Orekit-based applications at EUMETSAT

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Presentation summary

EUMETSAT brief overview

- Who we are
- What we do

Orekit use at EUMETSAT

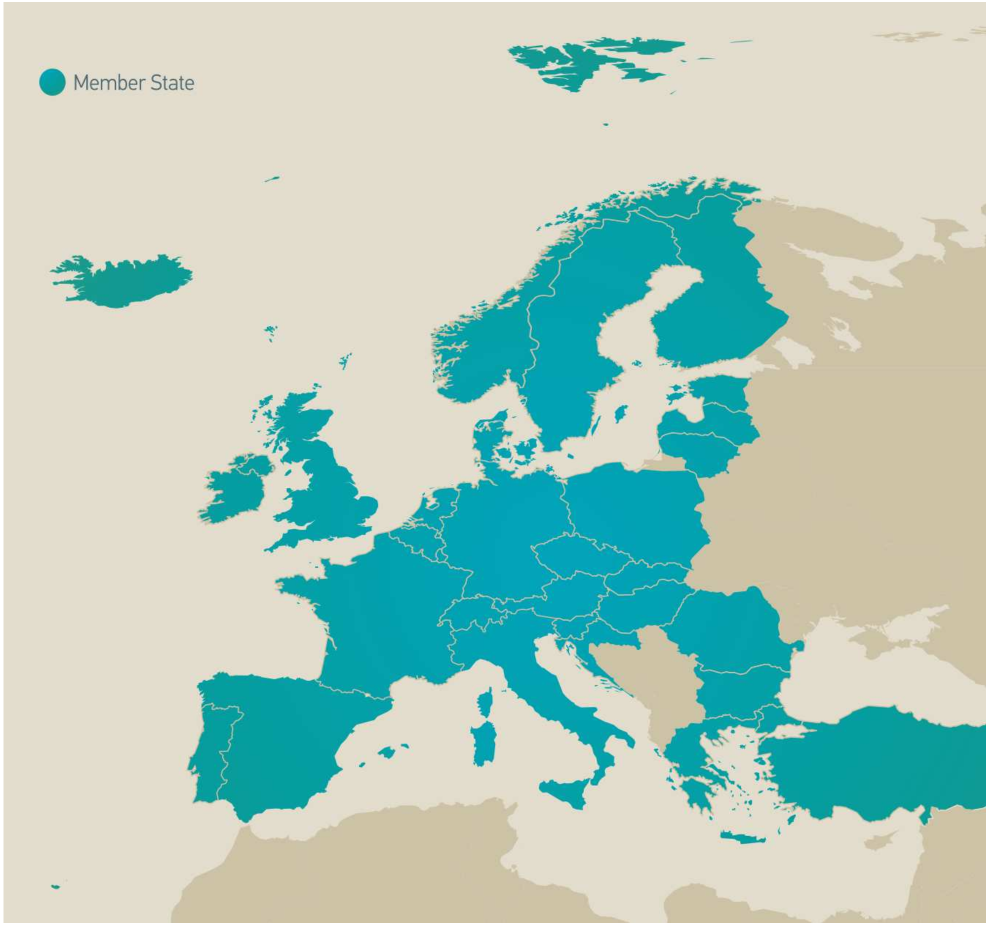
- **Station Keeping Analysis**
- **Station Keeping North South optimisation**
- Integration with Matlab
- Orbit analysis/comparisons (mean elements)
- Metop End-Of-Life Disposal
- Radio Occultation
- Space Situational Awareness

EUMETSAT – who we are

EUropean organisation for the exploitation of **MET**eorological **SAT**ellites

Intergovernmental organisation with 30 Member States

Member States have full access to data and services



STATE	SINCE
Austria	1993
Belgium	1986
Bulgaria	2014
Croatia	2006
Czech Republic	2010
Denmark	1986
Estonia	2013
Finland	1986
France	1986
Germany	1986
Greece	1988
Hungary	2008
Iceland	2014
Ireland	1986
Italy	1986
Latvia	2009
Lithuania	2013
Luxembourg	2002
Netherlands	1986
Norway	1986
Poland	2009
Portugal	1989
Romania	2010
Slovak Republic	2006
Slovenia	2008
Spain	1986
Sweden	1986
Switzerland	1986
Turkey	1986
United Kingdom	1986

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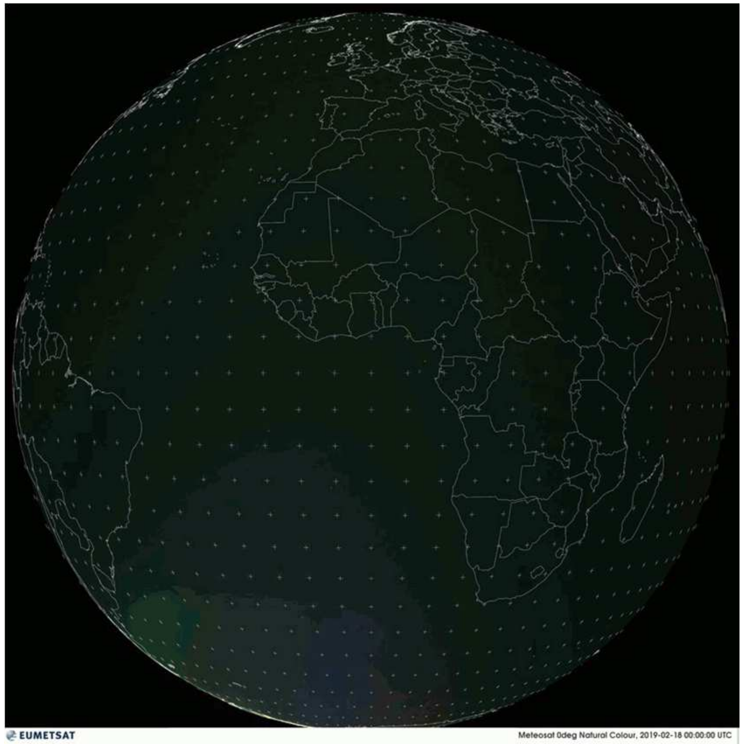
EUMETSAT – what we do

EUMETSAT operates a fleet of satellites in geostationary and polar orbit, which provide a wide array of Earth observation data for weather, climate and environmental monitoring

Flying satellites:

- Low Earth Orbit (LEO)
  Metop, Sentinel, Jason
- Geosynchronous Earth Orbit (GEO)
  Meteosat Second generation



Future programmes

- EPS-SG, Jason-CS (LEO)
- MTG (GEO)

Current EUMETSAT satellites

METOP-A, -B, -C (98.7° incl.)

