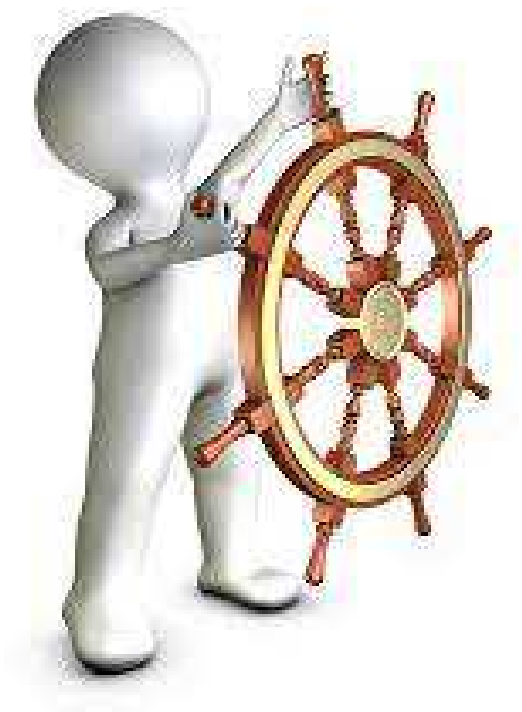
SWE – CNES OPS FEEDBACK

Gérard GALET – DTN/OP – Séverine BELLOIR & Sonia AitZaid - DTN/OP/S3A – Quentin Michaud DTN/OP/SOD

COMET Day – 13th of May 2022

TABLE OF CONTENT



REMINDER OF OPERATIONAL PRIORITIES

Main operational priorities:

- AVAILABILITY requirement => To maintain the mission execution as much as possible (No interruption)
- PERFORMANCE requirement => To be at the awaited orbital position at the correct time OR (for many missions) to know exactly where we were at precise occurrences of mission acquisitions (thus more a question of precise orbit restitution than orbit positioning)

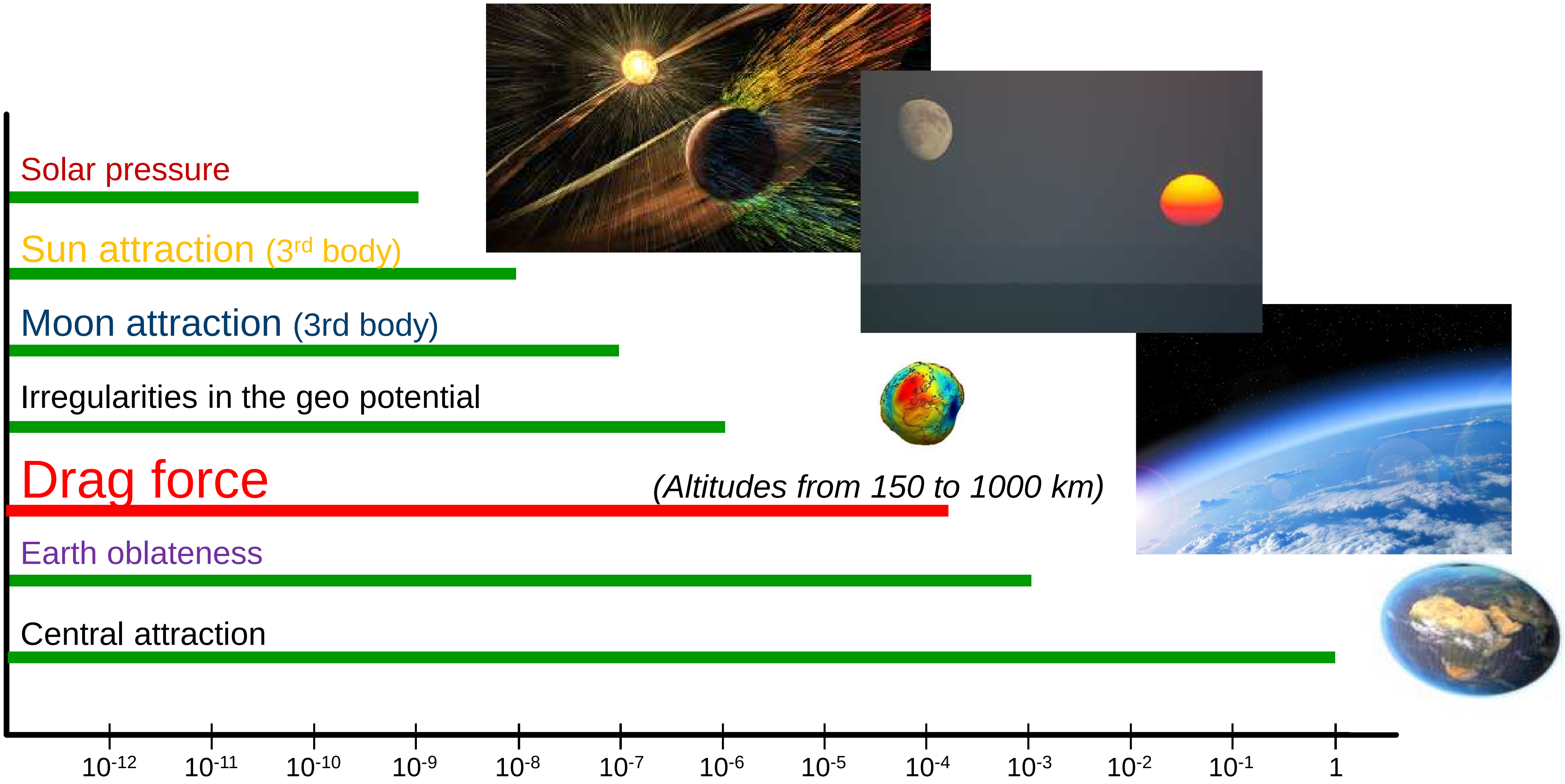
Secondary operational priorities:

- OPTIMIZATION of life duration => To follow an optimized orbital strategy to reduce propellant consumptions
- REDUCTION of operational workload => To do what is required (no less, no more) and to optimize the induced ops resources by automation

And thus:

- To not consider the orbital aspects as a “generic matter” but “per-mission reqts” as they can be from none to very strict
- To optimize the segregation between the operational activities based on Flight Dynamics tools and the expertise activities to develop / qualify and maintain these tools (done by experts only)

Perturbations on Low Earth Orbits



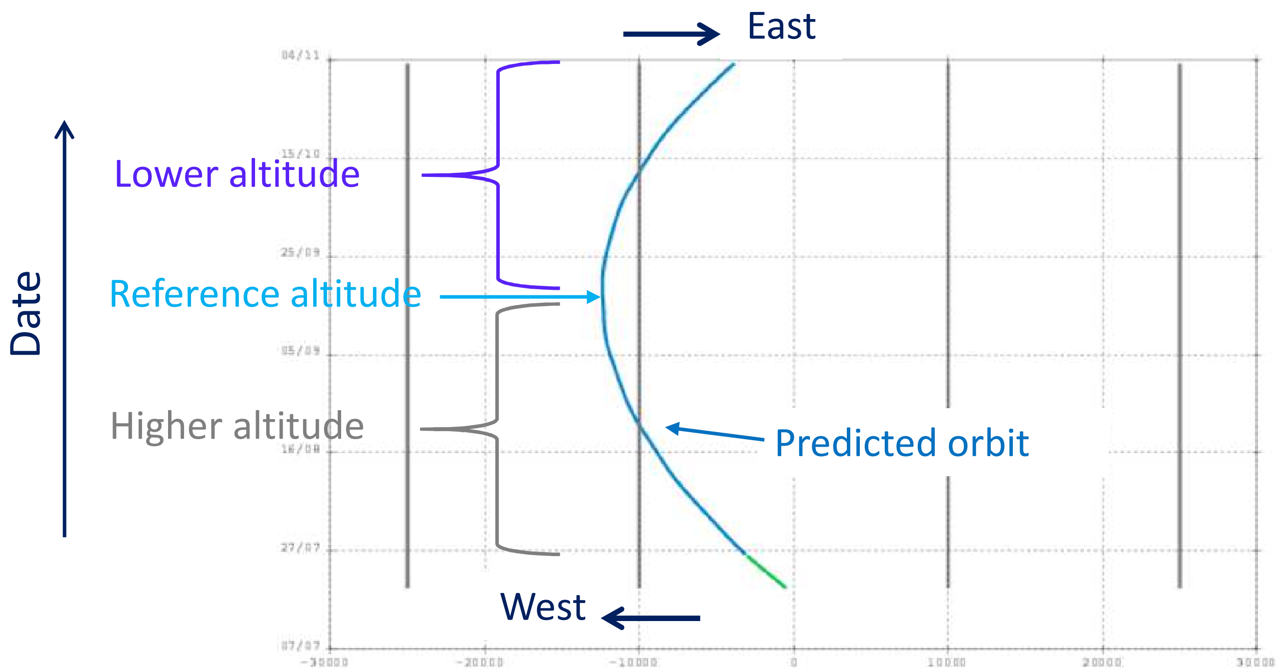
cnes

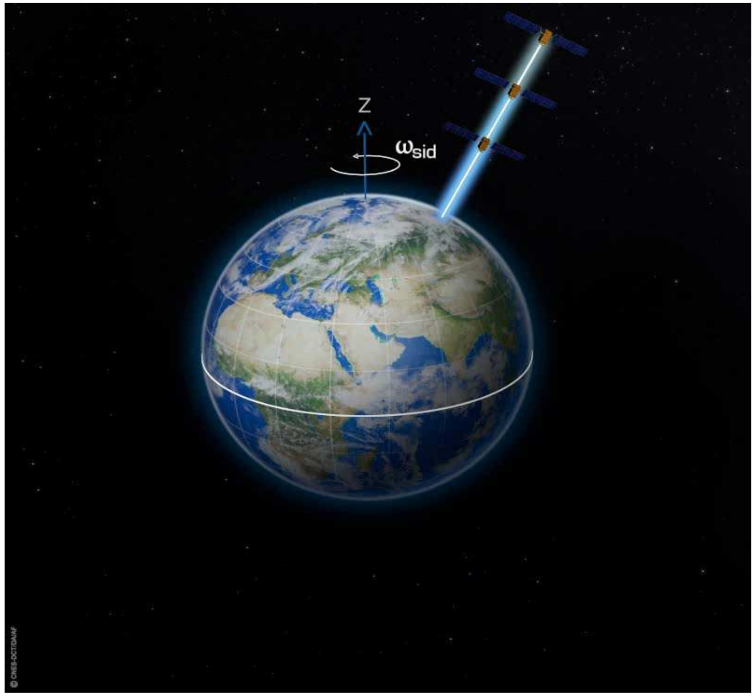
Equatorial drift at the Equator

Altitude ↘ with atmosphere drag

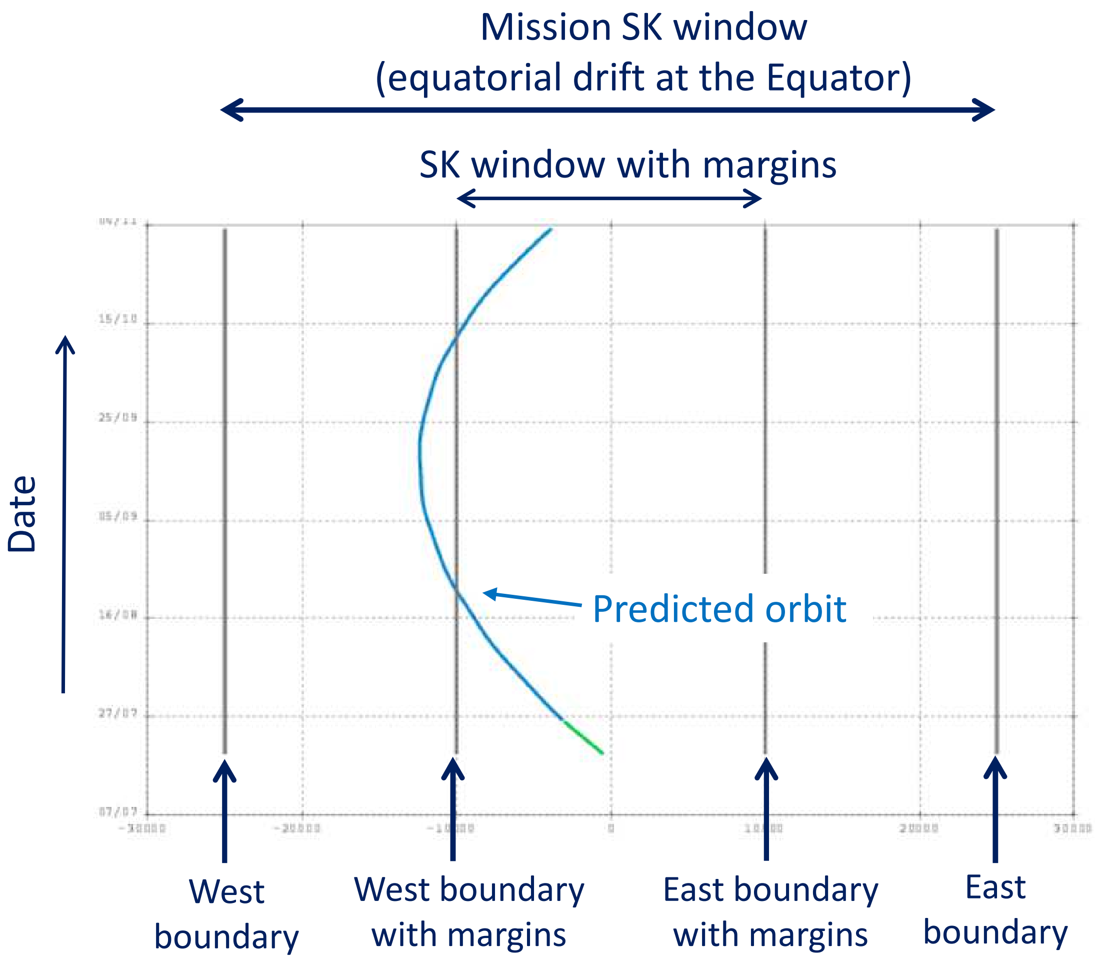
Altitude < reference **:** speed > speed_ref, longitude drifts towards East

