DESEO

Design Engineering Suite for Earth Observation

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DESEO Overview (I)

- **DESEO is a toolkit designed to support EO missions**
  - Mission analysis
  - Preliminary system/subsystem design activities

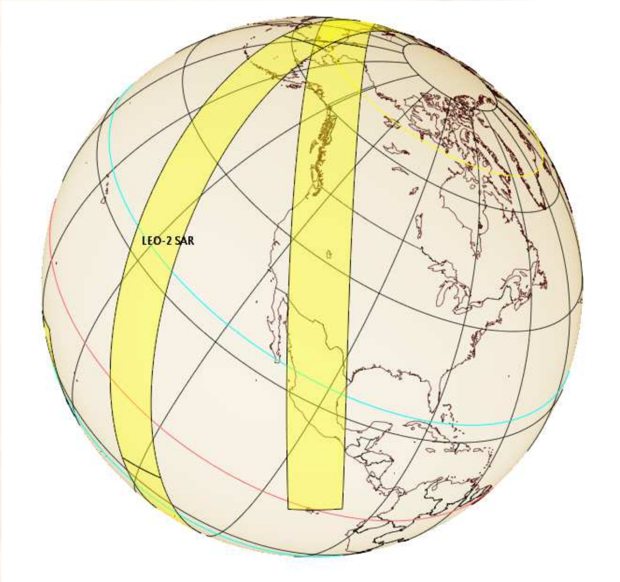
- **DESEO has been designed to be used**
  - by mission and system engineers
  - throughout all phases of an EO mission (from Phase 0 to E)
  - whenever accurate & fast quantitative results are needed
    - to support design trade-offs and assessment analyses

- **DESEO has been designed**
  - to be a modular, flexible and self-standing toolkit
  - to provide the user with
    - a comprehensive set of mission and system related computation modules
    - visualization capabilities to yield meaningful numerical and graphical results

DESEO Overview (II)

- **DESEO has been conceived as a tool**
  - in continuous evolution
  - suitable to be upgraded with further modules
  - able to be interfaced with external software

- **DESEO currently embeds in a Graphical User Interface**
  - 38 different analyses
  - an EO missions data repository
    - Satellites
    - Ground Stations
    - Thematic Areas of Interest
  - a results visualization module
    - 3D interactive visualizations
    - Gantt charts
    - Cartesian plots
    - Cartographic maps representations
    - Tables

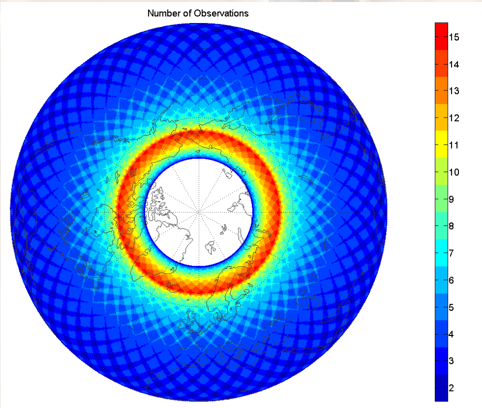


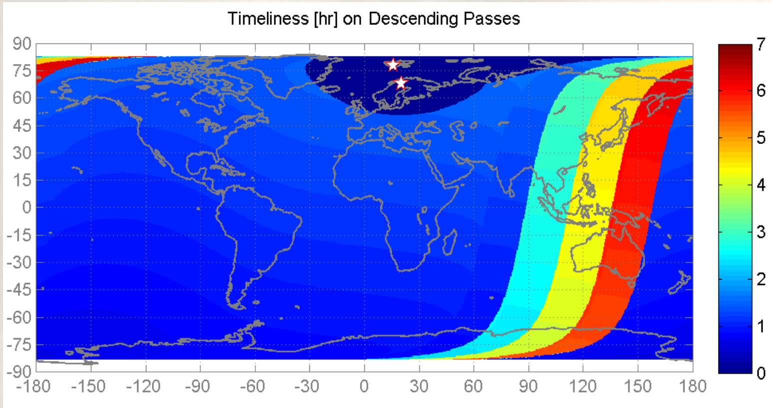
Toolkit Heritage (I)

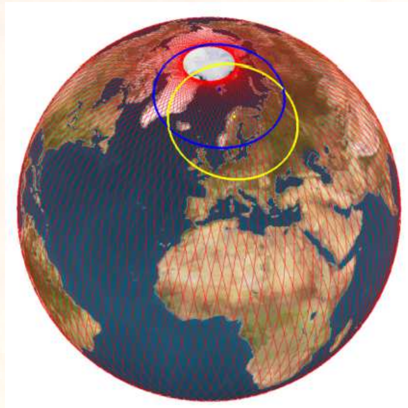
- **Mission and system analysis are continuously evolving disciplines**
  - connected with the evolution of the EO missions concepts
- **Analyst expertise is a key asset**
  - the analyst shall dynamically interpret new requirements and propose solutions through creative analysis approaches
- **A very large history of analyses allowed the experts to define best practices and optimal approaches to face a large number of recursive problems**
- **DESEO tries to implement all those best practices**
  - to provide the analyst with assessment and design means tailored on the basis of his/her specific needs

- **EO Customer Furnished Items (CFIs) as key asset**
  - Orbit propagation
  - Satellite attitude modes
  - Pointing laws

- **DEIMOS internal tools and algorithms represent the DESEO backbone**
  - State-of-the-art expertise in the mission analysis field
  - Robustness
    - applied and tested in a large number of analyses and in a wide spectrum of EO missions







Software Architecture

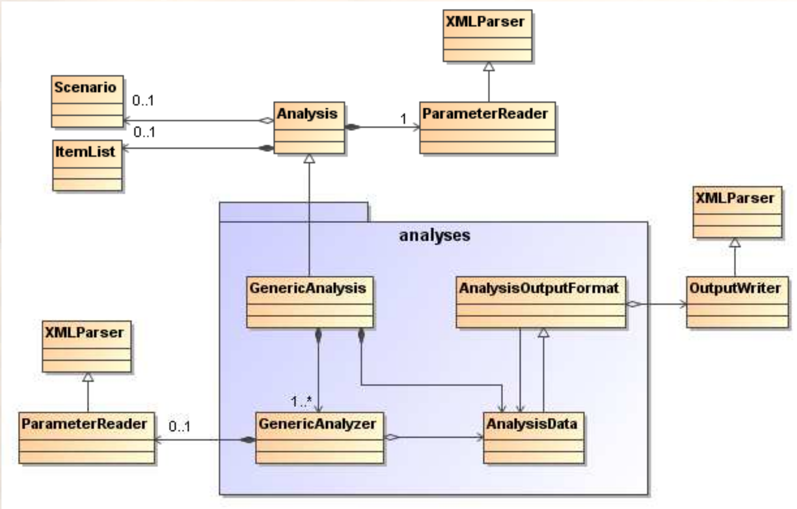
- **DESEO has been developed**
  - following the principles of flexibility and modularity
    - guaranteeing reduced maintenance and upgrading efforts

