Constellation Status of the Swarm Mission

Swarm Flight Dynamics Team

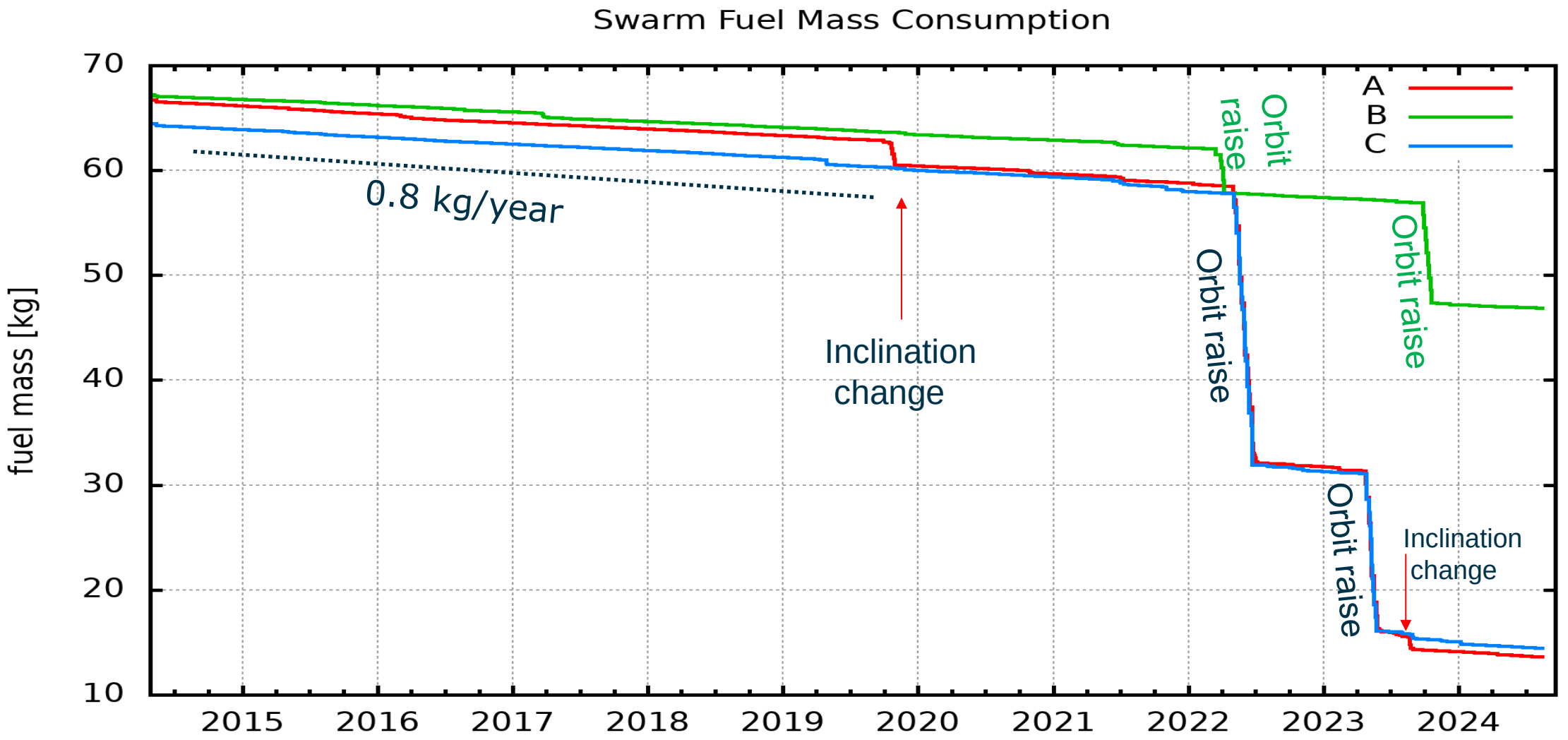
Content

- S/C mass and fuel status
- Yearly fuel consumption and lower pair formation maintenance

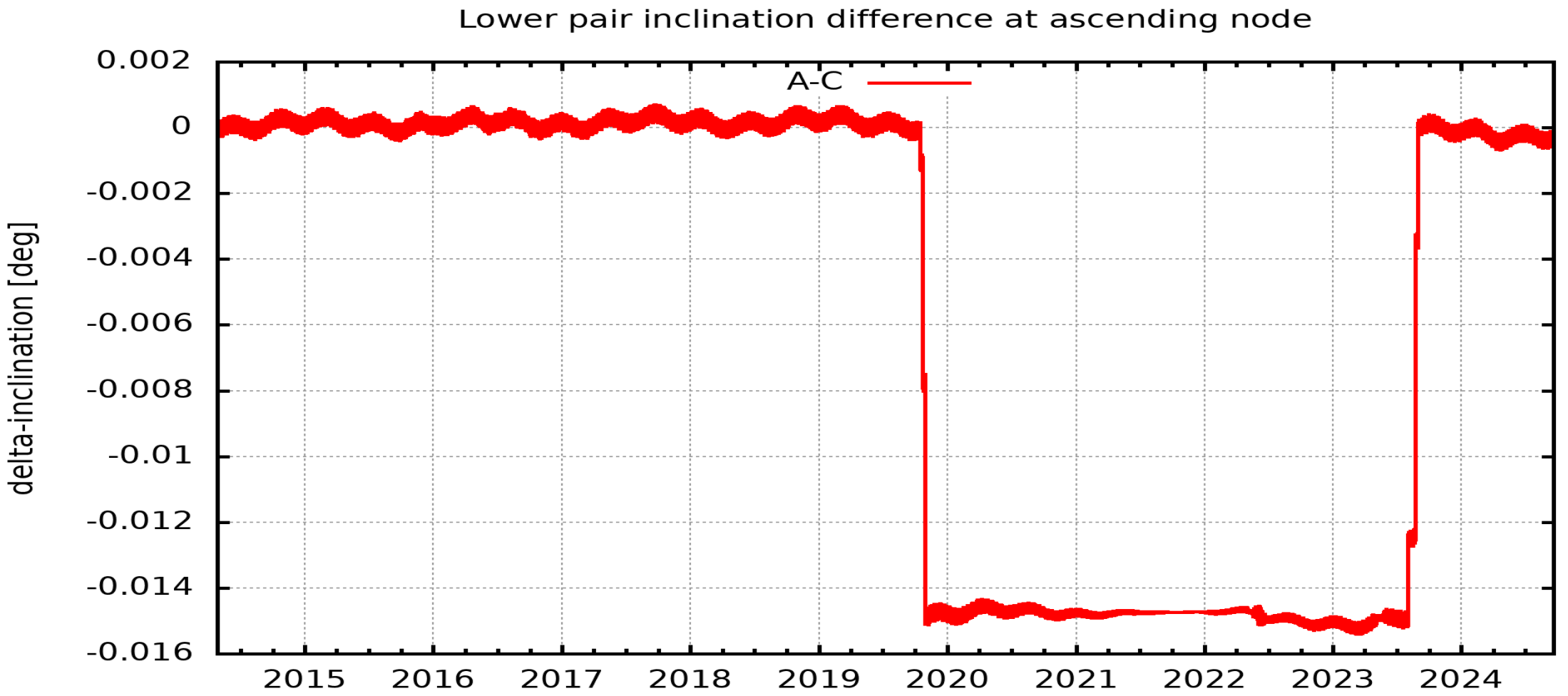
- Observed altitude evolution
- Status of the solar activity and evolution
- Predicted altitude evolution