Altitude > reference **:** speed < speed_ref, longitude drifts towards West





Mission Station-Keeping window - example



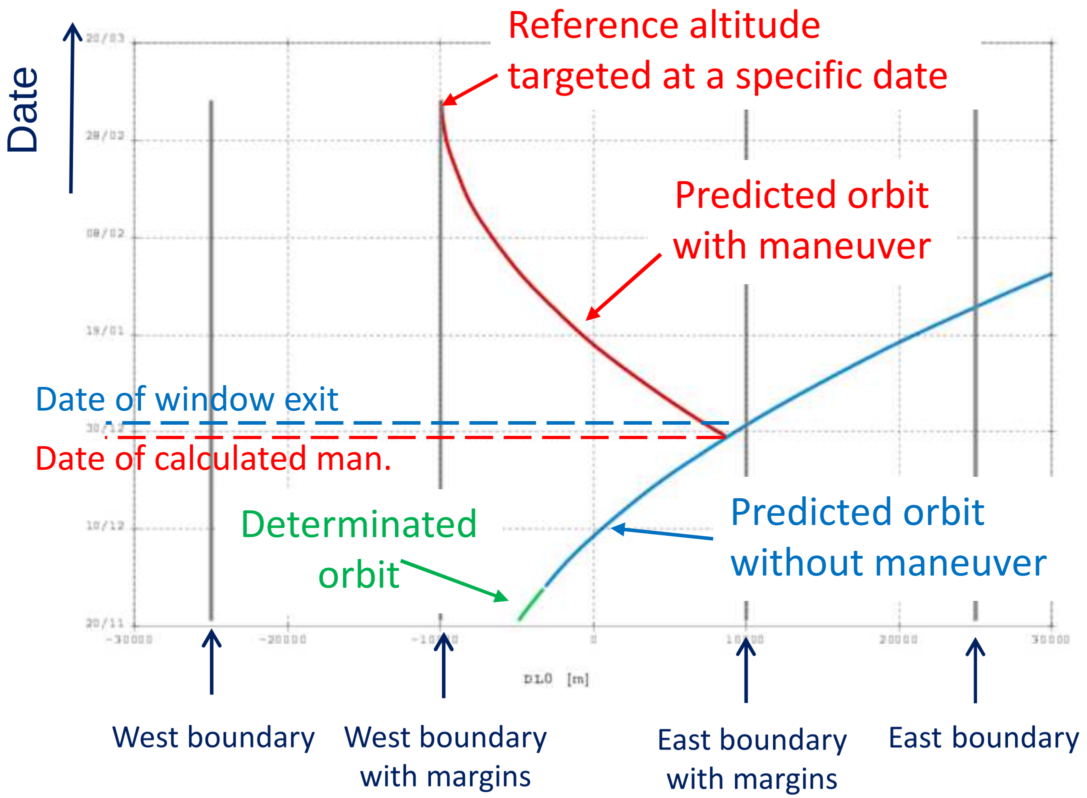
Mission SK window = f(mission needs)

SMOS (science, 755 km): +/- 25 km

PLEIADES (Earth obs., 700 km): +/- 12 km

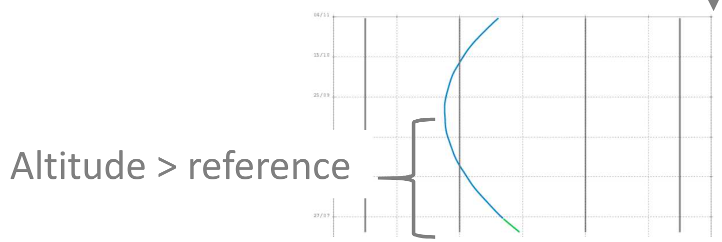
JASON (altimetry, 1336 km): +/- 1 km

Station-keeping maneuver



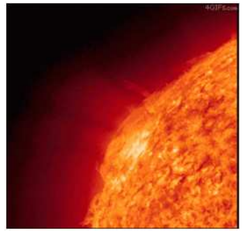
SK maneuver automatically calculated on ground

- Stay inside a smaller SK window, with margins
- **Optimize time in SK window**:
  - ✓ Date of maneuver just before predicted orbit reaches the small East boundary
  - ✓ Δa > 0 (→ altitude after man > reference)
  - ✓ Target a reference altitude (in practice not necessary tangent to west boundary with margins)