- **Re-engineering of existing algorithms in a unique but modular architecture**

- **Extended use of XML Schema Documents (XSD)**
  - external interfaces definition

- **Very flexible infrastructure**
  - integration of many different analyses in a unique paradigm
  - easy extendibility
    - prone to future improvements

- **Object-Oriented approach**



- **DESEO embeds 38 different analyses, organized in 9 core computational groups**
  – Orbit Propagation
  – Coverage Analyses
  – Ground Station Analyses
  – Orbit Control
  – System Analyses
  – Orbit Analyses
  – Manoeuvres Computations
  – Pointing Analyses
  – Tools

Applicability to Earth Explorers Phase A/B1

Analysis	CarbonSat	FLEX	Biomass
Orbit Propagation	Orbit Altitude Evolution	Formation Flying Stability (*)	Orbit Altitude Evolution
– Attitude	N/A	N/A	N/A
Coverage	Coverage, Sunglint Tracking (*)	Coverage, Duty Cycle	Coverage, Duty Cycle (*)
Ground Stations Visibility	GS Network	GS Network, Interference (*)	GS Network LEOP
Ground Stations Conflict	GS Network	GS Network	GS Network LEOP
Timeliness	N/A	On-board Timeliness	Data Latency (*)
Swath Properties	Coverage	Coverage	Coverage
Sun-Zenith Angle	Coverage	Coverage	N/A
Observation-Zenith Angle	Coverage	Coverage	Coverage
SC Topocentric Coordinates	GS-to-S/C Viewing Geometry (*)	GS-to-S/C Viewing Geometry	N/A
– Pointing Analysis	N/A	N/A	N/A
Semi-analytical Propagation	Delta-V Budget	Delta-V Budget	Delta-V Budget
Atmospheric Properties	Atmospheric Density Profile Delta-V Budget	Atmospheric Density Profile Delta-V Budget	Atmospheric Density Profile Delta-V Budget
Altitude Control	Delta-V Budget	N/A	N/A
Inclination Control	Delta-V Budget (*)	N/A	Delta-V Budget
Eq. Ground Track Control	N/A	GTE Control (*)	Delta-V Budget
– OA + OI Control	N/A	N/A	N/A
– EGT + OI Control	N/A	N/A	Delta-V Budget
EOL Decay	Delta-V Budget	Delta-V Budget	Delta-V Budget
Beta Angle	Beta Angle	Beta Angle	Beta Angle
Eclipses	Eclipse	Eclipse	Eclipse
– Ground Illumin.	N/A	N/A	N/A
– Time Tran.	N/A	N/A	N/A
– Coordinates Tran.	N/A	N/A	N/A
Injection Errors Correction	Delta-V Budget	Delta-V Budget	Delta-V Budget LEOP
Collision Avoidance	Delta-V Budget	Delta-V Budget	Delta-V Budget
Orbit Transfer	N/A	Formation Acquisition	Delta-V Budget
Master-Drone Control	N/A	Formation Control (*)	N/A
– Orbit Wizard	N/A	N/A	N/A
LEO Selection	Orbit Selection	N/A	Orbit Selection
– SSO Inclination	N/A	N/A	N/A
– Frozen Eccentricity	N/A	N/A	N/A
– RAAN Drift Rate	N/A	N/A	N/A
Basic Swath Geometry	Orbit Selection	N/A	N/A
– Geodetic Distance	N/A	N/A	N/A
ΔV & Fuel Budget	Delta-V Budget	Delta-V Budget	Delta-V Budget
OBDH	N/A	N/A	Data Volume
– Power Budget	N/A	N/A	N/A

Traceability matrix between DESEO analyses and Earth Explorer Phase A/B1 Mission Analysis Reports (MAR)

DESEO analyses cover almost all the EE MAR

- Few analyses partially cover the MAR(*). Little extensions or basic post-processing are needed for a full MAR(*) coverage
- Only specific mission related analyses are not included in the scope of DESEO

Applicability to DEIMOS-2

Analysis	DEIMOS-2	Analysis	DEIMOS-2
Orbit Propagation	Orbit Evolution	Beta Angle	Orbit Selection
Attitude	Agility (*)	Eclipses	Orbit Selection
Coverage	Coverage, Duty Cycle	Ground Illumin.	N/A
Ground Stations Visibility	GS Network	Time Tran.	N/A
Ground Stations Conflict	GS Network	Coordinates Tran.	Launch Scenario (*)
Timeliness	N/A	Injection Errors Correction	Delta-V Budget
Swath Properties	Coverage	Collision Avoidance	Delta-V Budget
Sun-Zenith Angle	Coverage	Orbit Transfer	Launch Scenario, Delta-V Budget
OZA	Coverage	Master-Drone Control	N/A
SC Topocentric Coordinates	GS Network	Orbit Wizard	Orbit Selection
Pointing Analysis	N/A	LEO Selection	Orbit Selection
Semi-analytical Propagation	Long-term Orbit Evolution	SSO Inclination	N/A
Atmospheric Properties	Atmospheric Density Profile Delta-V Budget	Frozen Eccentricity	N/A
Altitude Control	Delta-V Budget	RAAN Drift Rate	N/A
Inclination Control	N/A	Basic Swath Geometry	Orbit Selection
Eq. Ground Track Control	N/A	Geodetic Distance	N/A
OA + OI Control	N/A	ΔV & Fuel Budget	Delta-V Budget
EGT + OI Control	N/A	OBDH	Mass Memory Occupation (*)
EOL Decay	Delta-V Budget	Power Budget	Power Budget (*)