LOW EARTH, SUN-SYNCHRONOUS

EUMETSAT Polar System (EPS) / INITIAL JOINT POLAR SYSTEM

JASON-2 & -3 (63° incl.)

LOW EARTH, non-SYNCHRONOUS

Ocean Surface Topography mission, shared with CNES/NOAA/EU

SENTINEL-3 (98.65° incl.)

LOW EARTH, SUN-SYNCHRONOUS

COPERNICUS satellites delivering Marine and Land Observations

METEOSAT-8

GEOSYNCHRONOUS

Meteosat 2nd generation providing IODC, 41.5°E

METEOSAT-9, -10, -11

GEOSYNCHRONOUS

Meteosat 2nd generation

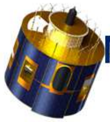
Two-satellite system

Full disc imagery mission (15 mins): Meteosat-11 (0°)
Rapid scan service over Europe (5 mins): Meteosat-10 (9.5° E)
***Meteosat-9 in orbit backup at 3.5°* E**

Meteosat spacecrafts

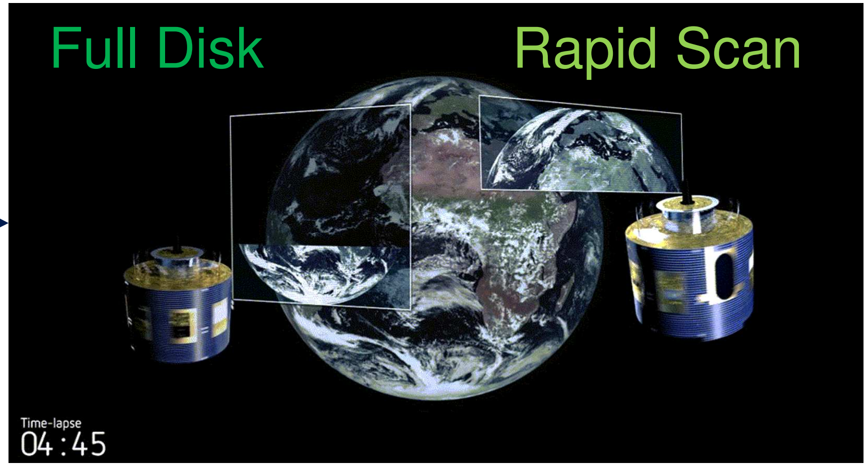
EUMETSAT geosynchronous satellites for weather forecast and climate-change monitoring

Meteosat First Generation (MFG)…till 2017



Meteosat Second Generation (MSG), current

- **2 services**
- **4 satellites, spin-stabilized (~100 rpm)**
- **Orbit Determination (OD): S-band ranging measurements from 2 stations per satellite (with swaps)**



Meteosat Third Generation (MTG)…from 2021

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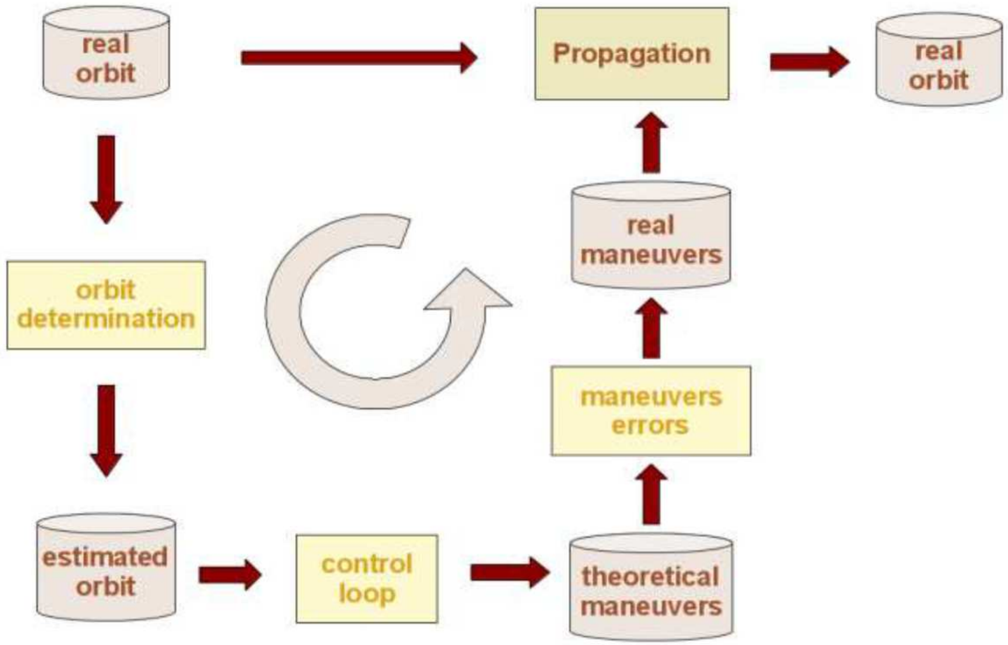
Orekit-based applications at EUMETSAT

Station Keeping Analysis Tool (SKAT)

Station Keeping Analysis Tool (SKAT)

- OPERABILITY: Realistic evaluation of orbit maintenance strategies in LEO&GEO missions, simulated over long time spans

- End-to-end, full-chain of orbit determination and control, simulated with uncertainties and automated control rules 'in-the-loop'



See ISSFD23 FDOP1-2 Paper: High Fidelity End-to-End orbit control simulations at EUMETSAT

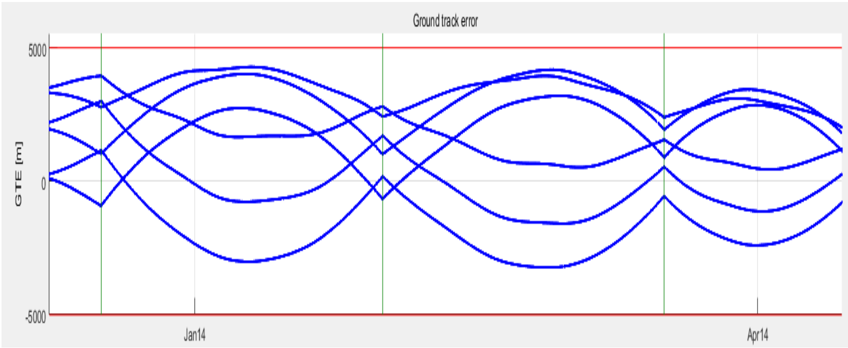
Station Keeping Analysis Tool (SKAT), controls

- Cross coupling , orbit determination and manoeuvre realisation error (deterministic or stochastic) , eclipse constraints are simulated.