- Swarm-B orbital plane rotation
- Conclusion and discussion points

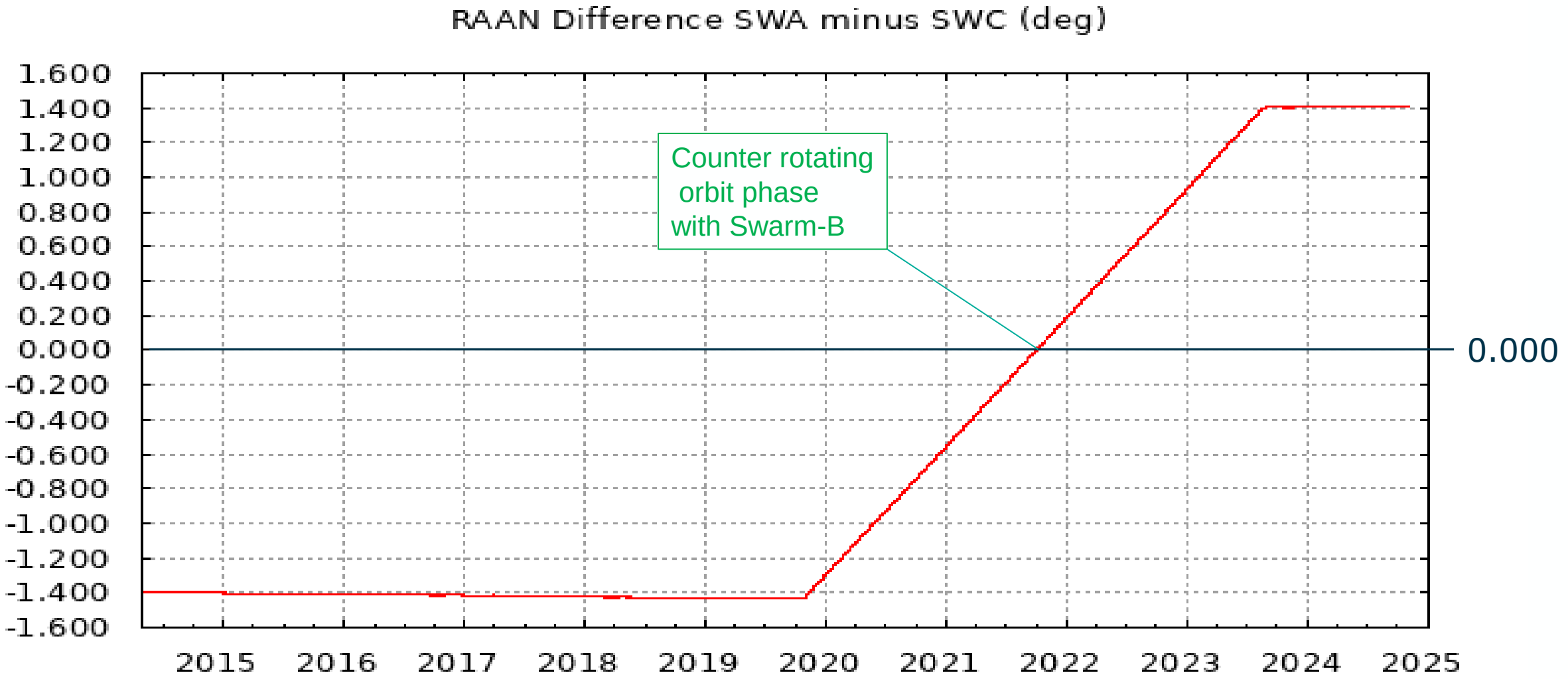
Fuel Consumption Since Start of Science Operations



Lower Pair Inclination Change



Evolution Of RAAN



S/C Mass and Fuel Status

Dry mass	Fuel loaded	Fuel after orbit acquisition (May 2014)
A: 367.23kg	105.5 kg	66.74 kg
B: 367.79kg	105.2 kg	67.24 kg
C: 370.59kg	102.8 kg	64.47 kg

DQW-13 → DQW-14		
Fuel (Oct 2022)		**Fuel (Oct 2023)**
14.30 kg	**-0.73**	13.57 kg
54.53 kg	**-7.71**	46.82 kg
15.33 kg	**-0.94**	14.39 kg

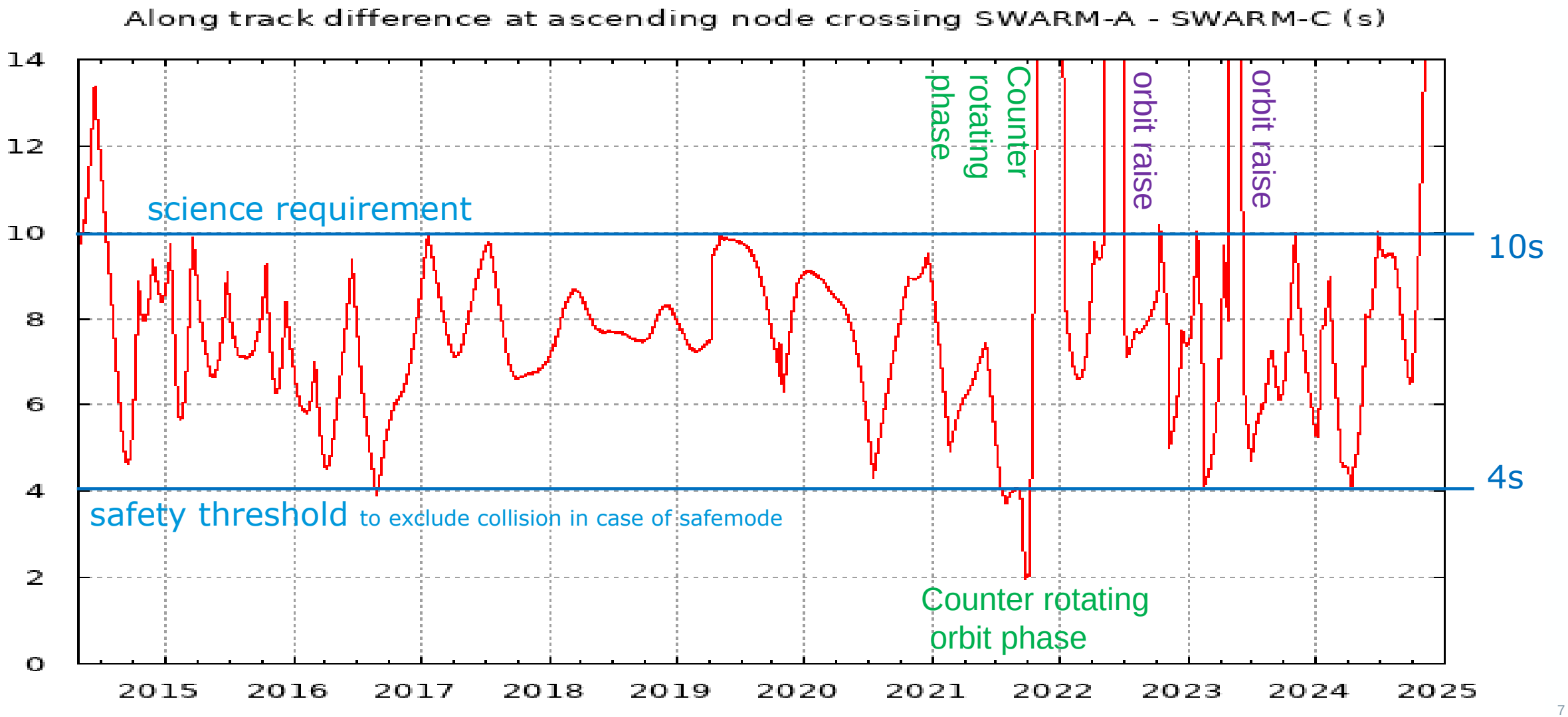
Total mass (Oct 2024)
380.80 kg
360.08 kg
384.98 kg

Swarm-A mass is 1.09% lower than Swarm-C mass

Current Fuel Pulse counting	**Current Fuel PVT**
13.57 kg	15.89 kg
46.82 kg	45.75 kg
14.39 kg	13.48 kg

During solar maximum the yearly fuel consumption is still less than 1kg / year

Lower Pair Formation, ΔTime



Lower Pair Yearly Fuel Consumption

Attitude control consumption is about **0.6 kg**

Each Swarm-A or Swarm-C **collision avoidance manoeuvre** requires typically **0.1kg** because of 180 deg attitude slews.

During the last 12 months **formation maintenance** required:

- 5 manoeuvres by Swarm-A
  Fuel spent: **0.042 kg**
- 2 manoeuvres by Swarm-C
  Fuel spent **0.007** kg

→The fuel consumption for formation maintenance remains minor.

