EUMETSAT

OREKIT DAY 2017
Orekit-based applications at EUMETSAT

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EUMETSAT

This presentation

- EUMETSAT brief overview

- Orekit use at EUMETSAT

  - Radio Occultations
  - Station Keeping Analysis
  - Metop End-Of-Life Disposal
  - Space Situational Awareness
  - Integration with Matlab
  - Orbit analysis (mean elements)

EUMETSAT - An intergovernmental organisation with 30 Member States and one Cooperating State

Member States

AUSTRIA
BELGIUM
BULGARIA
CROATIA
CZECH REPUBLIC
DENMARK
ESTONIA
FINLAND
FRANCE
GERMANY
GREECE
HUNGARY
ICELAND
IRELAND
ITALY
LATVIA
LITHUANIA
LUXEMBOURG
THE NETHERLANDS
NORWAY
POLAND
PORTUGAL
ROMANIA
SLOVAK REPUBLIC
SLOVENIA
SPAIN
SWEDEN
SWITZERLAND
TURKEY
UNITED KINGDOM

Cooperating State

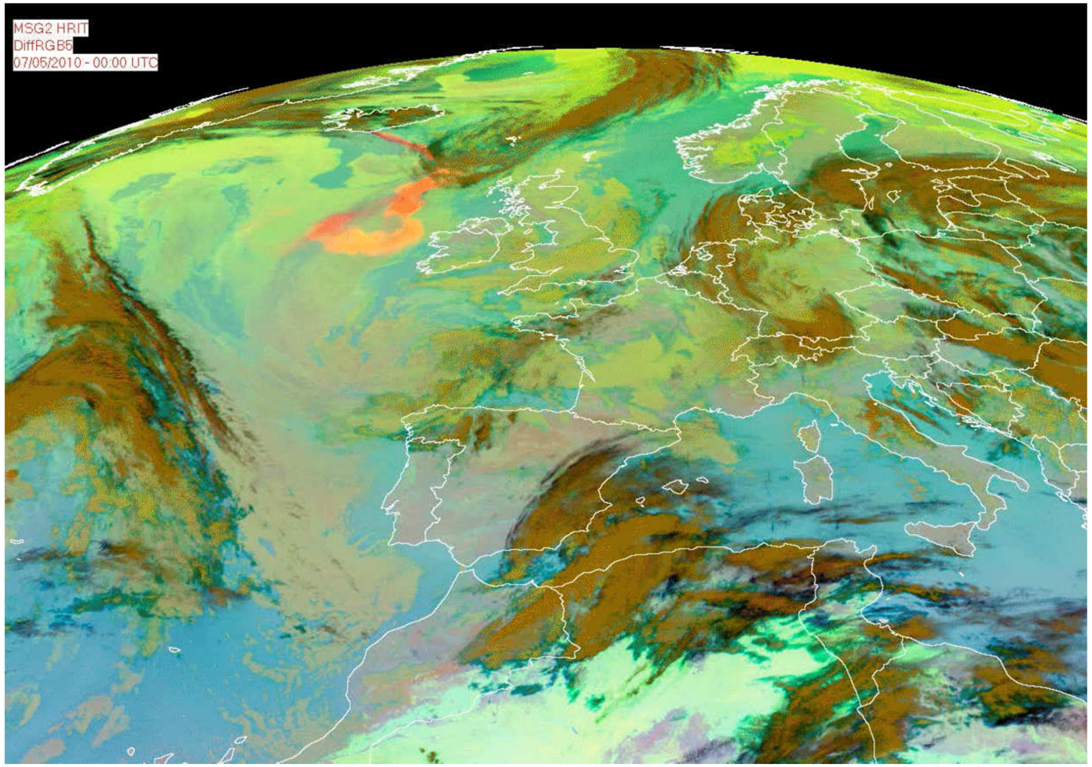
SERBIA

EUMETSAT. An overview

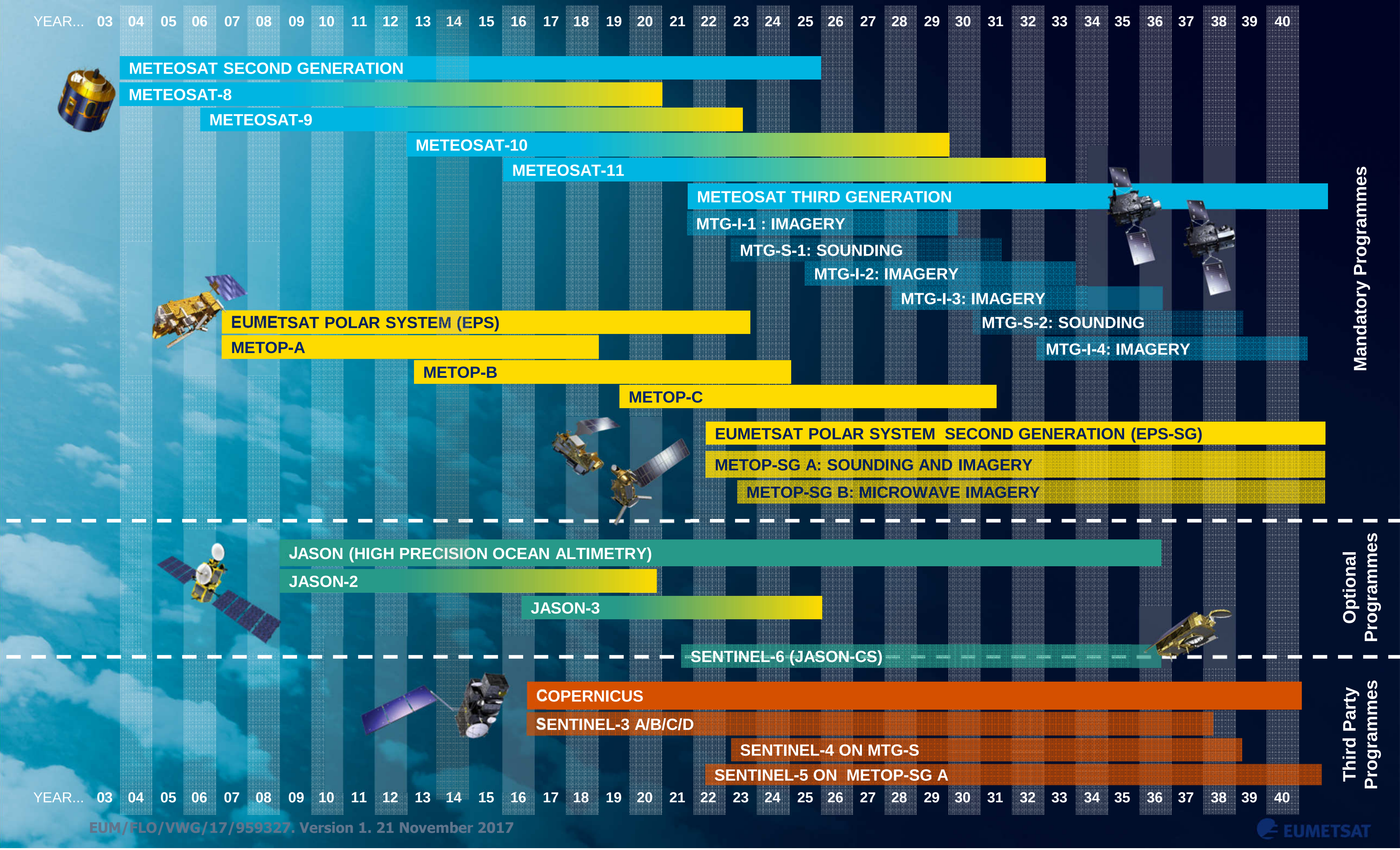
EUMETSAT
EUropean organization for the exploitation of METeorological SATellites

❑ Monitoring Weather and Climate from Space

- o Low Earth Orbit (LEO)
  - Metop-A/B/C, Sentinel-3A/3B
  - Jason2/3
- o Geostationary Orbit (GEO)
  - Meteosat series
- o Future programmes
  - MTG, EPS-SG, Jason-CS



EUMETSAT mission planning



Current EUMETSAT satellites

METOP-A & -B (98.7° incl.)

LOW EARTH, SUN-SYNCHRONOUS ORBIT

EUMETSAT POLAR SYSTEM (EPS) /
INITIAL JOINT POLAR SYSTEM

SENTINEL-3 (98.65° incl.)

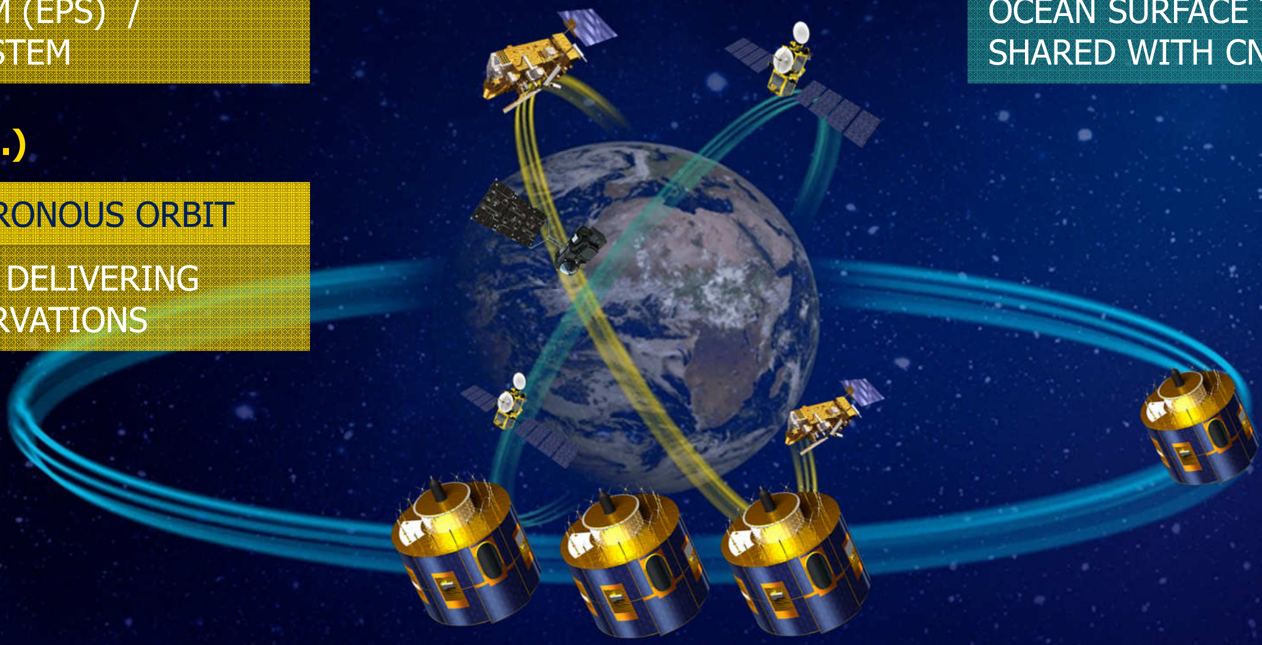
LOW EARTH, SUN-SYNCHRONOUS ORBIT

COPERNICUS SATELLITES DELIVERING
MARINE AND LAND OBSERVATIONS

JASON-2 & -3 (63° incl.)