- Monte Carlo option

Different 'Controls' implemented

LEO controls ----------------------------->



- Mean Local Solar Time
- In Plane Ground Track Grid
- Out-Of-Plane Ground Track Grid

GEO controls -----------------------------> *example next slide*

- Inclination (inclination vector circle)
- Longitude (parabolic longitude)
- Eccentricity (eccentricity circle; single or double burn type)
- Satellites Co-locations schemes

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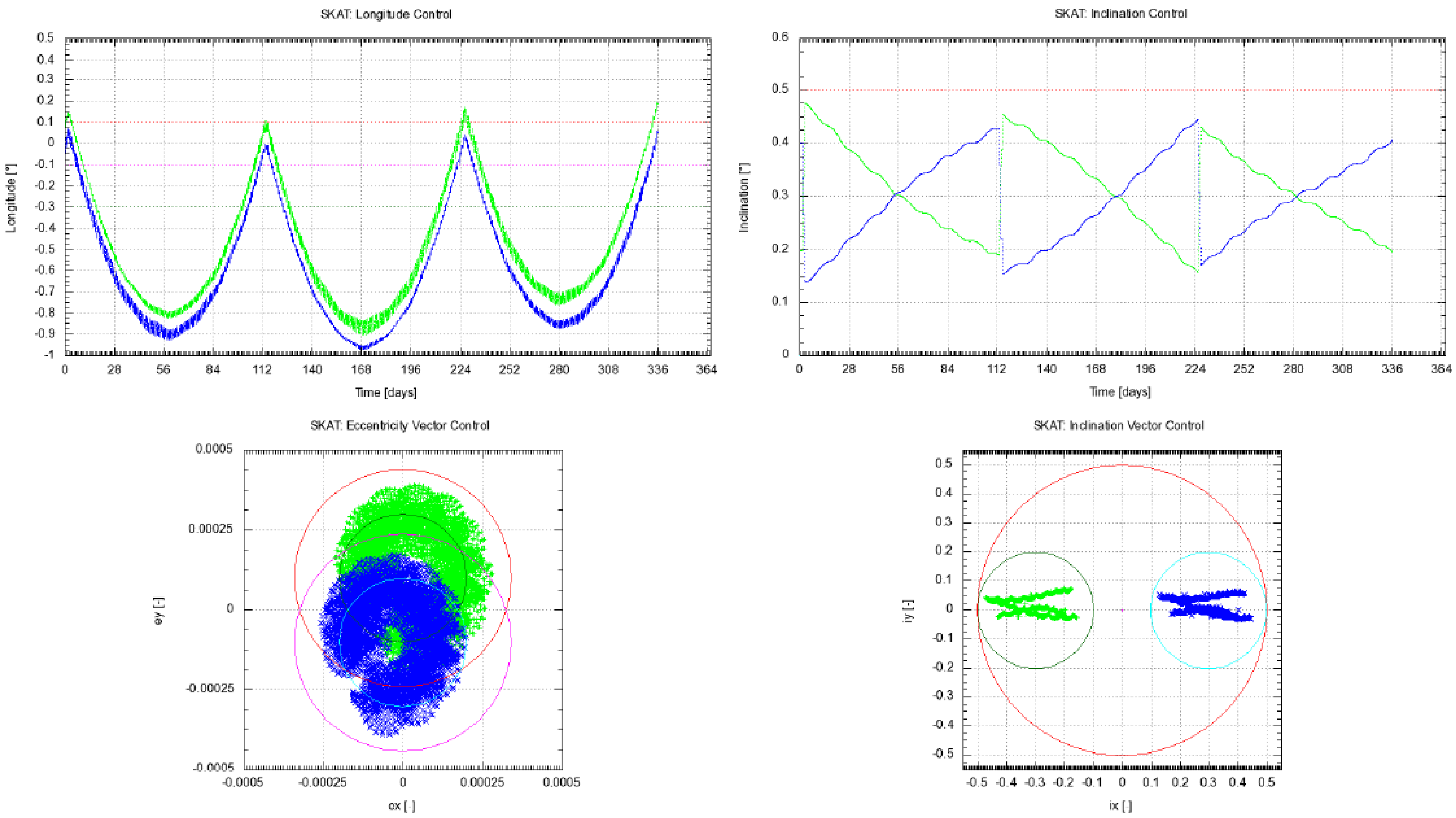
Station Keeping Analysis Tool (SKAT)
Example, 2xMTGs co-location by e-i separation



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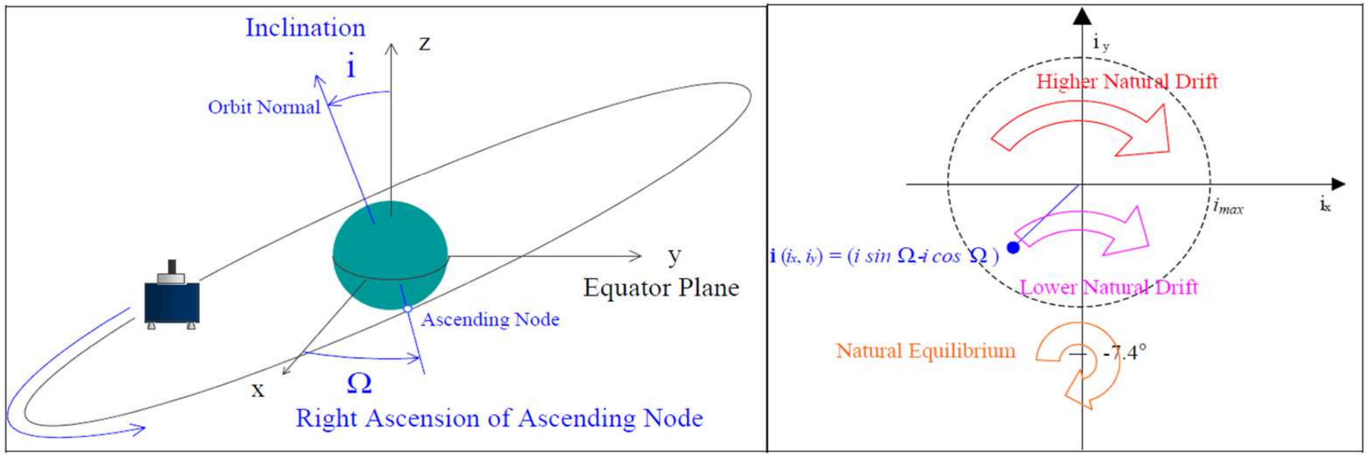
Station Keeping Optimisation of North South (SKONS)