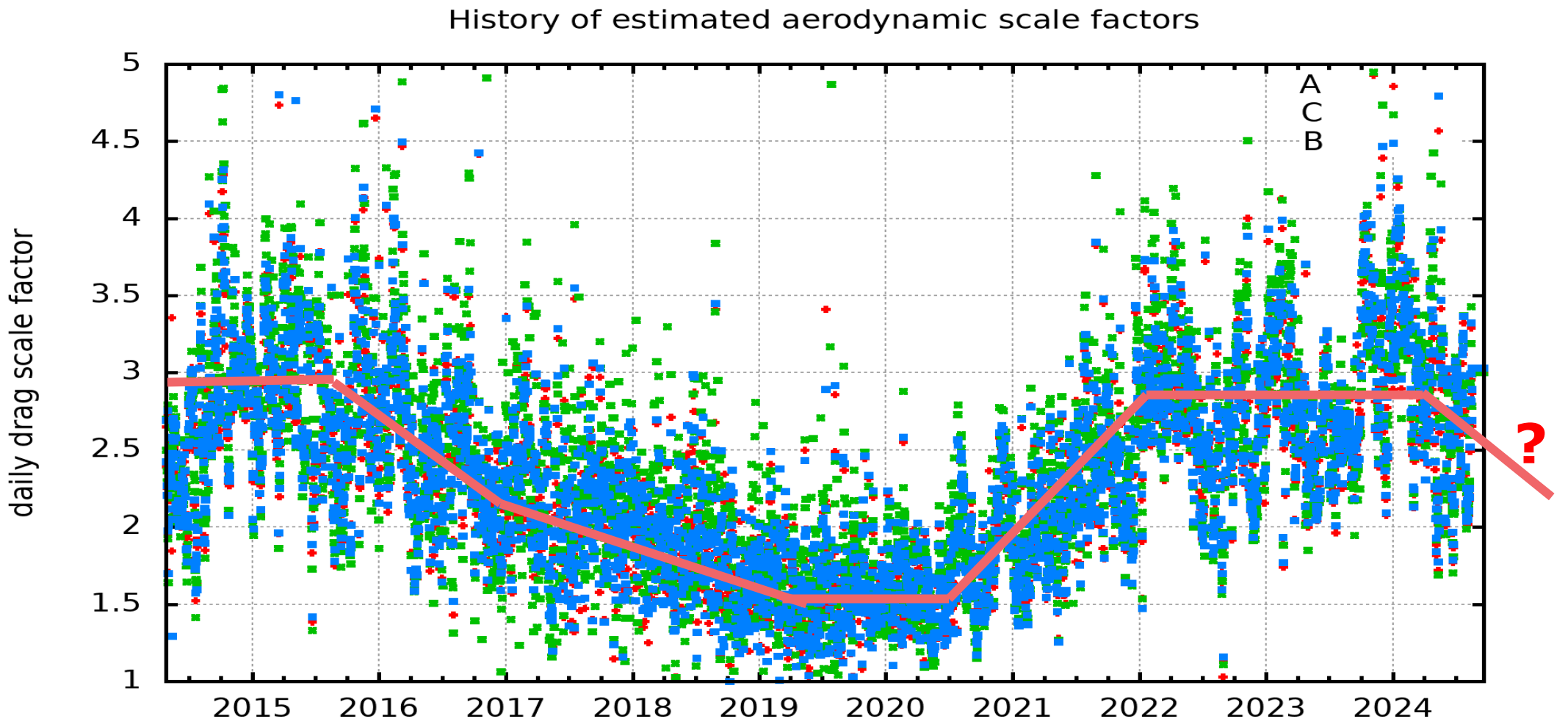
Swarm Altitude Evolution

Swarm altitude evolution and orbit determination and prediction model.

Swarm operational orbit determination at ESOC uses the NRLMSIS-00 atmosphere model.
One daily air drag force scale factor is estimated to match
the decelerations from the air density model
to the actually observed declaration.

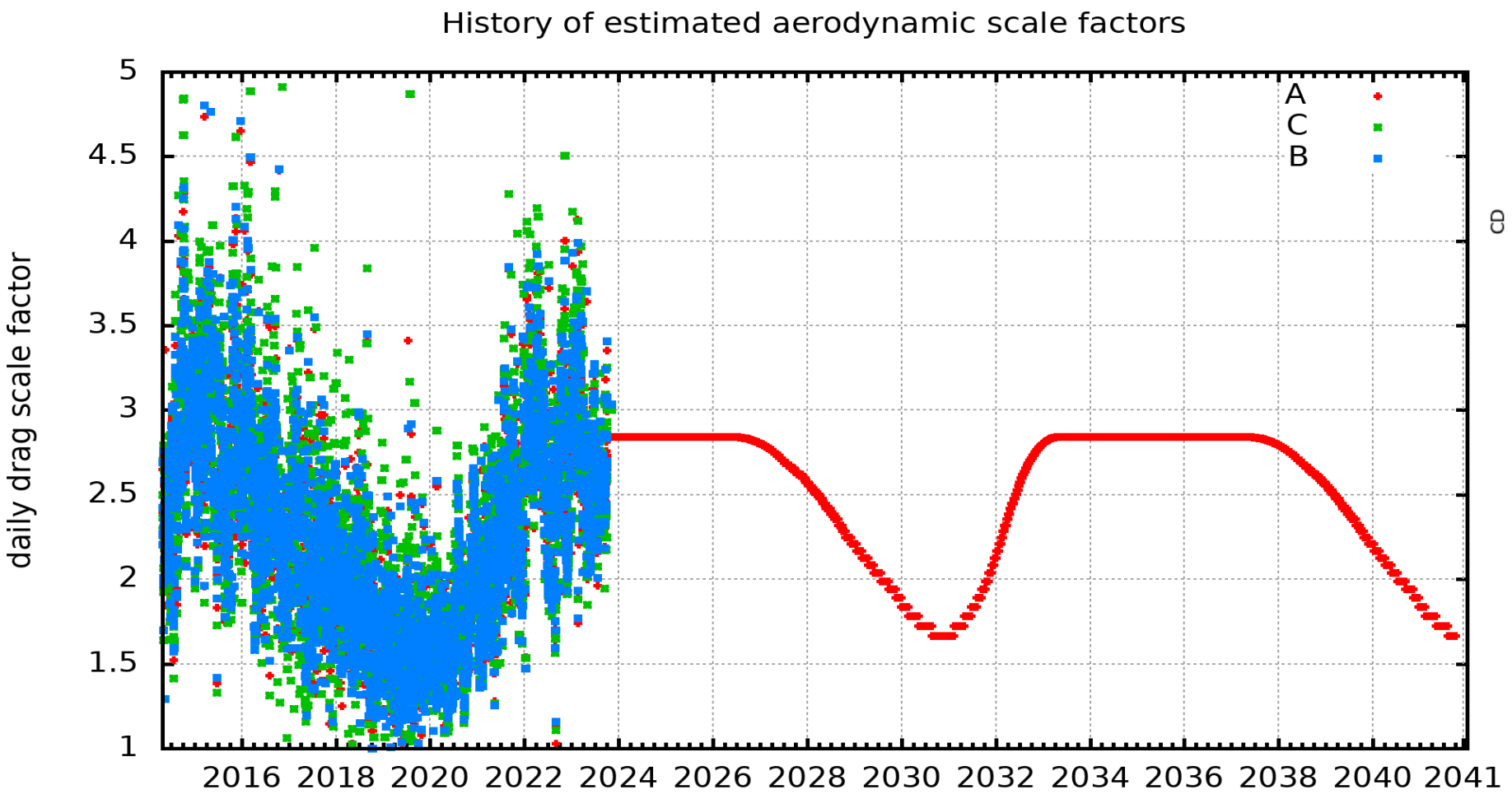
A higher scale factor is estimated during solar maximum as the modelled air drag is smaller than reality
A lower scale factor is estimated during solar minimum as the modelled air drag is higher than reality