LOW EARTH, NON-SYNCHRONOUS ORBIT

OCEAN SURFACE TOPOGRAPHY MISSION,
SHARED WITH CNES/NOAA/EU



METEOSAT-8 (41.5° E)

GEOSTATIONARY ORBIT

METEOSAT 2ND
GENERATION PROVIDING
IODC FROM FEBRUARY
2017 – MID-2020

METEOSAT-9, -10, -11

GEOSTATIONARY ORBIT	TWO-SATELLITE SYSTEM
METEOSAT 2ND GENERATION	FULL DISC IMAGERY MISSION (15 MINS) (METEOSAT-10 (0°)) RAPID SCAN SERVICE OVER EUROPE (5 MINS) (METEOSAT-9 (9.5° E)) *METEOSAT-11 STORED IN ORBIT (UNTIL MID-2018)*

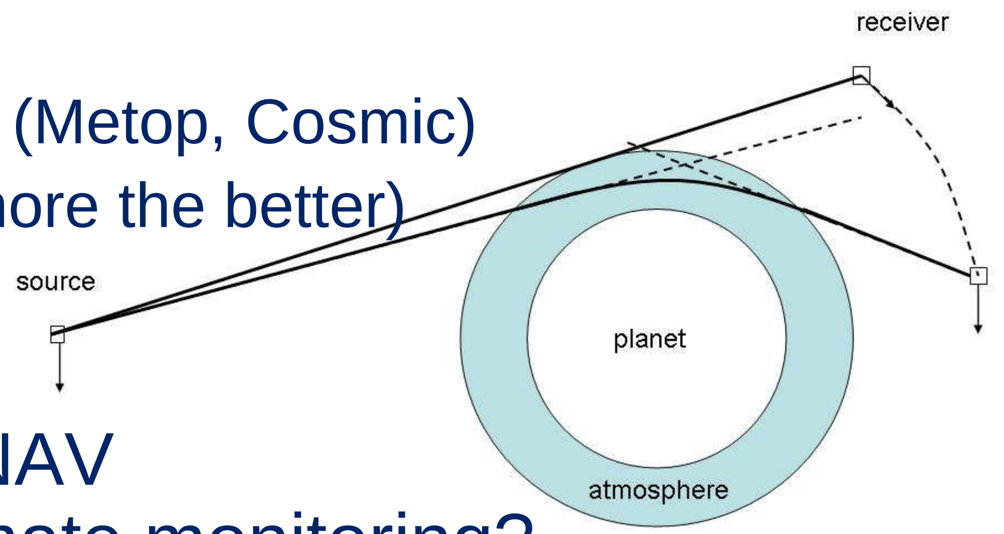
Orekit-based applications at EUMETSAT

- Orekit-based applications at EUMETSAT

Radio Occultations

- Radio Occultation: remote sensing technique to measure physical properties of Earth atmosphere, using the radio signals transmitted by navigation satellites (GPS, etc)
  - This is a powerful and inexpensive approach for sounding the global atmosphere with high precision, accuracy and vertical resolution

    [temperature and humidity profile information]
  - Very important for NWP (Numerical Weather Prediction) and Climate
  - Rear-view & front-view antennas
  - Currently about 2600 occult/daily (Metop, Cosmic)
  - NWP results not saturated (the more the better)



- Impact of future satellites and NAV constellations on NWP and climate monitoring?

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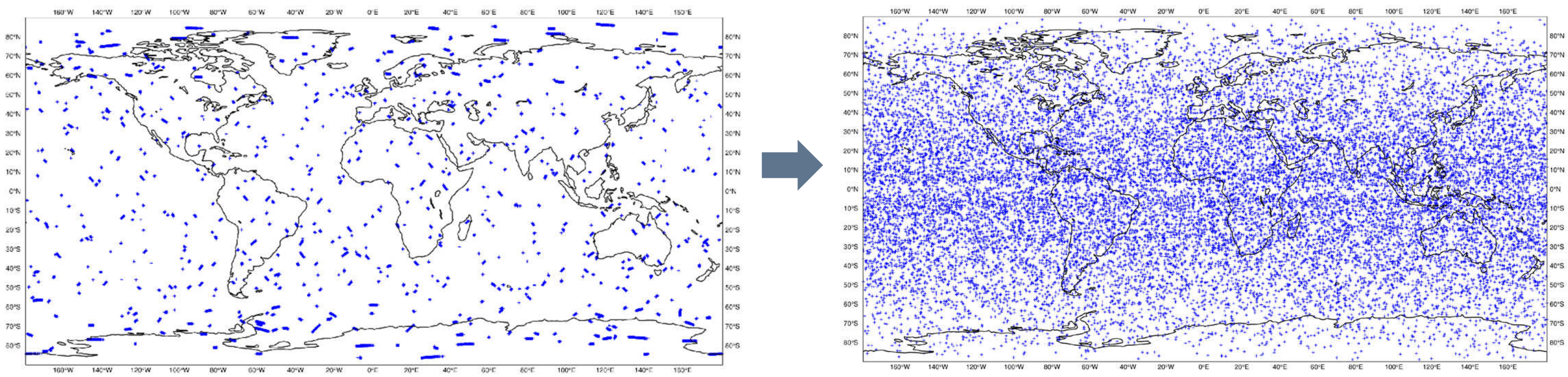
Radio Occultations (JOccultations)

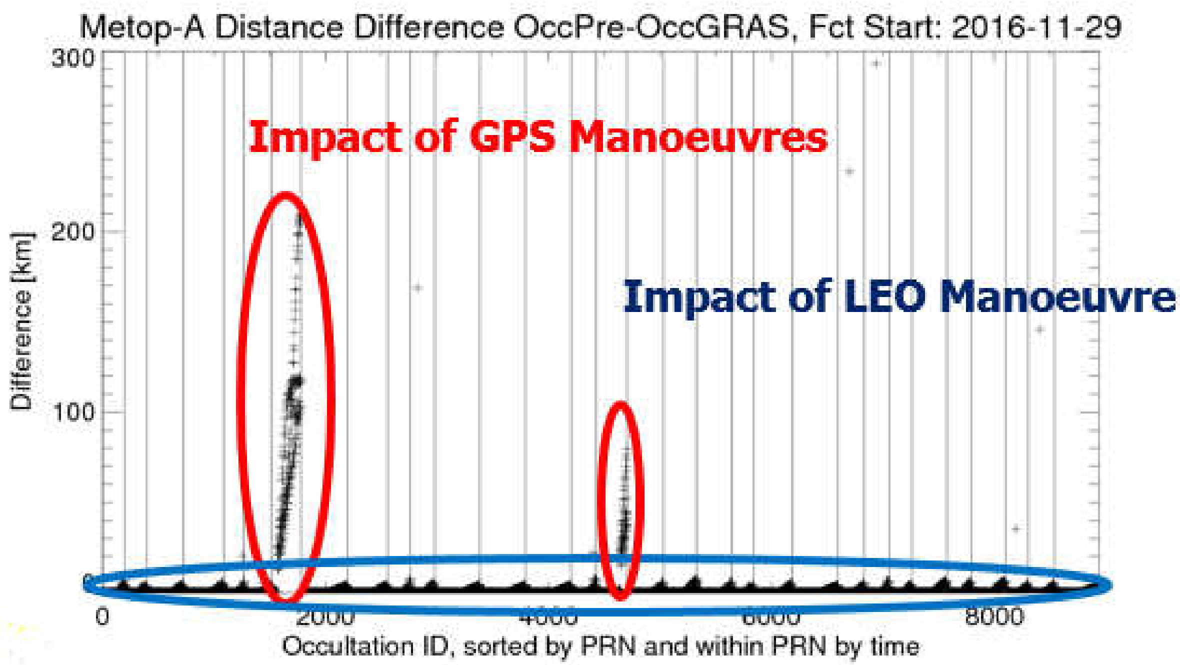
- JOccultations: tool for predicting radio-occultation events between multiple LEO satellites (primary objects) and multiple GNSS satellites (secondary objects), e.g. GPS, GALILEO, GLONASS, Beidou



- Tool used for supporting 'saturation' study (impact of future constellations on NWP and climate) as well as different scenario analyses (different combinations of receiving satellites and navigation constellations)
  - Numerical weather prediction improvements still with 128000 profiles and beyond; with 16000 profiles, 50% of impact with 128000 profiles
  - Impact of Jason-CS, also Metop-SG, FY…along with new constellations

Radio Occultations (JOccultations)

- Same tool also used operationally today for providing predictions
  - Based on accurate GNSS and LEO orbits, one can determine where occultations are expected (with some uncertainty)
  - Product delivered daily, covering 14 day
  - Allows to schedule observations (e.g. radio sonde, Lidar, etc) to coincide with potential RO observation
  - Allows additionally to schedule observations to coincide with Metop nadir sounder (e.g. IR and MW instruments) overpass



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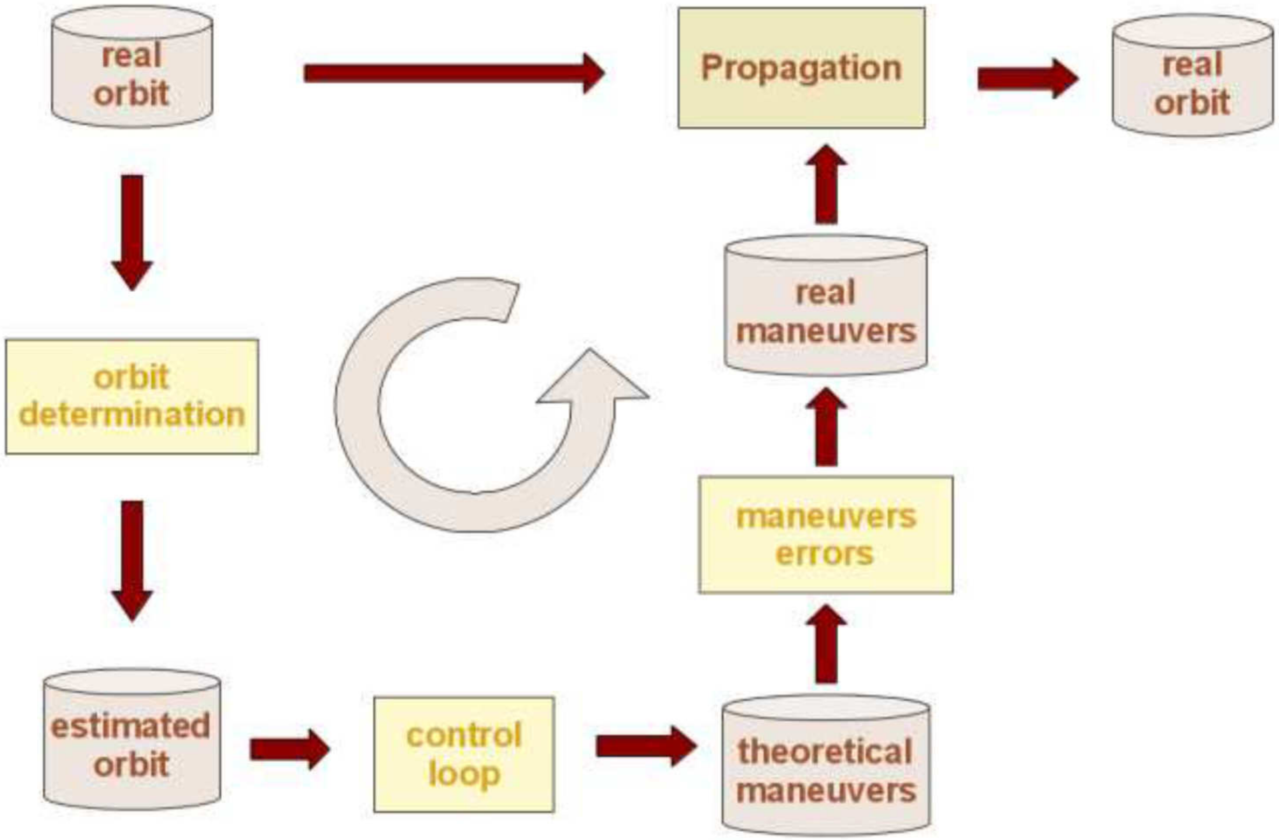
Station Keeping Analysis Tool (SKAT)

- Station Keeping Analysis Tool (SKAT).
- Realistically evaluating orbit maintenance strategies for LEO and GEO missions via simulations over long time spans.
- End-to-end, full chain of orbit maintenance and control, simulated uncertainties, automated control rules ‘in-the-loop’ (several ‘controls’, constraints between them, including also possible ‘nestings’)
- Paper at ICATT 2012



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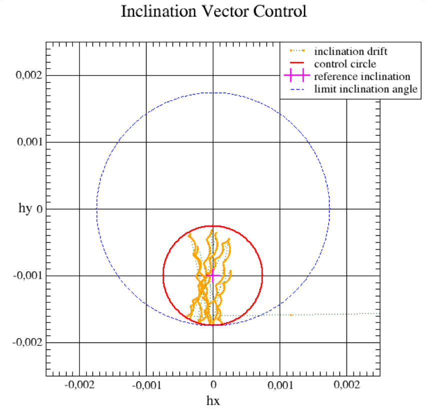
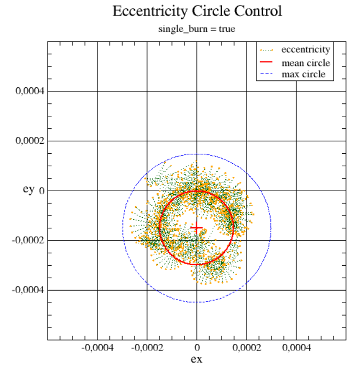
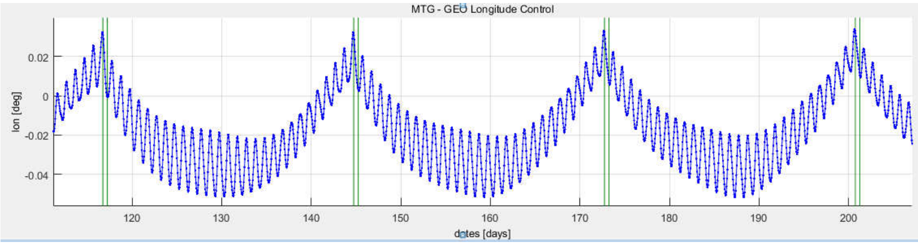
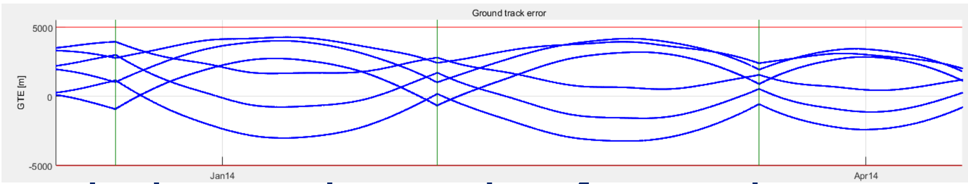
Station Keeping Analysis Tool (SKAT)

