TOOLS AND TECHNIQUES SUPPORTING THE OPERATIONAL COLLISION AVOIDANCE PROCESS AT ESOC

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Issue/Revision: .

Reference:

Status:

Outline

- Introduction : Collision avoidance at ESA
- Tools in use
  - Mission preparation:
    - DRAMA/ARES
  - Mission operations:
    - Back-end database
    - CRASS/CORAM
    - Minicat
    - Frontend: SCARF
- Summary

ESA's Space Debris Office

- Responsibilities: development and maintenance of an infrastructure in support of ESA's commitment on space debris mitigation and risk reduction
- Highlights:
  - Development and maintenance of debris environment and risk analysis tools (MASTER, DRAMA, DISCOS → sdup.esoc.esa.int, discosweb.esoc.esa.int)
  - Acquisition & processing of measurement data (e.g. OGS, TIRA, EISCAT)
  - **Operational & contingency support to ESA and 3rd party missions (mainly LEOP, collision avoidance & re-entry**)
  - Support activities
    - ESA's SSA program (lead Space Surveillance and Tracking segment)
    - Debris environment remediation technology development (i.e. active debris removal → ESA Clean Space initiative)
  - Coordination of ESA debris research
  - Contribution to ECSS/ISO standards, UN
  - Promotion of ESA-internal & public awareness on space debris issues
- Office has key members in the 13-nations Inter-Agency Space Debris Coordination Committee (IADC)

Covered missions at ESA / ESOC

Since 2006: Operational collision avoidance activities at SDO for ESA missions in LEO

- Conjunction event detection
- Collision risk assessment
- Chaser orbit determination and orbit and covariance propagation
- Manoeuvre recommendation

→ Current focus on ESA's/Copernicus EO (LEO)

Third party customer

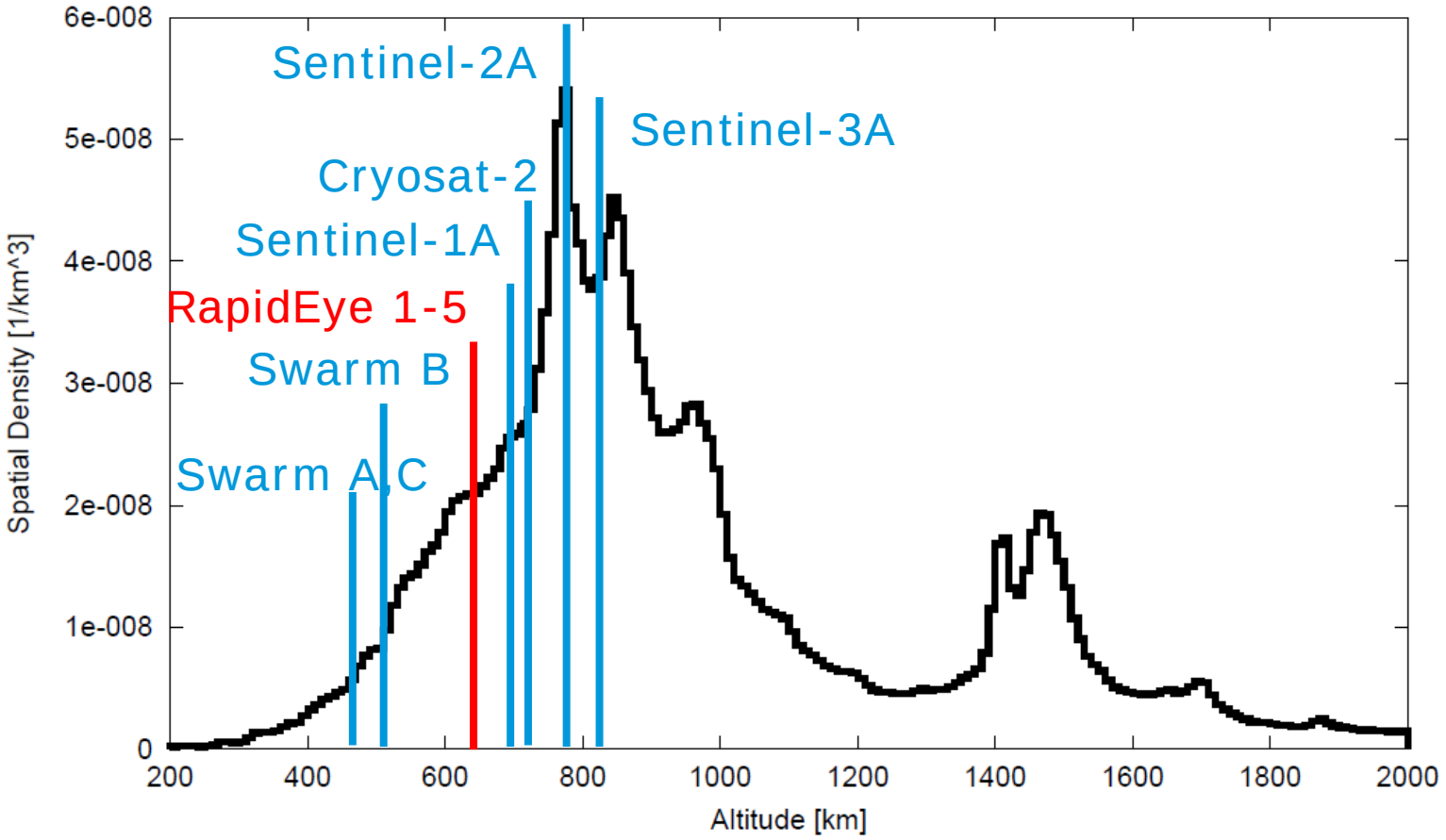
- Blackbridge (RapidEye: constellation of 5 satellites)
- EUMETSAT (Sentinel 3)
- other customers

