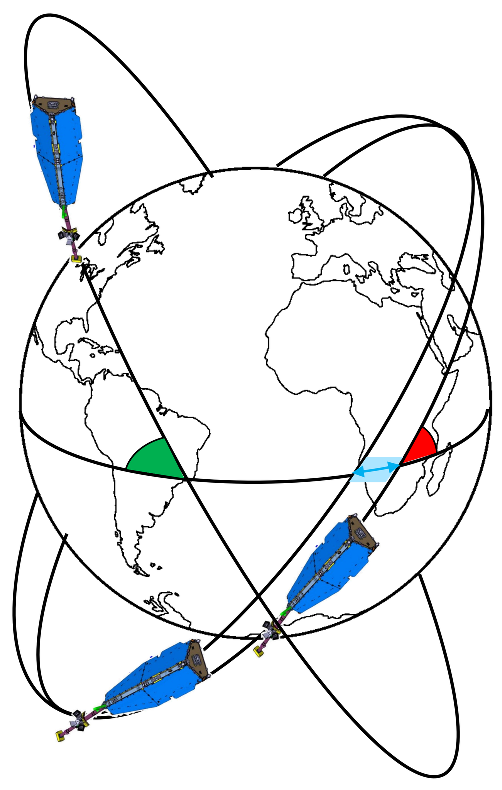
SWARM CONSTELLATION ORBITAL EVOLUTION UNDER SCIENTIFIC AND OPERATIONAL CONTRAINTS

MISSION ARCHITECTURE



Swarm mission consists of 3 identical satellites in Low Earth Orbit

- A and C operate at lower altitude
- B operates at higher altitude and at a different local time

Initial inclination of each satellite:

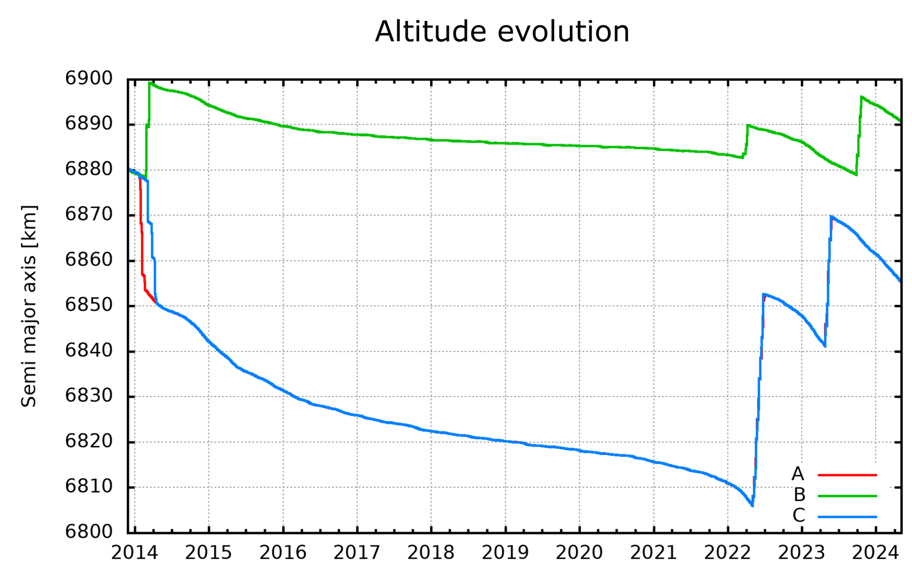
Swarm-A **87.35 deg**

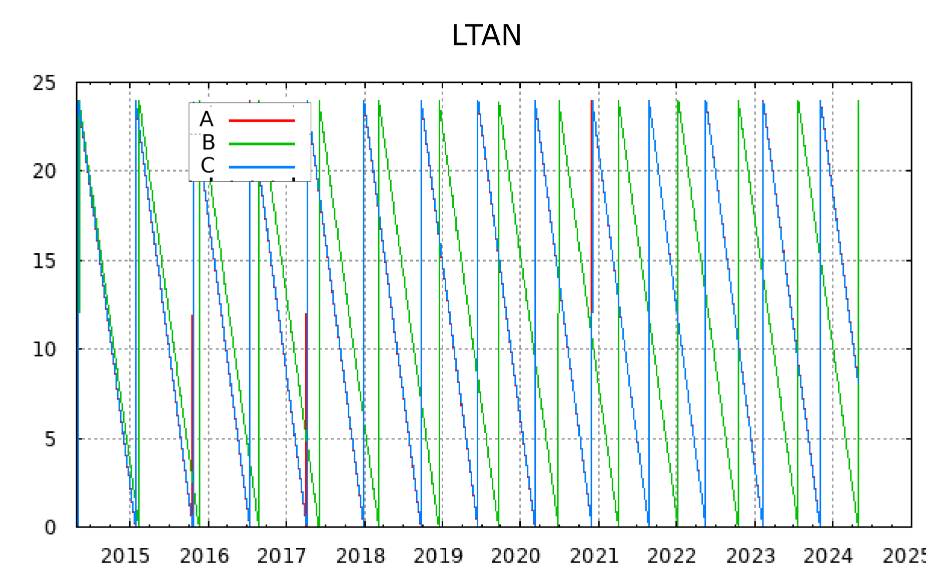
Swarm-B **87.75 deg**

Swarm-C **87.35 deg**

Initial delta-LTAN between A and C: **0.094h / 1.4deg**

ORBITAL EVOLUTION





Altitude and Local Time are not frozen:

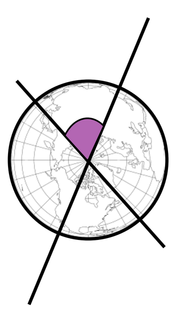
the 3 satellites are decaying freely under the effect of the atmospheric drag.

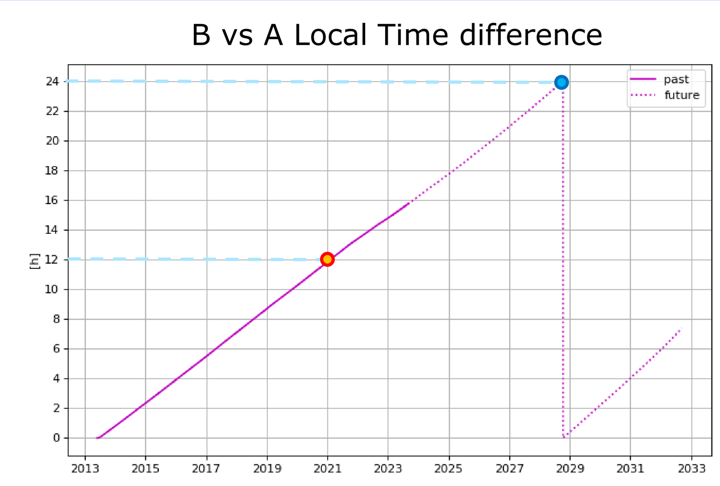
Local Time is drifting due to non spherical gravitational field

HOW ORBITS HELP SCIENCE

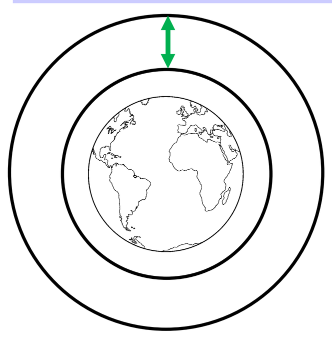
In order to achieve its scientific objectives, Swarm needs variability in space and time!

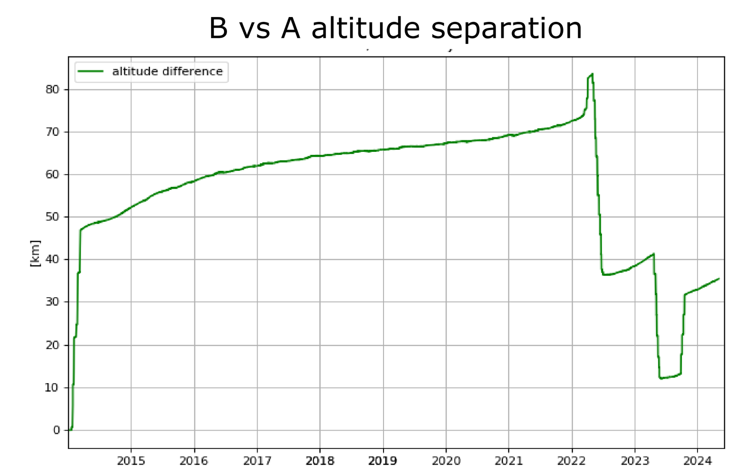
Keep variable LTAN separation between Swarm-B and lower pair