- Different 'Controls' implemented
- GEO controls:
  - Inclination (GEO control on inclination vector)
  - Longitude (GEO control; parabolic longitude)
  - Eccentricity (eccentricity circle; single or double burn type)
  - Inclination and longitude (own GEO 'combined' control)
- LEO controls:
  - Mean Local Solar Time
  - In Plane Ground Track Grid
  - Out-Of-Plane Ground Track Grid









All controls: time horizon, manoeuvre types, boundaries and margins for each control, time offset for first manoeuvre (wrt start of cycle), max number of manoeuvres, manoeuvre orbits separation…

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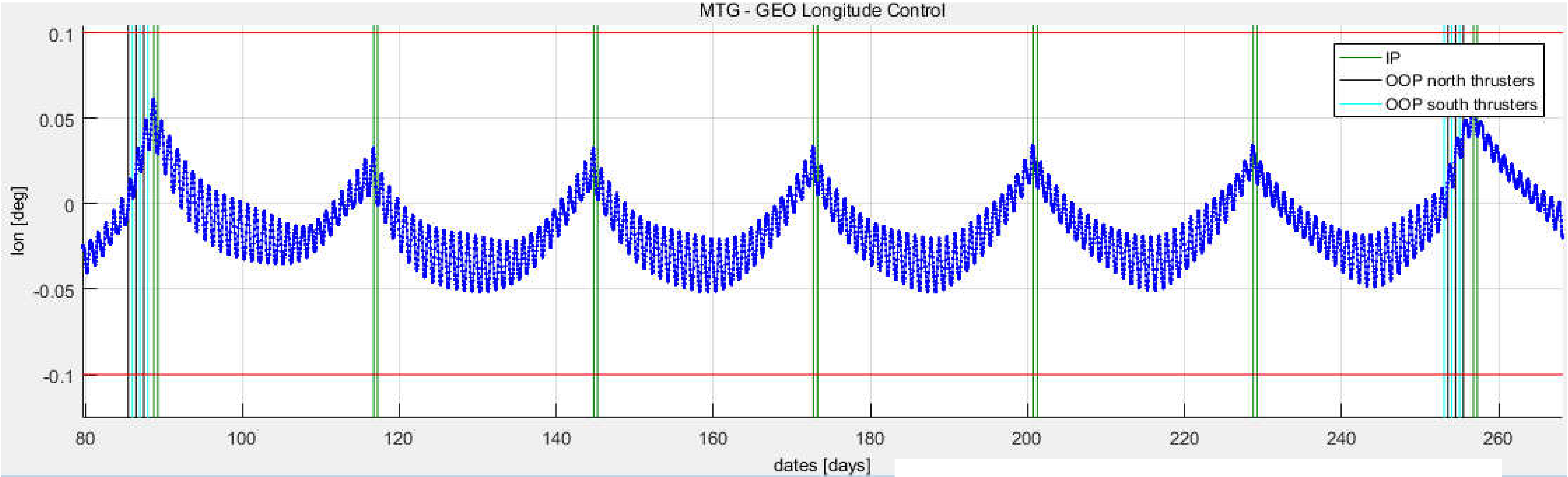
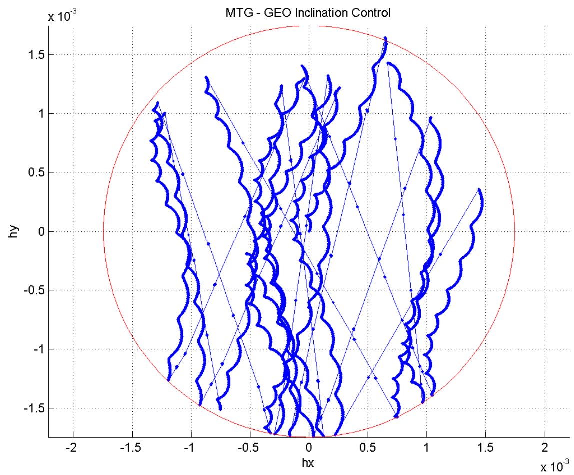
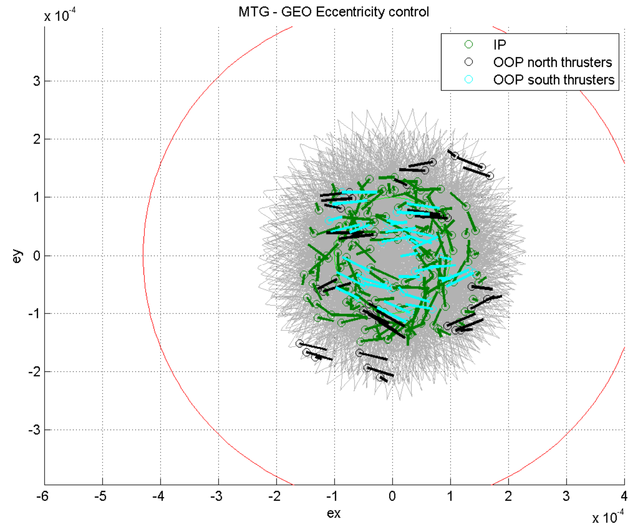
Station Keeping Analysis Tool (SKAT). MTG simulation example

- MTG example with inclination manoeuvres every 6 months (with ‘north’ and ‘south’ thrusters to compensate eccentricity), longitude cycles every 4 weeks.



- 10 year simulation





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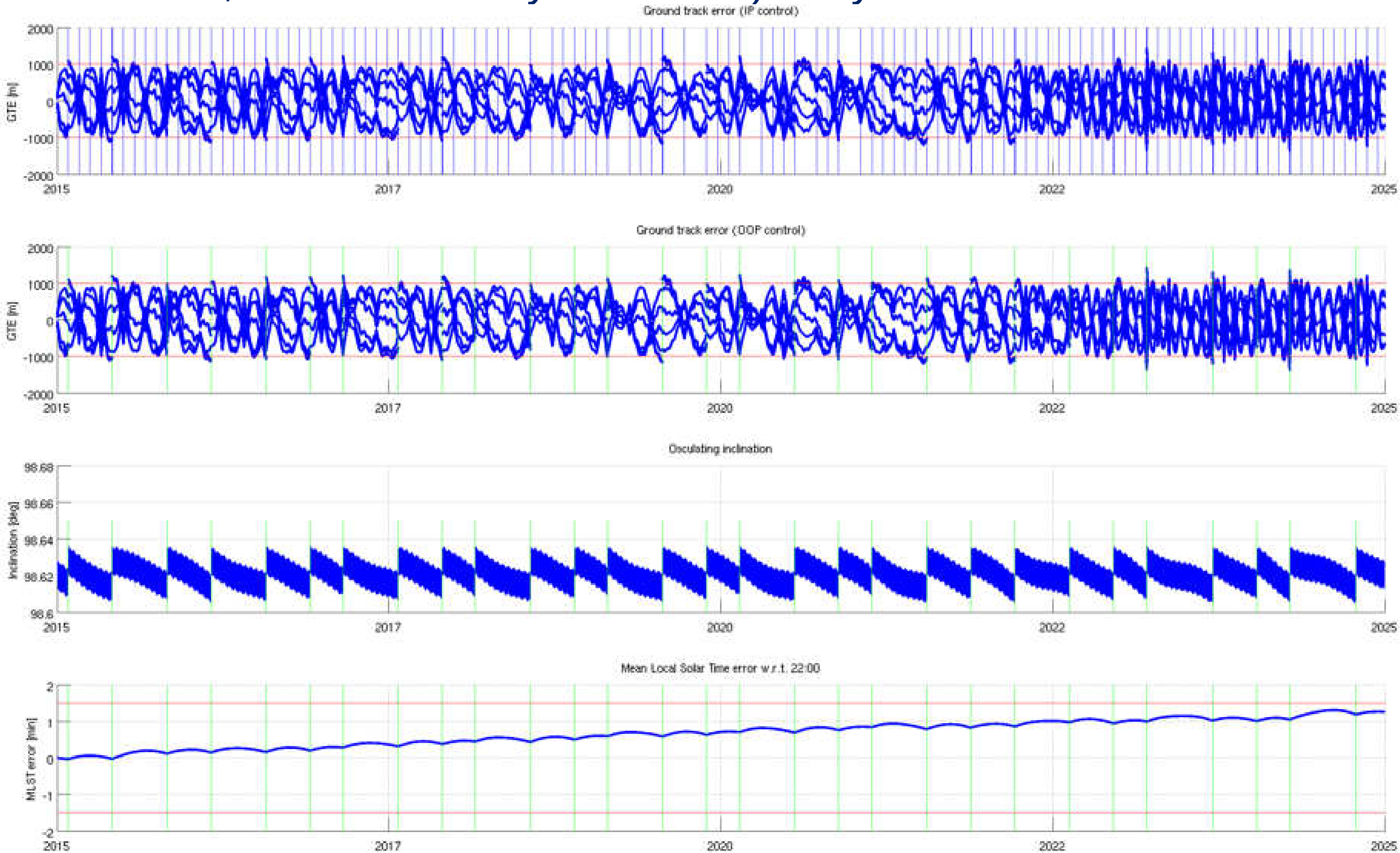
Station Keeping Analysis Tool (SKAT). Sentinel-3A simulation example

- Sentinel-3A example with Ground Track IP and OOP controls (GT to be < 1km at all latitudes; MLST indirectly controlled). 10 yrs simulation



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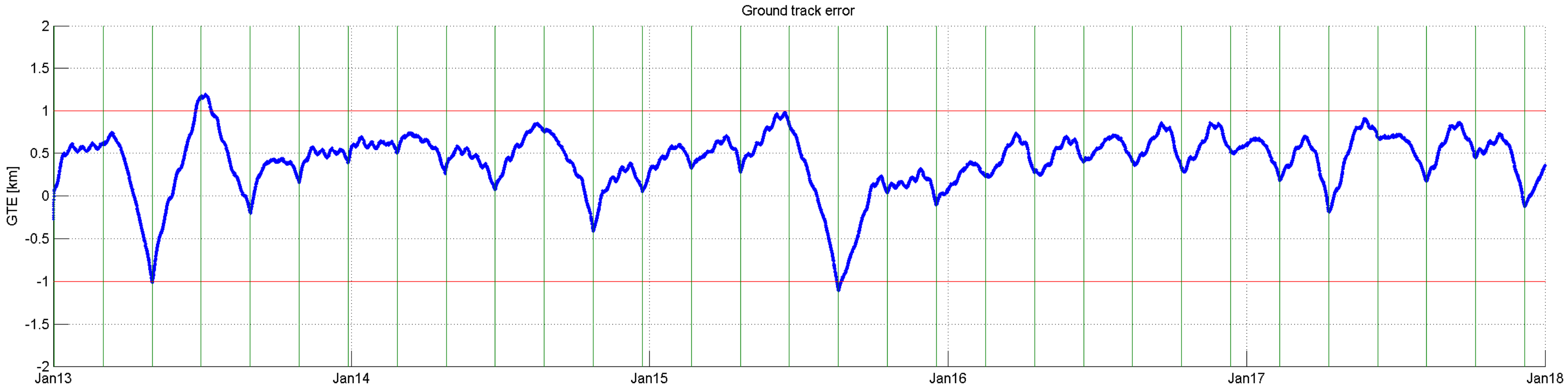
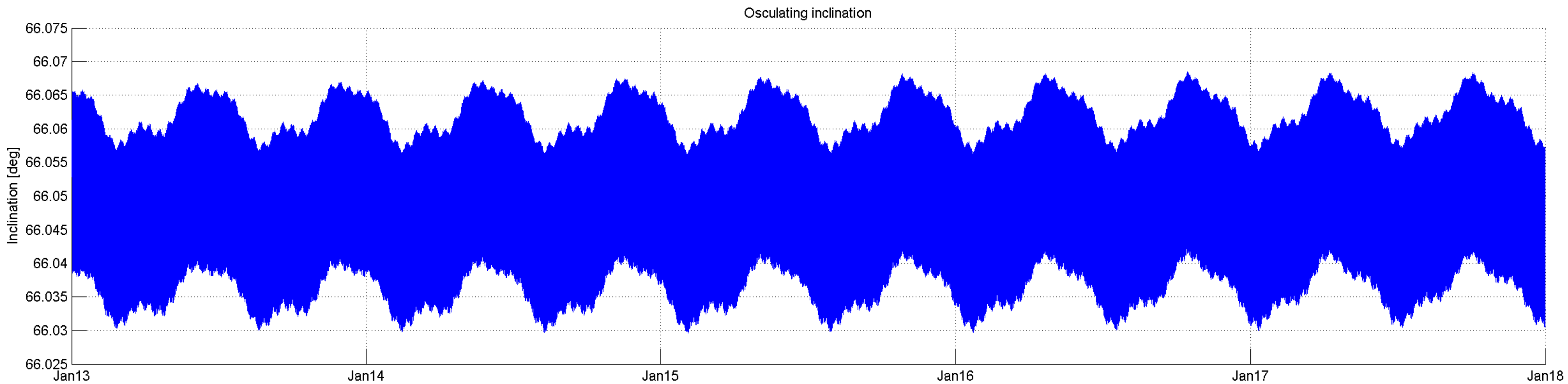
Station Keeping Analysis Tool (SKAT). Jason-CS simulation example

