Operational Collision Avoidance at ESOC

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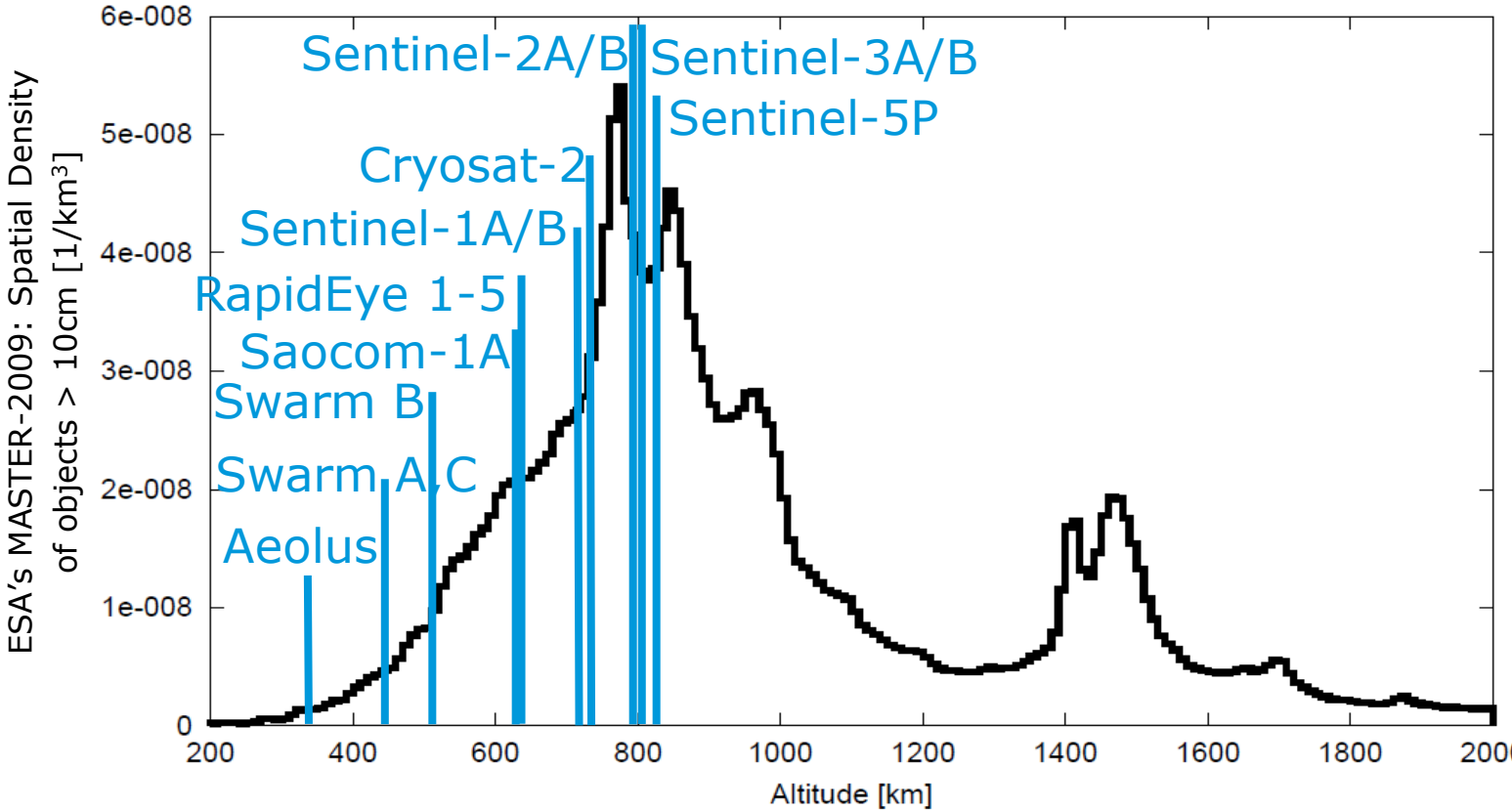
Outline

- Introduction
    - Collision avoidance at ESA
    - Avoidance manoeuvre reaction threshold
- Current process
    - Drivers
    - Back-end database and tools
    - Front-end
    - Process control
- Statistics
- Summary

Covered missions



Other missions:

- ERS-2
- Envisat
- Proba-1,2,V
- Cluster-II
- XMM
- Galileo/Giove
- METOP-A/-B/-C
- MSG-3/4
- Artemis