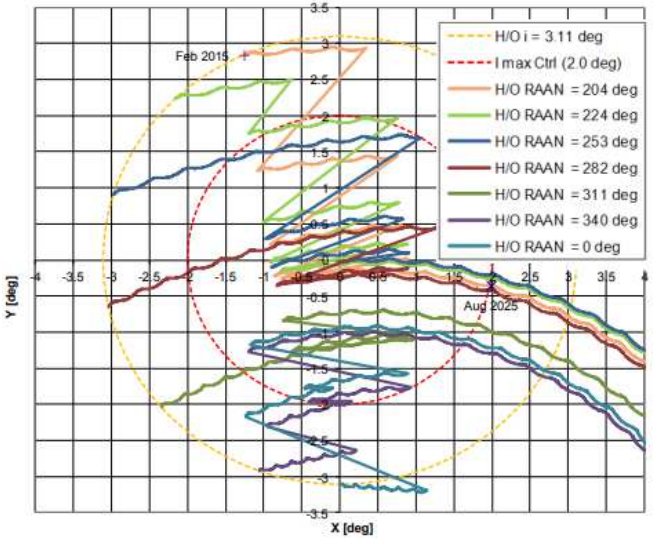
Station Keeping Optimisation of North South (SKONS) Simulation principle

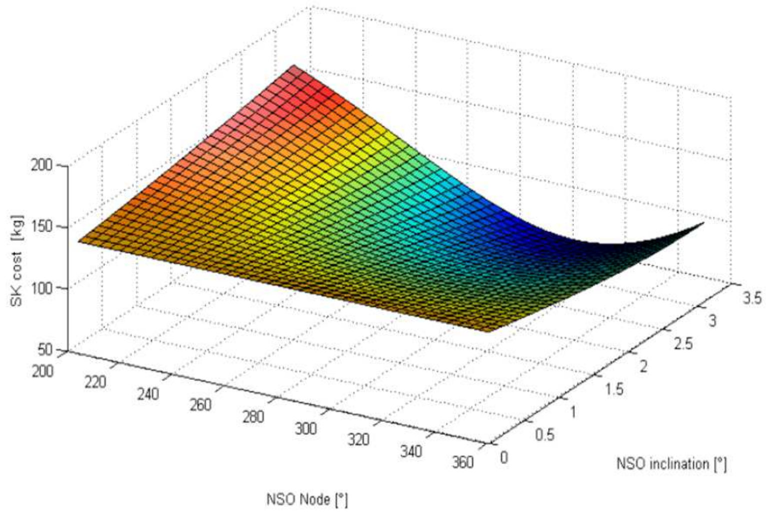
- PROPELLANT OPTIMISATION: Realistic evaluation of orbit long term control for mission analysis and eventual mission extensions studies for GEO (further sophistication with respect to SKAT)
- GEO inclination control problem is driven by J2 and Sun/Moon effects orbital plane precession around a stable configuration (Laplace plane)
- North/South Manoeuvre execution can take advantage of reduced natural drift within wide inclination control dead-band

$$\mathbf{i}\,(i_x, i_y) = (i \sin \Omega, -i \cos \Omega) \qquad (2)$$



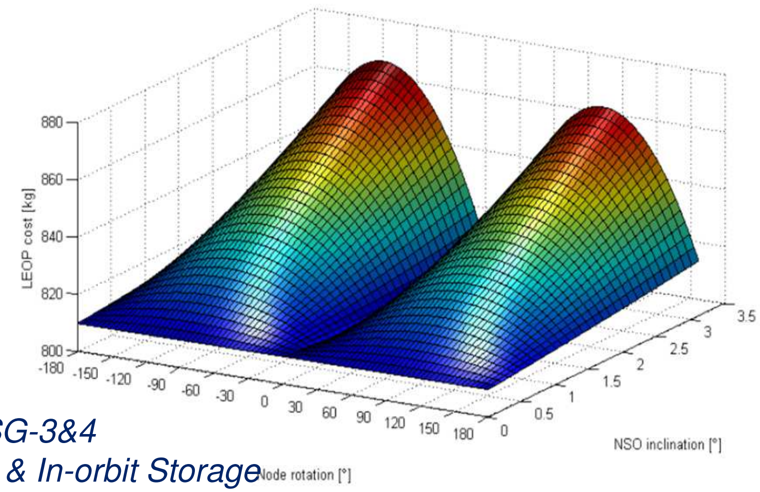
Station Keeping Optimisation of North South (SKONS)
LEOP+SK optimisation for GEO





SK

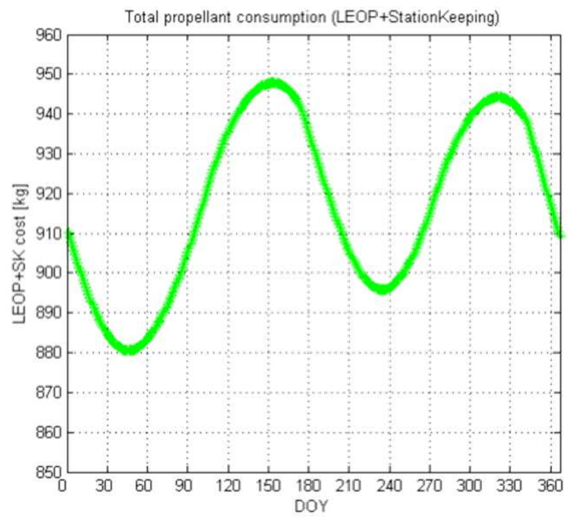
LEOP



SKONS need

MSG-4 Case

(MTG-I1 work in progress)



See ISSFD24 S14-5 Paper: Mission Analysis for MSG-3&4 Considering Combined LEOP/Station-keeping costs & In-orbit Storage