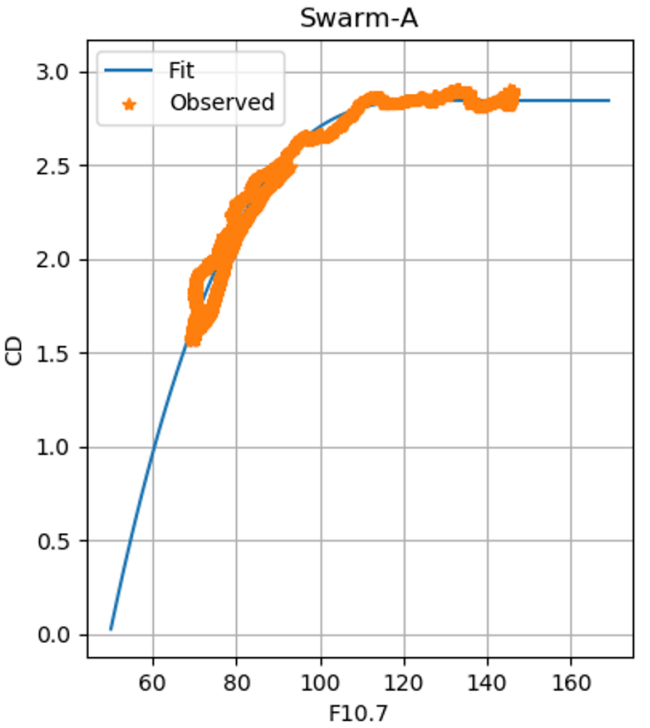
History of Air Density Scale Factors



Has the drop of CD already started? This might just be a temporal fluctuation

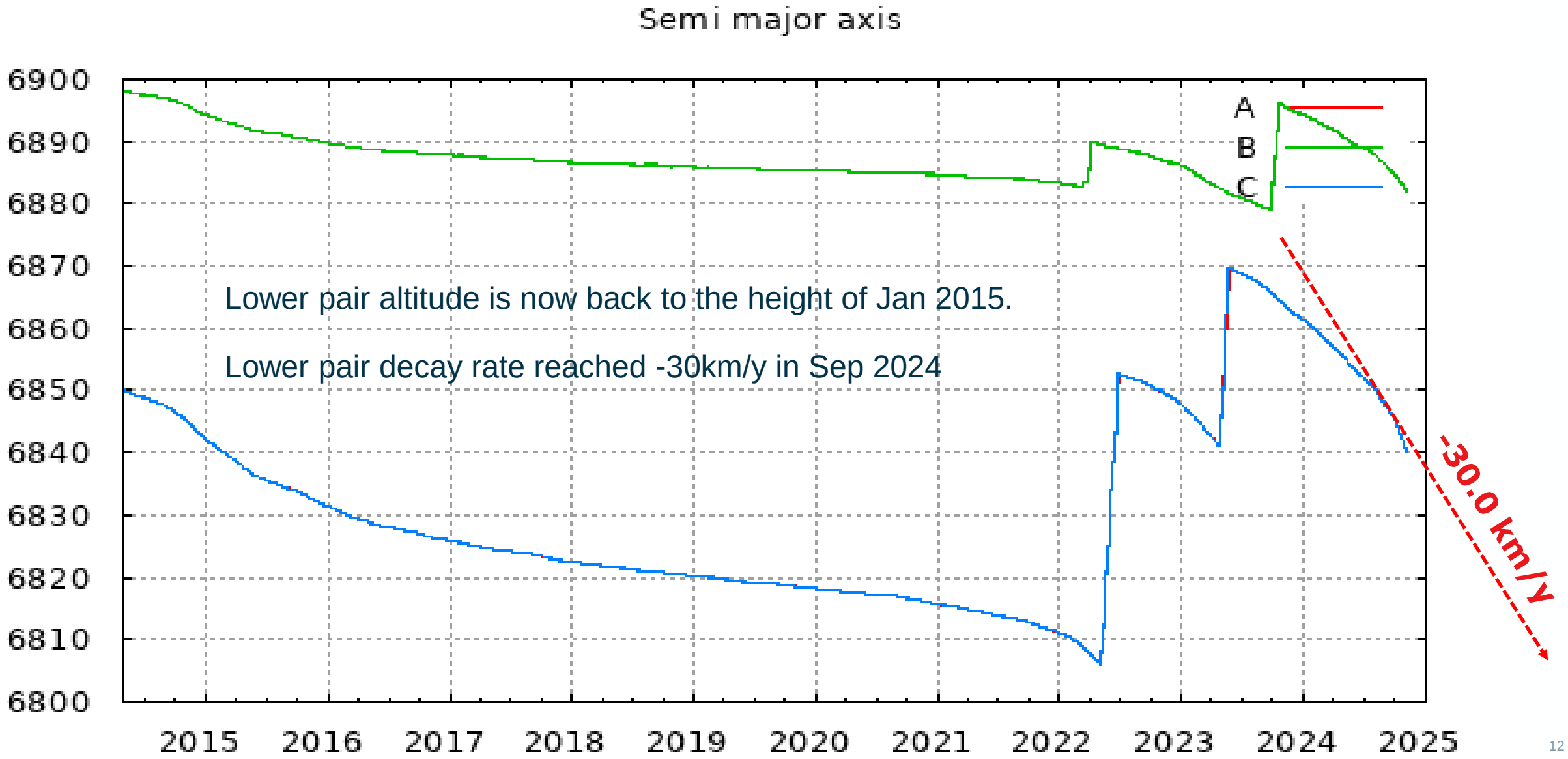
History of Air Density Scale Factors





For long term orbit propagation the NRLMSIS model is "calibrated" assuming a correlation between the CD value and the predicted solar activity index F10.7

Observed Altitude Evolution

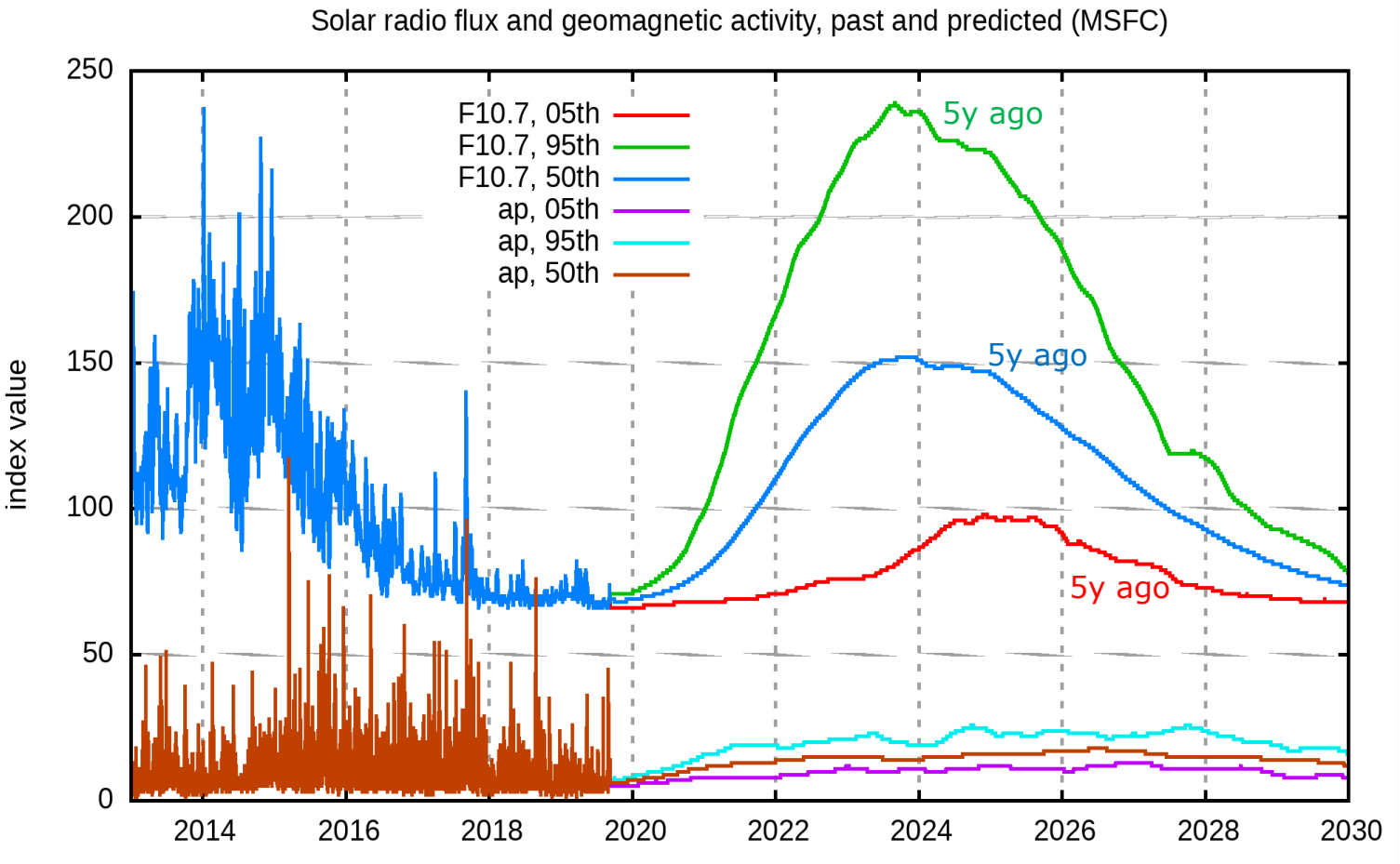


Solar Cycle 25, Evolution of MSFC Predictions

Input to atmosphere density model NRLMSIS-00 are solar radio 10.7 cm flux, **F10.7**, and **Ap**, the geomagnetic planetary index.

Values shown are from Space Environments Team at Marshall Space Flight Center, **MSFC**.