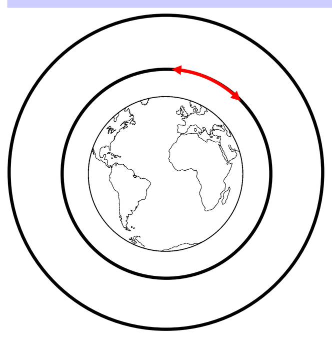


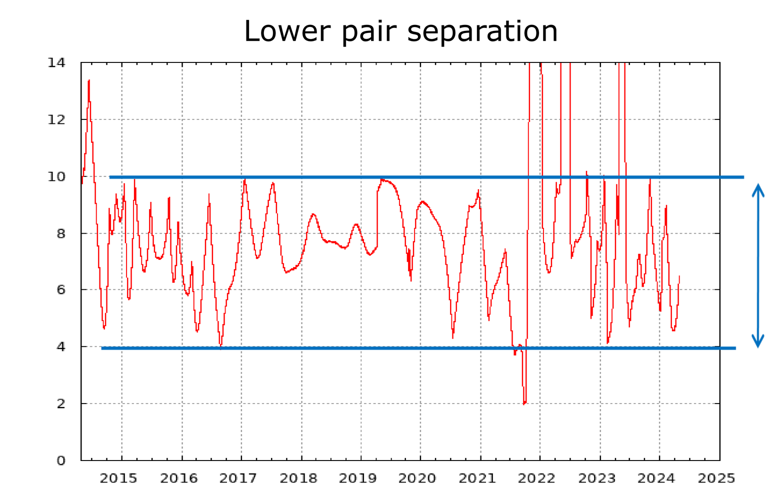
Keep altitude separation between Swarm-B and A/C bounded





Keep along track separation between 4 and 10 seconds





CHANGING ORBITS TO MAXIMISE SCIENTIFIC RETURN

Trajectory adjustments are required to meet specific requirements:

- Exploit counter rotating orbits configuration
- Be at lower altitude at next solar minimum
- Keep Swarm mission until next solar minimum

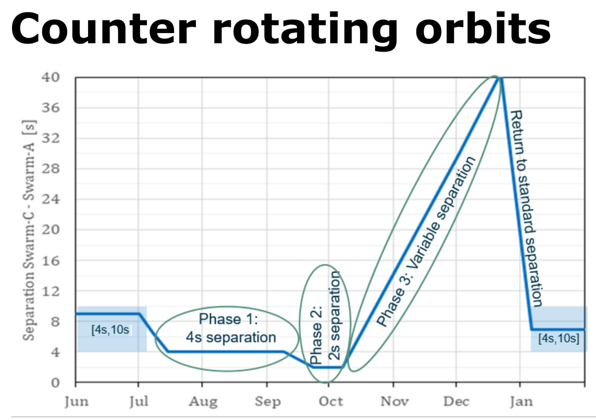
October 2019

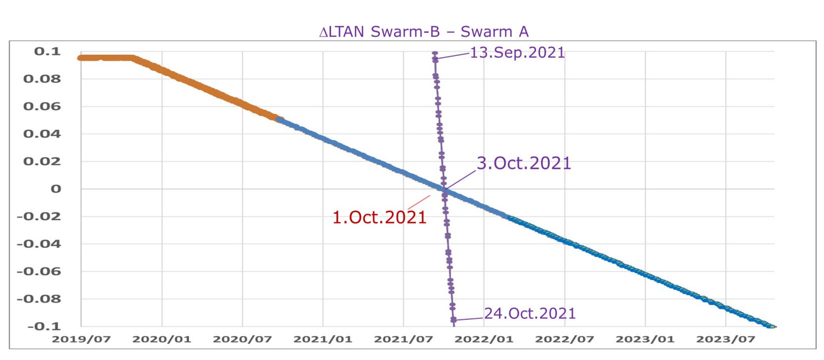
Inclination change #1

- Introduce **15 mdeg inclination difference** between Swarm-A and C to start a Local Time drift
- Usage of **Y thrusters** (more convenient as it does not imply slews)