At varying support level

Avoidance manoeuvre reaction threshold

- Requires a management decision
- Trade ignored/accepted risk vs. risk reduction
- Estimate cost i.e. manoeuvre frequency for selected reaction threshold
  - Depends on orbit uncertainties of the secondary (chasing) objects
- ESA's ARES tool, part of DRAMA SW suite, https://sdup.esoc.esa.int
- Need consistent setup of operational and analysis approach (SC area)
- Typical managerial target function:
  - avoid 90% of the accumulated collision probability
- Typical result:
  - Threshold of 10^{-4} one day to TCA using encircling sphere
  - for 90% risk reduction at cost of 1-3 manoeuvres per year

Assessment of Risk Event Statistics

https://sdup.esoc.esa.int

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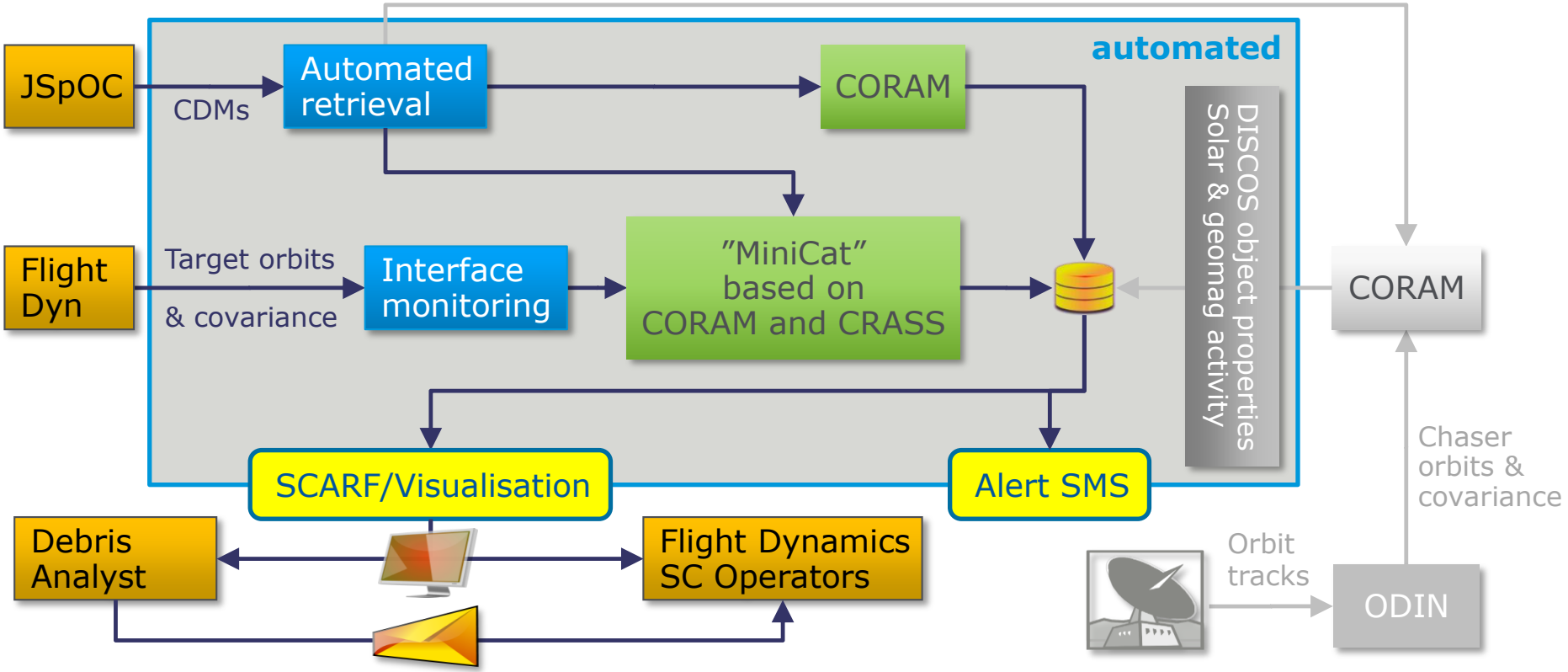
Operational process - drivers

- CDM information for enlarged screening volumes used as baseline
    - CDM superior to TLE in accuracy and its knowledge
- Automation of CDM processing due large number of CDMs
- Including combined/mixed processing using OO information on target and JSpOC CDM information on chaser (“Mini-Catalogue”)
- Interface to mission control teams streamlined
    - Simplifying data provision and interpretation
    - Providing concise status display to missions
- Internal coordination within collision avoidance support team simplified with help of a conjunction management tool and manoeuvre monitoring system
- Overall driver: support of task automation thereby reducing process risk