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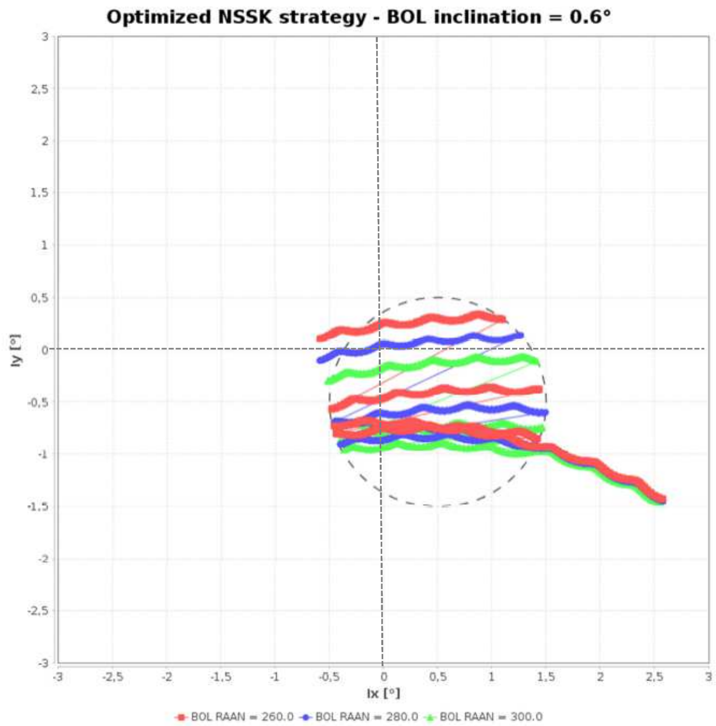
Station Keeping Optimisation of North South (SKONS) Software design

Four-stages optimisation:

1) Initialisation & setup of BOL orbits and *PropagatorFactory* (DSST or numerical)
2) Manoeuvre free BOL period towards the Routine inclination control circle, till 1st exit violation (*EventDetector*) and computation of 1st manoeuvre
3) Routine phase sequence of NS: optimal direction for manoeuvres to move the inclination vector in control circle with approximate orbit pole drift model
4) Manoeuvre free EOL period, with adjustment of last routine manoeuvre to reach the target EOL inclination



Various constraints applied in the optimisation:

- manoeuvre-free periods every year(eclipse)
- minimal duration between NS manoeuvres
- days in the week for manoeuvre execution

JAVA 8 environment+3 open-source libraries:

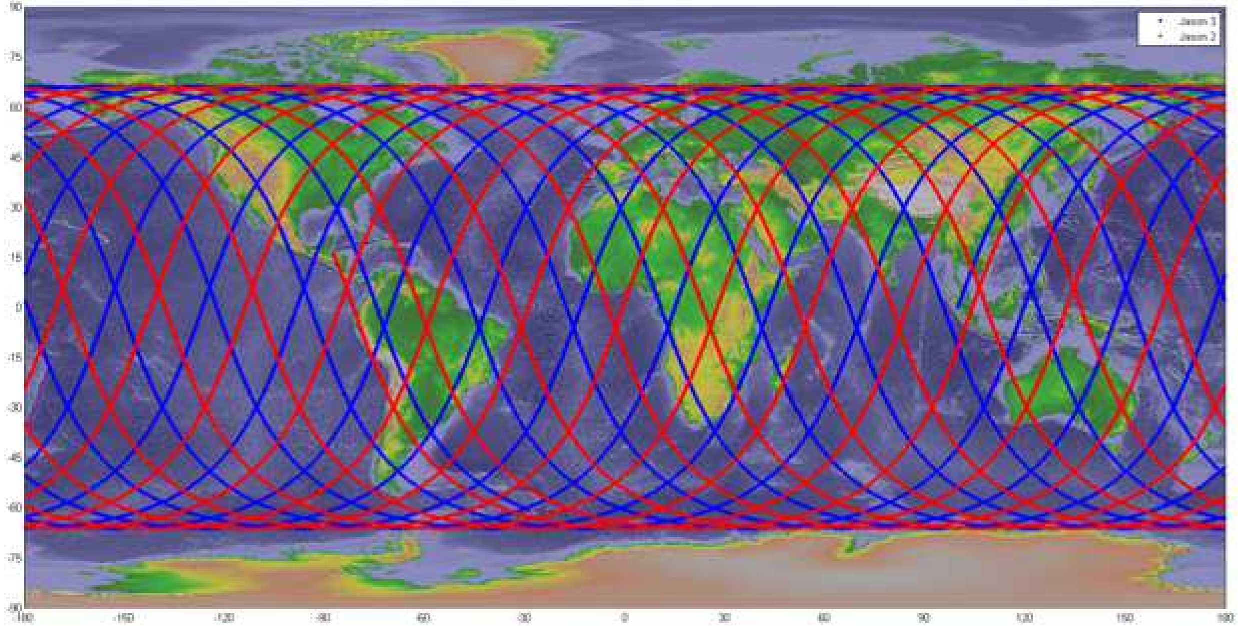
- OREKIT-9.2, for flight dynamics
- HIPPARCHUS-1.3, for mathematics
- JFreeChart, for plotting

Integration with Matlab

Integration with Matlab

- Matlab offers many advantages (with the drawback you need a license)
- Rapid prototyping, access to powerful toolboxes and graphics
- Orbit propagation and orbital events detection (including attitude laws) for multi-mission multi-purpose analysis

Example: Jason-2 and Jason-3 ‘interleave’ orbits (one-day tracks)