Predictions of cycle 25 shown here are based on statistical estimation technique
https://www.nasa.gov/sites/default/files/atoms/files/tm4759_0.pdf



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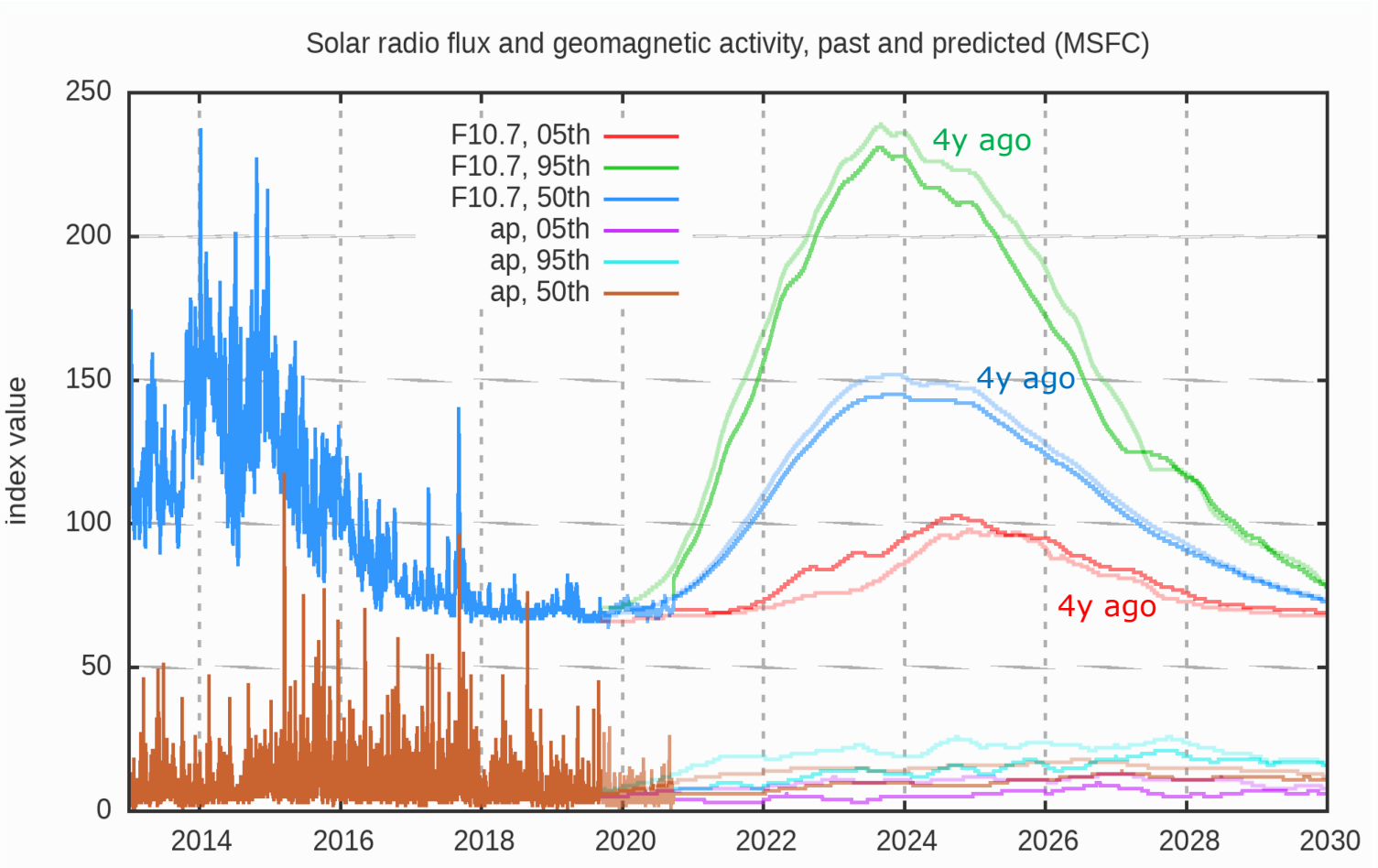

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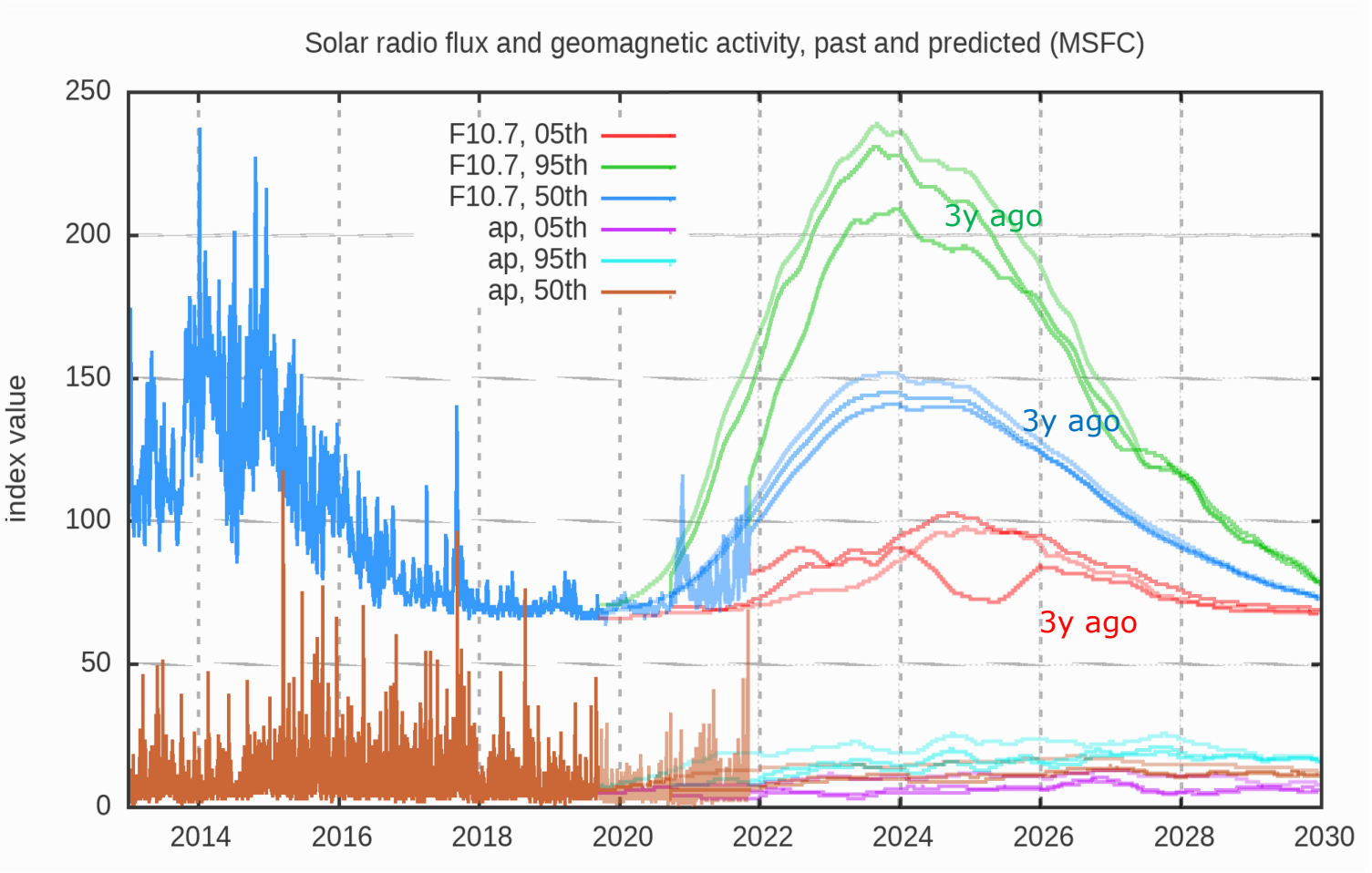

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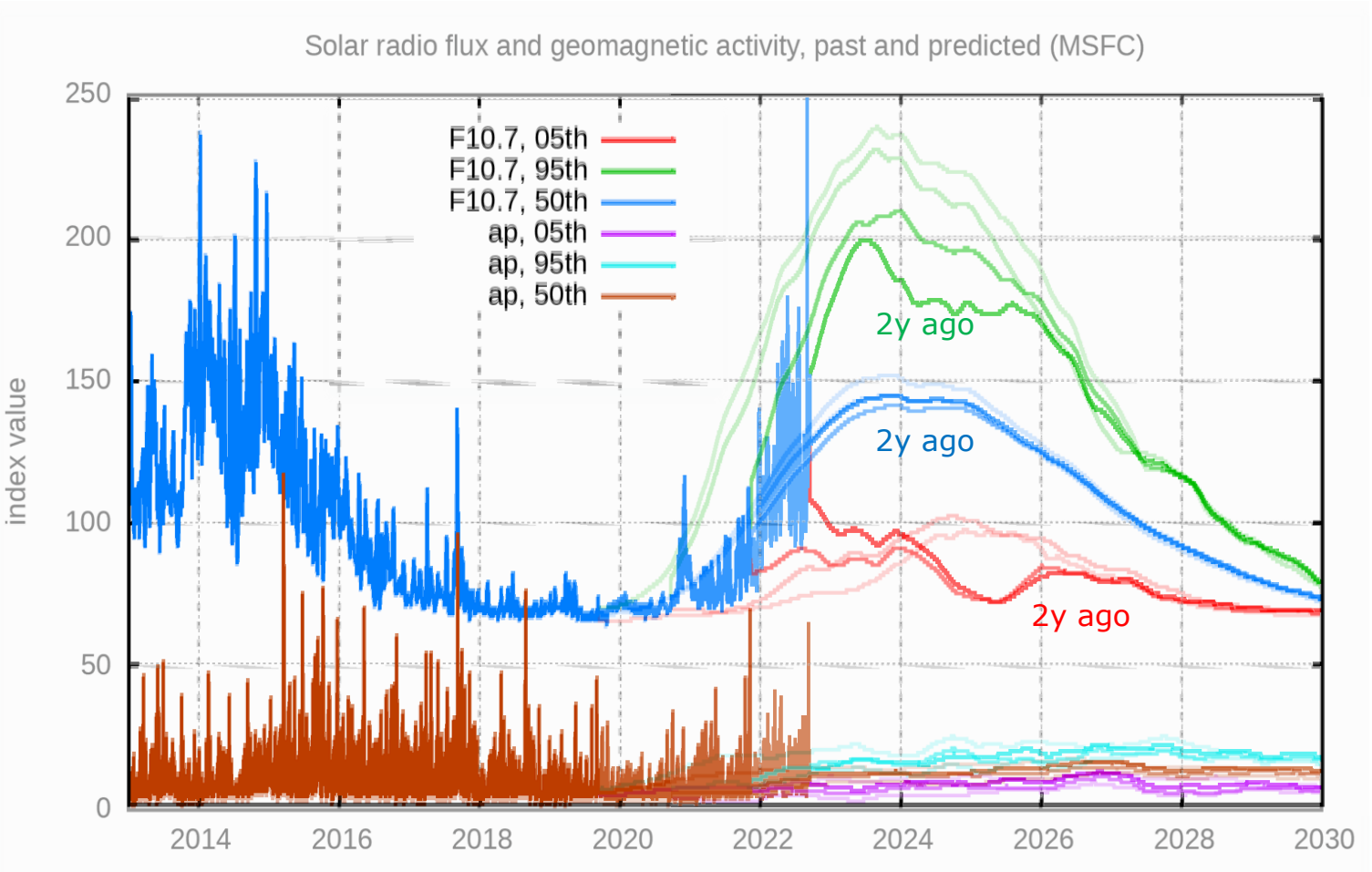