- Jason-CS example, on stable inclination plane (66 deg) with only Ground Track IP control (GT to be < 1km at all latitudes). 10 yrs simulation
- It flies higher than SSOs, at ~1334 km => very ‘weak’ atmosphere





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)…
- Manoeuvre sequence in different potential phases:

  [depending on maximum manoeuvre duration and minimum altitude constraint]

  1. circularize down,
  2. target perigee,
  3. lower perigee while possible (min altitude respected) and fuel margin available,
  4. lower apogee while margin available,
  5. last possible burns in 'extended' visibility (over north pole),
  6. passivate quickly
- Developed in Matlab (calling Orekit), then moved to Python (getting rid of Matlab)

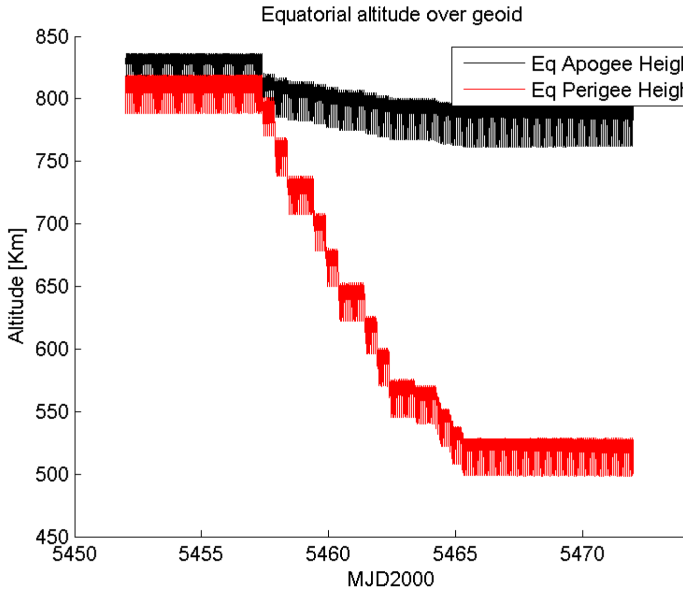
Metop EOL Disposal. Metop-A rehearsed disposal

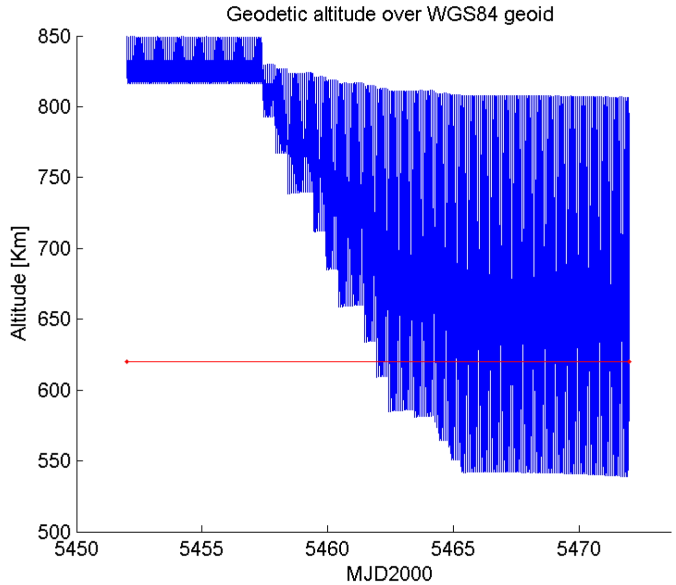
- Paper at 25th ISSFD Munich (2015)
- 2-day manoeuvre sequences, each with 3 x 30 min (max) manoeuvres, at ~9, 21, then 9 UTC, with O.D. and planning of next sequence

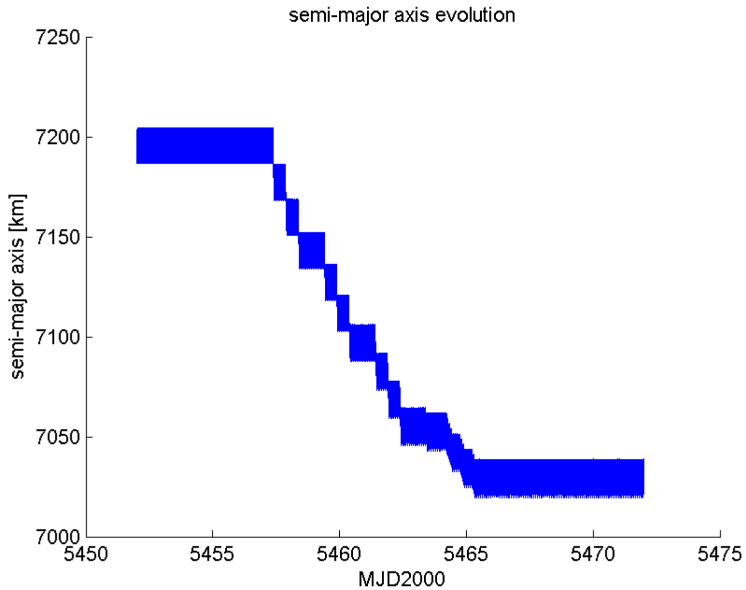
```
  X:                            -4914.892433km
  Y:                            -2767.712535km
  Z:                            -4484.002770km
  Vx:                               3.246651km/s
  Vy:                               3.478082km/s
  Vz:                              -5.710987km/s

  Mean equatorial perigee:            809.09km
  Mean equatorial apogee:             825.84km
  Mean argument of perigee:            85.65deg

CD:                                     2.20
CR:                                     2.17

Initial target AoP:                   290.00deg
```

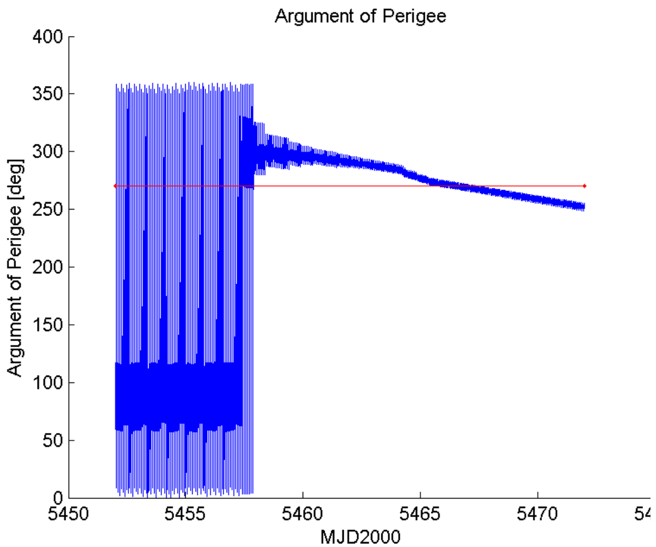
ID	Burn start time	Burn end time	Time[s]	F[N]	r	Isp[s]	DVr[m/s]	DVa[m/s]	DVc[m/s]	DV[m/s]	M[kg]	m[kg]	Dm[kg]	P[bar]	DP[bar]	Perigee[km]	Apogee[km]	w[deg]	Phase
1-B1	2014/12/10-09:19:00.753	2014/12/10-09:49:00.753	1800.00	21.35	1.056	216.6	-0.346	-9.549	-2.210	9.807	3915.09	145.42	18.12	8.372	0.528	790.04	808.28	312.72	targeting perigee
2-B1	2014/12/10-21:05:47.301	2014/12/10-21:35:47.301	1800.00	20.29	1.061	216.4	-0.329	-9.113	-2.118	9.361	3897.86	128.20	17.23	7.925	0.447	758.07	805.17	297.91	targeting perigee
3-B1	2014/12/11-08:53:48.444	2014/12/11-09:23:48.444	1800.00	19.38	1.065	216.3	-0.314	-8.739	-2.038	8.979	3881.40	111.73	16.46	7.541	0.385	727.21	802.61	299.26	lowering perigee
4-B1	2014/12/12-09:56:52.962	2014/12/12-10:26:52.962	1800.00	18.59	1.069	216.1	-0.302	-8.414	-1.970	8.647	3865.60	95.94	15.80	7.205	0.335	697.51	799.98	297.27	lowering perigee
5-B1	2014/12/12-21:35:49.028	2014/12/12-22:05:49.028	1800.00	17.89	1.073	216.0	-0.291	-8.128	-1.909	8.354	3850.39	80.73	15.21	6.909	0.296	669.33	797.60	296.30	lowering perigee
6-B1	2014/12/13-09:12:22.508	2014/12/13-09:42:22.508	1800.00	17.27	1.076	215.9	-0.281	-7.874	-1.855	8.095	3835.71	66.04	14.68	6.646	0.264	641.77	795.79	295.40	lowering perigee
7-B1	2014/12/14-10:01:02.192	2014/12/14-10:31:02.192	1800.00	16.71	1.079	215.9	-0.273	-7.647	-1.806	7.862	3821.49	51.83	14.21	6.409	0.237	615.11	793.59	292.44	lowering perigee
8-B1	2014/12/14-21:33:28.649	2014/12/14-22:03:28.649	1800.00	16.21	1.082	215.8	-0.265	-7.441	-1.762	7.651	3807.71	38.04	13.79	6.195	0.214	589.62	791.43	290.98	lowering perigee
9-B1	2014/12/15-09:03:36.842	2014/12/15-09:33:36.842	1800.00	15.75	1.085	215.7	-0.258	-7.255	-1.722	7.460	3794.31	24.64	13.40	6.001	0.195	565.12	789.78	289.94	lowering perigee
10-B1	2014/12/16-09:51:17.814	2014/12/16-09:57:08.760	350.95	15.48	1.087	215.7	-0.049	-1.392	-0.331	1.431	3791.74	22.08	2.57	5.965	0.036	560.19	789.29	286.57	lowering perigee
11-B1	2014/12/17-05:17:00.000	2014/12/17-05:23:00.000	360.00	15.40	1.088	215.7	-0.050	-1.421	-0.338	1.462	3789.12	19.46	2.62	5.929	0.036	555.53	787.48	282.95	possible final thrusts
12-B1	2014/12/17-06:54:00.000	2014/12/17-07:00:00.000	360.00	15.31	1.088	215.7	-0.050	-1.415	-0.336	1.455	3786.52	16.85	2.60	5.893	0.036	551.02	785.69	281.88	possible final thrusts
13-B1	2014/12/17-08:34:00.000	2014/12/17-08:40:00.000	360.00	15.23	1.089	215.6	-0.050	-1.408	-0.335	1.448	3783.93	14.26	2.59	5.858	0.035	546.46	783.89	280.87	possible final thrusts
14-B1	2014/12/17-10:20:00.000	2014/12/17-10:26:00.000	360.00	15.16	1.089	215.6	-0.050	-1.402	-0.334	1.442	3781.35	11.68	2.58	5.824	0.034	541.61	782.95	280.17	possible final thrusts
15-B1	2014/12/17-18:26:00.000	2014/12/17-18:32:00.000	360.00	15.08	1.090	215.6	-0.049	-1.396	-0.332	1.436	3778.78	9.12	2.57	5.790	0.034	536.98	781.25	278.42	possible final thrusts
16-B1	2014/12/17-20:04:00.000	2014/12/17-20:09:60.000	360.00	15.00	1.090	215.6	-0.049	-1.390	-0.331	1.429	3776.23	6.57	2.55	5.757	0.033	532.46	779.66	277.61	possible final thrusts
17-B1	2014/12/17-21:43:00.000	2014/12/17-21:49:00.000	360.00	14.93	1.090	215.6	-0.049	-1.384	-0.330	1.423	3773.69	4.03	2.54	5.724	0.033	527.70	778.29	276.84	possible final thrusts
18-B1	2014/12/18-05:49:00.000	2014/12/18-05:54:60.000	360.00	14.86	1.091	215.6	-0.049	-1.378	-0.328	1.417	3771.16	1.50	2.53	5.692	0.032	523.17	776.56	275.21	possible final thrusts
19-B1	2014/12/18-07:26:60.000	2014/12/18-07:32:60.000	360.00	14.78	1.091	215.6	-0.049	-1.372	-0.327	1.411	3768.65	-1.02	2.52	5.661	0.032	518.67	774.87	274.31	possible final thrusts