Upcoming missions (selection)

Sentinels, Earth Explorers, **LEOPs**

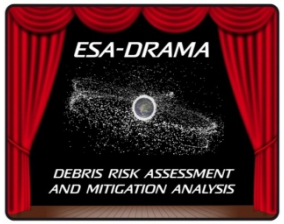
Satellite	Comment
ERS-2	Manoeuvre/TLE screening, CDM processing including de-orbiting phase in 2011
Envisat	Manoeuvre/TLE screening, CDM processing until failure in 2012
Cryosat-2	**Manoeuvre / MC screening, CDM processing since launch**
Swarm-A, B, C	**Manoeuvre / MC screening, CDM processing since launch**
Sentinel-1A, 2A, 3A	**Manoeuvre / MC screening, CDM processing since launch**
Proba 1, 2, V	Only review of JSpOC alerts, support of thruster experiments
RapidEye 1-5	**Manoeuvre screening, CDM processing, since 2012**
Cluster-II 1-4	Manoeuvre/TLE screening, during GEO passages
XMM	Manoeuvre/TLE screening, during GEO passages and LEO passages
Galileo/Giove/Met Op-A/B/MSG-3/4	JSpOC alerts received for a limited period of time
Artemis	CSM/JSpOC alert received until operations handed over, now case-by-case support

ESA's MASTER-2009: Spatial Density > 10cm



ESA's DRAMA SW Tool Suite

*"The **aim of DRAMA is** to support the objectives of the ESA Space Debris Mitigation Requirements by **enabling satellite programs** in Europe **to assess their compliance** with the recommendations contained in that document."*



ARES
Assessment of Risk Event Statistics:
Analyze requirements for collision avoidance manoeuvres expected for a mission.

MIDAS
MASTER (-based) Impact Flux and Damage Assessment Software:
Modeling of the collision flux and damage statistics for a mission.

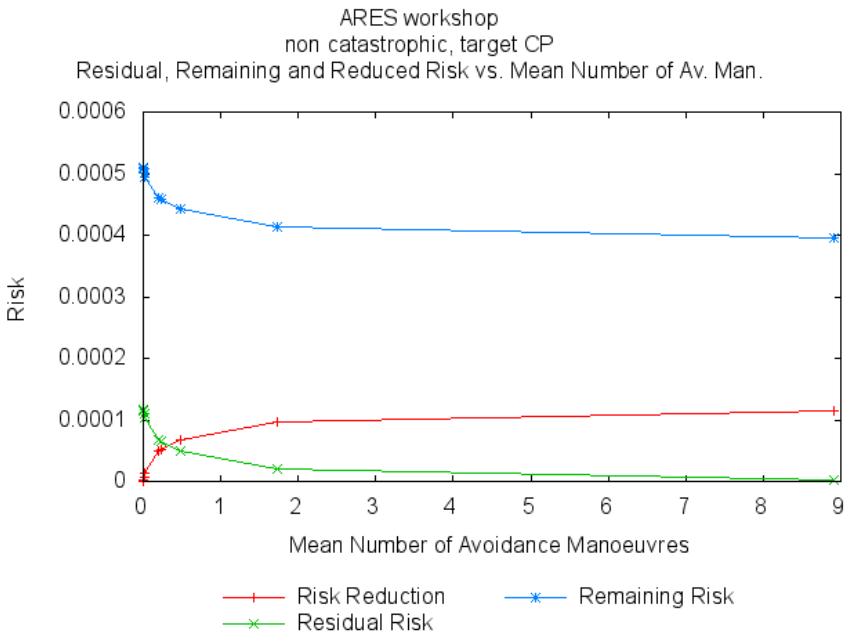
OSCAR
Orbital Spacecraft Active Removal:
Analyze disposal manoeuvres of spacecraft and compliance with ESA's mitigation requirements.

CROC
Compute projected cross-sectional areas of complex bodies

SARA
Spacecraft Entry Survival Analysis Module (SESAM):
Modeling the re-entry of a spacecraft.
Spacecraft Entry Risk Analysis Module (SERAM):
Assessing the on-ground risks of objects surviving re-entry.

