> Next steps after contract signature:

- Instrument requirements consolidation phase
- Equipment Qualification Status Review (EQSR)
- To catch up with the Genesis PDR foreseen in Oct.

MAIN CHALLENGES



1st DORIS instrument at 6000km !!

➢ Technical risk mitigation plan

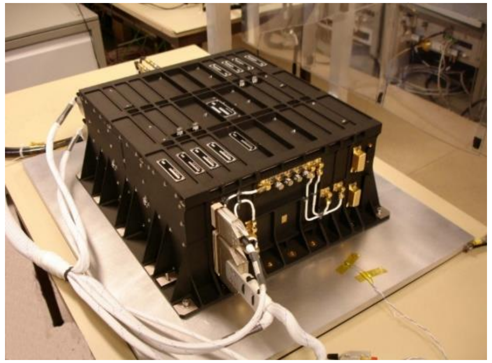
To further analyse the impact of

- The altitude :
  - On the link budget and SNR
  - On the received Doppler pattern (flattened)
  - On the visibility of multiple beacons
    (Doppler crossings causing internal jamming)
- The on-board clock
- The radiation environment

& to identify appropriate mitigation actions

➢ Ensure compatibility with the Genesis platform

Adaptations to be considered on a case-by-case basis



➢ Next steps

New set of tests to be done at the CNES DORIS laboratory

Capability to simulate 12 beacons in the coming months

⇒ **Deeper caracterization of the effects of the Genesis orbit**

…in order to optimize the quality & nb of measurements

light SW adaptations, designation strategy, system adaptations ?

ITERATIONS WITH WG-4

Feedback needed, for instance to:

- assess the impact of Doppler crossings
- agree on a strategy of designation of beacons to be observed
- consider a DORIS sub-network to be prioritized for Genesis

Topics to be investigated together with the WG (s):

- On-board clock performances (and impact of radiations)
- All information related to the platform and instrument calibration to clarify the needs
- Provision of DORIS RINEX generated during tests at the DORIS lab
- All feedback that may highlight a need of OBSW or system adaptations

eg. link with colocated GNSS receivers on ground, shifting of frequency, need of more colocated sites (ex: Matera)