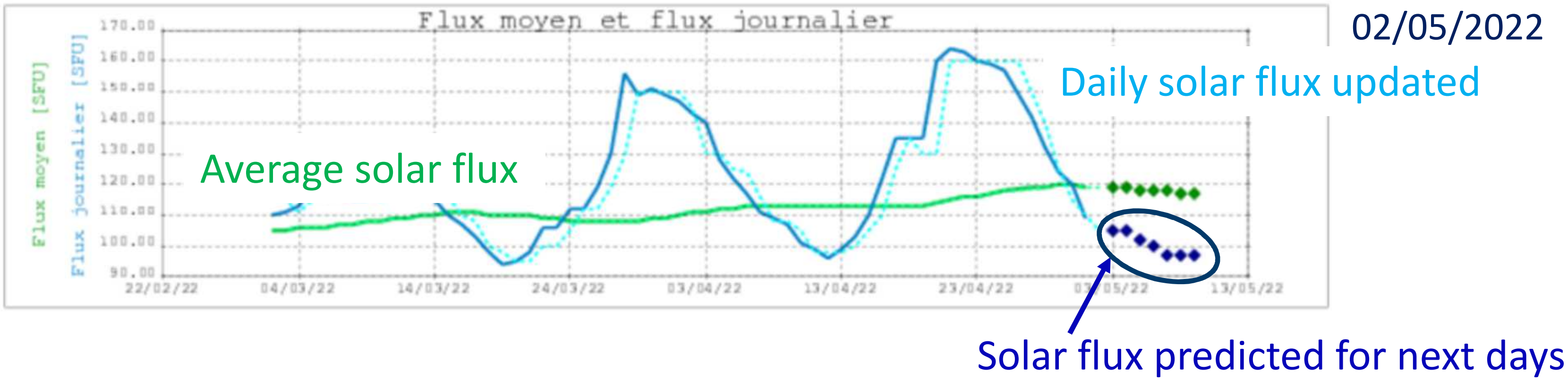


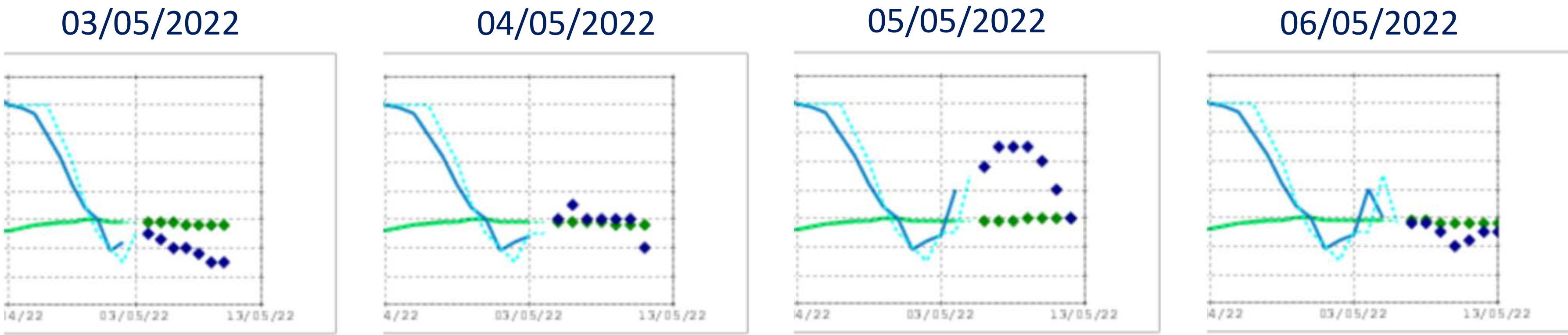
cnes

Unpredictable solar activity

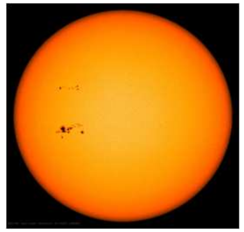


- **Ex. of SMOS: solar flux prediction variation from one day to another** (beginning of a new long-term solar cycle (11yrs)



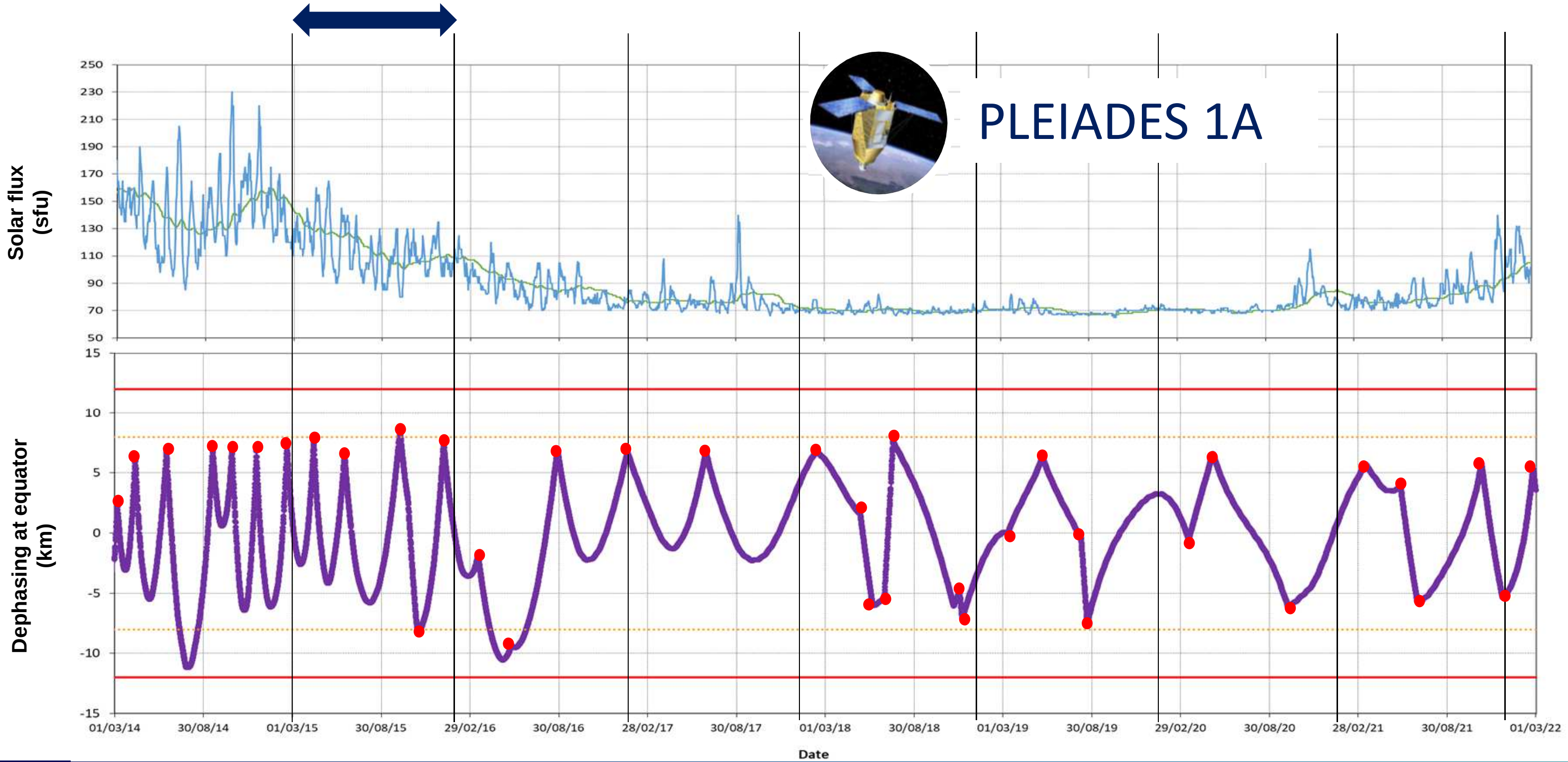


Influence of solar activity on Station-Keeping



- **Higher solar activity → Denser atmosphere → More drag** applied on satellite
- Solar activity **influences station-keeping**