DRAMA / ARES

- Providing statistics related to the collision risks for a mission.
- Determines required CAM fuel mass
- Quantifies the risk of a mission loss
- Flux based on MASTER-2009
- Results **statistical**, providing so-called “average encounters”
- Four functionalities:
  - Annual collision probability
  - Manoeuvre rate as a function of **accepted collision probability level** (ACPL), false alarm rates, risk reduction, residual & remaining risk
  - Estimate ΔV to perform CAMs
  - Estimate propellant mass for CAMs



Reduced: risk actually removed by manoeuvres

Residual risk: risk not intended to be reduced (although it would be possible)

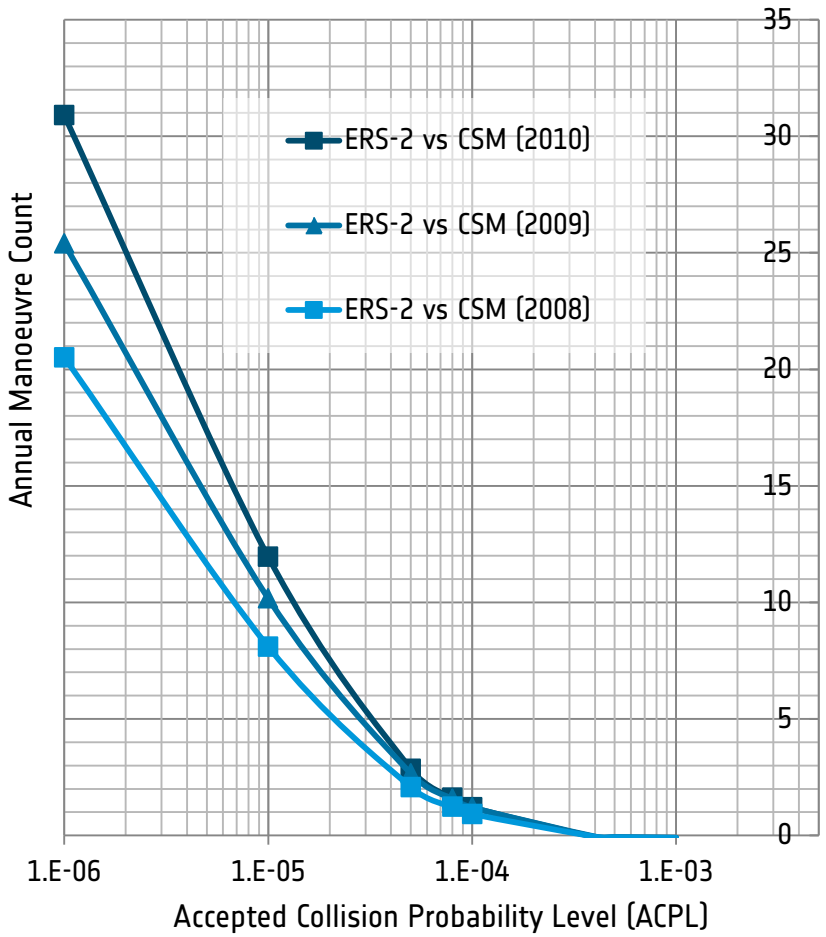
Remaining risk: risk which cannot be reduced (caused by undetectable objects) + Residual risk

What is a recommended reaction threshold (or target risk)

- What is a good reaction threshold? → Requires a management decision
- Annual collision probability as function of the quality of the orbital information of the secondary (chasing) objects → trade **ignored risk vs. risk reduction**
    - **Estimated manoeuvre frequency** for the selected reaction threshold and orbit uncertainties
    - Managerial **target function**: improvement of uncertainties by one order of magnitude → avoid 90% of the accumulated collision probability
- → TLE vs CDM: collision avoidance manoeuvres reduced by roughly one order of magnitude
- NB:
    - CSMs validated through dedicated tracking (→ CSM 2010 workshop at ESOC)
    - Uncertainties of TLEs for collision risk assessment? → see detailed studies

DRAMA / ARES Cross-Verification

- ARES module: assessment of the annual collision risk and manoeuvre rate, typical uncertainties associated with TLE or JSpOC CSM/CDM
- MASTER-2009 filtered as an (assumed) TLE or CSM/CDM catalogue
- Example for ERS-2: expect about 1 annual manoeuvre for 10^{-4} ACPL, in fact:
  - 2011: 1
  - 2010: 4*
  - 2009: 0
  - 2008: 0