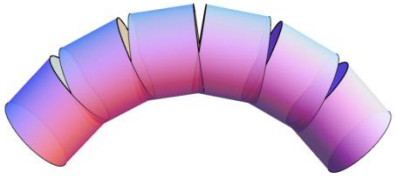
Collision avoidance process

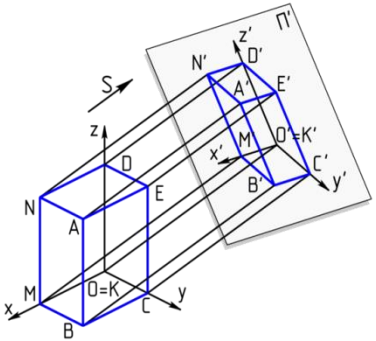


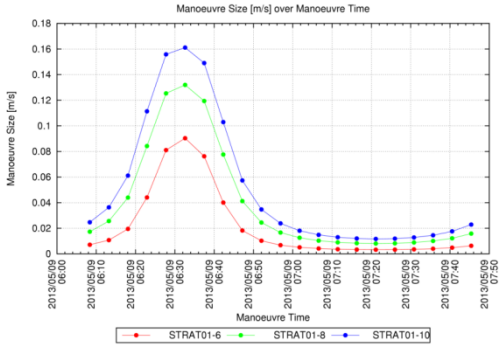
Risk assessment and manoeuvre planning

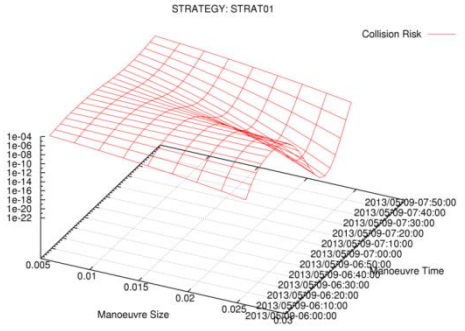
Collection of Algorithms for collision risk assessment among two objects (**CORCOS**):

- Alfriend Akella
- Maximum Probability
- Covariance scaling
- Algorithms for low delta-v approaches
- Non-spherical objects
- Monte-Carlo









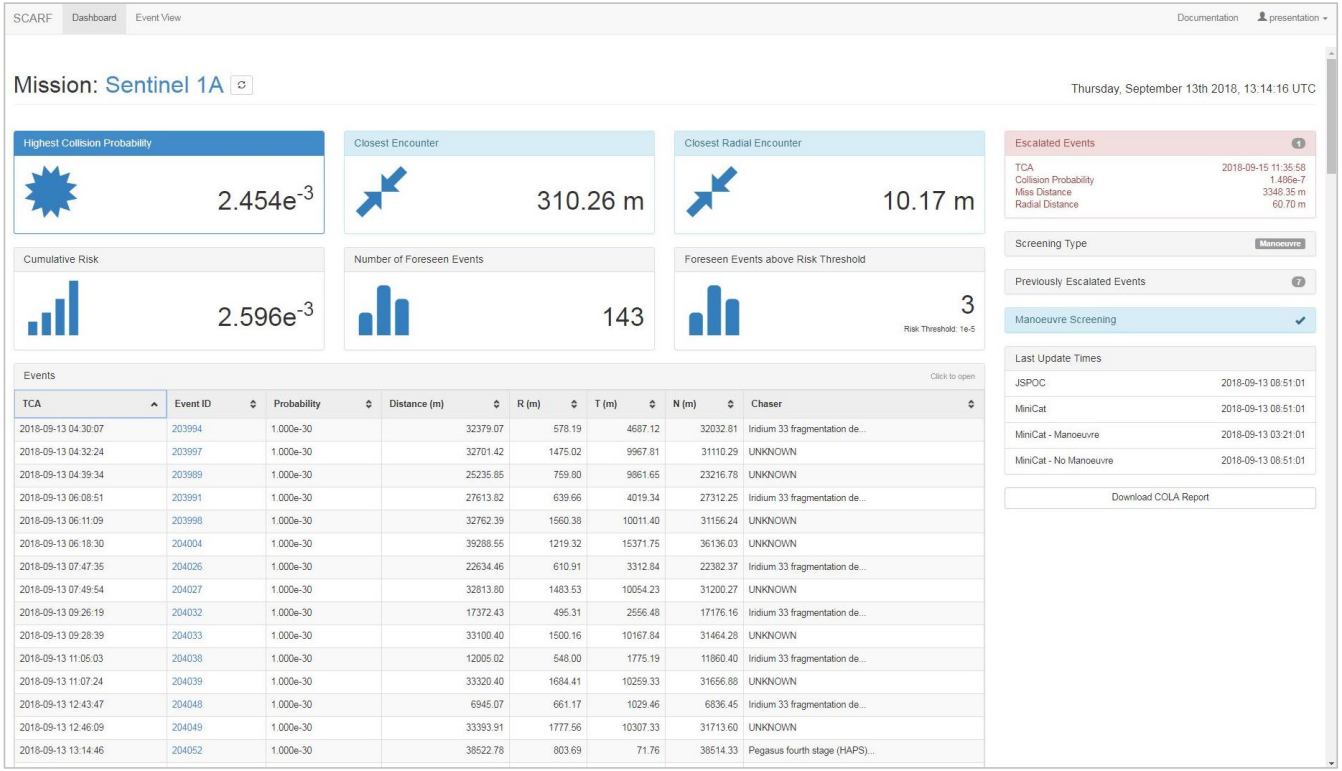
Support of manoeuvre planning (**CAMOS**)