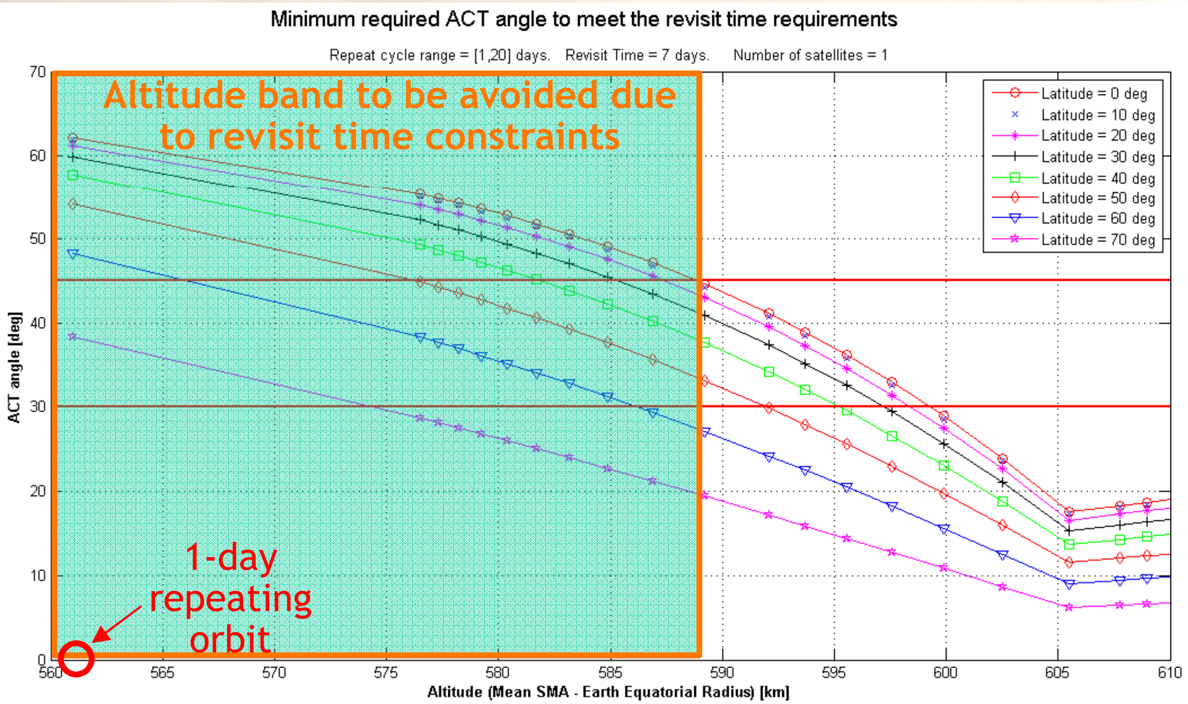
Traceability matrix between DESEO analyses and DEIMOS-2 Mission Analysis (Phase A to E)

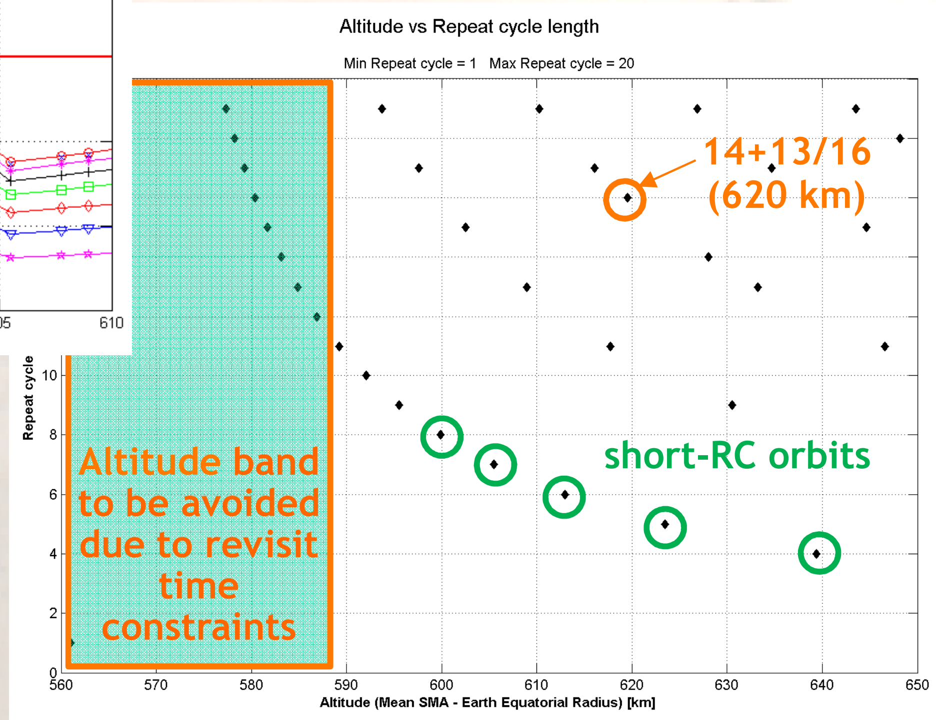
DESEO analyses cover almost all the needs!

– Only specific mission related analyses have been performed with post-processing