* CSM/CDM introduction phase, no full covariance

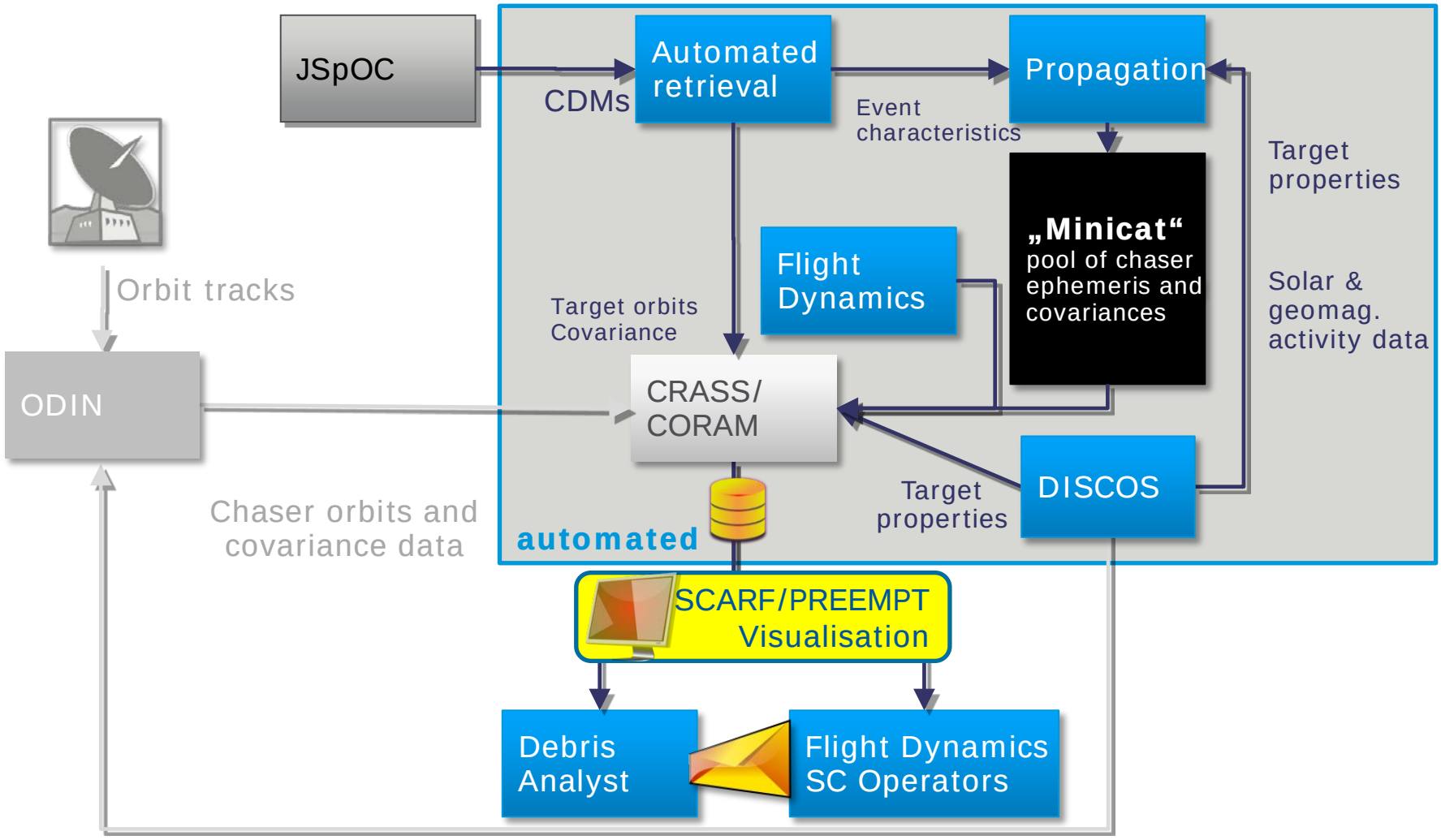
Space Debris User Portal

Provides users world wide free access to:

- **DRAMA**
- **MASTER**
- **Oriundo**
  - Installers
  - Patches
  - Documentation