- 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)

SCARF – Collision Avoidance Web-Frontend

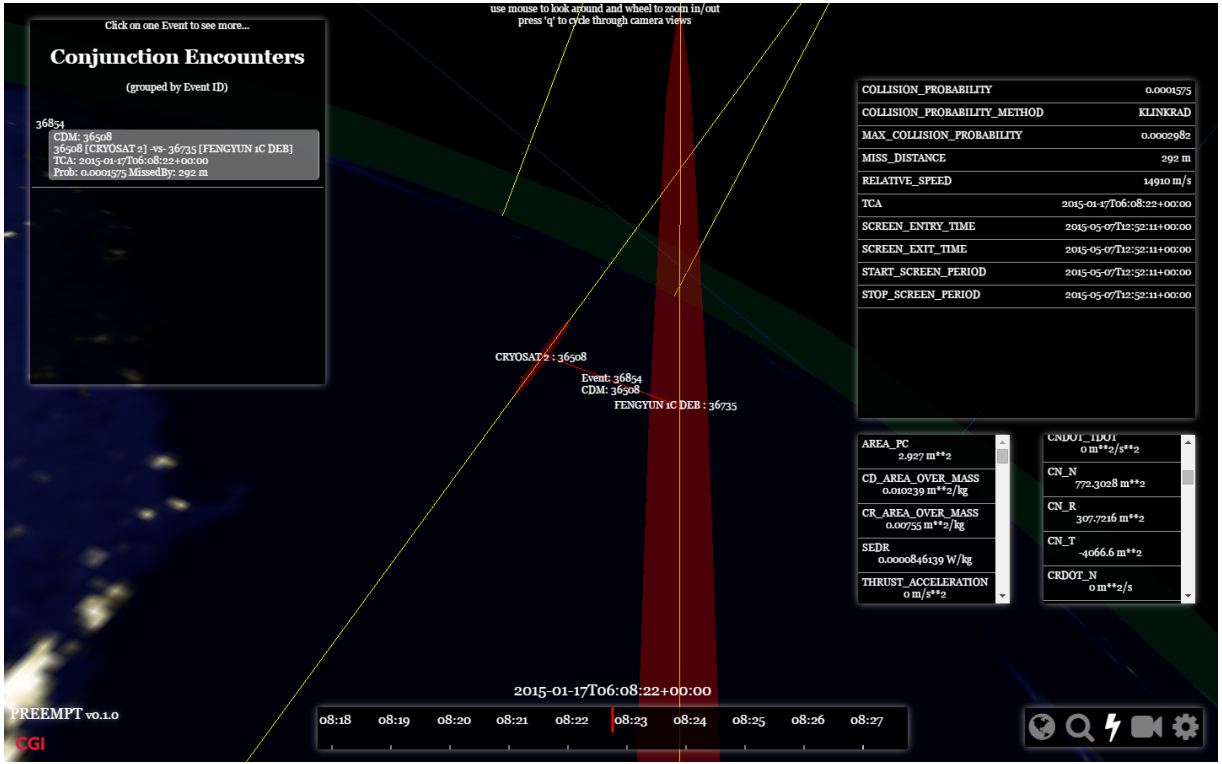
Web-frontend to CDM/Event database

- Mission dashboard view
  - Sortable event list
  - Escalated events
  - Switch between screening options
  - Last update times
  - Informative charts
- Event view
- Analyst view
- Actively development