DEIMOS-2 Orbit Selection

- **Candidate Orbit Identification**

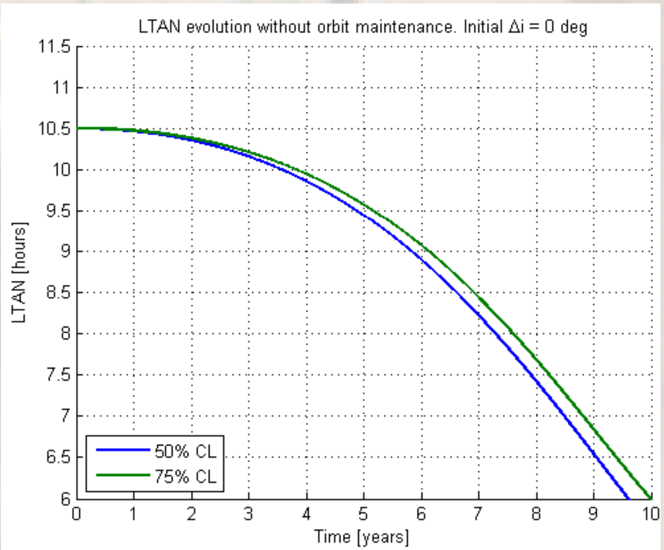




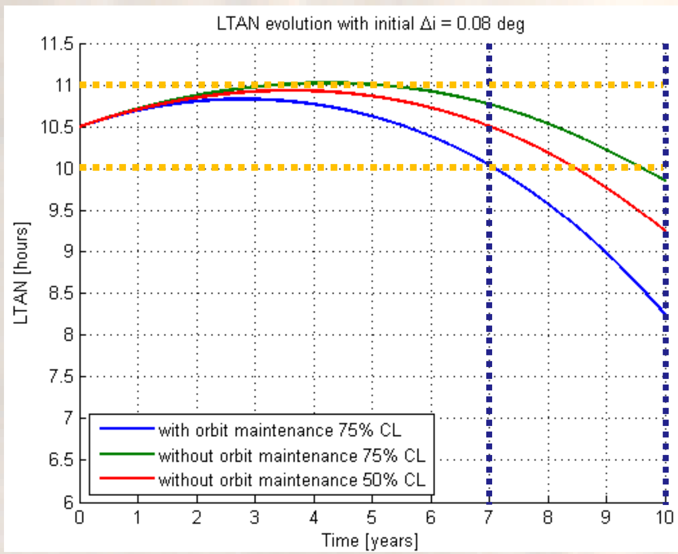
DEIMOS-2 Orbit Selection

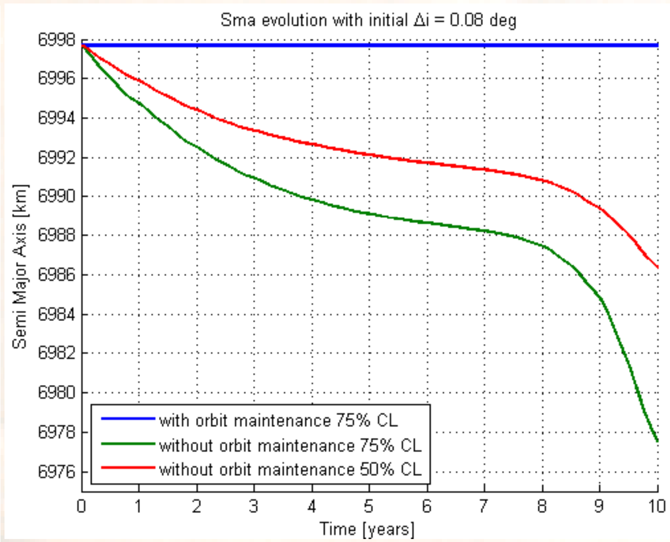
- **Injection Orbit Selection**
  - Optimise LTAN evolution applying initial **Δi w.r.t. SSO** inclination
    - ✓ Initial inclination affects LTAN drift and provides **better LTAN profile**
    - ✓ LTAN & SMA profiles with **small deviation from 10h30**
    - ✓ **Avoid dedicated LTAN control** by out-of-plane manoeuvres
    - ✓ Controlled orbit (altitude maintenance) and uncontrolled orbit (free orbit decay) with different solar & geomagnetic activity levels