July/ December 2021

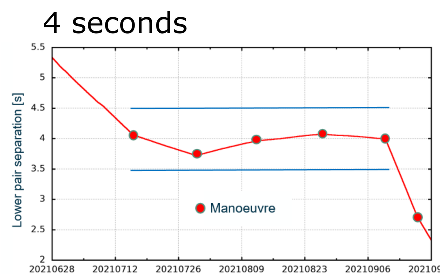
Counter rotating orbits



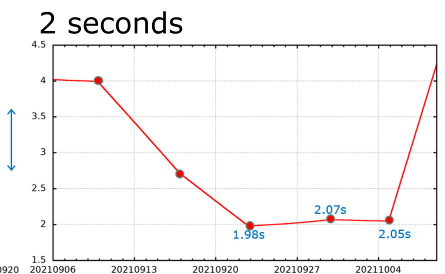


3 phases:

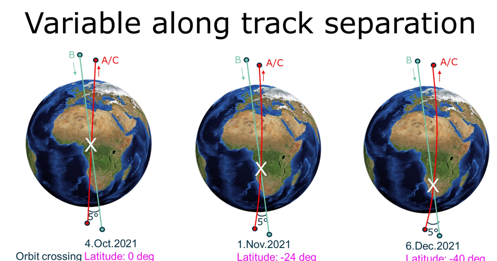
4 seconds



2 seconds



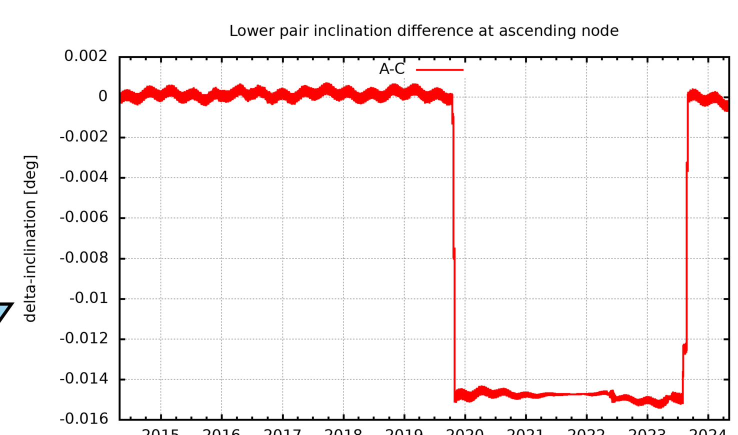
Variable along track separation

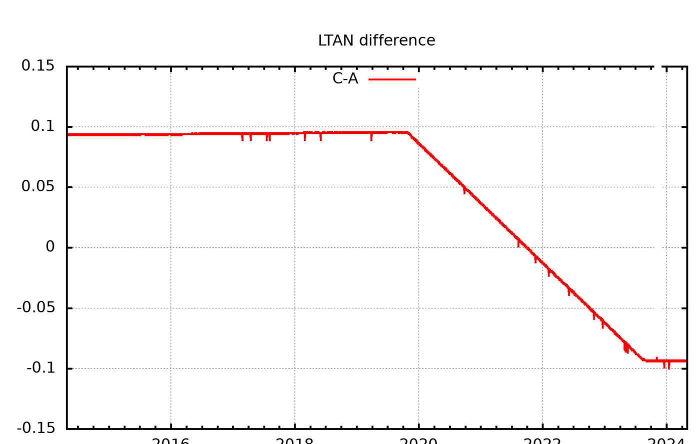


August 2023

Inclination change #2

- inclination difference between A and C is back to 0 deg
- Current LTAN difference: -1.4 deg / -0.094 h
- The Local Time drift has stopped