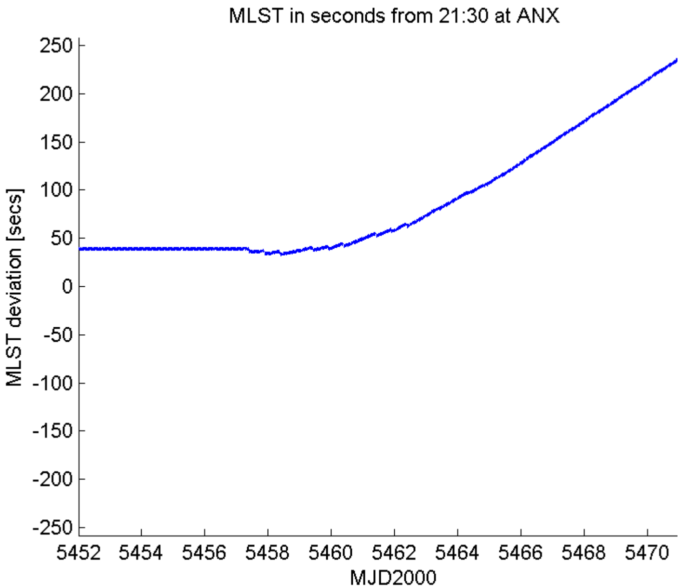
Metop EOL Disposal. Metop-A rehearsed disposal

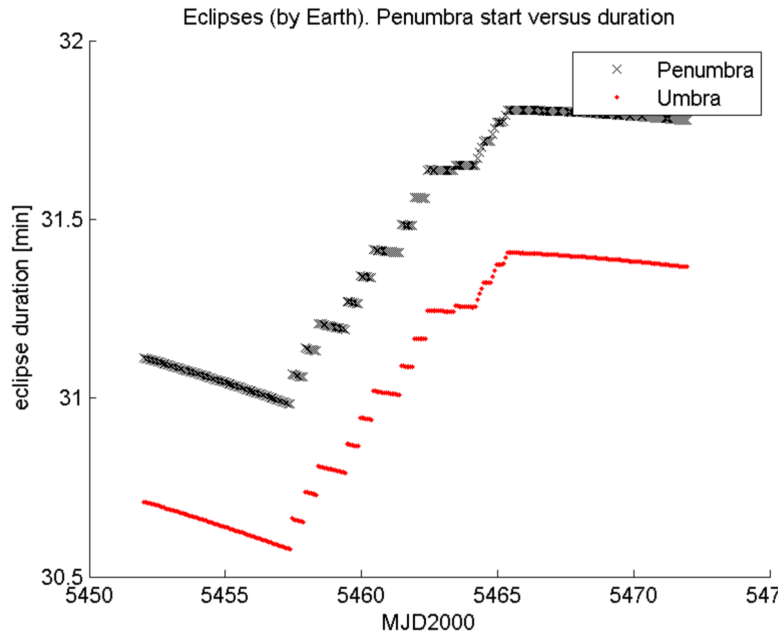




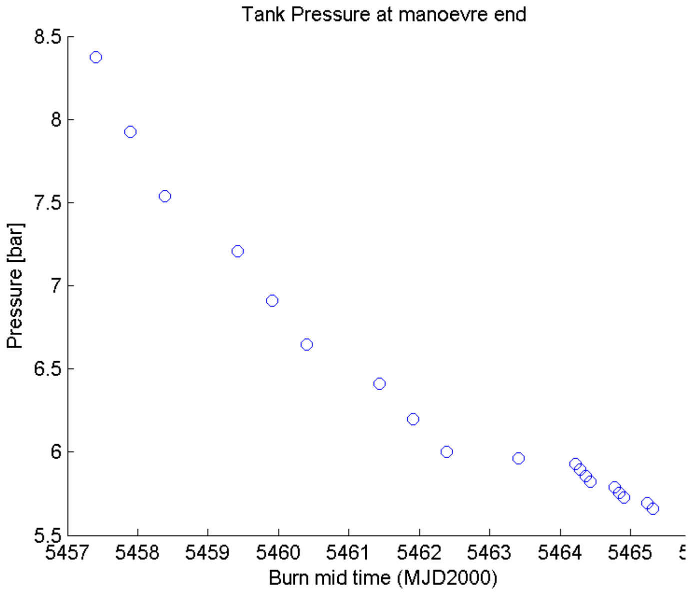


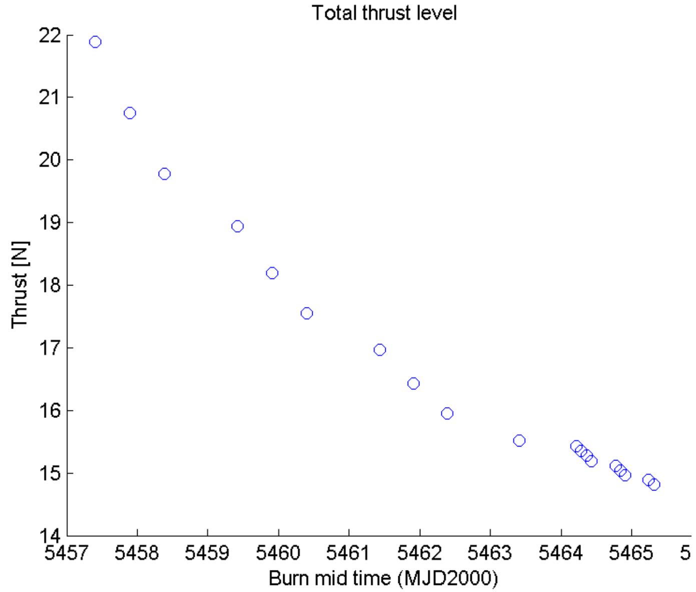


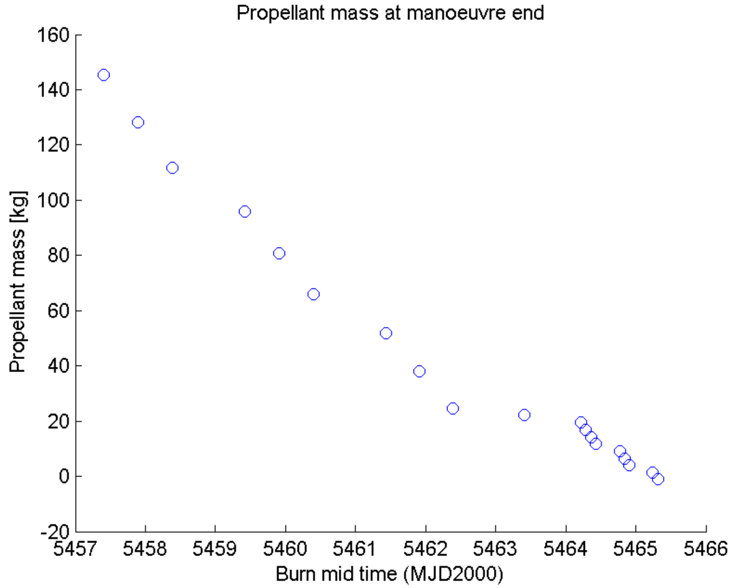


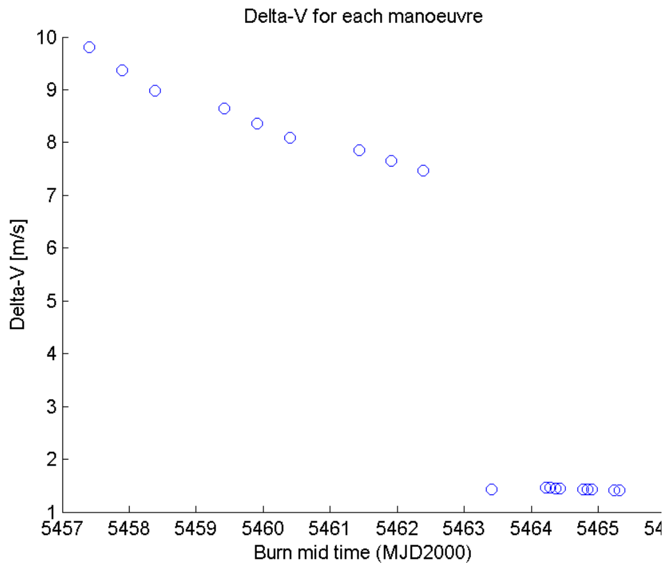


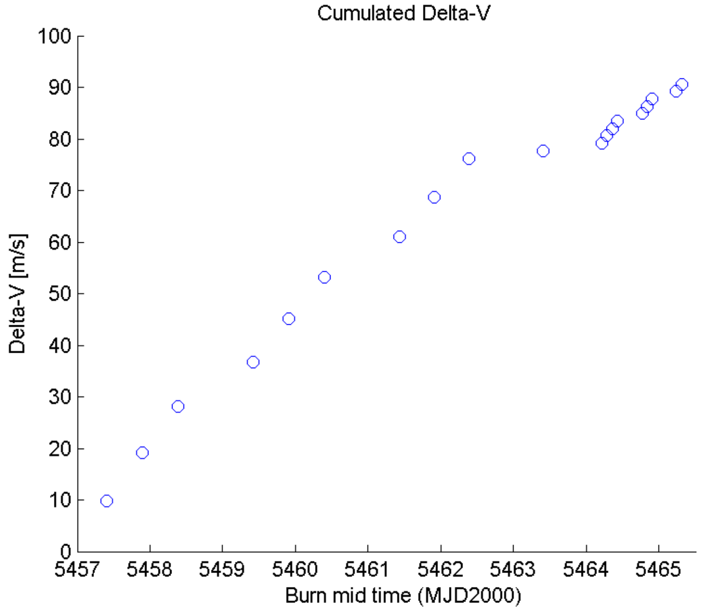
Metop EOL Disposal. Metop-A rehearsed disposal