Uncontrolled orbit



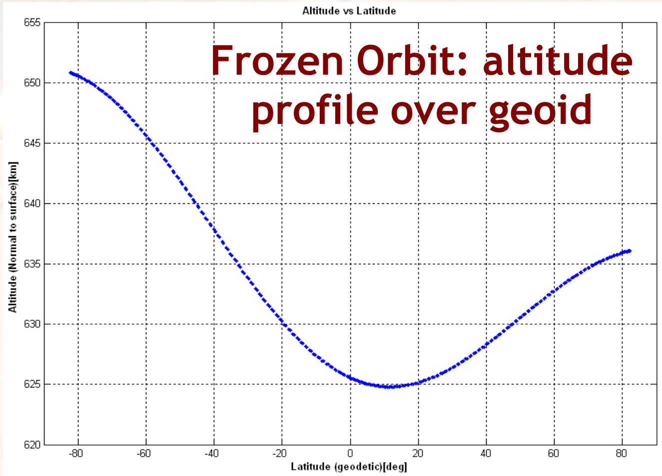
Controlled & uncontrolled orbit

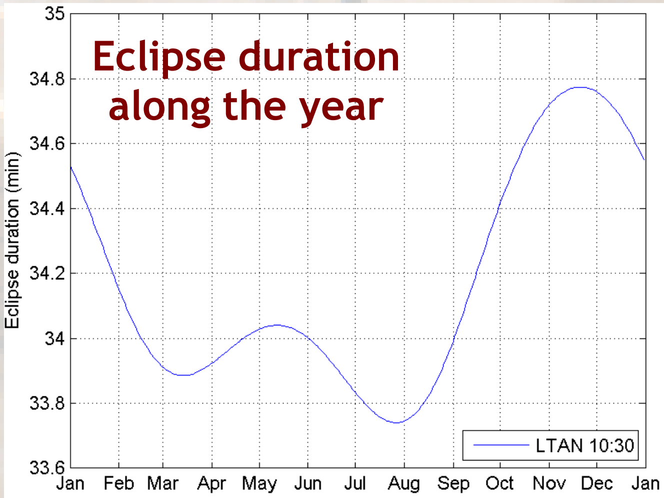


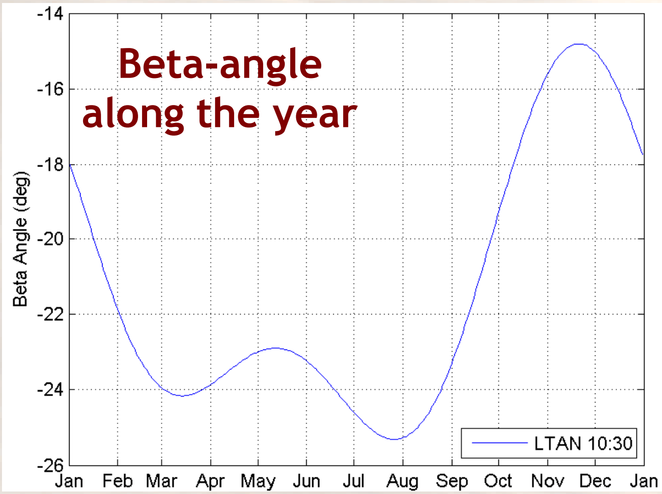


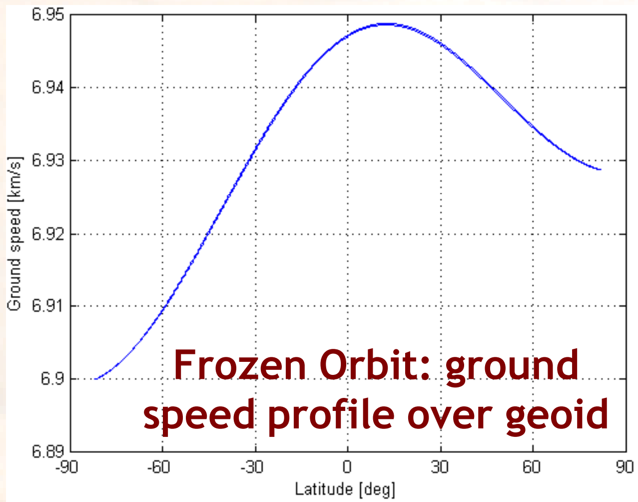
DEIMOS-2 Reference Orbit Characterization

- **Orbit Characteristics**
  - **Sun-synchronous** and **frozen** orbit
    - ✓ Constant altitude profile vs. arg. of latitude
- **Eclipse and Beta-Angle Analysis**
  - Evolution of eclipse duration & beta-angle along the year
  - Eclipse duration and beta-angle statistics





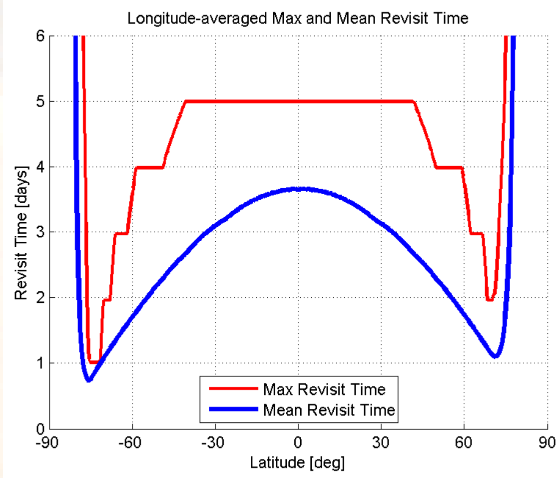




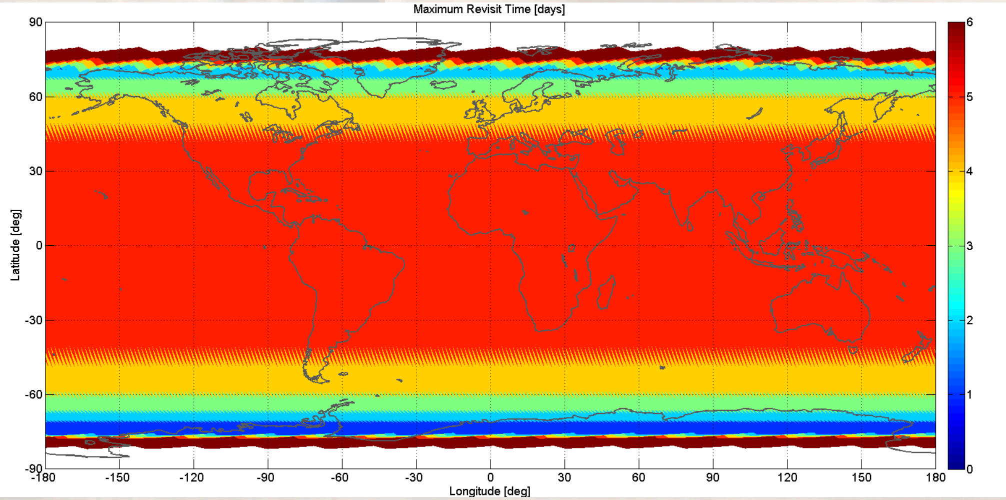
DEIMOS-2 Coverage Analysis

- **Coverage Analysis**
  - Mission scenario
    - ✓ SSO 14+13/16 (~620 km), LTAN = 10:30
    - ✓ Nadir-centred FoR: ±30º (nominal), ±45º (extended), ±15º (background mapping)
    - ✓ Observation constraints: SZA < 80º
  - Coverage performance figures of merit
    - ✓ **Revisit time**: max, average (maps, statistics)

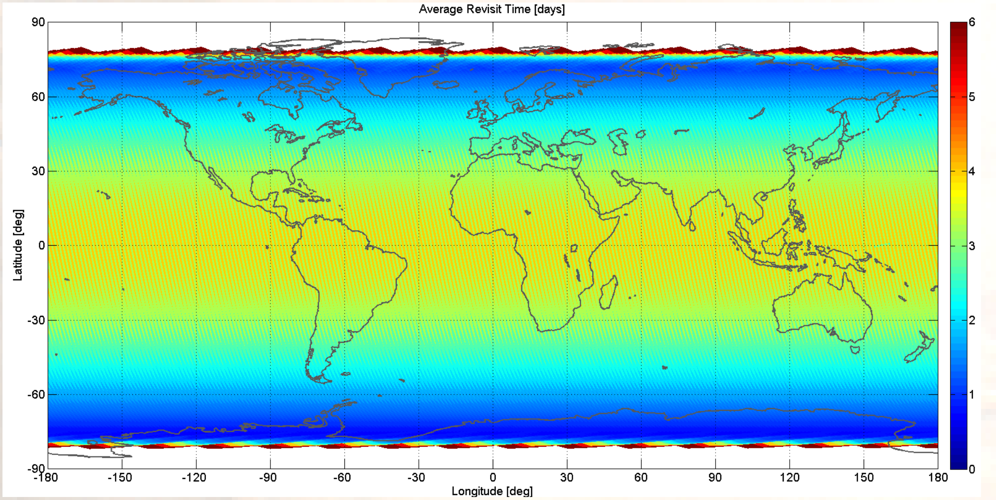
Longitude-Averaged Max and Mean RT vs. Latitude (FoR = ±30°)