DORIS NETWORK OF BEACONS

63 sites

4 MB

1 TB

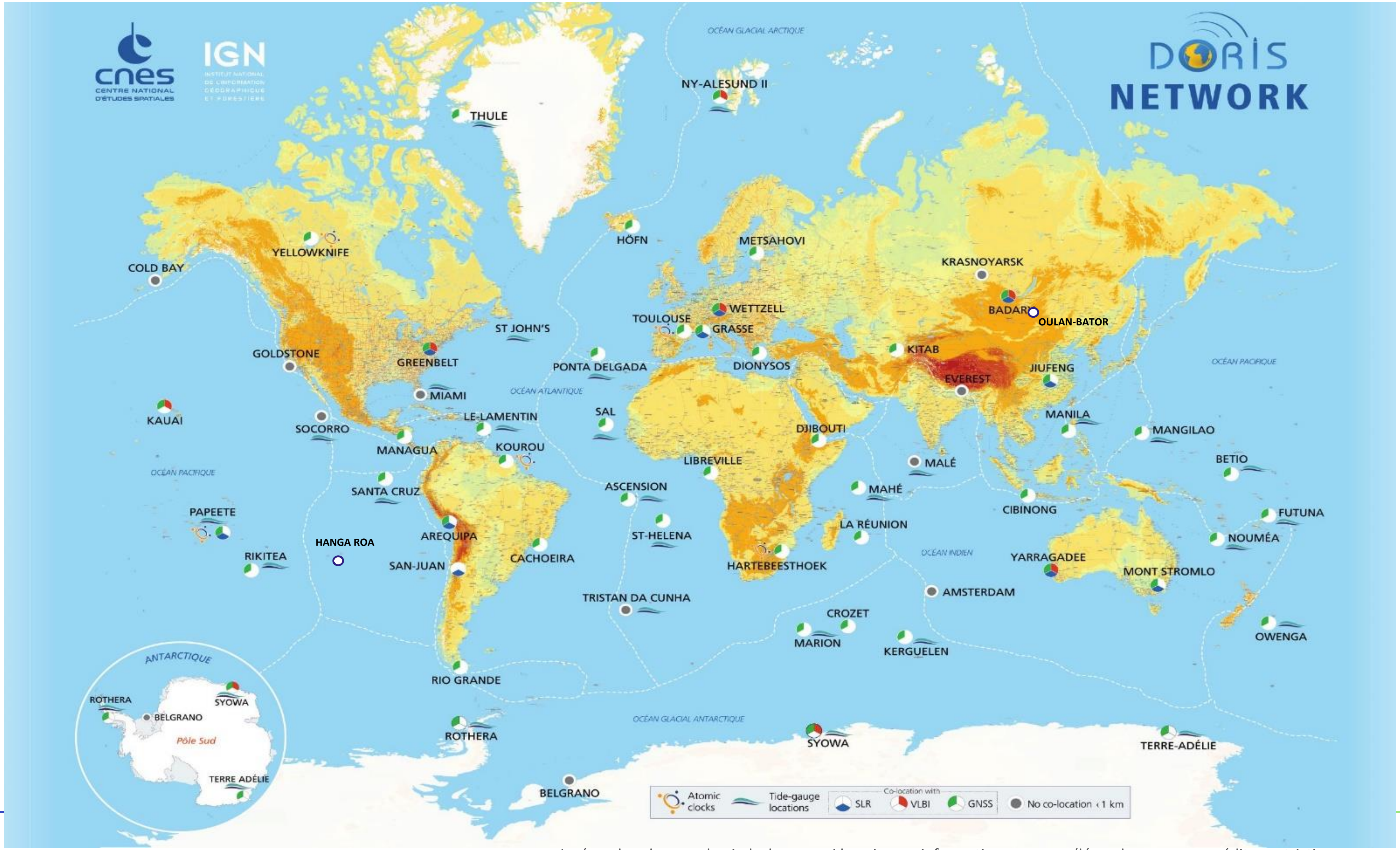
2 IDS sites

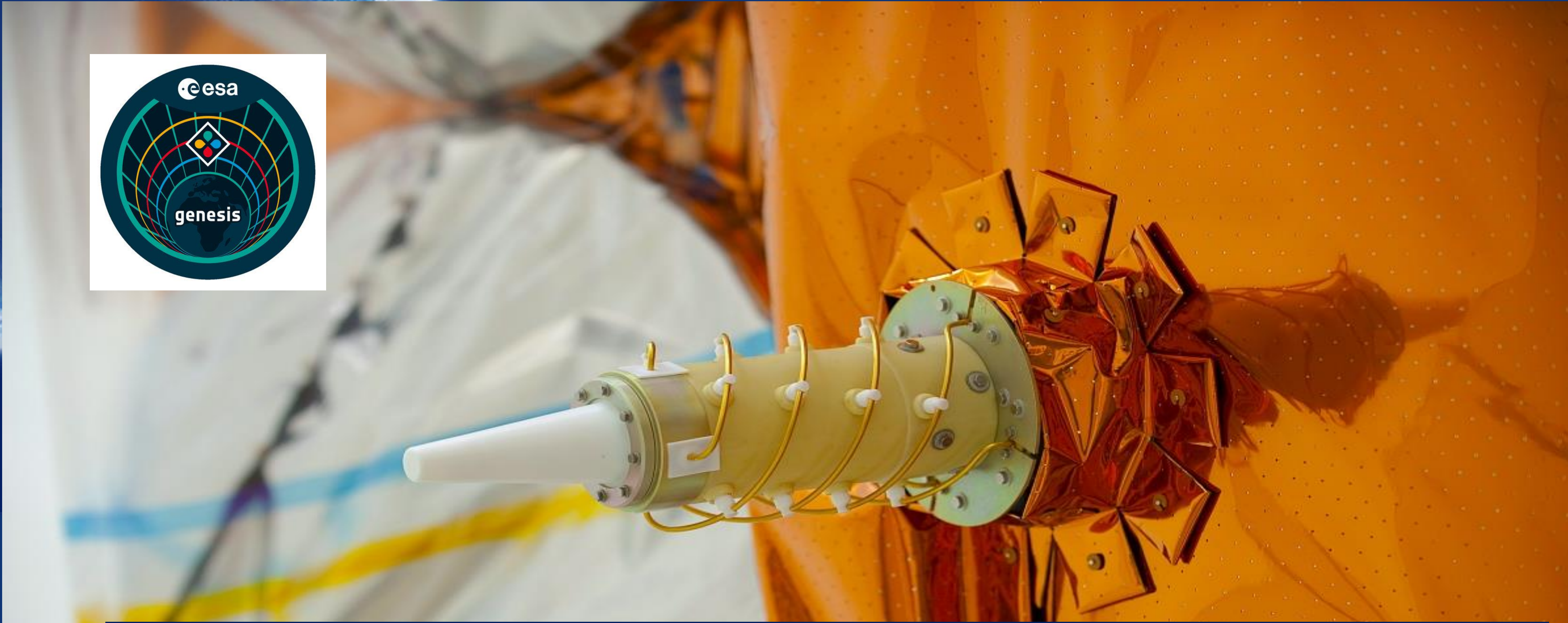
1 test site

Co-location with other techniques

B4G deployment
⇒ 46/63

Precise clocks reference
⇒ 9 sites





GENESIS WG 4 session

First Genesis DORIS simulations and observations by CNES POD team

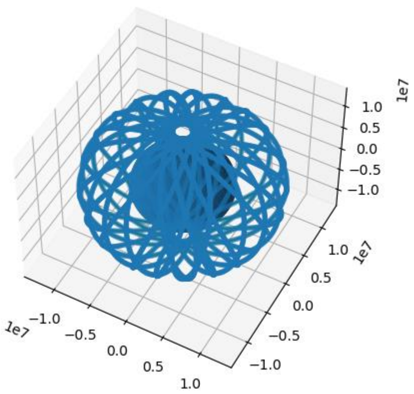
Flavien Mercier, John Moyard, Alexandre Couhert, Suzanne Blondel

ITALY MATERA, 4 april 2025

CONTENTS

CONFIGURATION & HYPOTHESIS

Simulation	Orbit Determination
3-day arc { altit. 6 000km, inclin. 96°, eccentr. very small } No dynamic model errors	
On board & ground OUS DORIS clock frequency noise model Phase measurement noise 3mm (iono-free) Complete DORIS network (60 beacons) Tropospheric model GP2/VMF1	Frequency adjustment {bias, drift} by pass measurement : phase variation (10s) visibility pass with possible interruptions due to Doppler collisions Tropospheric model GP2/VMF1 adjusted parameters (constant ZTD) by pass
	Adjustment of : Initial position and velocity Daily empirical 1/rev accelerations along-track & cross-track (12 coefficients)



Possibility to activate :

Threshold on Doppler collision, i.e. *300 cycles x* λ_{2Ghz} *x sampling* $\leftrightarrow$ *(300 Hz)*

Threshold on number of receiver channels, i.e. limitation at 7-channel

Warning : all the orbit performances are 'optimistic' as no dynamic and propagation model errors were added

CONFIGURATION & HYPOTHESIS, USO MODEL

The USO model is constructed from analysis of real measurements.

- random walk and random polynomial global variation
  - to be used with frequency bias+drift adjusted by pass
- same model for receiver and beacons
- no other effect on beacons (thermal)

Example of the current modelization (60 beacons USOs), Allan deviation, no long-term contribution :