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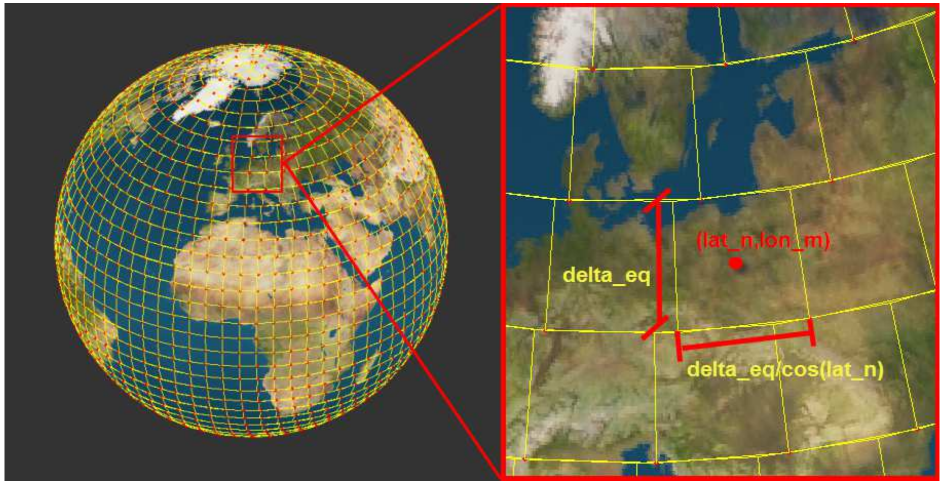
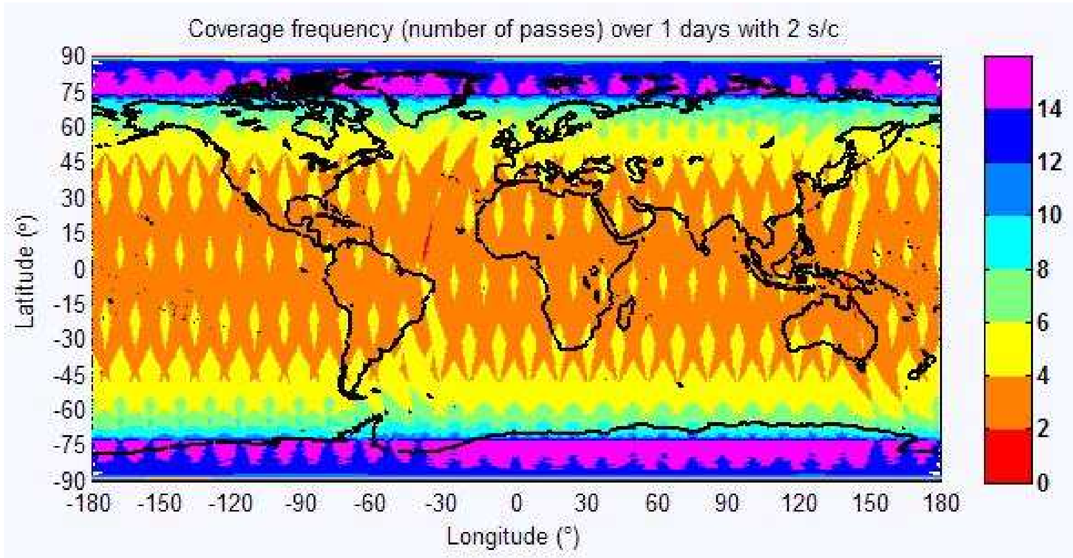
Integration with Matlab

- Revisiting and coverage (with equispaced Earth grid)





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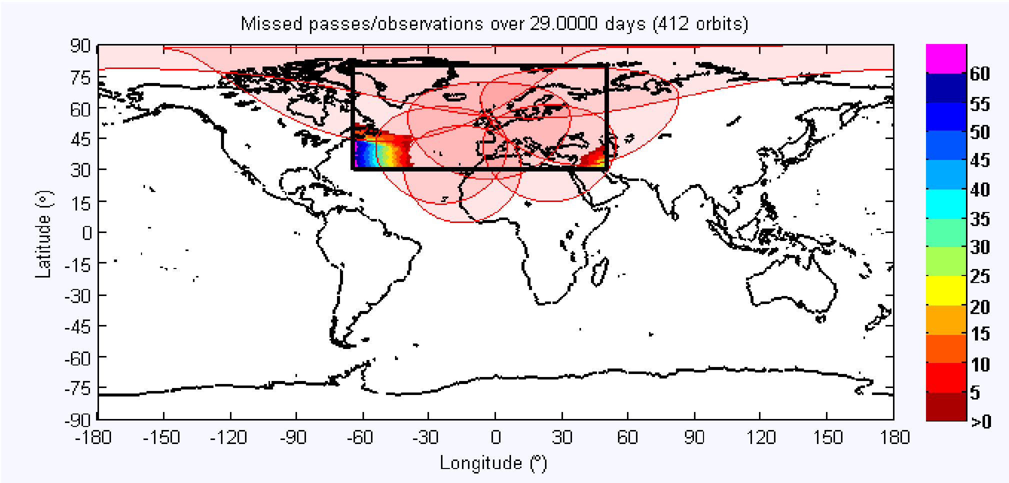
Integration with Matlab

- Direct Broadcast antenna coverage for given instrument swath

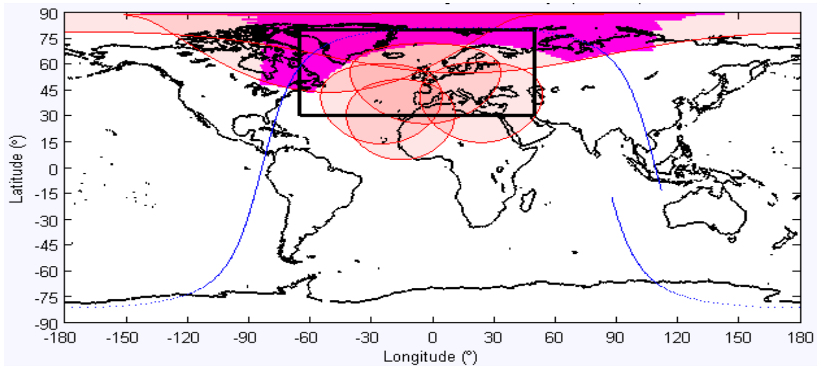


412 orbits. Misses within AOI

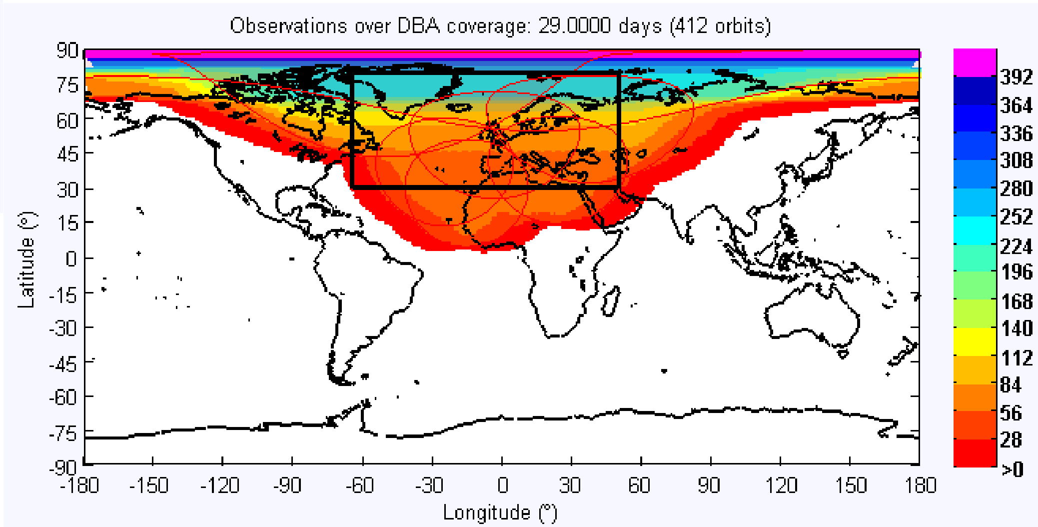
AOI = Area Of Interest

(longitudes -65 to 50 deg,

latitudes 30 to 80 deg north)