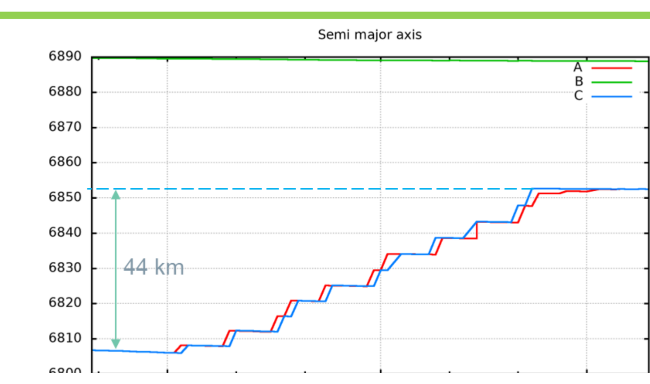


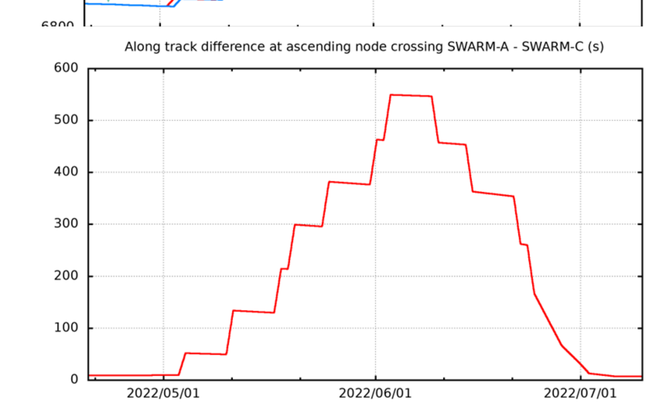
A/C Altitude raise part #1

- Swarm-B: 3 (test) burns
- Swarm-A: 2 (test) + 16 burns
- Swarm-C: 2 (test) + 9 burns

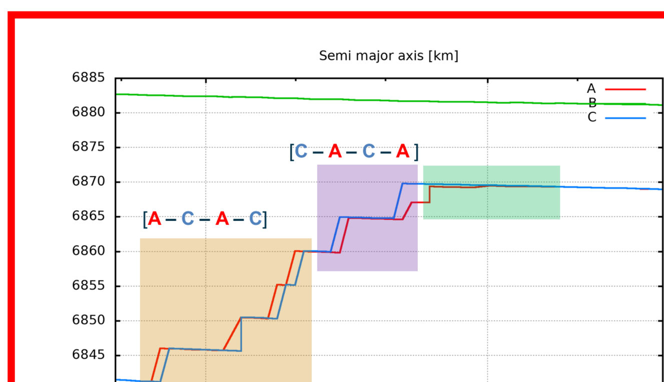
Swarm-A needed touch-up manoeuvres:

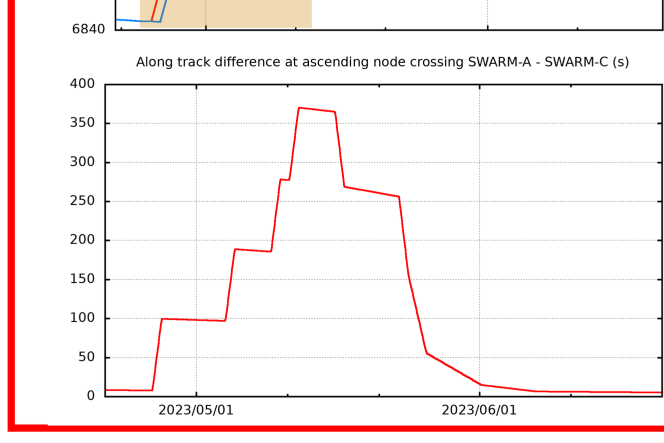
- Reach Swarm-C altitude
- Adjust eccentricity difference
- Constellation back inside the [4s—10s] boundaries