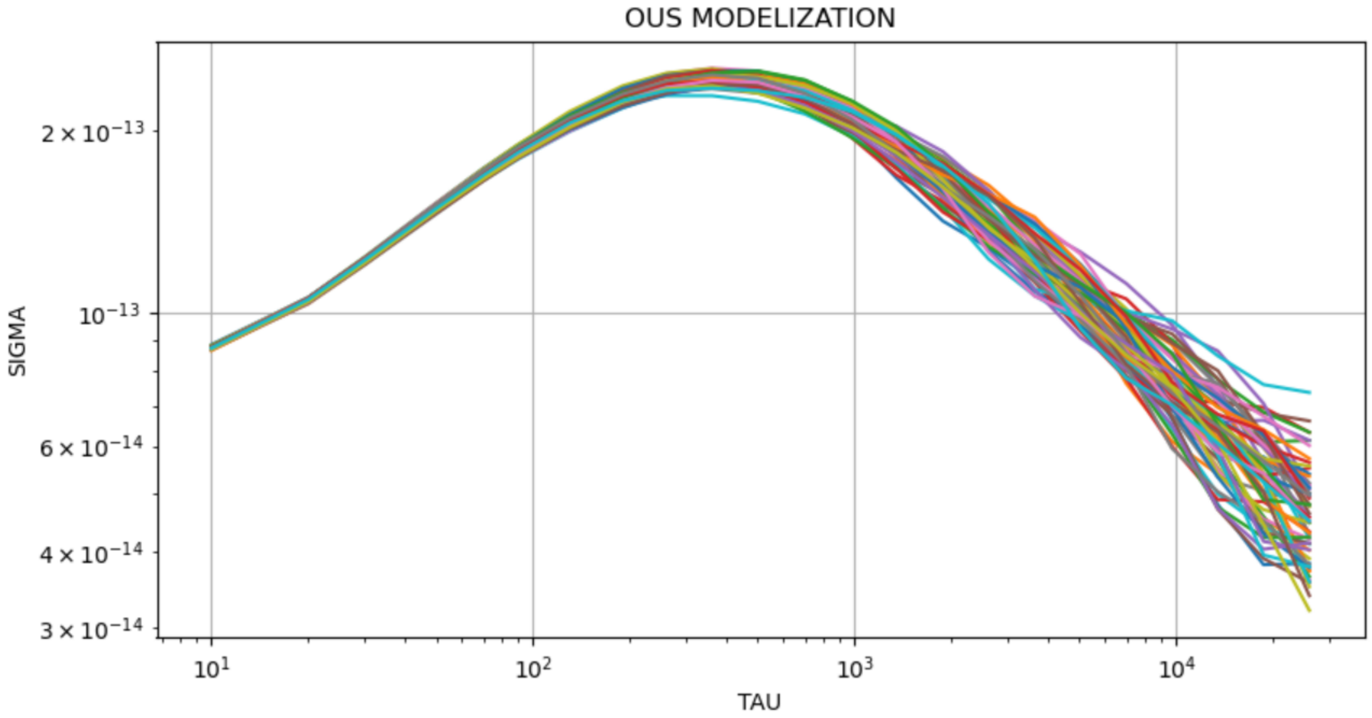
$$x_{n+1} = x_n + a v_n$$ (random walk)

$$y_{n+1} = b y_n + (1-b) x_n$$ (Low pass filter)