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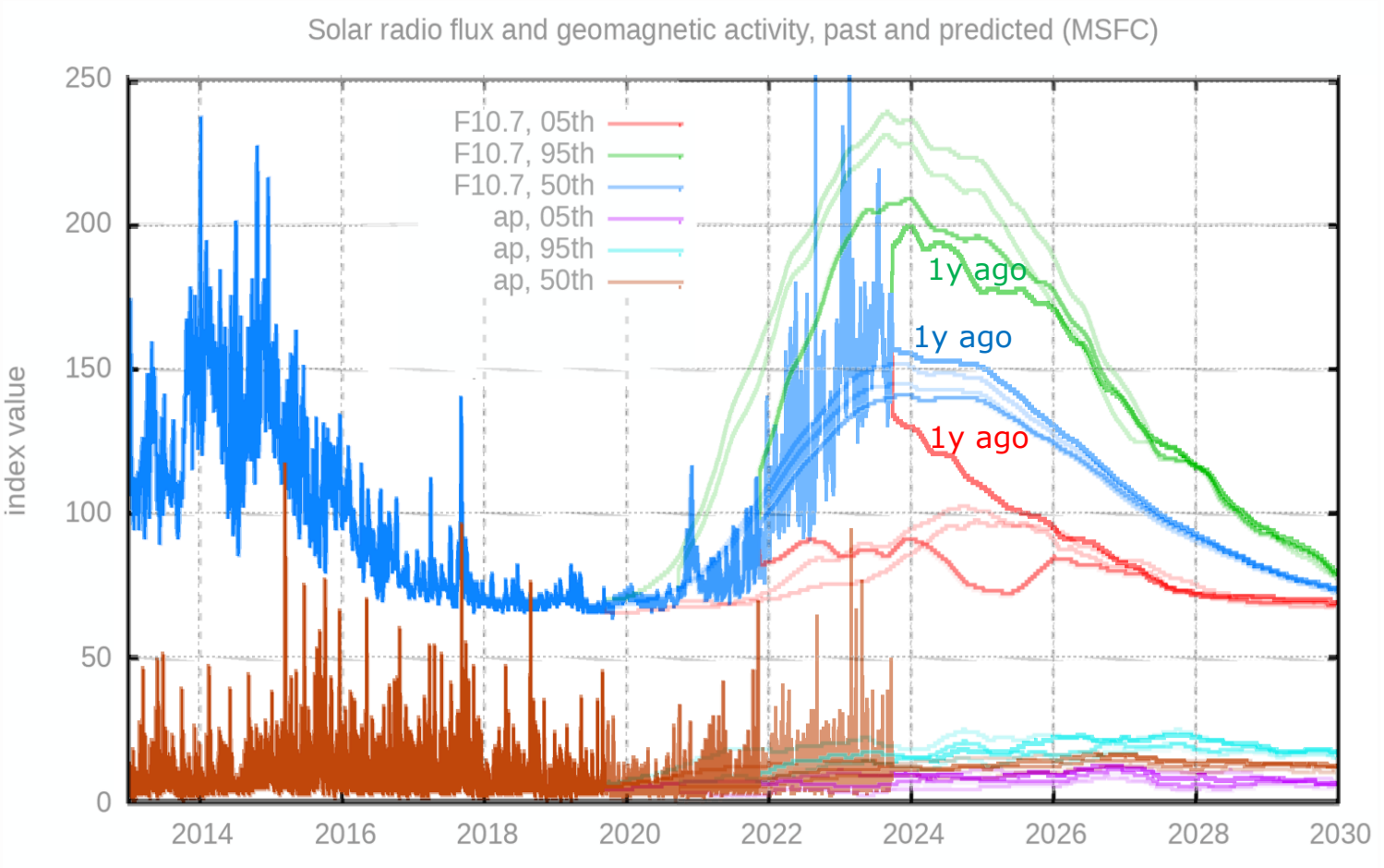

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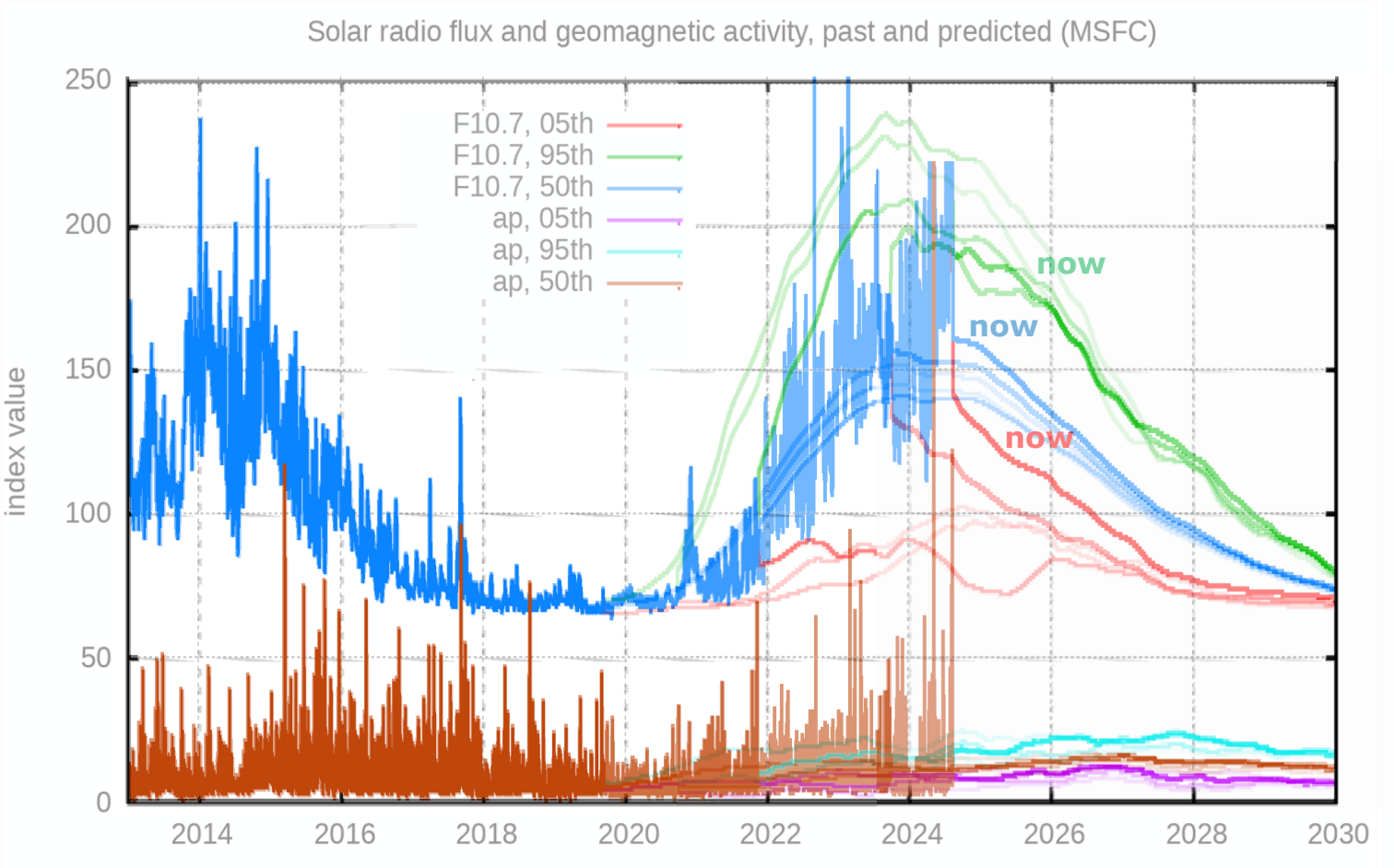