1 year



Weaker solar activity
→ Fewer SK maneuvers

Mission threshold

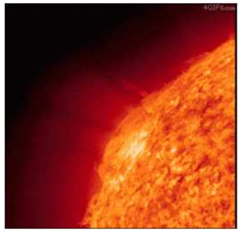
Targeted threshold

● = maneuver

Targeted threshold

Mission threshold

Influence of solar activity on orbital prediction



- Bigger impacts for missions:
  - ✓ with a small SK window (Jason)
  - ✓ with sensitive mission planning (Earth observation, formation flying)

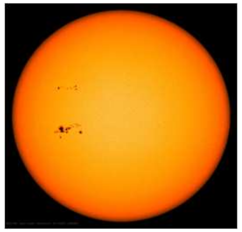
High solar activity period

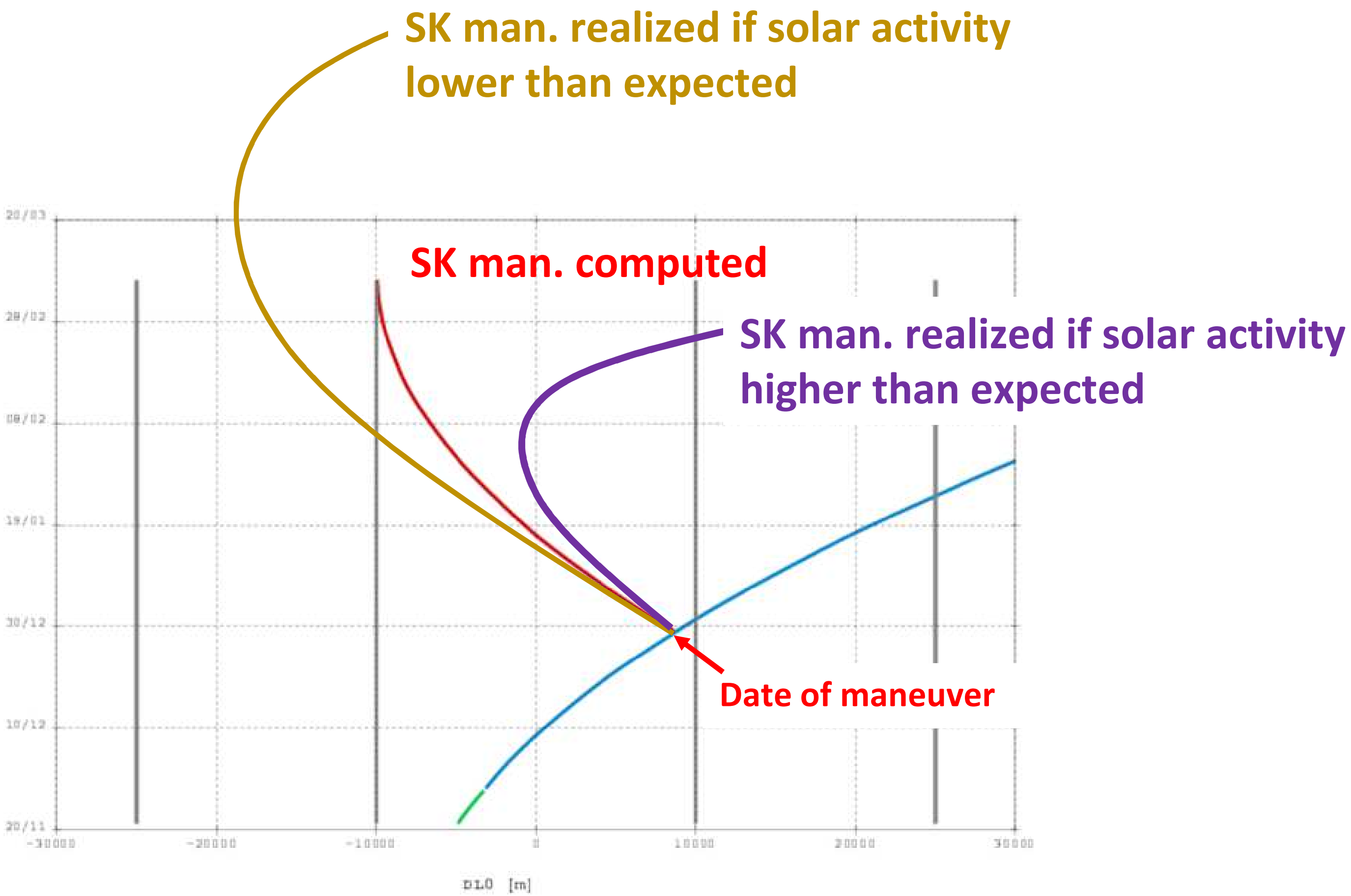
→ Solar flux is harder to predict, more disrupted
→ Orbit predicted is less accurate, propagation error bigger
→ Manoeuvers are harder to design
→ Risks of collision computations can give fluctuating probabilities until last moment