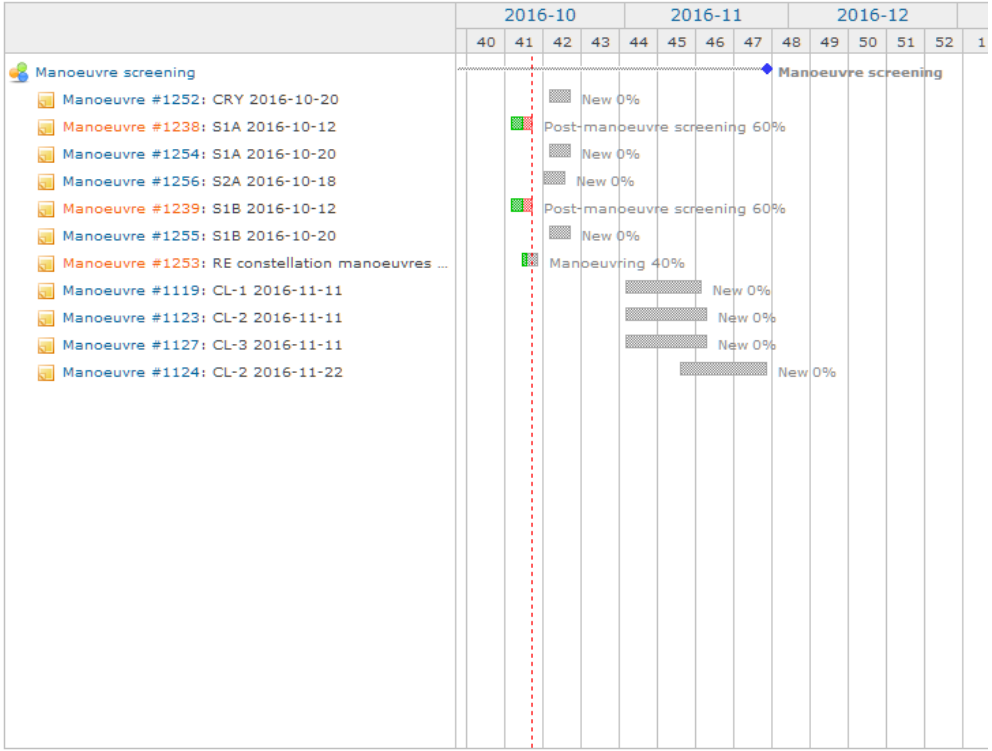
Conjunction visualisation

- Web-based 3D dynamic visualisation of close approaches: Earth, trajectories, covariance ellipsoids, CDM data, …
- Interactive control of camera position, view angle, time, zoom, …



Manoeuvre Monitoring System

- Process control and tasks allocation system
  - “ticket” per manoeuvre
  - Assignee management
  - Status transitions
- Views:
  - Status filter
  - Gantt
  - Calendar
  - Wiki (procedures)
- Redmine-based