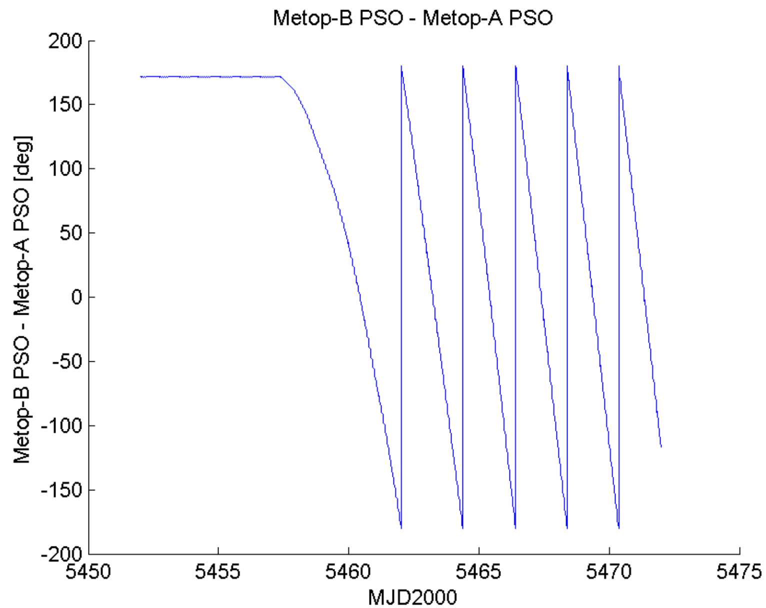












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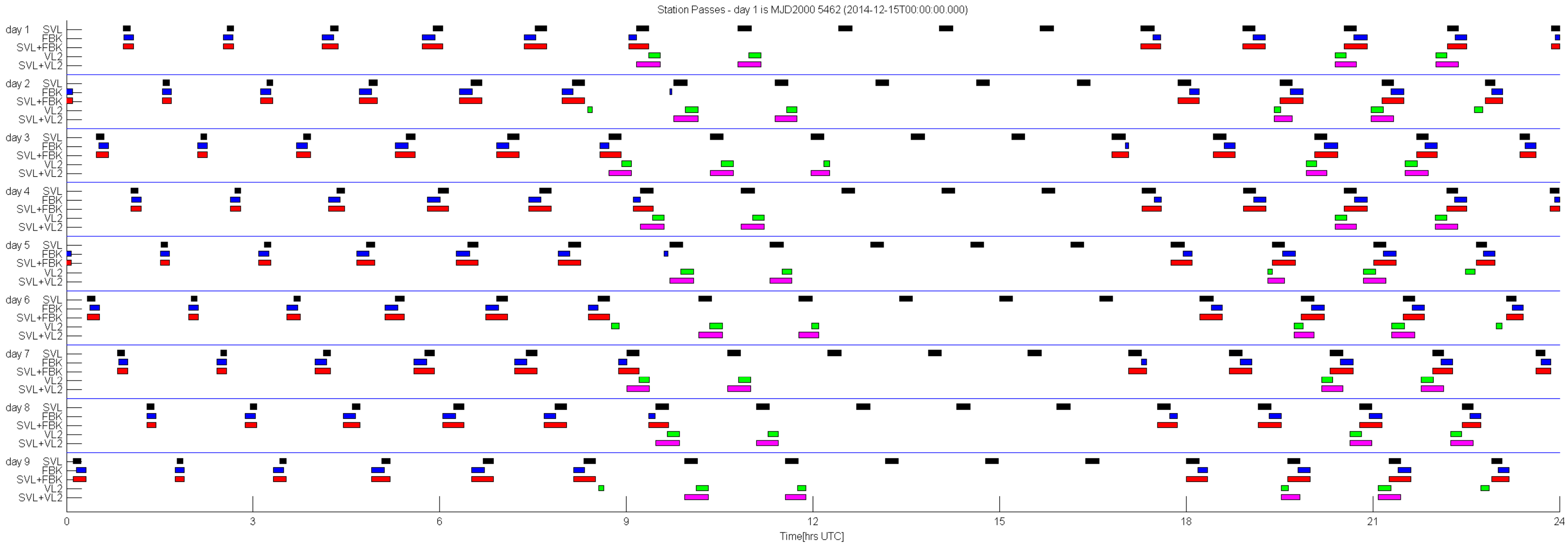
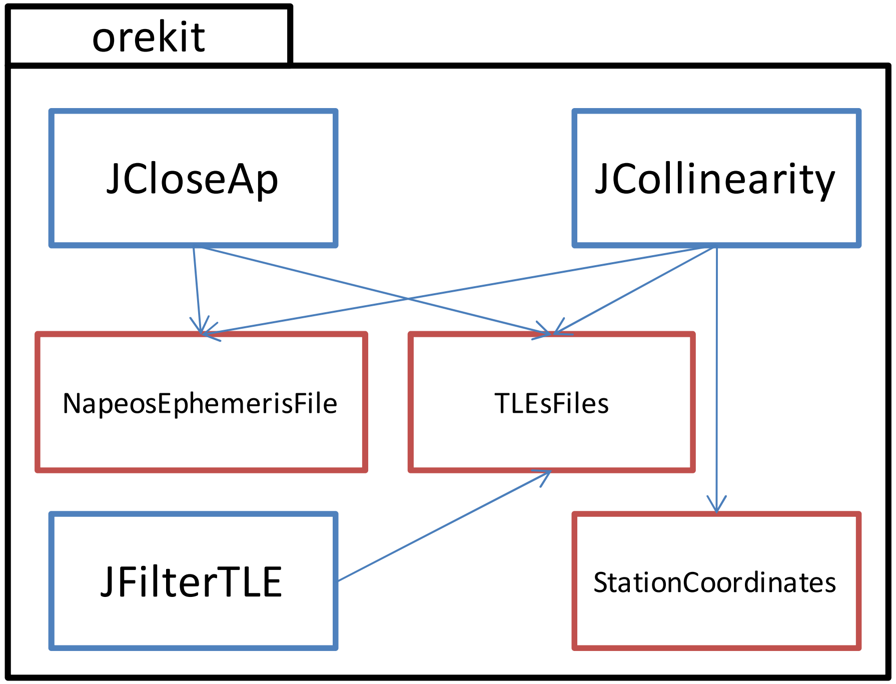
Metop EOL Disposal. Metop-A rehearsed disposal

- Last PFTs (Possible Final Thrusts) in extended visibility for allowing passivation actions right after



Other tools. Space situational awareness

- JFilterTLE
  - filters from TLE catalogues
- JCloseAp
  - detects close approaches



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

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Other tools. Space situational awareness

- Possibility to filter catalogue for only ‘Operational Objects’ (normally from UCS Satellite Database) or specific list of Norad IDs (i.e. potential interference satellites)

- Example of JFilterTLE

[output truncated to fit slide]

```
TLE FILTERED FILE
HEADER_START
  MINIMUM SMA           = 0.0 km
  MAXIMUM SMA           = 1.0E8 km
  MINIMUM PERIGEE       = 301000.0 km
  MAXIMUM PERIGEE       = 1346000.0 km
  MINIMUM APOGEE        = 1326000.0 km
  MAXIMUM APOGEE        = 1.0E8 km
  MINIMUM INCLINATION   = 0.0 deg
  MAXIMUM INCLINATION   = 360.0 deg
  MINIMUM RAAN          = 0.0 deg
  MAXIMUM RAAN          = 360.0 deg
  TLE CATALOG           = /tcenas/home/fdfca/FDF_DATA/interface/mcs/in/tleCatalog.txt
  FILTER TLE FILE       = None
  LEGEND_START
    NORAD               = NORAD Id of the object.
    SMA                 = Semi-Major Axis [km].
    Ecc                 = Eccentricity.
    Inc                 = Inclination [deg].
    RAAN                = Right Ascension of Ascending Node [deg].
    AoP                 = Argument of Perigee [deg].
    Perigee             = Distance from center of the Earth to Perigee [km].
    Apogee              = Distance from center of the Earth to Apogee [km].
    Name                = Object name (line 0 from TLE).
  LEGEND_END
HEADER_END
```

NORAD	SMA [km]	Ecc	Inc [deg]	RAAN [deg]	AoP [deg]	Perigee [km]	Apogee [km]	Name
2223	7688.994293	0.00935470	101.201	189.384	13.124	1238.929058	1382.785528	DELTA 1 DEB
2657	7760.743631	0.00729360	102.087	168.862	278.780	1326.002871	1439.210390	ESSA 4 (TOS-B)
2661	7768.533647	0.00651830	101.913	66.400	37.382	1339.759014	1441.034280	DELTA 1 R/B
2976	7711.634163	0.00977630	102.183	10.702	225.432	1258.105914	1408.888412	DELTA 1 DEB
3051	7792.084993	0.00886980	101.350	225.625	264.775	1344.833758	1483.062229	DELTA 1 DEB
4388	7783.424504	0.00812970	74.031	39.199	183.130	1342.010598	1468.564410	COSMOS 341
5216	7795.318221	0.00958750	74.015	263.782	215.869	1342.443607	1491.918834	COSMOS 417
6159	7699.328866	0.00580820	101.241	222.136	287.780	1276.472624	1365.911107	THORAD AGENA D DEB *
6265	7777.977996	0.00862110	74.033	129.450	85.832	1332.786269	1466.895722	COSMOS 530
6268	7770.064264	0.00974840	74.037	49.121	356.070	1316.181570	1467.672959	COSMOS 533
6319	7738.224101	0.00246340	74.015	185.340	249.834	1341.024760	1379.149442	COSMOS 539
6320	7731.975699	0.00242440	74.013	118.050	163.431	1335.093297	1372.584101	SL-8 R/B
6681	7786.769097	0.00924480	74.017	195.950	203.759	1336.644974	1480.619220	COSMOS 570
6849	7785.224878	0.00983050	73.998	159.042	31.757	1330.555224	1483.620531	COSMOS 592
6985	7786.771825	0.00953830	74.028	212.768	115.348	1334.362259	1482.907390	COSMOS 617
7024	7730.850348	0.00758160	101.887	51.756	6.105	1294.101133	1411.325563	DELTA 1 DEB

Other tools. Space situational awareness

- Example of Collinearities

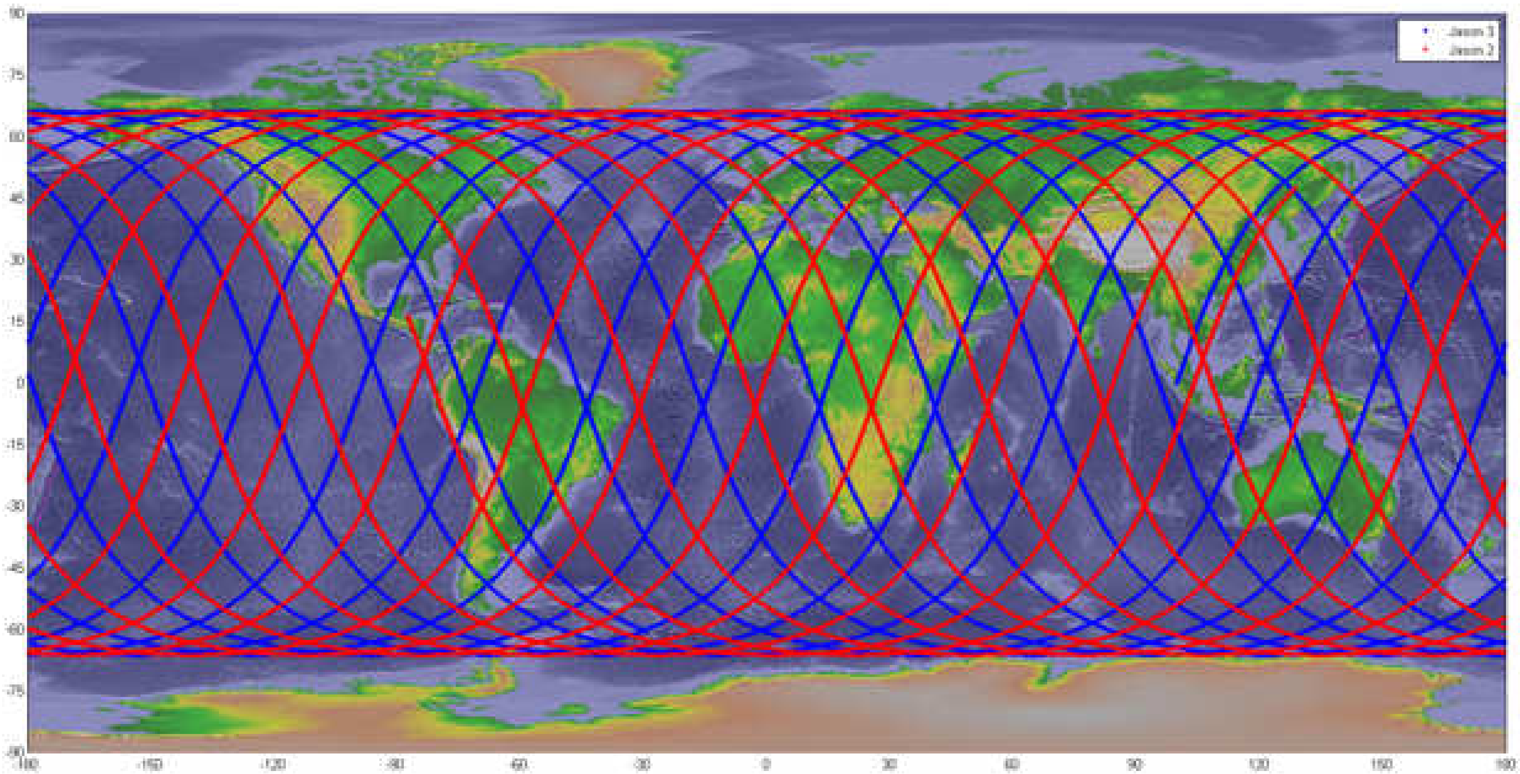
```
COLLINEARITY EVENTS FILE
HEADER_START
  OBJECT1_NAME         = SENTINEL-3A
  EXECUTION_START      = 2017-11-18T07:35:17.297 UTC
  START_TIME           = 2017-11-18T00:00:00.000 UTC
  END_TIME             = 2017-11-23T12:00:00.000 UTC
  DURATION             = 475200.0 sec
  COLLINEARITY_ANGLE   =    4.000 deg
  MINIMUM_ELEVATION    =    5.000 deg
  LEGEND_START
    Object2            = Id of secondary object.
    StationId          = Ground station Id.
    StartCollinearity  = Start date [UTC] of the collinearity.
    MinCollinearity    = Date [UTC] of the minimum collinearity angle.
    EndCollinearity    = End date [UTC] of the collinearity.
    Duration           = Duration [sec] of the collinearity
    StartColl          = Collinearity angle [deg] at StartCollinearity.
    MinColl            = Minimum collinearity angle [deg] at MinCollinearity date.
    EndColl            = Collinearity angle [deg] at EndCollinearity.
    StartEle1          = Elevation angle [deg] of primary object at StartCollinearity date.
    MinEle1            = Elevation angle [deg] of primary object at MinCollinearity date.
    EndEle1            = Elevation angle [deg] of primary object at EndCollinearity date.
    StartEle2          = Elevation angle [deg] of secondary object at StartCollinearity date.
    MinEle2            = Elevation angle [deg] of secondary object at MinCollinearity date.
    EndEle2            = Elevation angle [deg] of secondary object at EndCollinearity date.
    Name               = Object name (line 0 from TLE).
  LEGEND_END
HEADER_END
```