Push-broom instrument. 1 orbit only



412 orbits. Total Observations

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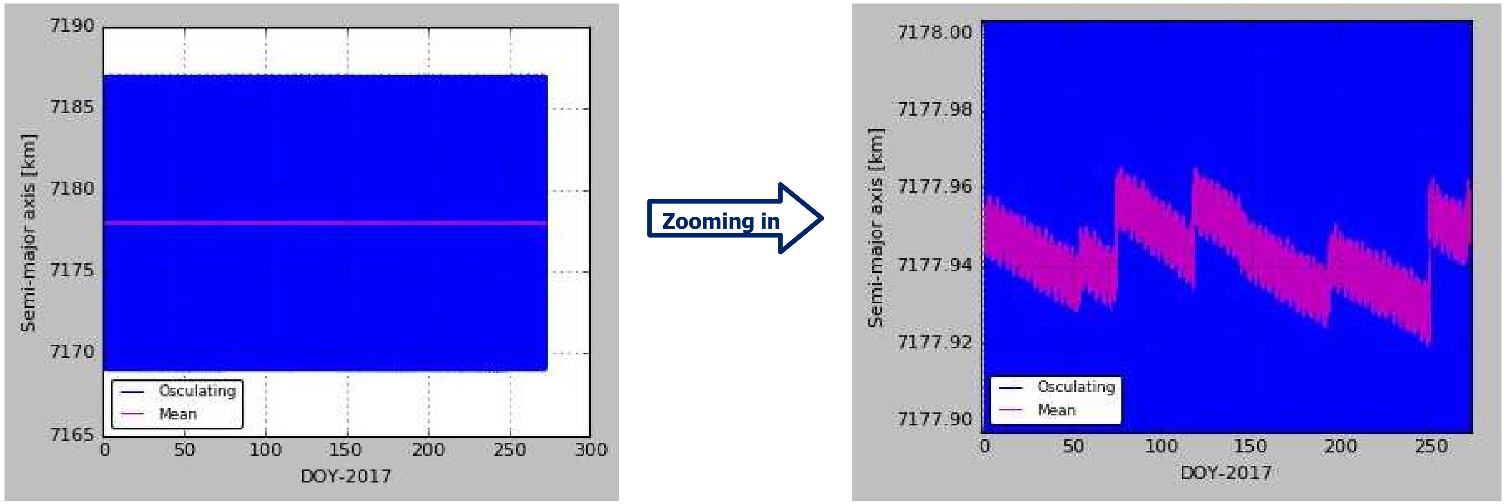
Orbit Analysis/Comparison

Orbit Analysis/Comparison. Mean elements (1/2)

- Mean elements analysis
  - supported by Orekit/DSST
  - or by simply integral average over integer number of orbits

- Semi-major axis mean elements show ‘manoeuvres’ out of the much larger orbital variations (Sentinel-3 example, 1000 times more)



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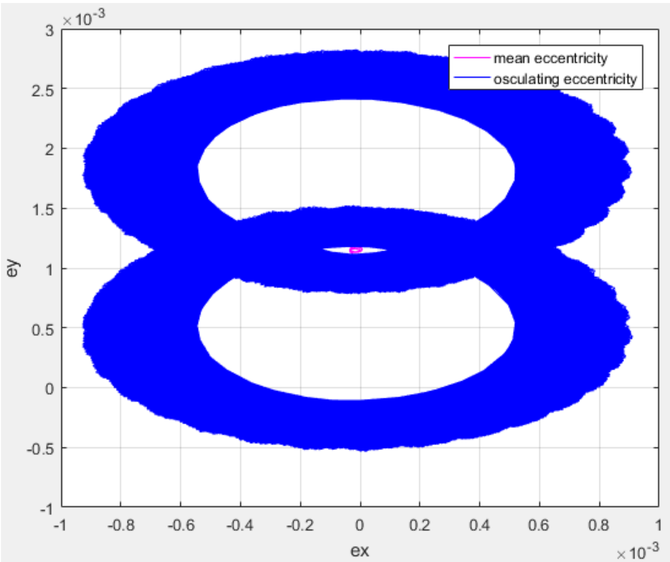
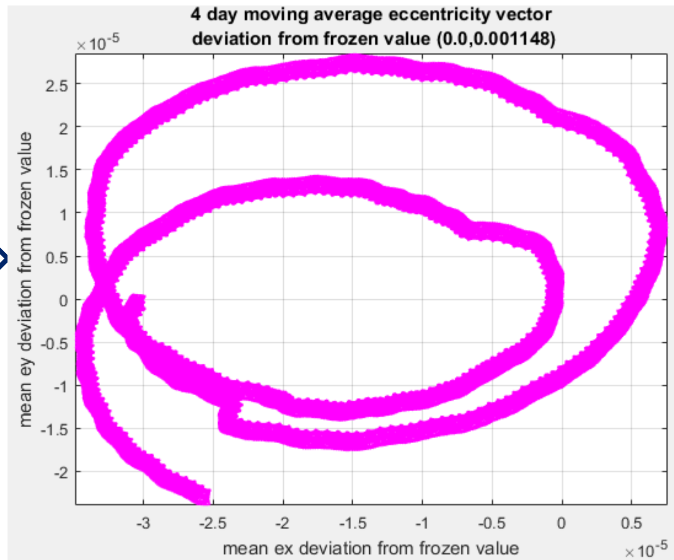
Orbit Analysis/Comparison. Mean elements (2/2)

- **Mean eccentricity vector evolution**
  - **Full earth 'cycle' (or subcycle) to be averaged to obtained mean eccentricity**
  - **100 times smaller variation that osculating orbital values**
  - **4-month rotation around theoretical frozen eccentricity value (with additional up/down seasonal movement due to solar radiation pressure)**
  - **Manoeuvres planned looking at 'mean evolution' to guarantee frozen conditions**
  - **Impact of manoeuvres visible**



Zooming in



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Other tools

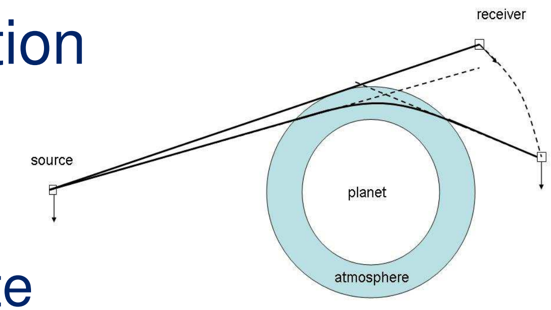
Metop End-Of-Life Disposal.