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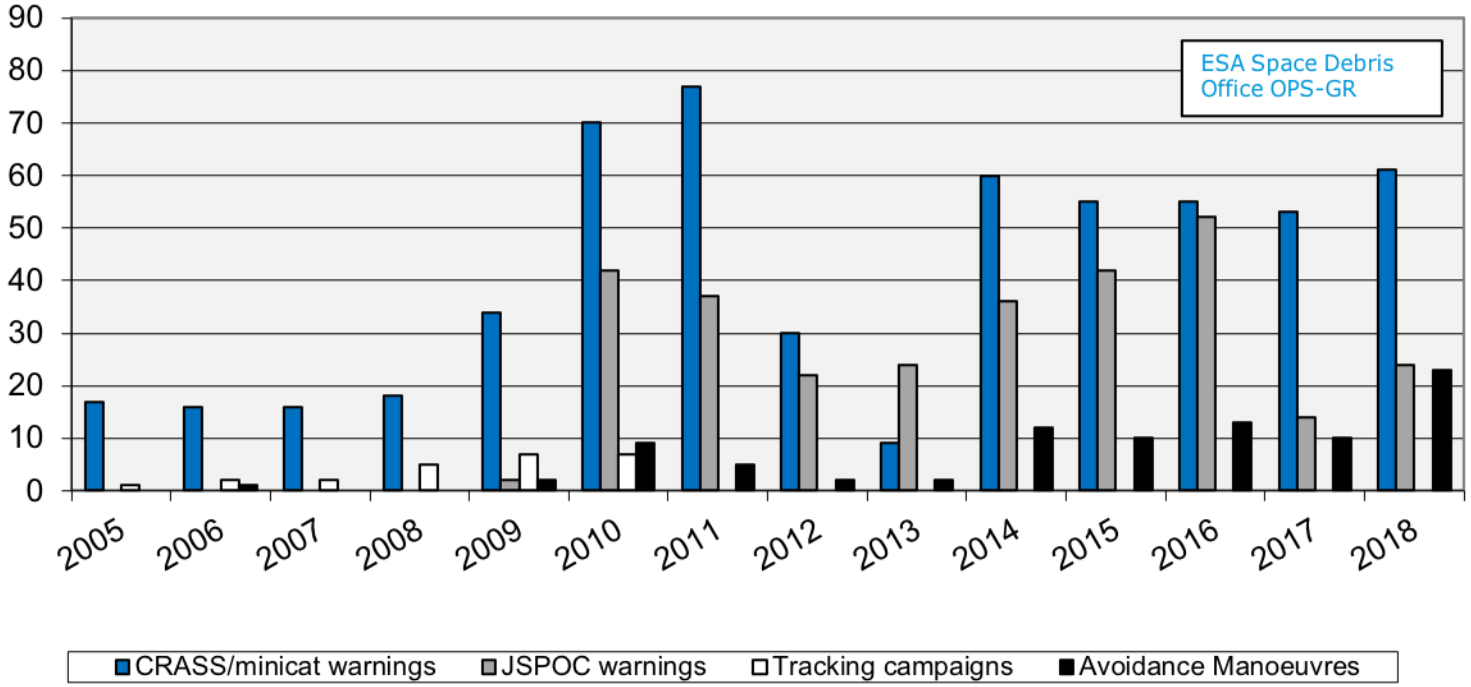