https://sdup.esoc.esa.int

Current operational collision avoidance process at ESA / ESOC



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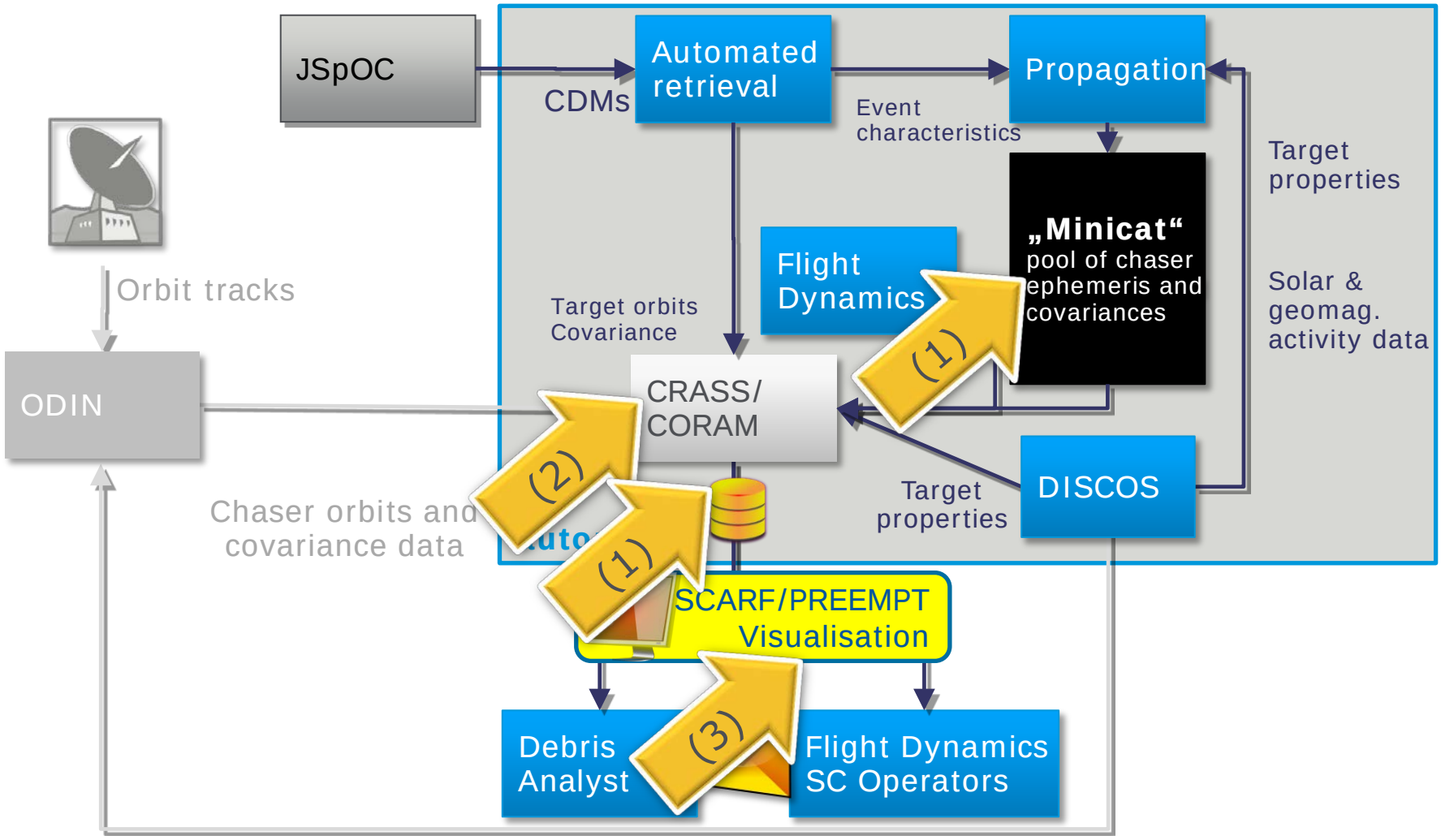
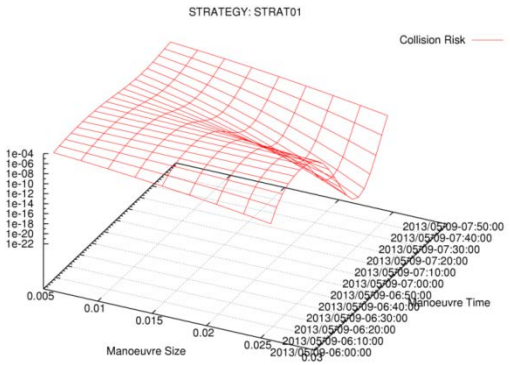


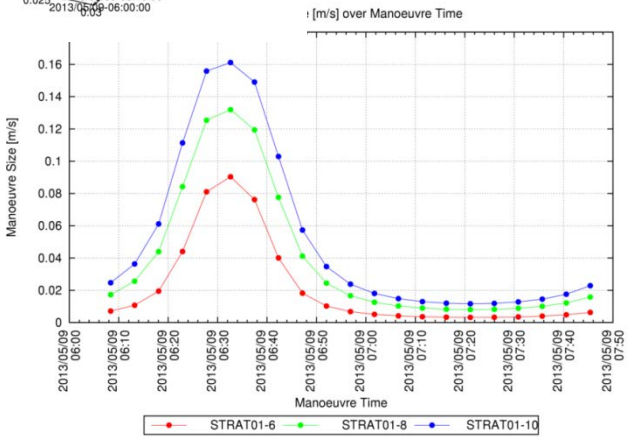
(1) Database of conjunction events / “Minicat”

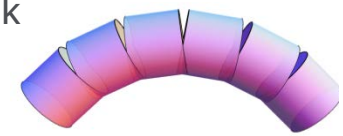
- **Central DB** for all automatic and manual processing
- Grouping by conjunction event ID: unambiguous description by 2 conjunction partners and TCA
- DB content
  - **CDMs data** obtained from JSpOC
    - Augmented by collision risk and other analyses results/sources
    - Automated insertion and standard analysis
  - **“Mini-catalogue”** (=propagation) results, operational ephemeris/cov.
    - Same data model as CDM (but different originator)
    - Automated insertion and standard analysis after each update
  - **Scenario results** for collision avoidance
    - Same data model as CDM (but different originator, multiple eph.)
    - Fed manually by analyst

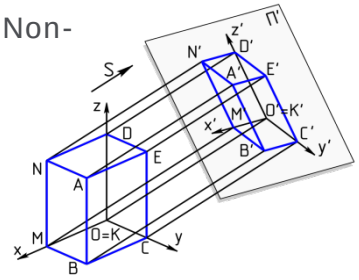
(2) Support to manoeuvre planning (CORAM)

- Support of manoeuvre planning **(CAMOS)**
  - Minimising risk or maximising (radial) separation at TCA
  - Varying size, direction, epoch
  - Constraints (bounds, fixed, free)
  - Parametric or evaluation mode
  - Trajectory parameters (latitude/longitude, eclipses, SAA crossing)
- Collection of Algorithms for collision risk assessment among two objects **(CORCOS)**:
  Alfriend Akella, Maximum Probability, Covariance scaling, Algorithms for low delta-v approaches, Non-spherical objects, Monte-Carlo