Object2	StationId	StartCollinearity [UTC]	MinCollinearity [UTC]	EndCollinearity [UTC]	Duration [sec]	StartColl [deg]	MinColl [deg]	EndColl [deg]	StartEle1 [deg]	MinEle1 [deg]	EndEle1 [deg]	StartEle2 [deg]	MinEle2 [deg]	EndEle2 [deg]	Name
40697	10403KIR1	2017-11-18T11:04:21.867	2017-11-18T11:04:21.867	2017-11-18T11:04:43.360	21.493	3.878	3.878	4.000	5.000	5.000	6.548	1.185	1.185	2.555	SENTINEL 2A
40697	10403KIR1	2017-11-18T12:43:56.664	2017-11-18T12:44:10.616	2017-11-18T12:45:41.152	104.488	3.168	3.154	4.000	5.000	5.889	12.192	1.927	2.769	8.815	SENTINEL 2A
37847	10403KIR1	2017-11-18T12:49:23.240	2017-11-18T12:49:35.130	2017-11-18T12:49:47.057	23.816	4.000	2.353	4.000	25.689	25.674	25.533	23.275	23.323	23.371	GALILEO-FM2
40697	10403KIR1	2017-11-18T14:22:56.017	2017-11-18T14:25:12.028	2017-11-18T14:27:11.734	255.716	4.000	2.926	4.000	5.434	13.780	19.432	2.665	10.867	17.870	SENTINEL 2A
40697	10403KIR1	2017-11-18T14:28:52.671	2017-11-18T14:30:48.809	2017-11-18T14:32:50.889	238.218	4.000	2.740	4.000	19.021	13.114	5.611	20.067	15.830	8.258	SENTINEL 2A
40697	10403KIR1	2017-11-18T16:05:25.413	2017-11-18T16:08:51.680	2017-11-18T16:11:44.665	379.252	4.000	0.180	3.147	22.817	16.940	5.000	19.137	16.792	5.706	SENTINEL 2A
40697	10403KIR1	2017-11-18T17:47:31.470	2017-11-18T17:49:24.233	2017-11-18T17:51:14.011	222.541	4.000	2.230	2.925	26.942	13.848	5.000	22.951	12.026	3.928	SENTINEL 2A
40697	10403KIR1	2017-11-18T19:29:16.168	2017-11-18T19:31:06.785	2017-11-18T19:31:06.785	110.617	4.000	2.660	2.660	14.491	5.000	5.000	10.925	2.444	2.444	SENTINEL 2A
39634	10403KIR1	2017-11-19T17:25:12.779	2017-11-19T17:25:23.075	2017-11-19T17:25:23.075	10.296	4.000	2.931	2.931	5.701	5.000	5.000	8.329	7.660	7.660	SENTINEL 1A
37847	10403KIR1	2017-11-19T19:03:55.644	2017-11-19T19:04:34.805	2017-11-19T19:05:11.954	76.311	4.000	2.466	3.597	11.165	7.812	5.000	7.976	7.800	7.632	GALILEO-FM2
38257	10403KIR1	2017-11-21T18:12:02.983	2017-11-21T18:12:18.571	2017-11-21T18:12:34.637	31.654	4.000	2.435	4.000	11.412	10.051	8.720	8.085	7.729	7.277	YAOGAN 14

Integration with Matlab

- Matlab offers many advantages (with the drawback you need a license)
- Rapid prototyping, access to powerful toolboxes and graphics
- Jason-2 and Jason-3 ‘interleave’ orbits (one-day tracks)

on a ‘topographic color and shaded relief from GLOBE Elevations with bathymetry from Smith and Sandwell, at 4 arcmin grid’ (from NOAA Gallery of High Resolution Images)



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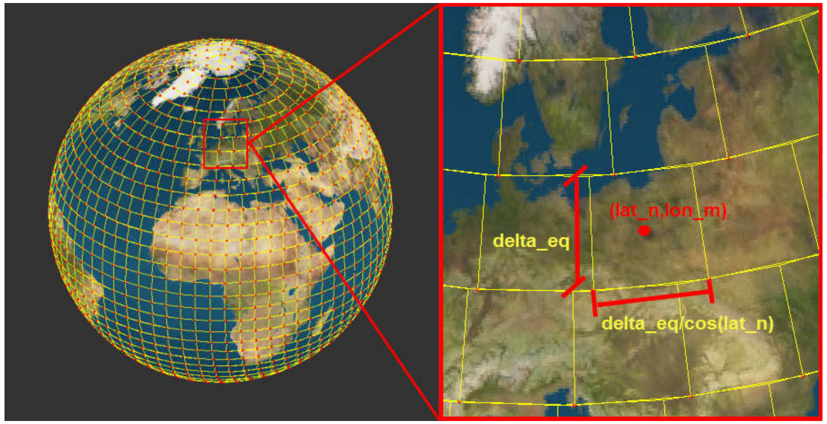
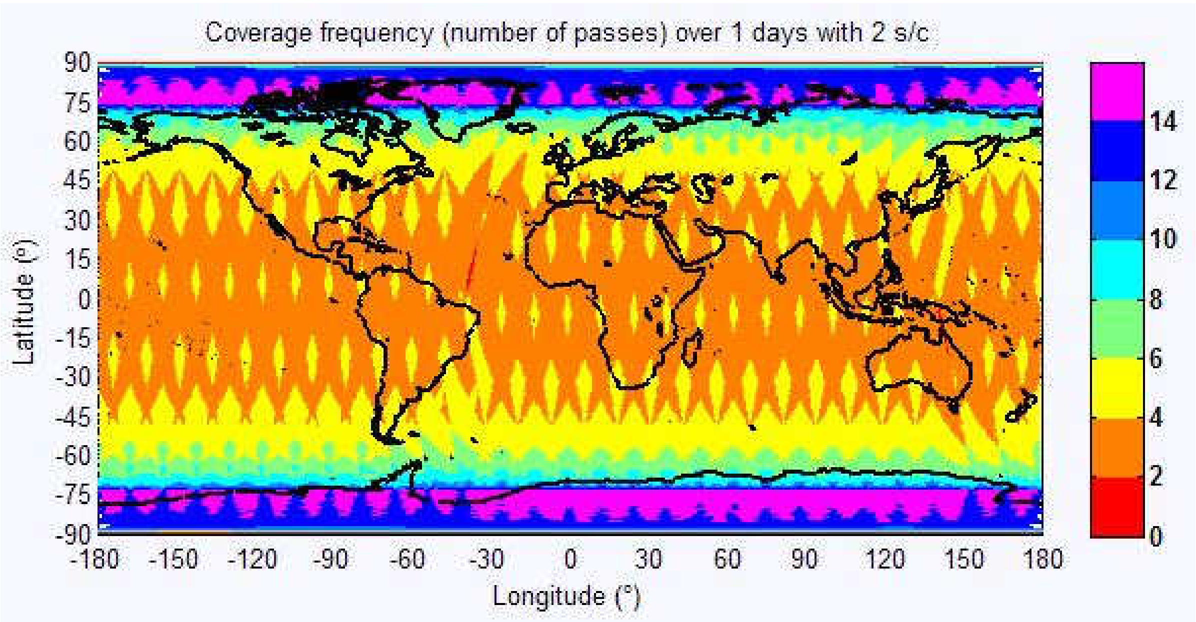
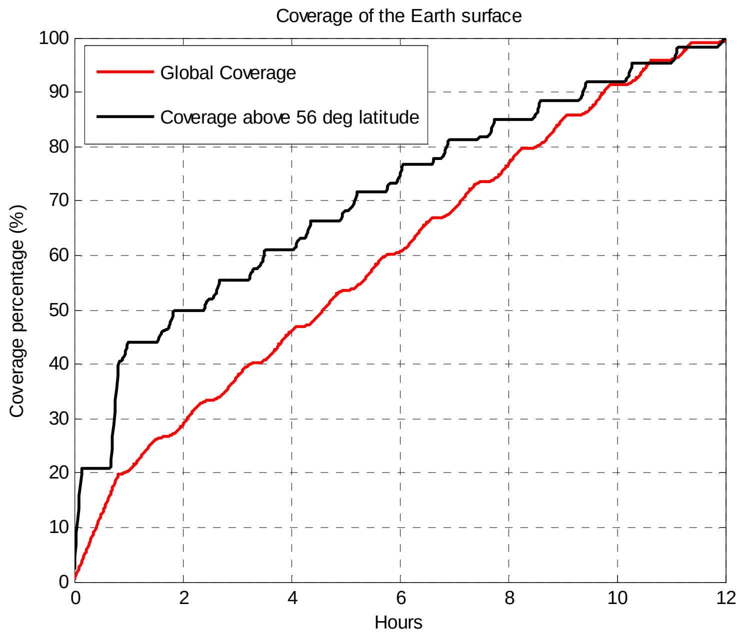
Integration with Matlab

- Revisiting and coverage (with equispaced Earth grid)



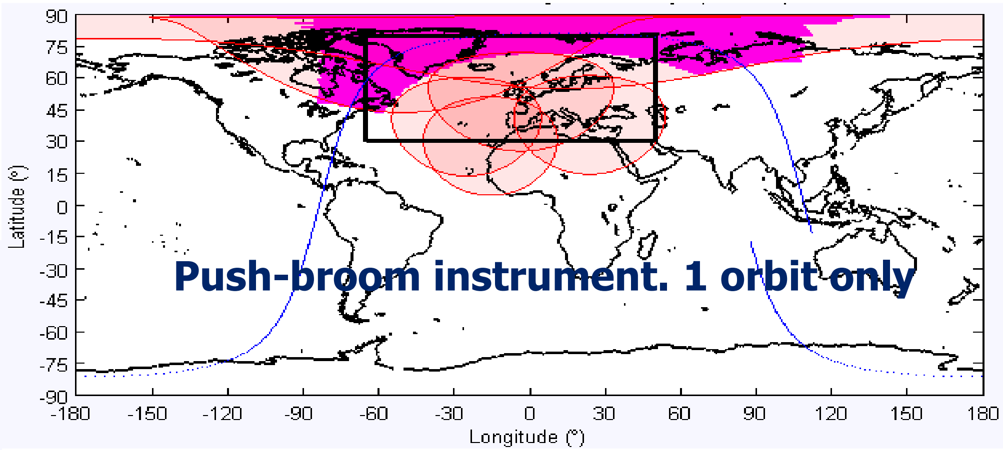
- Example for 2 equal push-broom instruments (OZA<53 deg) on-board different s/c phased 180 deg in orbit, observations over daylight only (SZA<90 deg)…