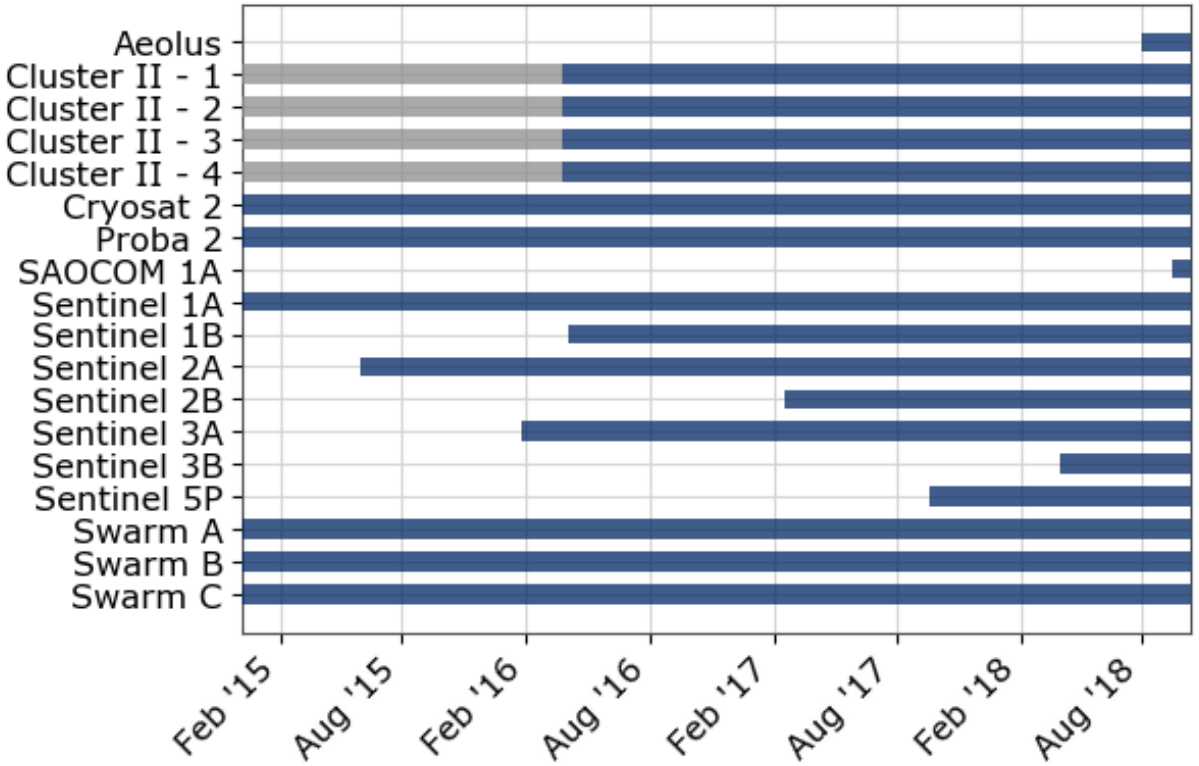
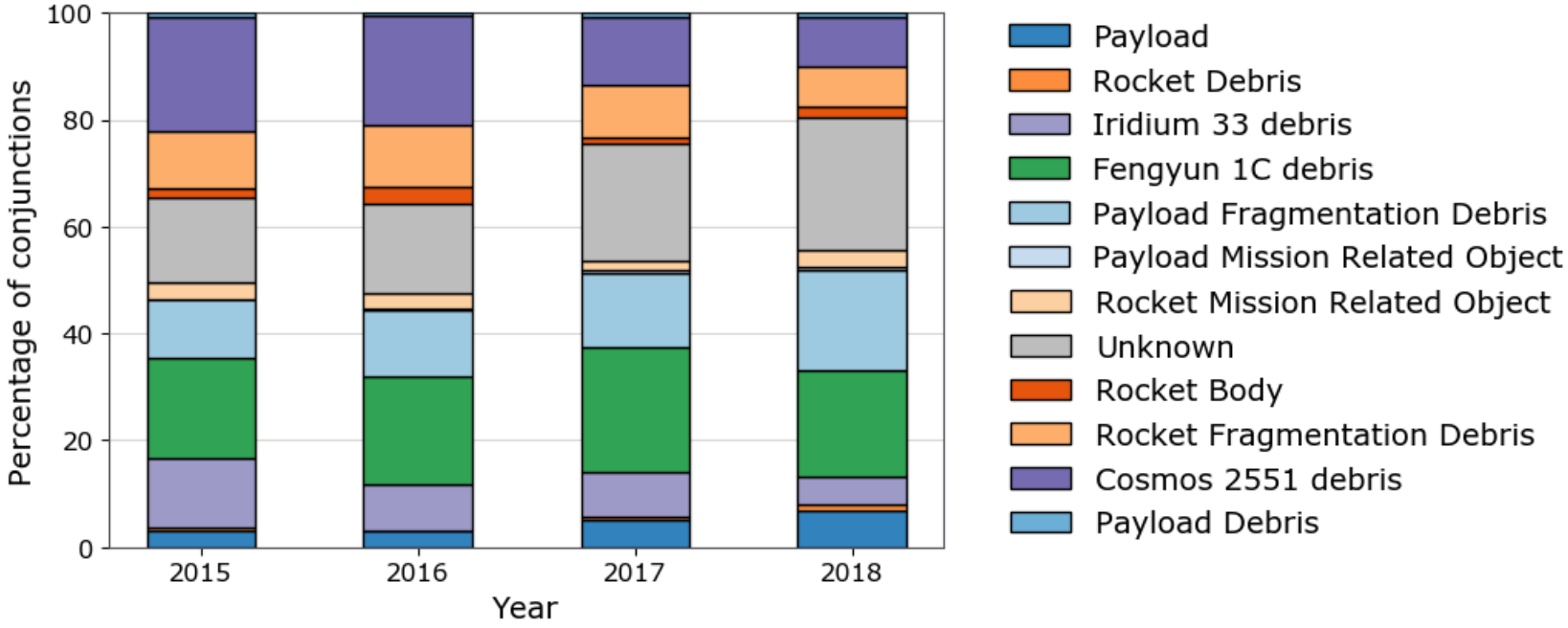
Event Statistics