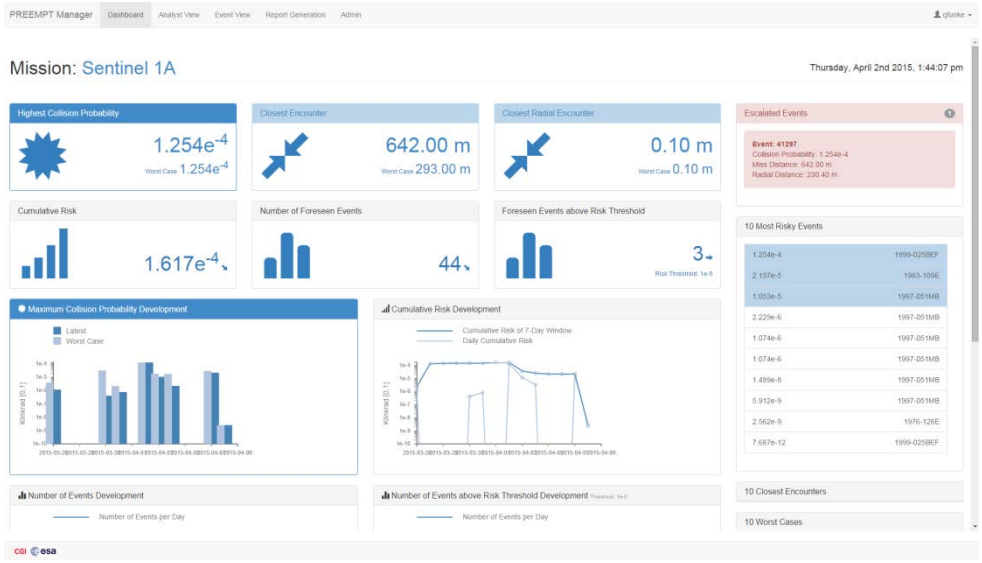




(3) SCARF / PREEMPT overview

Goals:

- Internal **coordination** within collision avoidance support team
- Concise “dashboard”: status **display to missions**
- Support of task **automation**
- Risk reduction

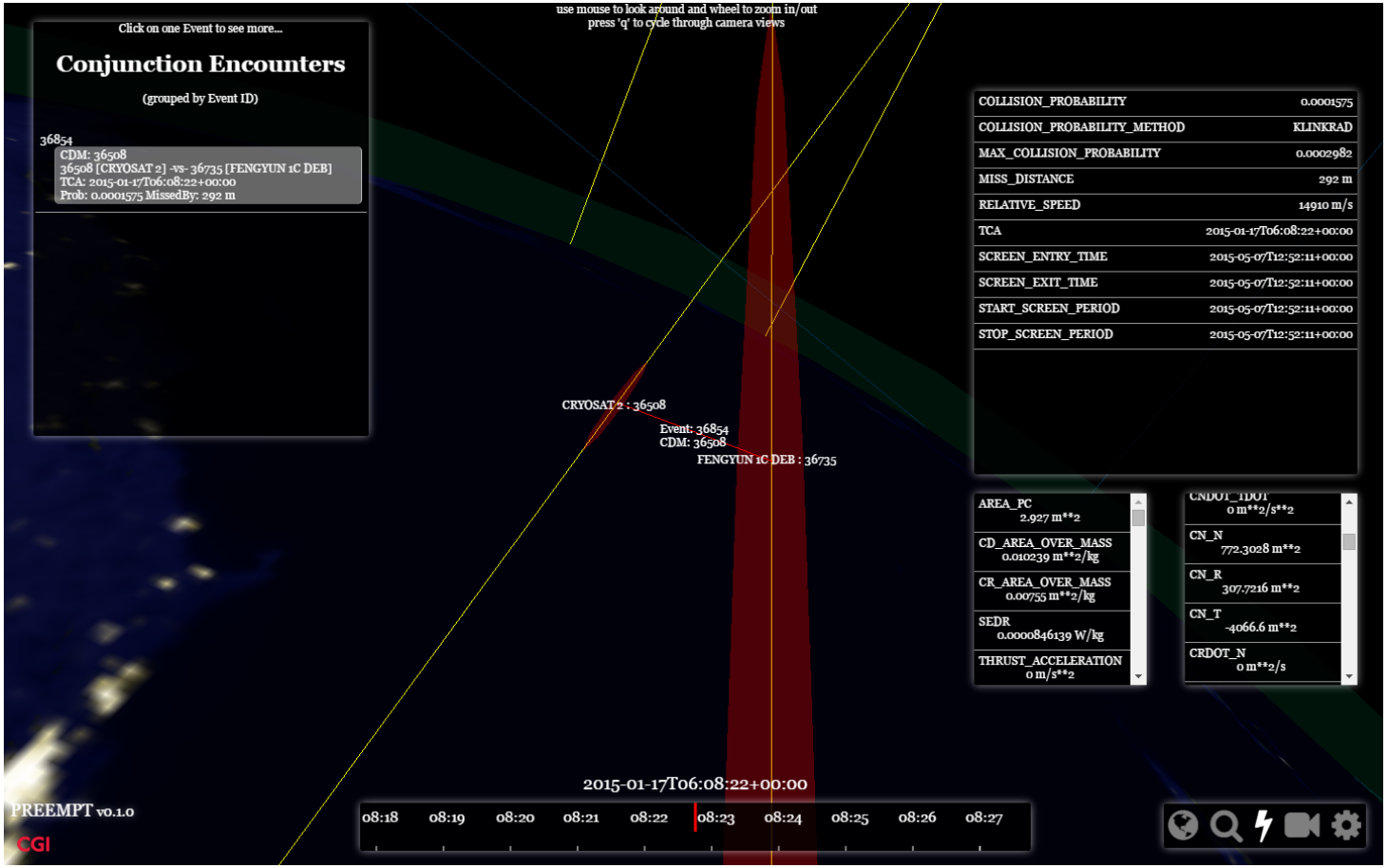


Features:

- Fully web-based
- Graphical presentation of CDMs and trends
- Risk highlighting
- Filtering/sorting
- Assigning and recording of escalation steps, timeline
- Condensed views for analysts
- Email generation from templates
- Report generation from templates
- Direct link to 3D interactive approach geometry visualisation, and to trigger further analysis (CORAM)

Developed by CGI for ESA

(3) Conjunction visualisation



Evolution of used technologies

Year	CRASS (TLE)	CRASS and tracking with radar	CRASS CSM, CDM	CRASS OEM	MINI-CAT	Visuali-sation	CORAM (Man. Optimis)
2004	X						
2005	X						
2006	X	X					
2007	X	X					
2008	X	X					
2009	X	X					
2010	X	X	X				
2011		X	X				
2012		(x)	X				
2013		(x)	X	X			
2014		(x)	X	X	X		
2015		(x)	X	X	X	X	X

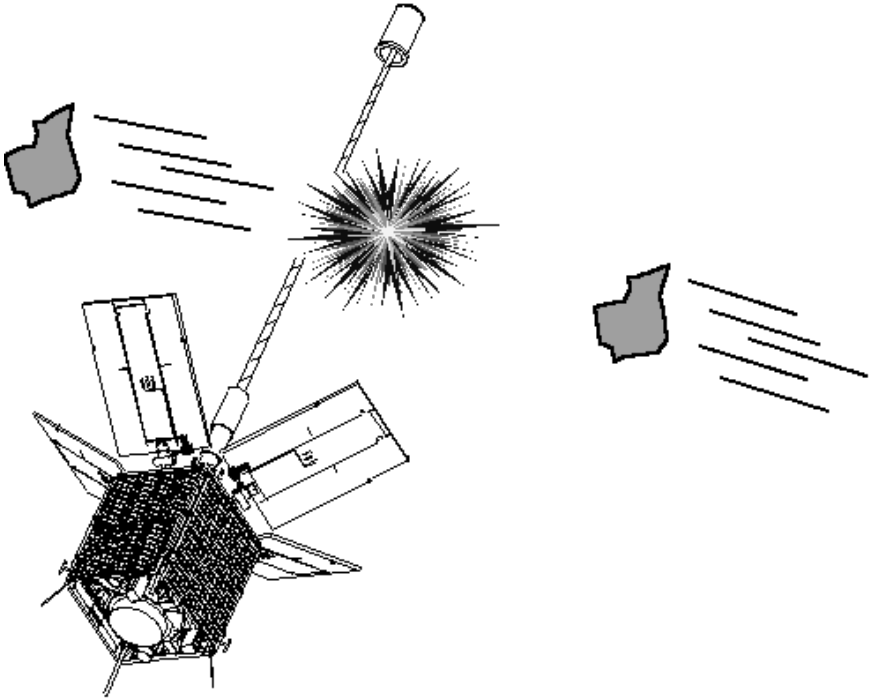
Summary and outlook

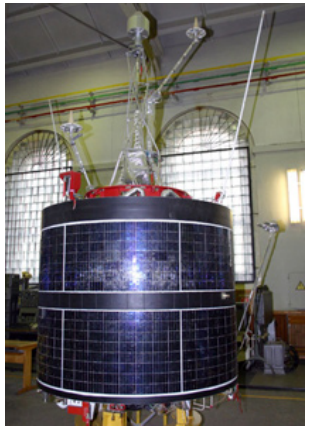
- ESA's DRAMA/ARES supports the mission design phase to estimate collision avoidance needs (https://sdup.esoc.esa.int)
- For ~one decade, ESA has a well-established collision avoidance process supporting several own and third party missions
- Excellent collaboration with USSTRATCOM/JSpOC
- Operational toolchain evolved significantly to meet growing needs
  - "minicat" / database-centered approach: flexibility, manoeuvre support
  - Support tools (CORAM) for specific analysis in back-end
  - Automation of CDM mixed CDM/OO processing
  - Web-based interfaces for visualisation and coordination
- combination of orbit maintenance and CAM manoeuvres wherever possible
- Future and tool challenges:
  - Standardisation in approach to collision avoidance (target risk reduction per mission life?)
  - Is advanced trend analysis / "predicting" risk evolution possible at all? What about repeating conjunctions?
  - Realism of covariance data, handling large data volumes, …