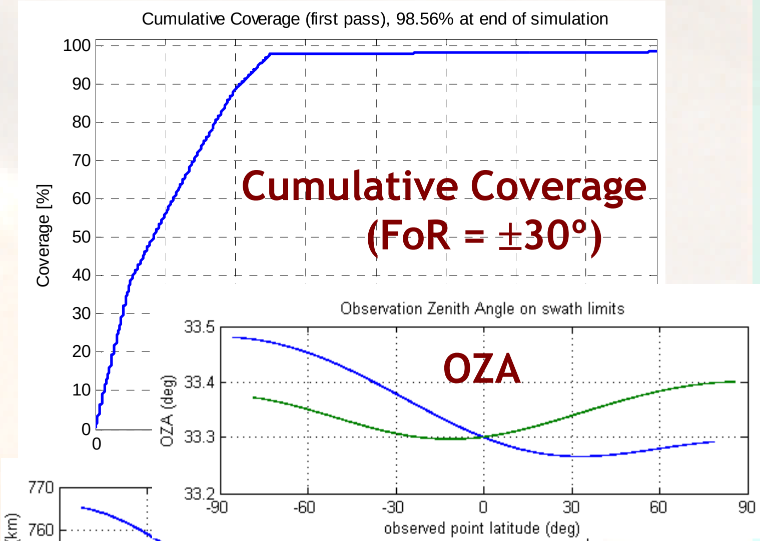
Max Revisit Time Map (FoR = ±30°)

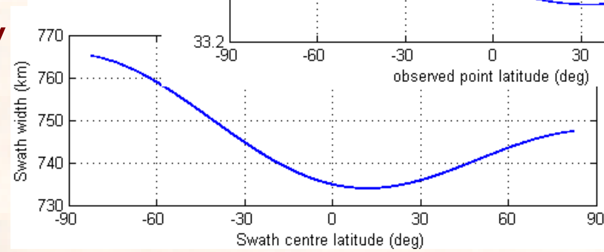


Mean Revisit Time Map (FoR = ±30°)



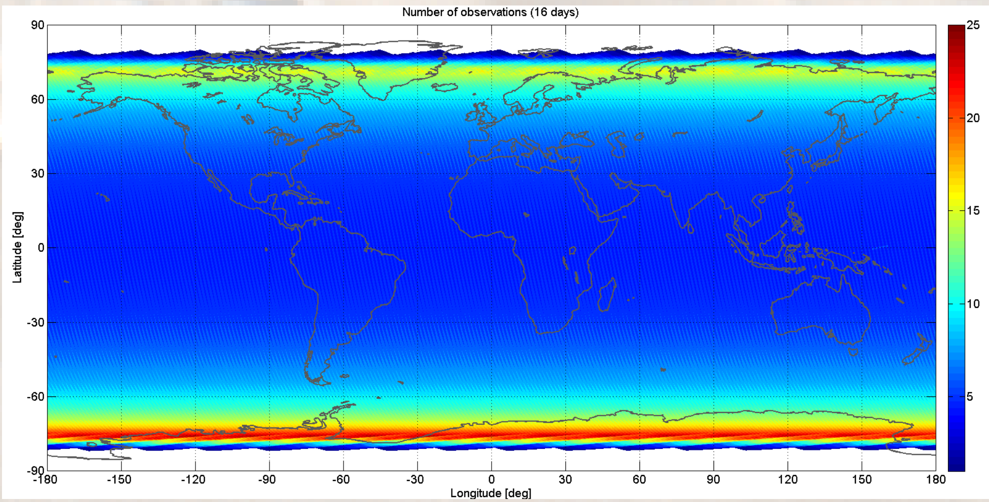
- **Coverage Analysis**
  - Coverage performance figures of merit
    - ✓ **Revisit time**: max, average (maps, statistics)
    - ✓ **Coverage**: % of area of interest, cumulative vs. time
    - ✓ **Observations**: entire simulation, per day
    - ✓ **Observation geometry**: OZA, swath

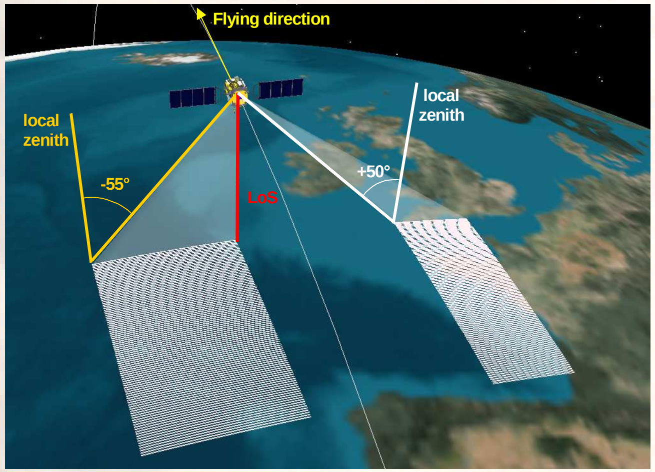




Swath Width

Observations Map (FoR = ±30°)



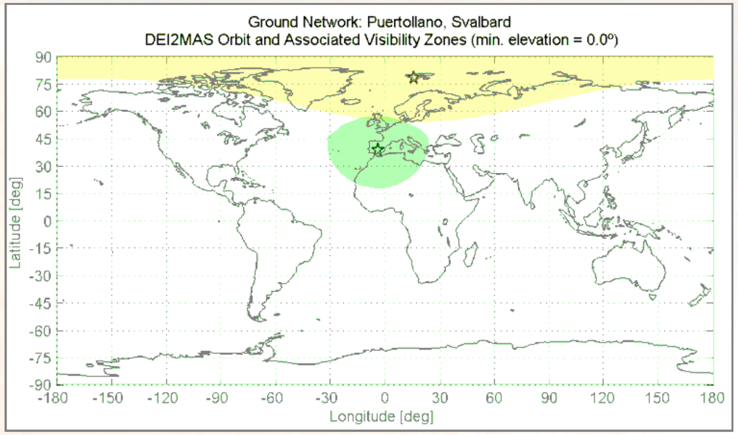


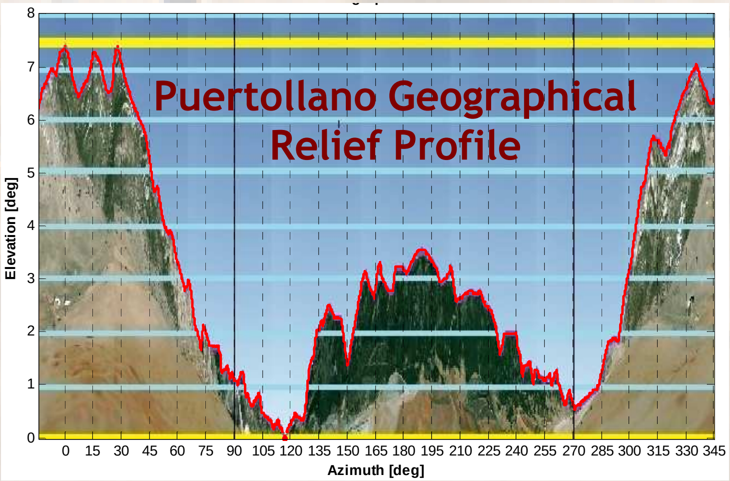
DESEO – Design Engineering Suite for Earth Observation