with

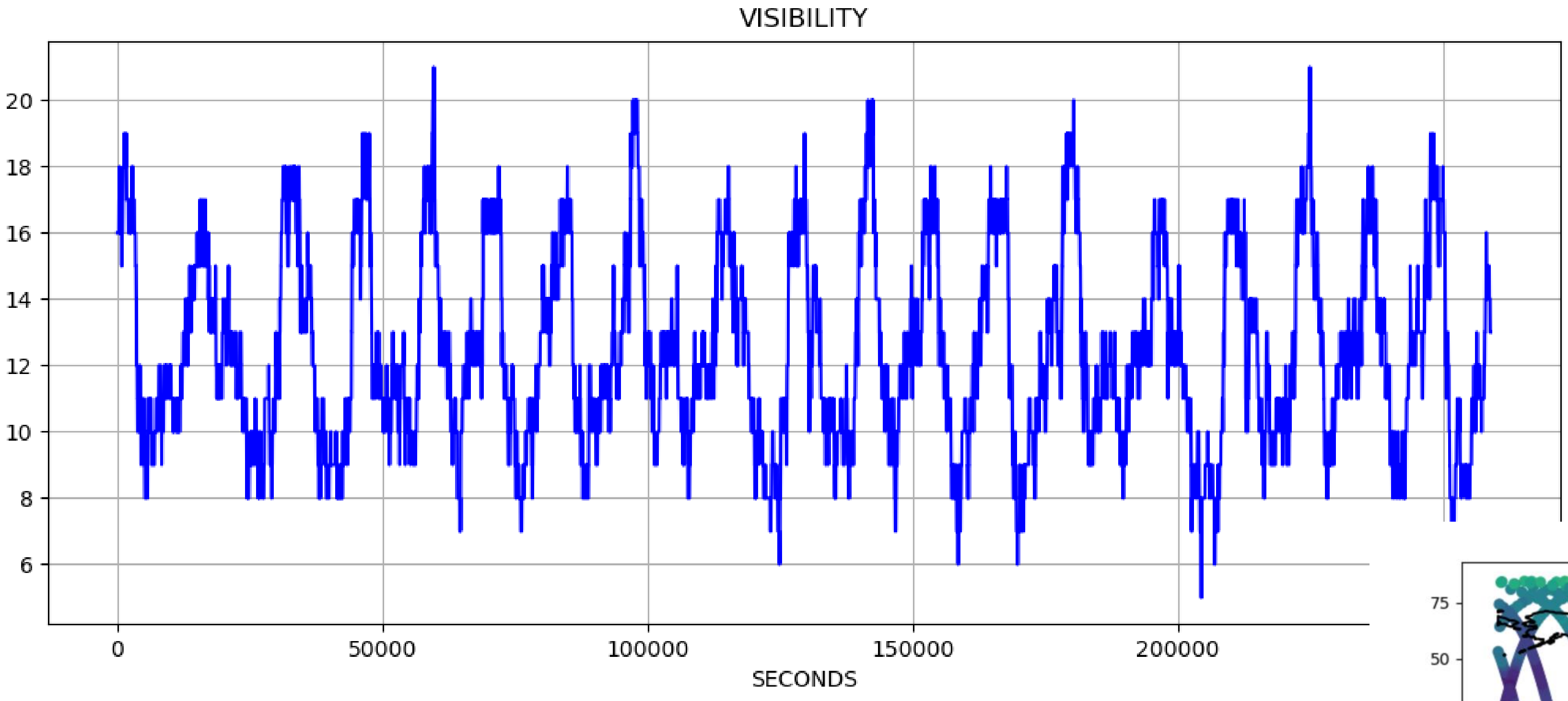
a = 2.5 10^{-11} s

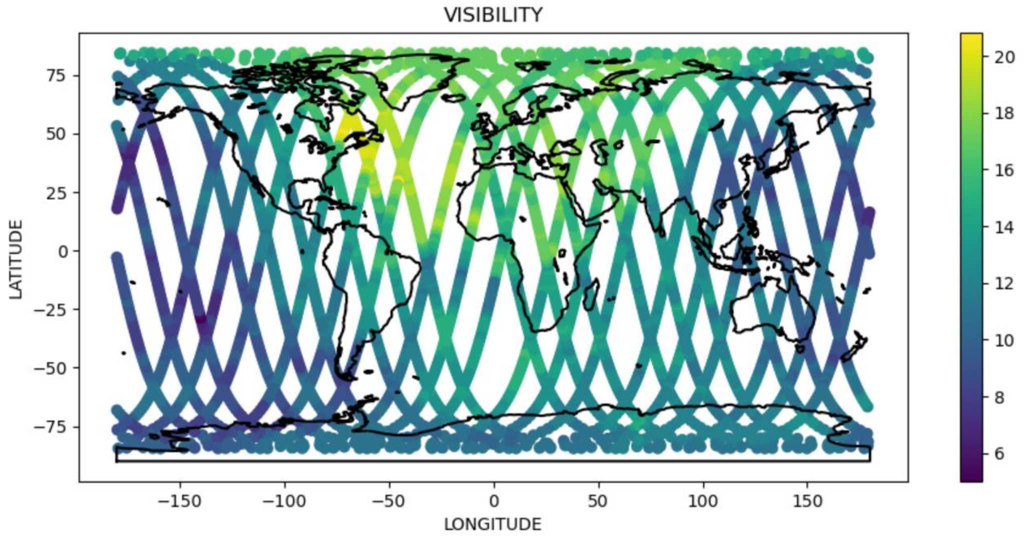
b = 0.95



The datation and the time reference beacons are assumed perfect in these simulations.