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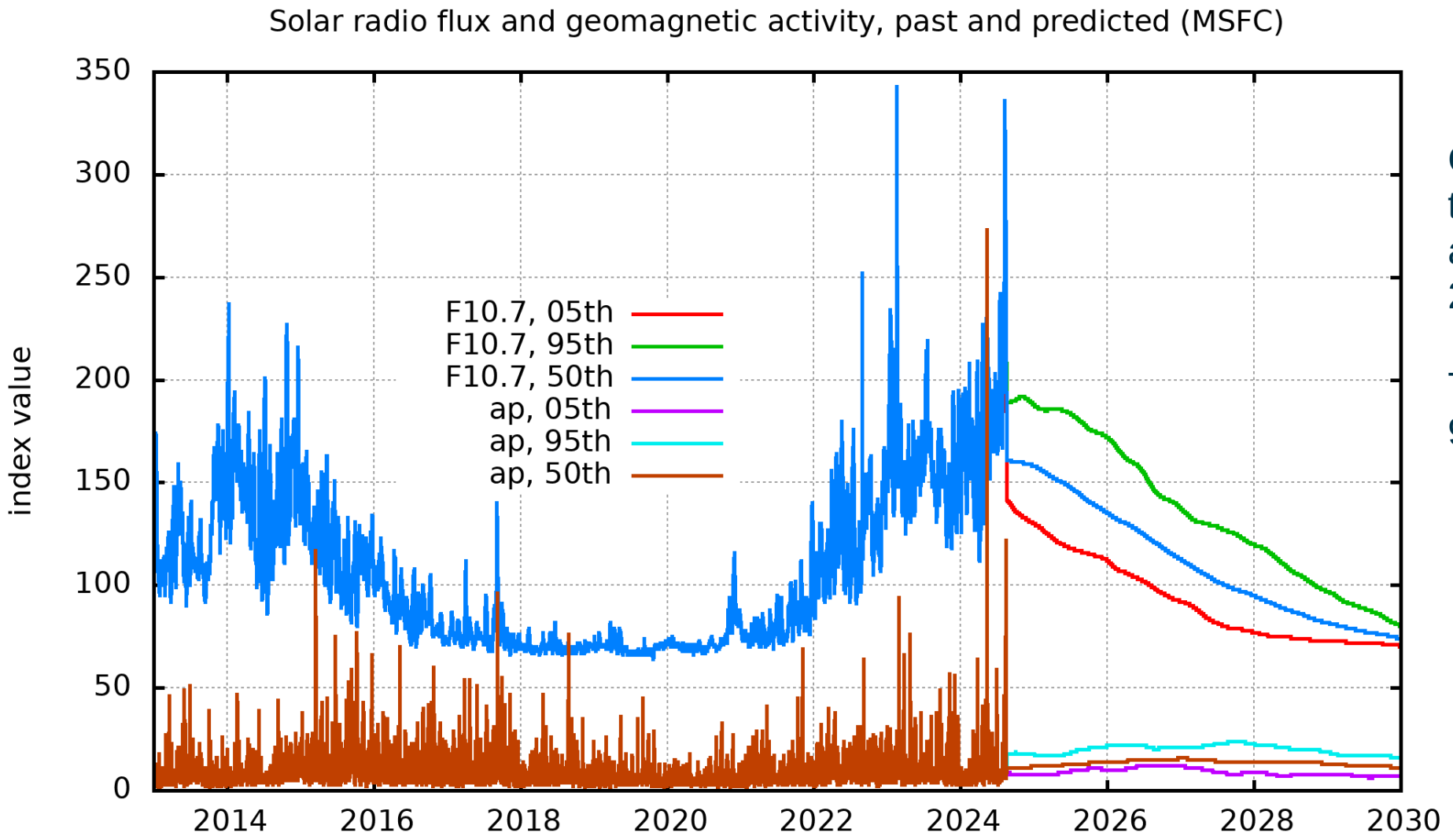
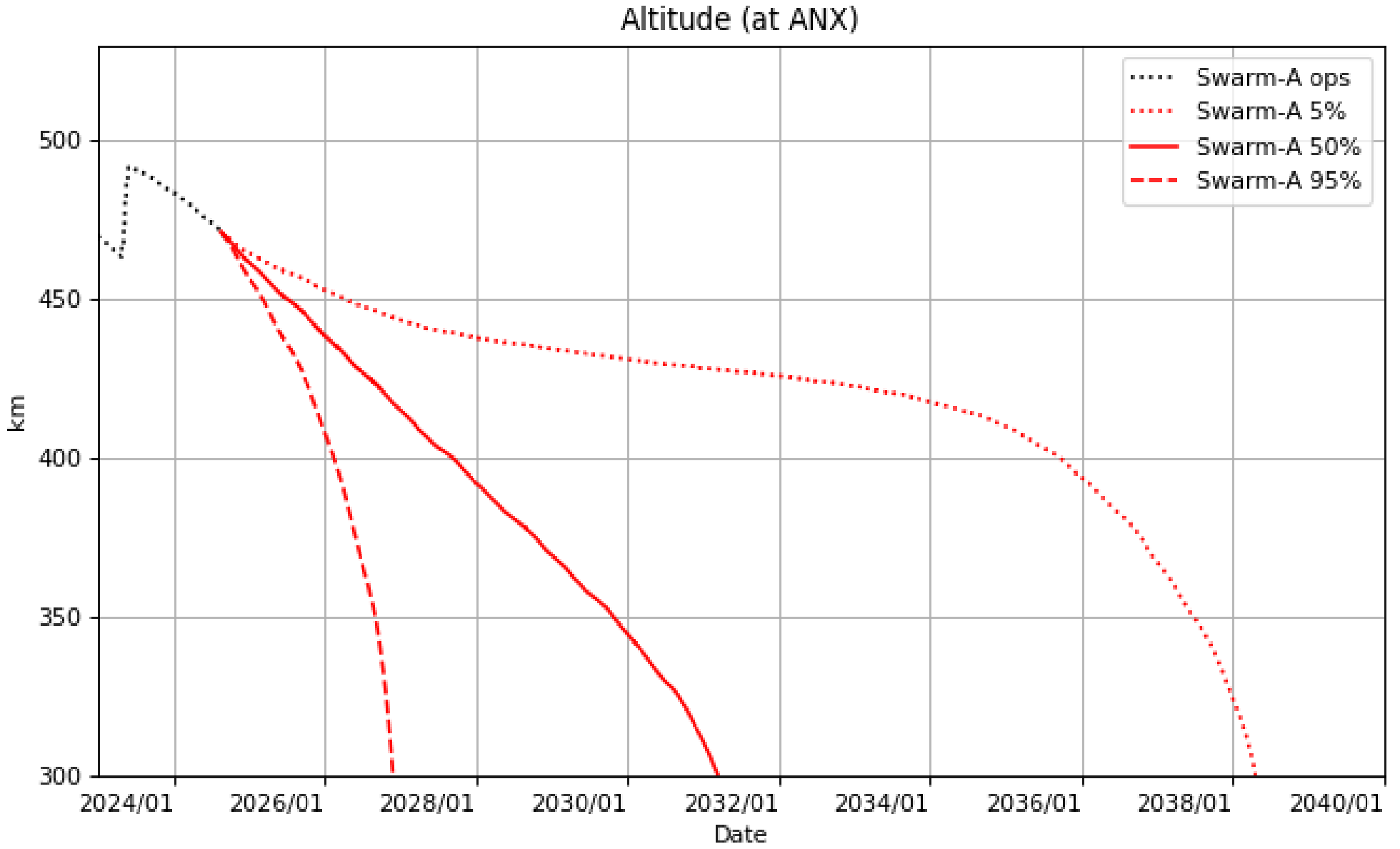