DEIMOS-2 Ground Stations Analysis

- **Ground Station Contact Analysis**
  - Mission and ground station scenario
    - ✓ SSO 14+13/16 (~620 km), LTAN = 10:30
    - ✓ GS: **Puertollano** (TTC in S-band, data in X-band), **Svalbard** (data in X-band)
    - ✓ Visibility constraints: az-el mask, min elevation, min contact time
  - GS contact performance
    - ✓ GS visibility maps, GS contacts statistics
    - ✓ O/B & O/G visibility geometry

Svalbard and Puertollano Coverage Zones





GS Contact Statistics

GS	Min Elev [deg]	Contacts / Max Blind Orbits	Average Contact Time [min/day]	Average Contact Time [s/orbit]	Average Contact Time [s]	Max gap [hrs]
Svalbard	0º	237 / 0	172.5	698.6	696	1.5
	2º	237 / 0	153.7	622.4	624	1.5
Puertollano (with relief profile)	3º	74 / 6	38.7	156.8	504	11.7
	5º	69 / 6	34.9	141.3	486	11.7
Svalbard + Puertollano (with relief profile)	0º, 3º	311 / 0	210.1	851.0	648	1.5
	0º, 5º	306 / 0	206.3	835.5	648	1.5
	2º, 3º	311 / 0	192.2	778.6	594	1.5
	2º, 5º	306 / 0	188.4	763.2	594	1.5

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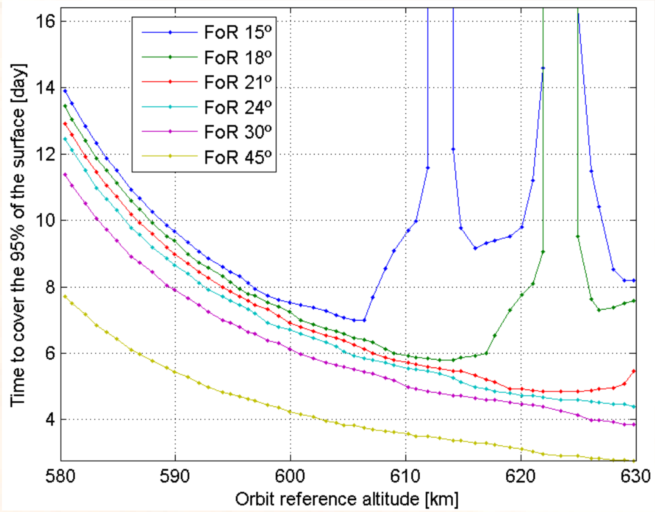
Analysis of Free-Orbit Decay Scenario

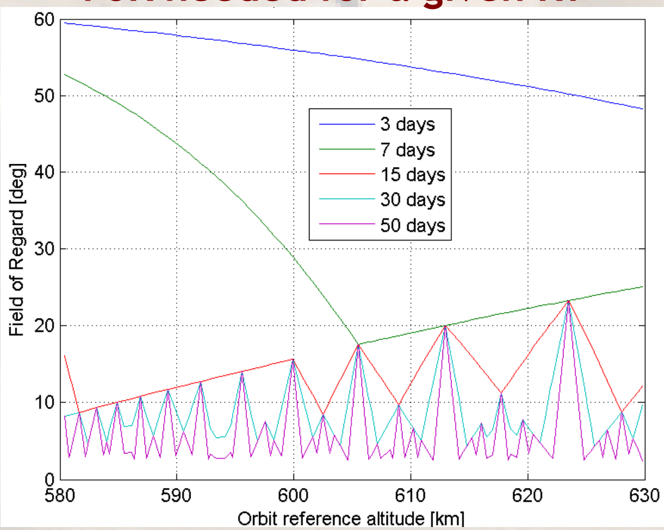
- **Impact of Free Orbit Decay on Mission Performance**
  - **No orbit altitude control** implemented during mission lifetime
  - **Coverage analysis vs. altitude**
    - ✓ Time to cover 95% of Earth surface
    - ✓ Percentage of area covered
    - ✓ Max and mean revisit time
    - ✓ FoR to achieve a given revisit time
    - ✓ Max OZA at swath edges

Time to cover 95% of the Earth

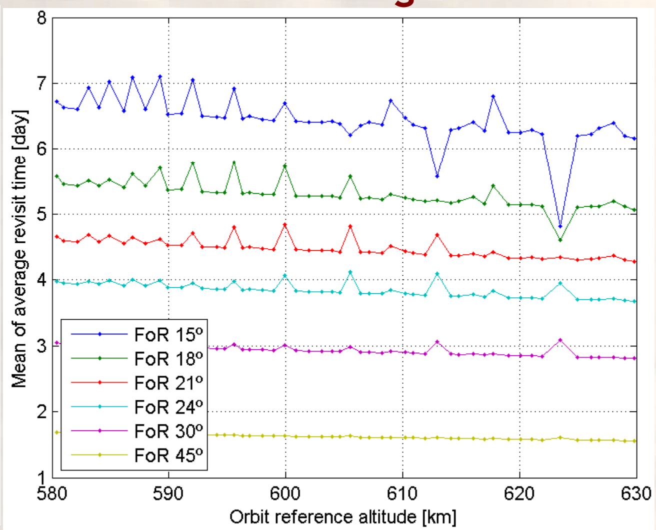


- ✓ RT increases when altitude gets lower
- ✓ Large-enough FoRs, enabled by S/C agility, lead to **smooth effect of altitude on RT** in 590-620 km range