OBSERVATIONS & RESULTS, VISIBILITY





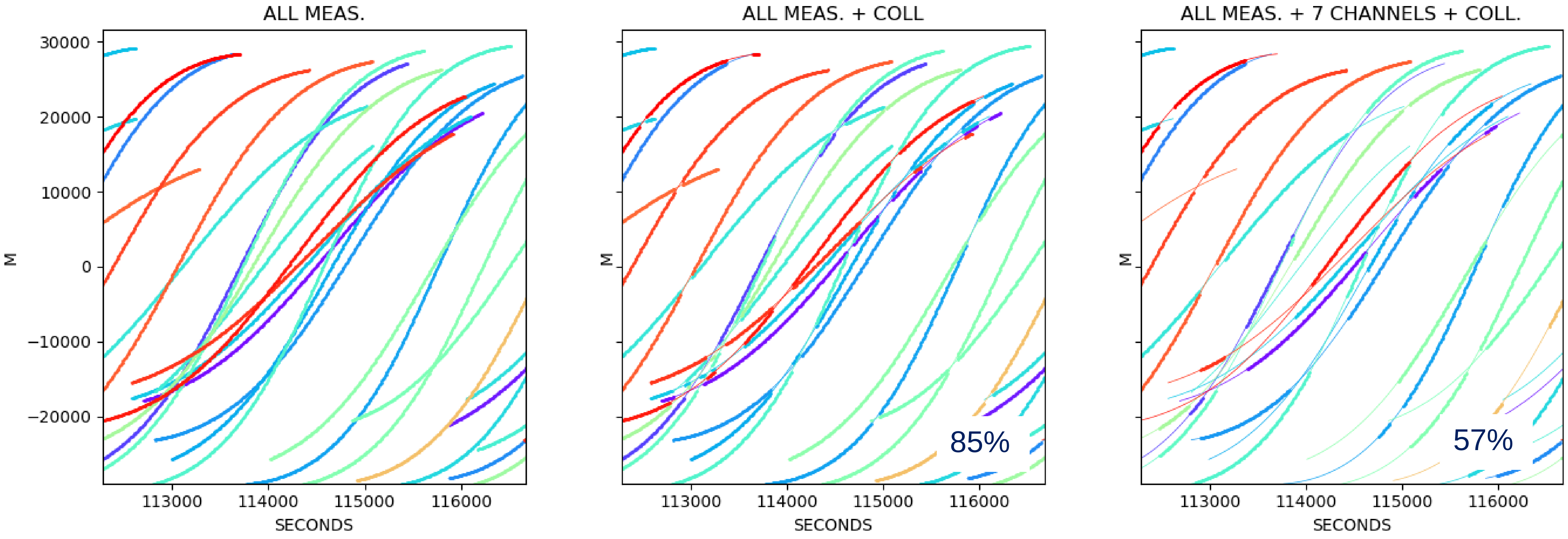
10 to 20 beacons in visibility

The maximum is located over the North Atlantic ocean

Probably an important number of Doppler collisions :
How to model this in the simulation?