May/July 2022





A/C Altitude raise part #2

It was needed to avoid reentry before 2030

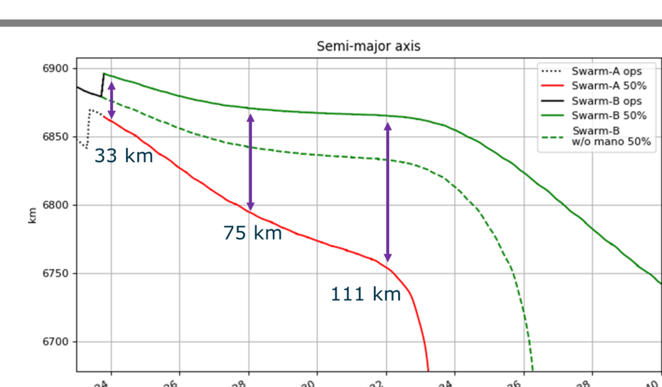
Same concept as in 2022

- 2 test manoeuvres
- [A-C-A-C] sequence followed by [C-A-C-A] sequence
- Touch-up manoeuvres on Swarm-A

April/ June 2023

Swarm-B altitude raise

- Increase altitude separation between Swarm-B and the lower pairSwarm-A



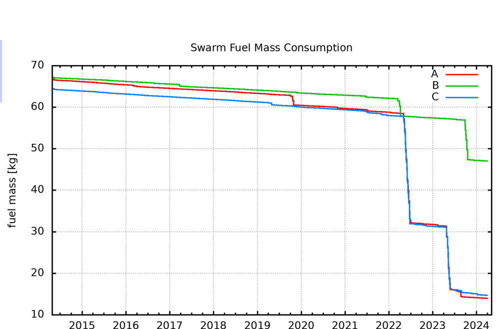
September/ October 2023

Current Fuel status:

Swarm-A : 13.9 kg

Swarm-B : 47.1 kg

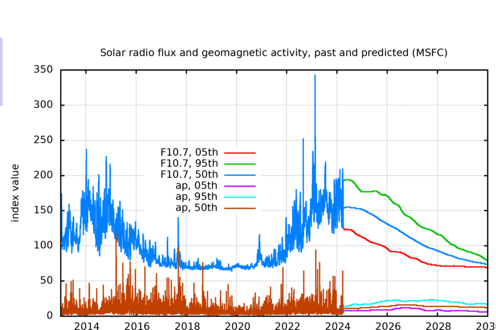
Swarm-C : 14.7 kg



Predicted solar activity:

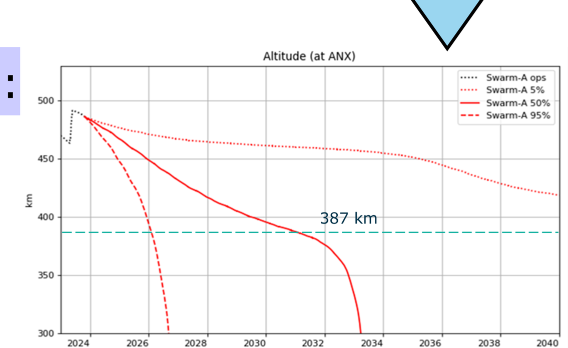
Solar maximum 2025

Solar minimum 2030



Predicted A/C altitude evolution:

If solar activity follows 50%, the altitude will be 387 at beginning 2031



CONCLUSIONS AND OUTLOOK

With current fuel levels, assuming a consumption rate of 1 kg/year for attitude control and CAMs, the lower pair of Swarm satellites should be able to maintain **operation** until the next solar minimum in **2031**, barring a significant increase in solar activity. Due to limited fuel, **no further adjustments to the altitude of Swarm-A/C** will be possible. The inclination difference between Swarm-A and C has been reduced to 0 deg, stabilizing the RAAN difference at 1.4 degrees. Whether further adjustment is needed before the next solar minimum is still under discussion. Swarm-B's altitude has been raised 32 km above the lower pair. However, due to differential decay, the spread in altitude will increase over time. The orbital plane of Swarm-B is drifting in relation to Swarm-A/C, with the orbital planes expected to be perpendicular in 2025/2026 and coplanar in 2029/2030. Given the remaining fuel on board of Swarm-B, it is **possible to slow down the drift** to achieve coplanar orbital planes by 2031

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