FoR needed for a given RT



Mean Average RT

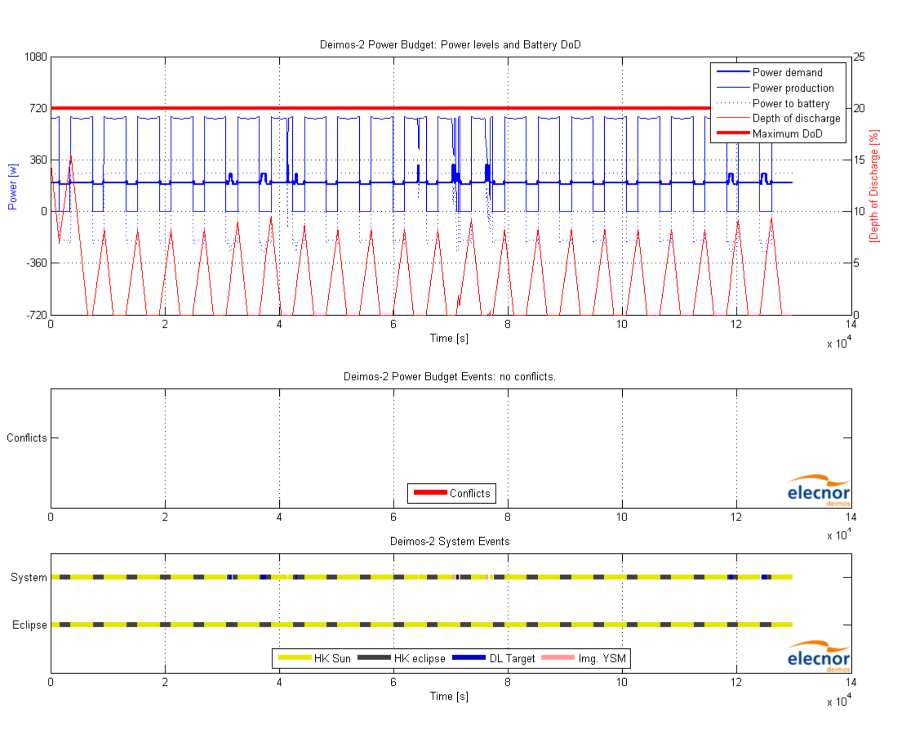


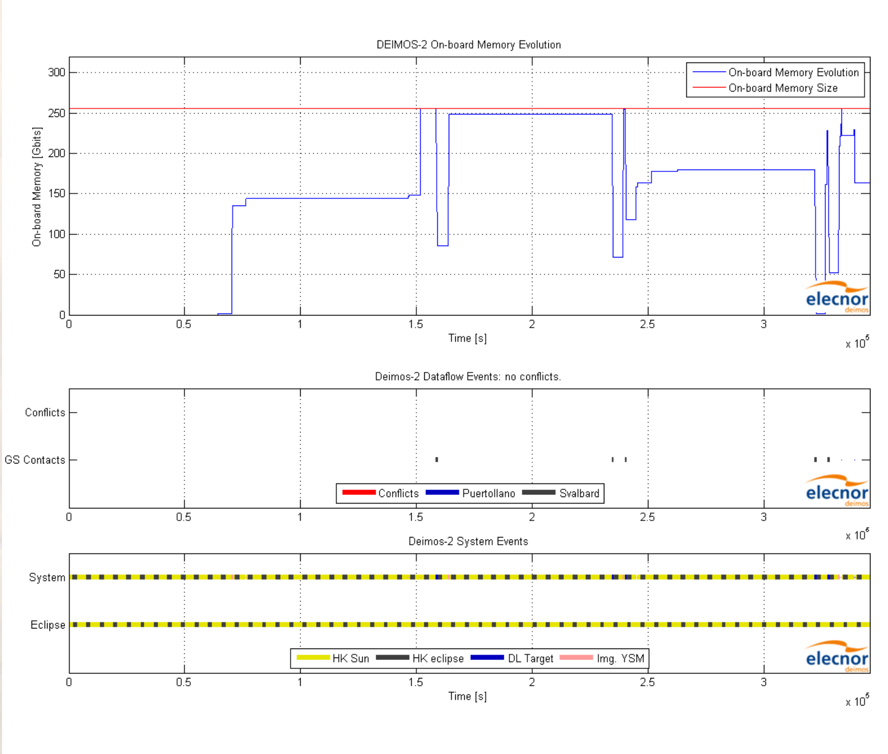
Orbit Manoeuvre Scenario and ΔV Budget

- **ΔV and Fuel Budgets**
  - ΔV, fuel: per manoeuvre and total, no margins
  - Technically feasible manoeuvre scenario w.r.t. S/C capacity (power, battery DoD) & thruster performance

Manoeuvre	ΔV [m/s]	Fuel Mass [kg]
Initial Orbit Acquisition		
Injection Error Correction	**18.6**	**0.6**
In-plane manoeuvres	5.4	0.2
Out-of-plane manoeuvres	13.2	0.4
Orbit Maintenance		
Tot in-plane orbit control	**5.6**	**0.2**
Average in-plane orbit control manoeuvre	0.002	0.0001
Collision Avoidance		
Tot in-plane collision avoidance	**3.8**	**0.1**
Average in-plane collision avoidance manoeuvre	0.54	0.02
EOL Disposal		
In-plane de-orbiting manoeuvre	**19.7**	**0.6**
Total Budget		
Total results	**47.6**	**1.5**

- **Power and Mass Memory Budgets**
  - Agile mission with very complex power and mass memory management





Conclusions

- **DESEO is a powerful toolkit, designed to**
  - supply an exhaustive set of functionalities, covering the most common and frequent mission/system analysis needs
  - obtain fast quantitative results to support trade-offs and internal analyses
  - manage large analysis campaigns
    - a complete EO mission Phase 0 or Phase A study
  - minimize future developments implementation effort
    - modular and generic architecture

- **DESEO has a wide margin of extendibility covering**
  - the increase of computation capabilities
    - other system and more specific mission analyses modules
  - the consolidation of GUI for improving the user experience

- **DESEO has been proven successful in different missions**
  - EE Phases A/B1 and DEIMOS-2 Phases A/B/C/D/E