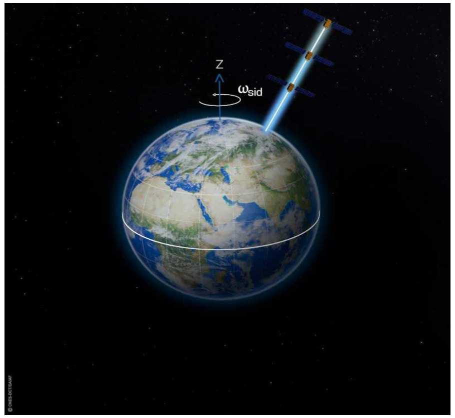
Low solar activity period

→ Solar flux is more stable (solar activity prediction is quite reliable for the 7 coming days)
→ It is easier to design maneuver

Influence of solar activity on Station-Keeping



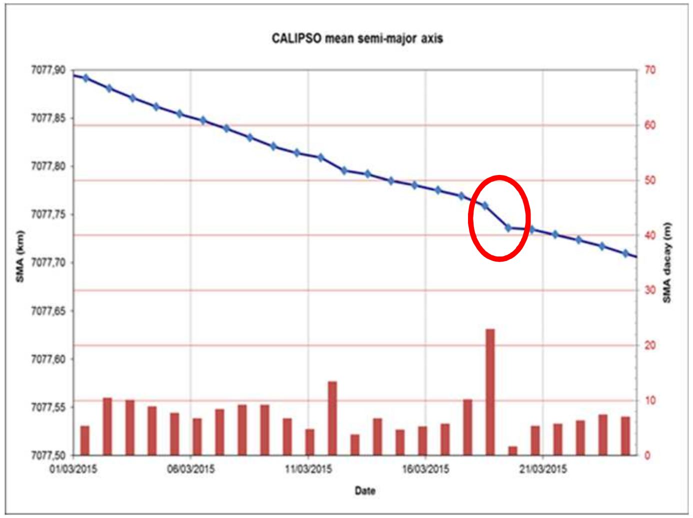




Station-Keeping conclusion

No need to have urgent solar activity predictions

- ✓ Date of SK maneuver is fixed several days even weeks before satellite reaches SK window boundaries
- ✓ Maneuver amplitude (Δa) can be modified a few days before the maneuver depending on predicted solar activity
- ✓ Station-keeping manoeuver are computed with margins to face solar activity variations



Solar activity peak

→ Impact on semi-major axis but Calipso stays in SK window

Orbit determination

Ground stations

GNSS measurements

DORIS measurements

Solar Activity + geomagnetic act. of the day before + predicted

IERS data

Measurements

Environment (via OOC from NOAA)

Flight Dynamics Software

- ✓ Contains a complex atmospheric model, which requires:
- F10.7 = solar activity: daily + average
- KP/AP = geomagnetic activity

Estimated parameters update

Least square method

Convergence?

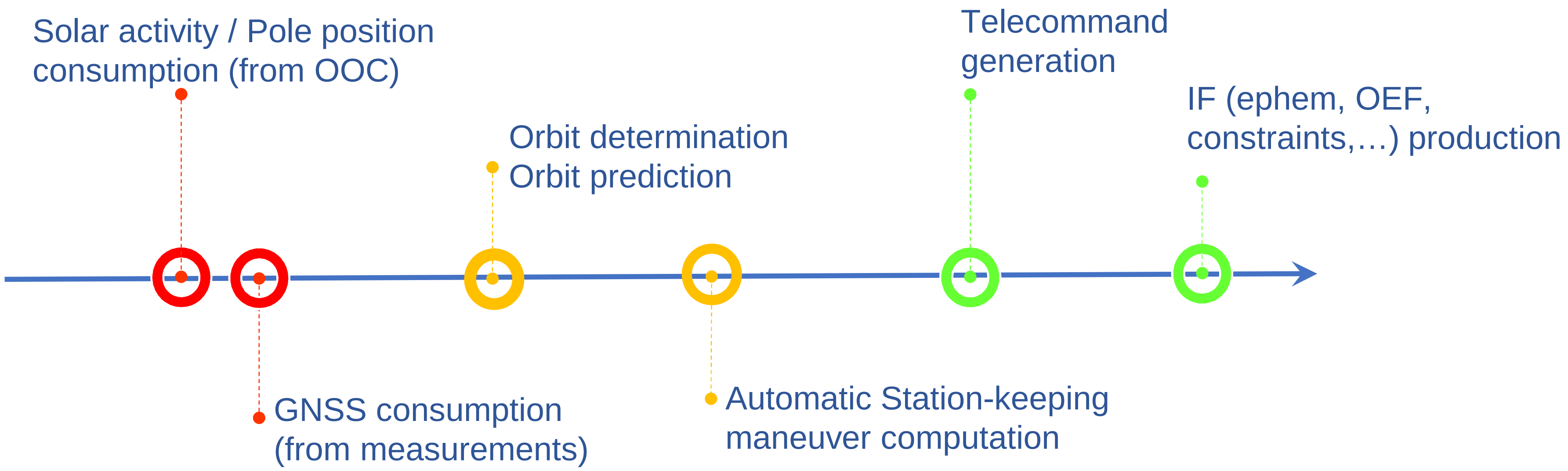
NO

YES

- ✓ **Determinated orbit** (in the past)
- ✓ **Predicted orbit** (in the future) with current daily data
- ✓ **Final estimated parameters update** (Cd, SRP, …)