- Metop-A to be disposed, complying with ECSS and ISO standards:
  - 25 year decay orbit to be reached via de-orbiting manoeuvres, followed by s/c passivation
- Orekit implementation for planning manoeuvre sequence(s)
- Monitoring fuel on-board and fulfilling constraints:
  - last burns in combined GS visibility (implying perigee targeting),
  - minimum geodetic altitude to be respected (AOCS constraints),
  - freeing operational orbit (additional safety rules)…
- Developed in Matlab (calling Orekit), then moved to Python

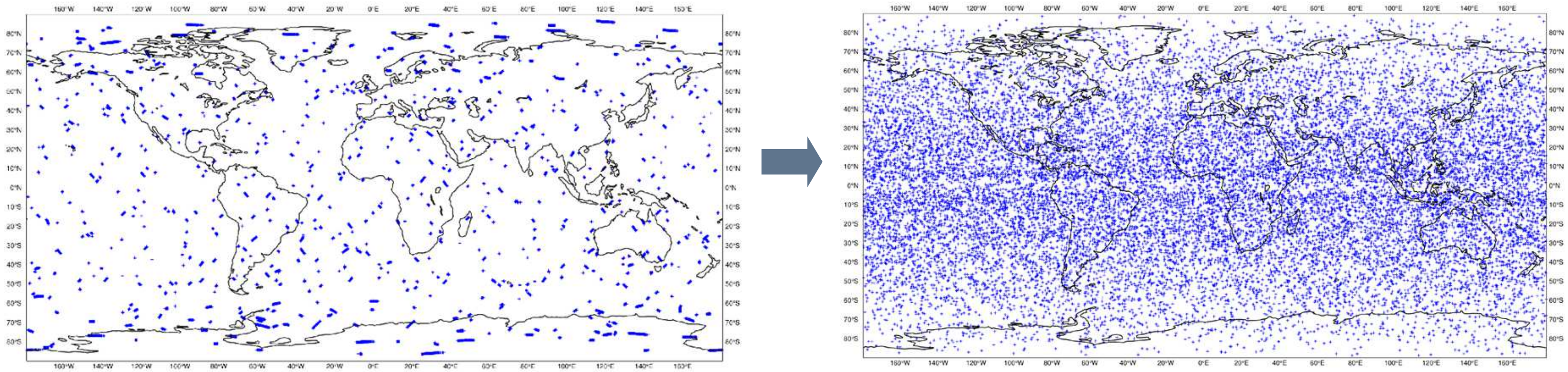
Radio Occultations (JOccultations)

Technique to measure physical properties of atmosphere, with radio signals by navigation satellites (GPS, etc)

- Sounding powerful and inexpensive
- NWP (Numerical Weather Prediction) and Climate



JOccultations: tool for predicting radio-occultation events between multiple LEO satellites (primary objects) and multiple GNSS satellites (secondary objects), e.g. GPS, GALILEO, GLONASS, Beidou



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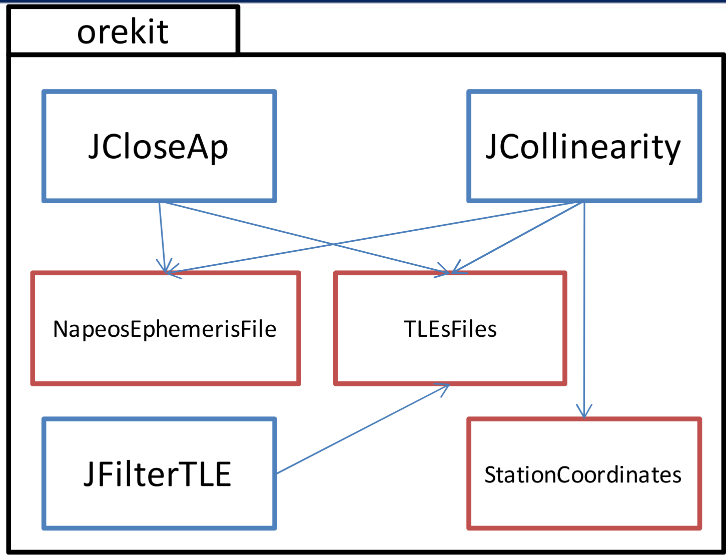
Space situational awareness



- JFilterTLE
  - filters from TLE catalogues

- JCloseAp

The minimum approach is defined mathematically as the epoch when:

$$f(\vec{r_1}, \vec{r_2}, \vec{v_1}, \vec{v_2}) = (\vec{r_2} - \vec{r_1}) \cdot (\vec{v_2} - \vec{v_1}) = 0$$

$$\dot{f} > 0$$

where:

- $\vec{r_1}, \vec{v_1}$ are the position and velocity vectors of the primary satellite in inertial frame
- $\vec{r_2}, \vec{v_2}$ are the position and velocity vectors of the secondary satellite/object in inertial frame

- JCollinearity
  - detects collinearities

(from stations; for RF interferences)

The collinearity entry and exit events are defined mathematically as the epoch when:

$$\gamma - \gamma_0 = acos\left(\frac{\vec{r_1} \cdot \vec{r_2}}{|\vec{r_1}| \cdot |\vec{r_2}|}\right) = 0$$

$$\dot{\gamma} > 0 \; for\ collinearity\ exit\ event$$

$$\dot{\gamma} < 0 \; for\ collinearity\ entry\ event$$

where:

- γ is the angular separation (collinearity angle) between the primary satellite and the secondary satellite/object as seen from a given ground station
- γ_0 is the user-defined collinearity angle

Conclusions

EUMETSAT and Orekit: Summary

- Orekit is used for a wide variety of applications at EUMETSAT,
  - stand-alone apps, also relatively complex
  - also integrated with Python and/or Matlab

  [main operational Flight Dynamics or related Data Processing chains rely however on other s/w packages]

  => future evolutions may well consider Orekit

- Our experience: It allows rapid development of powerful and reliable applications, as well as quick analyses (also for the non-Java expert when for example integrated into Matlab)

- For cases where accuracy or integrity is necessary, results need cross-validation with other independent s/w (as usual)

Orekit and EUMETSAT

Questions?

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