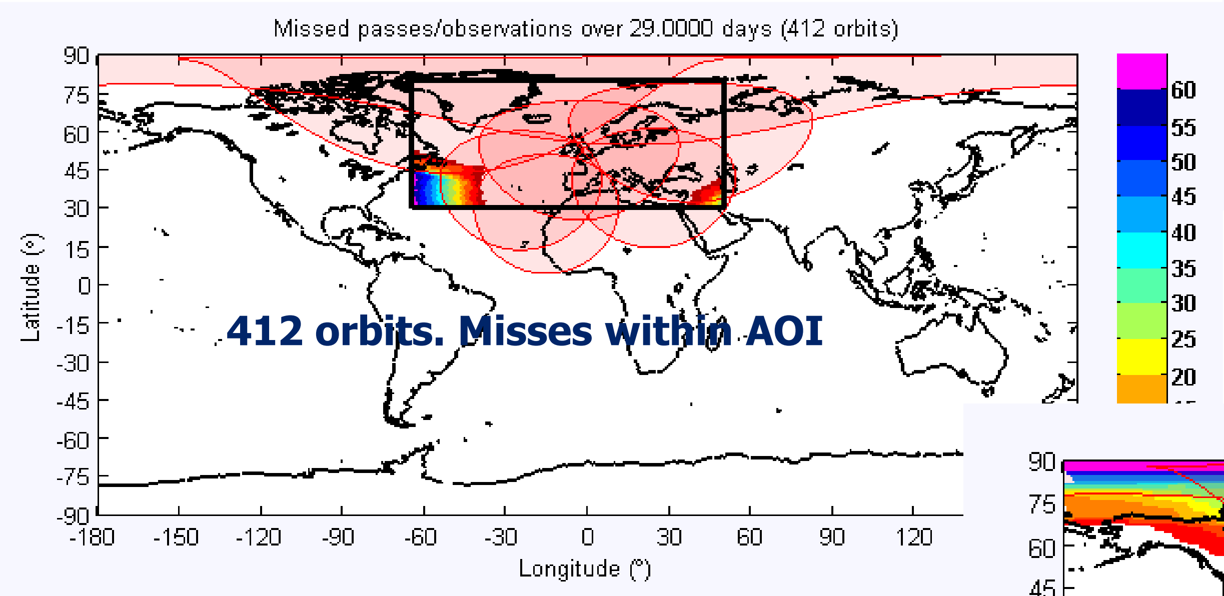


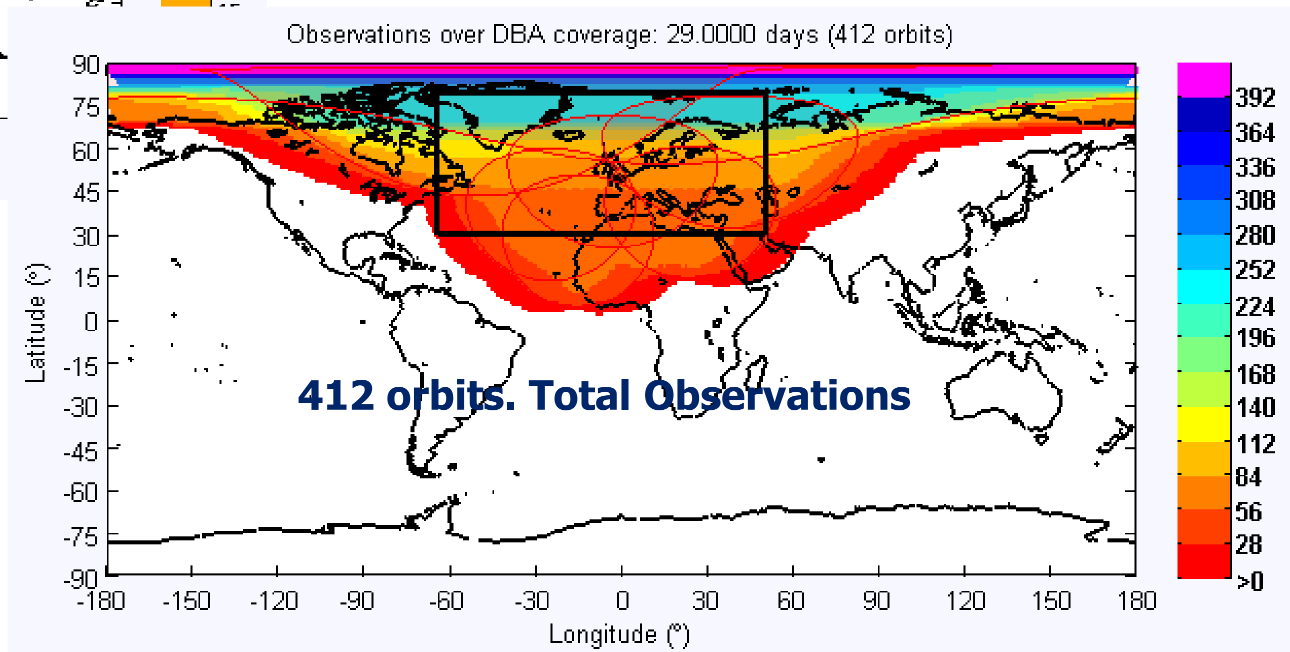


Integration with Matlab

- Direct Broadcast antenna coverage for given instrument swath







AOI = Area Of Interest
(longitudes -65 to 50 deg,
latitudes 30 to 80 deg north)

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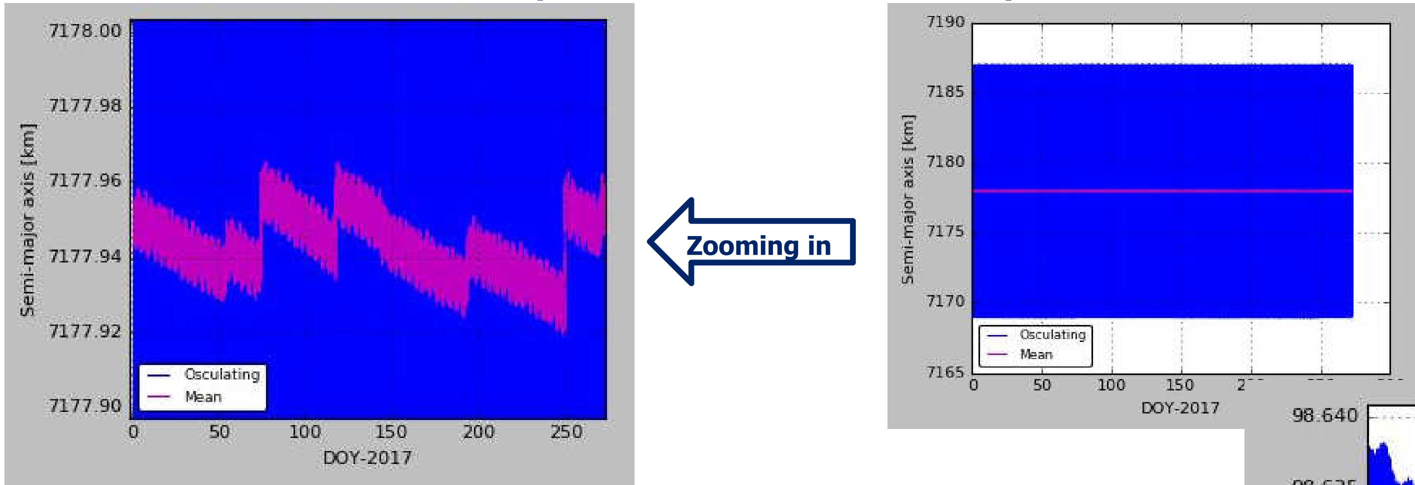
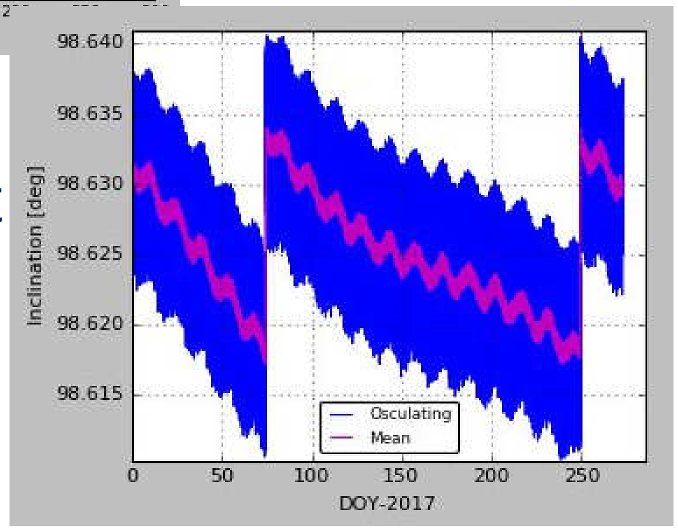
Orbit Analysis. Mean elements analysis (1/2)

- 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)

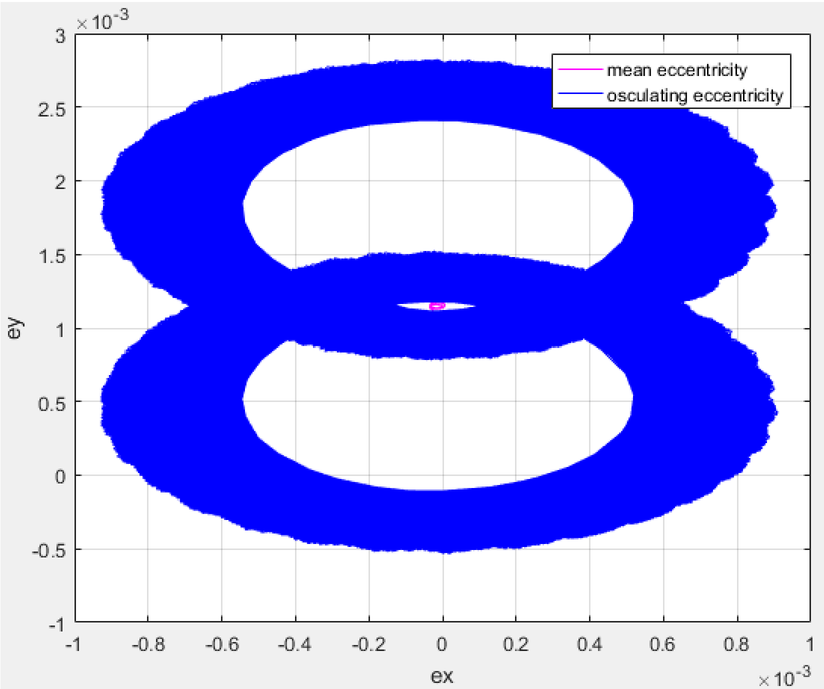


- Similarly, inclination mean elements for SSO orbit
  - inclination drift driven by Sun, Moon and solid tides
  - manoeuvres

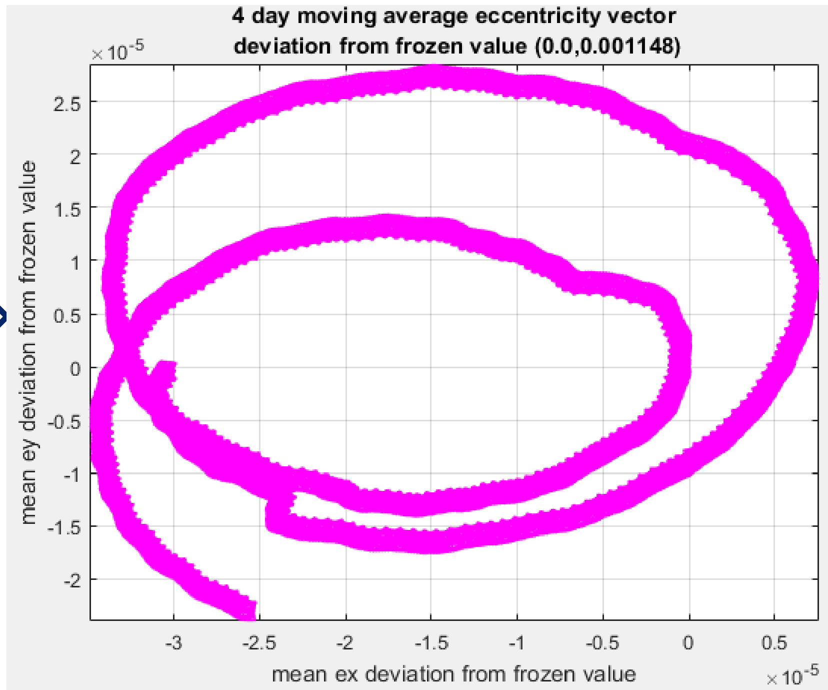


Orbit Analysis. Mean elements analysis (2/2)

- 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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EUMETSAT and Orekit. Summary

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

  [main operational Flight Dynamics or related Data Processing chains rely however on other, older, 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 some accuracy or integrity necessary, results normally need cross-validation with other independent s/w (as usual)

Orekit and EUMETSAT

…and that’s all. Thank you!