Extra Slides

Significant On-orbit Collisions

- 24-Jul-1996: Cerise - Ariane-1 upper stage fragment
- Dec-1991: Cosmos 1934 – Cosmos 926 fragment
- 17-Jan-2005: Thor Burner IIA upper stage – CZ-4B (third stage) fragment
- 11-Jan-2007: Fengyun 1C intentional destruction by ASAT
- 10-Feb-2009: Iridium 33 – Cosmos 2251





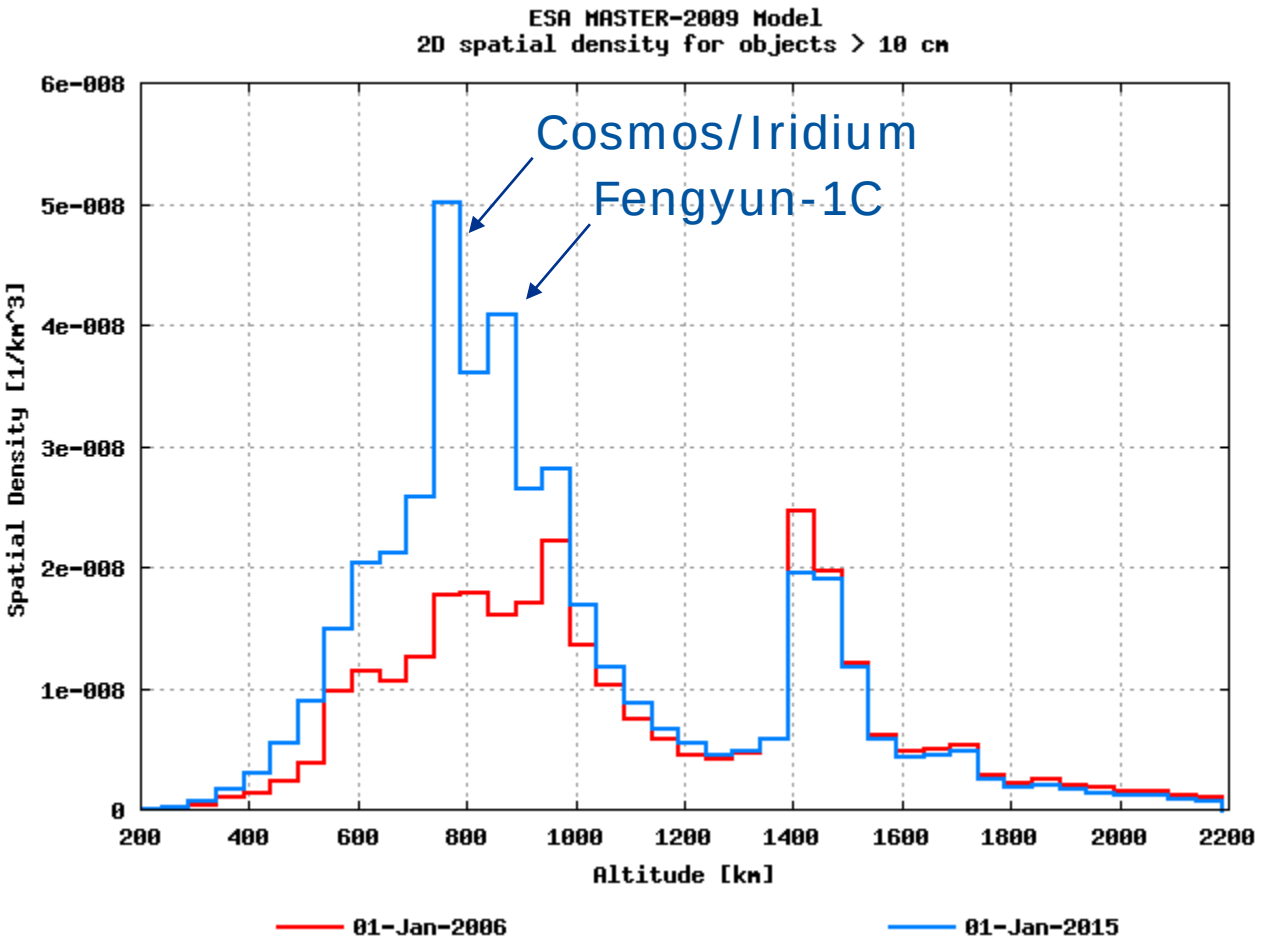
Catastrophic Collision Effects

2007: Intentional destruction at about **850 km** altitude of the Chinese satellite **Fengyun 1C** (957 kg) by an Anti-Satellite (ASAT) Dong Feng missile

→ > 2700 catalogued debris

2009: Accidental collision at **790 km** altitude (relative velocity of 11.6 km/s) between **Iridium 33** (US Operational communication satellite, 560 kg) and **Cosmos 2251** (Russian decommissioned communications satellite, 900 kg)

→ > 2000 catalogued debris



Collision Risk Guidelines

- International guidelines exist:
  - UN Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space (United Nations (UN), 2010): *Guideline 3: Limit the probability of accidental collision in orbit*
  - IADC Space Debris Mitigation Guidelines (IADC-02-01, Rev. 1, 01/09/2007): *5.4 Prevention of On-Orbit Collisions*
  - Under discussion for ISO 24113 review
- CCSDS Conjunction Data Messages (CDM) as recommended standard for data exchange (508.0-B-1), June 2013