Current F10.7 three month average value is 217

This is above the 95th percentile

Predicted Altitude Evolution



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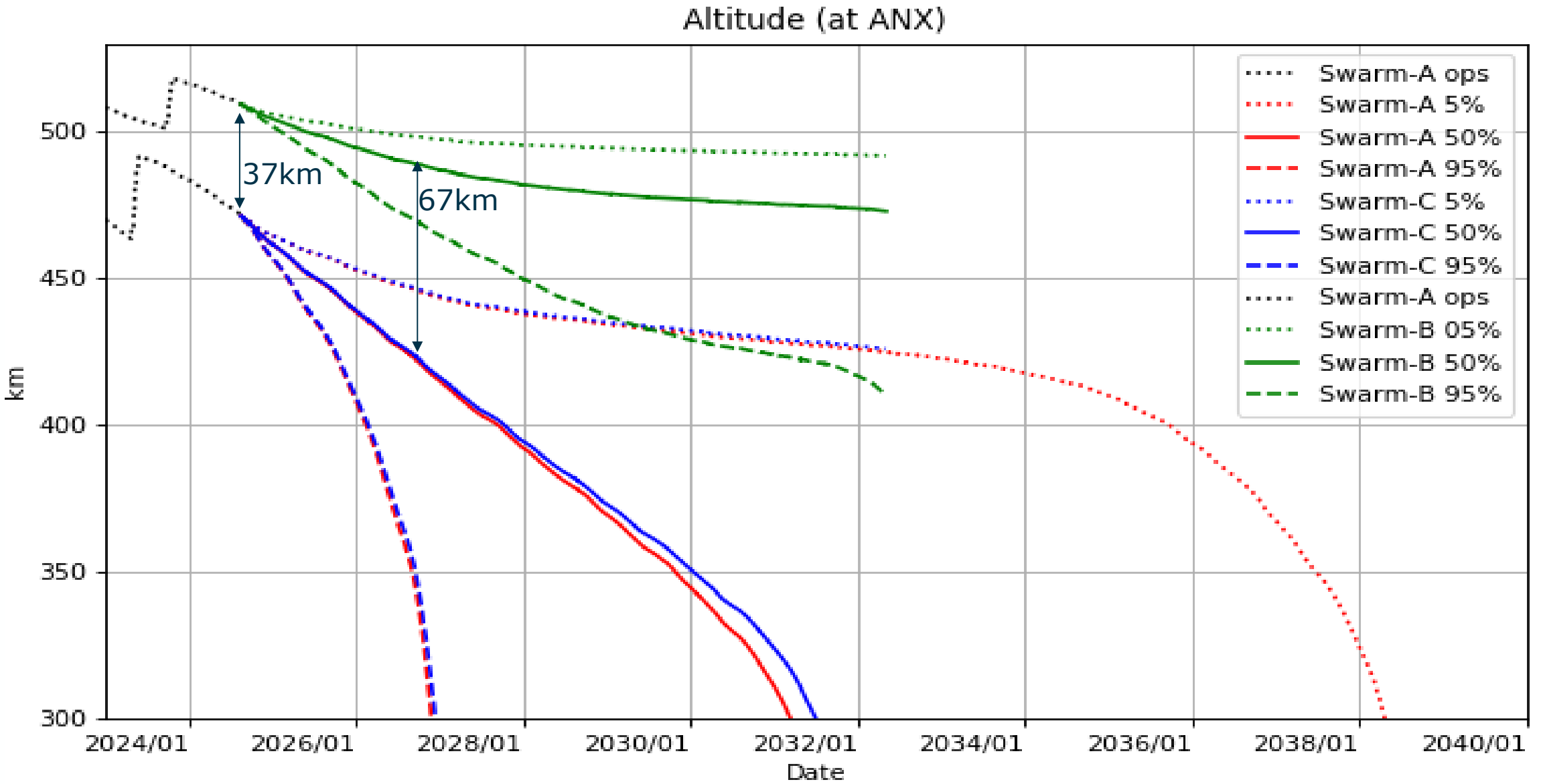


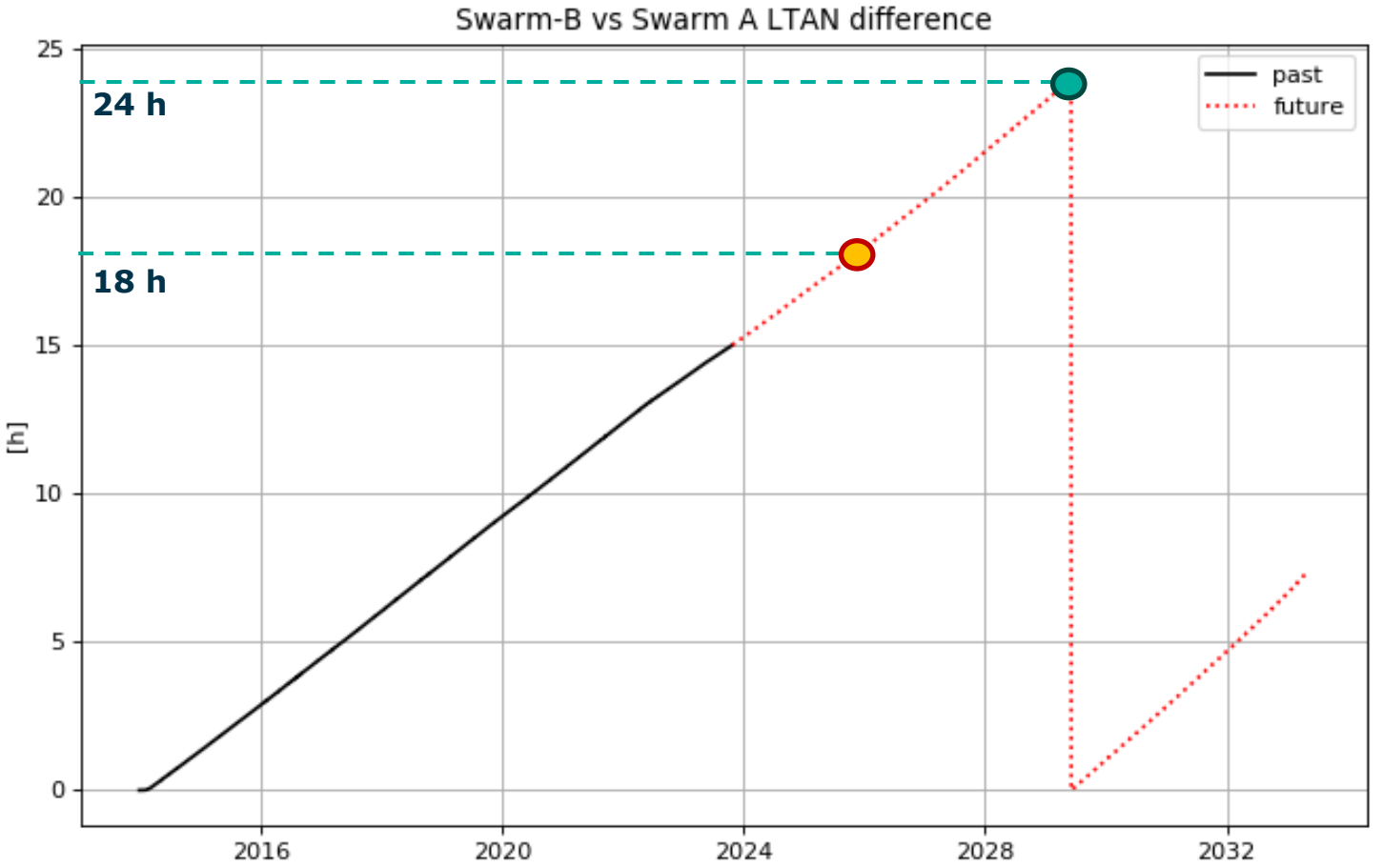
Swarm-B Orbital Plane rotation

LTAN difference between Swarm-B and lower pair orbital plane keeps increasing. In particular , the orbital planes will become:

- **perpendicular** (18 h LTAN difference**) in 2025 and corotating**
- **coplanar (**24 h LTAN difference**) in 2029**

To stop the relative rotation would require almost all the fuel on board of Swarm-B, so this possibility has been discarded.

However, there is still the possibility to **slow down the drift** in order to get the **corotating orbital planes in 2031**



Wrap up and points for Discussion:

- Fuel on board(PVT): 15.89 kg / 45.75 kg / 13.48 kg -> spending 1 kg/year for attitude control and CAMs, the lower pair is expected to have **6 to 8 kg left at next solar minimum in 2031**
- If solar activity remains at the higher end of the MSFC prediction, then the **Swarm-A and C re-entry can occur already 2027**. No further significant change of Swarm-A/C altitude is possible with the remaing fuel. (With 5kg of fuel an altitude change of only 8km can be achieved).
- At the next DQW we most likely know when the solar maximum was.
- **Swarm-A and C RAAN difference is now stable at 1.4 deg**

  Discussion point: Shall it get adjusted again before the next solar minimum?
- **Swarm-B is now 37km above** lower pair, increasing to 67km during the next two years.

  Discussion point: Is it desired to keep the altitude difference within boundaries ?
- The Swarm-B orbital plane is drifting with respect to the Swarm-A/C ones.; **orbital planes will be perpendicular in 2025/2026 and coplanar 2029/2030**.

  Discussion point: is it desired to slow down the drift to have coplanar orbital planes in 2031 instead?