Cd = Drag coefficient ; SRP = Solar Radiation Pressure coefficient ; IERS = International Earth Rotation & Reference Systems service

Automatic tasks



For all missions: 1/day, early in the morning

- If needed, orbit determination are computed twice with the same solar activity (Autonomous Orbit Control)

For formation flight and/or specific mission needs: 2+/day, with an update of solar activity

- Unexpected solar activity peak can impact mission planning
- No impact on SK (SK maneuver fixed several days before the maneuver date)

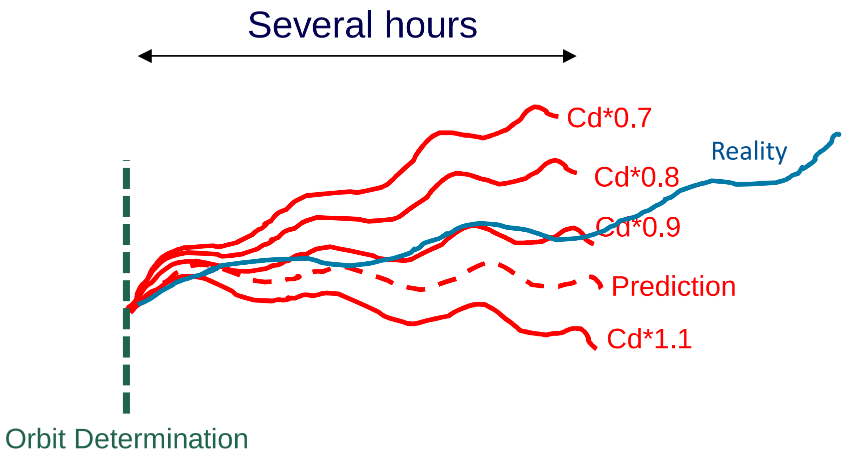
OEF = Orbital Events File

Specificities on missions with Onboard Autonomous Orbit Control

Autonomous Orbit Control (AOC) ➔ Collision Risk Assessment (CRA) analyses performed at ground

Problem: we do not know the exact future solar activity – a simple AOC simulation with the predicted solar activity is not sufficient to correctly predict the maneuvers to come.

Solution:



Onboard Autonomous Orbit Control:
- **Real** solar activity

Ground Collision Risk Assessment Analysis:
- **Predicted** solar activity
- **Dispersions on the drag coefficient Cd**

➔ In case of high dynamics (high solar activity for example), necessity to perform Orbit Determination and CRA analyses several times a day in order to be fully representative of the onboard Autonomous Orbit Control.

Orbit determination conclusion

Daily FDS inputs and actual atmospheric model are reliable enough for our needs

Orbit determination (m): it is necessary to know where the satellite is on its orbit:

- To satisfy mission's specifications
- To guarantee close formation flying

Precise orbit determination (cm): Mission products may need more complex model, several sources of measurements and an accurate solar activity knowledge

- ❑ Case of altimetry missions (JASON)
- ❑ DTN/DV/OR service : for science use, delivery of delayed products using more data for more advanced theoretical model and restituted solar activity

Orbit predicted: long-term ephemeris are based on current daily activity solar propagated

- Mission planning, power analyses, propellant budget (SK manoeuver), …

A daily update of solar activity is used to compute determined and predicted orbits (every morning)

Another update of solar activity can be performed for specific mission planning needs

OVERALL CONCLUSION

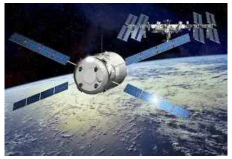
- **There is no need of SWE forecasting / Alert system** with respect to station-keeping manoeuvers and orbit aspects for our current missions

- **A daily update of solar activity** is used to compute determined and predicted orbits

- **Additional daily update of solar activity** can be required :
  - The case for sensitive mission which need to be aware of any unexpected solar flux spikes

- **Alert system** (< 1h) **can be pertinent** in case of an on-board part sensibility linked to radiations
  - Currently the case for Calipso payload

  - ATV mission: a daily evaluation of the risk of a solar flare + real time alert when proton flux > given threshold
    - ❑ *ATV RDV/DOCKING shall be postponed*
    - ❑ *ATV undocking operations shall be postponed*



QUESTIONS FOR THE FUTURE

1. In the frame of **Ops costs reduction**, how could we imagine to simplify our current processes?
    - By using very simplified FDS?
    - By reducing the frequency of orbit management ? Longer and more reliable predictions?
    - By using external service (Orbital Management As A Service)?

2. In the frame of **Innovative Ops**, what about disruptive processes through AI implementation (ML, neural networks, etc.) for atmospheric density estimation? "Manual process" could be used only in case of significant solar activity change

3. In the frame of **Autonomy**, for on-board Autonomous Orbit Control and collision risks management, how could we estimate and extrapolate the density prediction autonomously?

4. In the frame of **future missions**, will the future orbital requirements be more constraining than the current ones? (for instance Close Ops like IOS / formation flying / RDV will be covered by relative navigation) - In other words, is the air density prediction a "**hot topic**" for the future?

Thank you for your attention – Any questions?