OBSERVATIONS & RESULTS, SCENARII

3 configurations



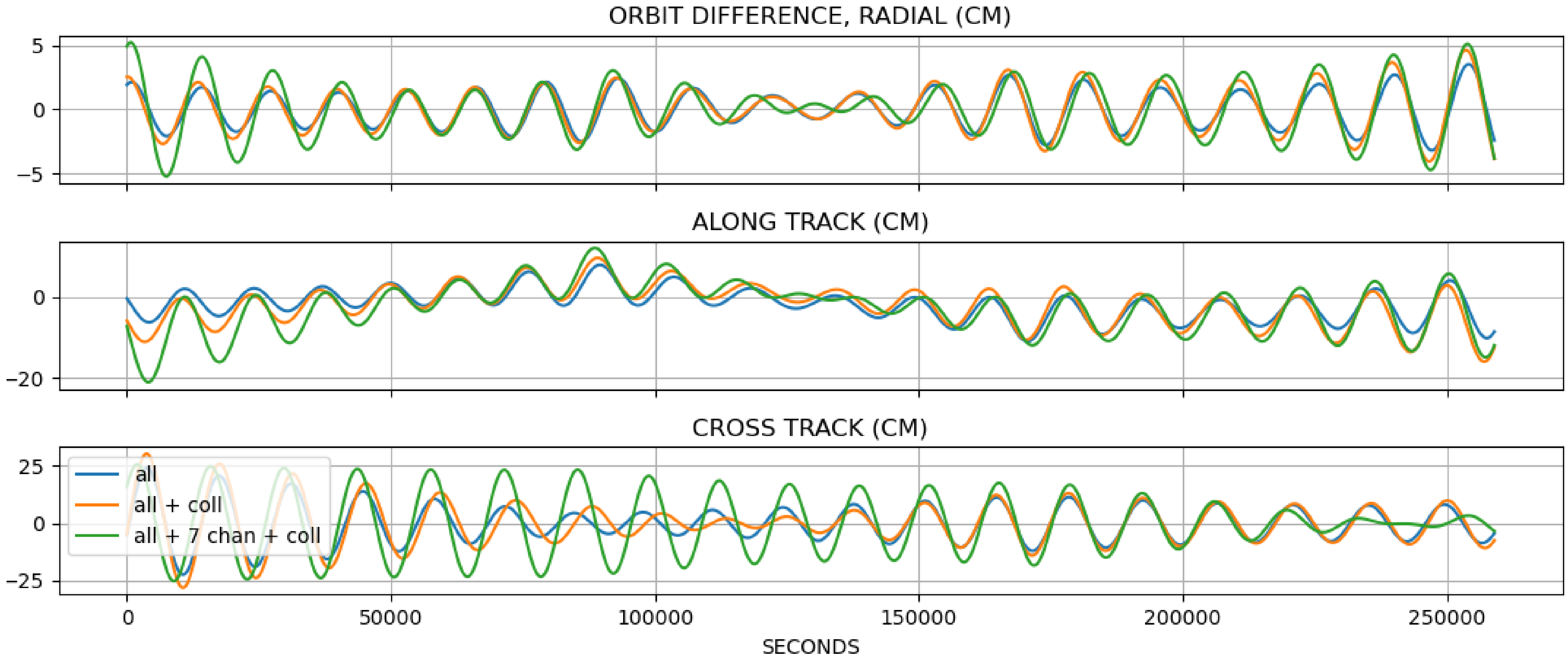
7-channel tracking principle :

When the measurement is interrupted, start an acquisition with highest S/B ratio in the available measurements

(to be validated with hardware simulator on the receiver)

Merge the different acquisitions on the same beacon in a single pass

OBSERVATIONS & RESULTS, ORBIT COMPARISON



Difference with a reference orbit, which was used for the measurement simulation.

Limited effect of the doppler collisions (without 7 channels limitation, blue and yellow)

7-channel limitation does not degrade too much the performance (green and yellow)

CONCLUSION

Orbit determination taking into account the Doppler collisions and the 7-channel limitation is not significantly worse than the reference case with all measurements.

Performance of (R : 10 cm , T : 20 cm , N : 50 cm) taking into account only the measurements errors (noise and USO).

Some hypotheses need to be confirmed :

- Receiver and doppler collisions modelling
  - loss of lock /reacquisition time, i.e. S/B criterion ? , …
- Limitation on subset of the network to improve geometry ?
  - K factor need ?
- Effect of the chosen on board oscillator

Others issues should be adressed :

- Zero doppler measurement eliminations have not been tested
- Specific beacon designation strategy to be defined
- Model errors for the simulation (tropos., USO perturbations, SRP, …)

THANK YOU FOR YOUR ATTENTION
ANY QUESTION ?