Evolution of supported missions

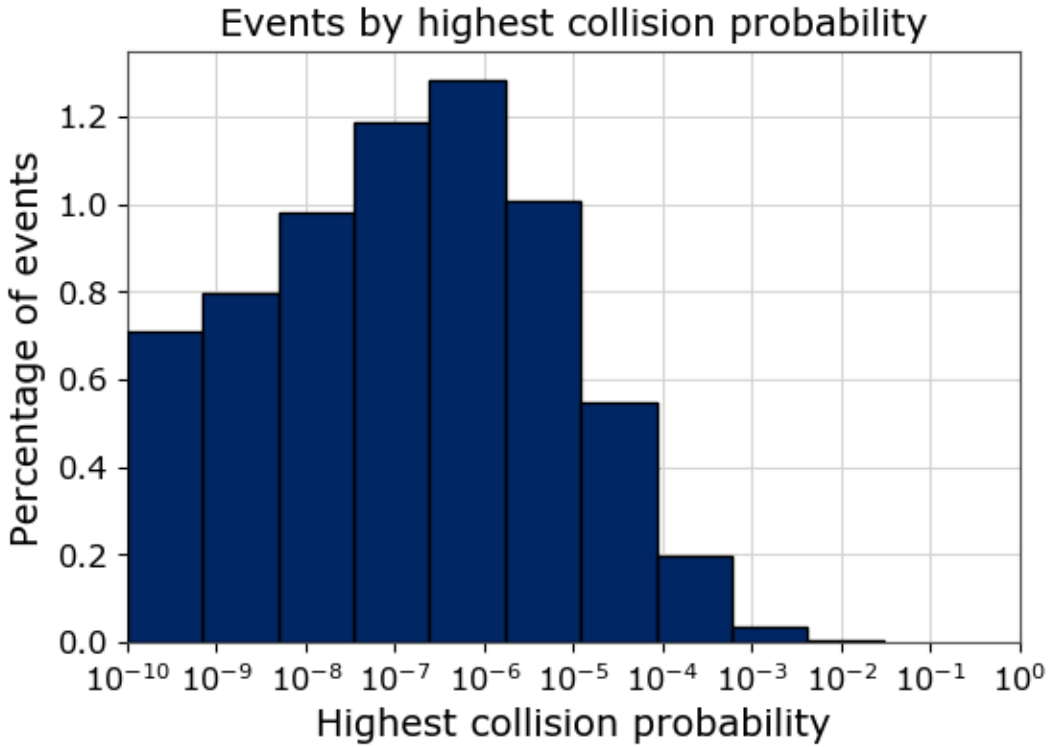


Classes of chasers

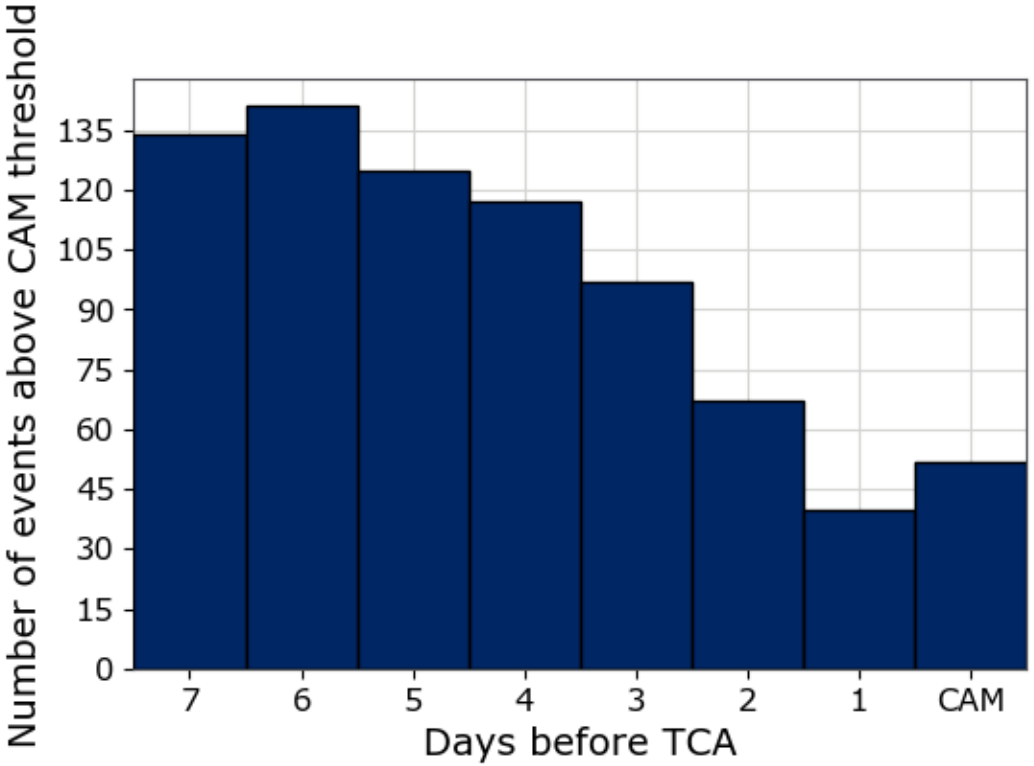


Frequency of events per risk level

- Highest risk of all CDMs for a given event
- CDMs received from JSpOC (SP vs SP)



Time evolution of high risk levels



Summary

- **Well-established collision avoidance process for more than 15 years**
  - supporting several own and third party missions
  - Excellent collaboration with USSTRATCOM/JSpOC for years
- **Operational toolchain evolved significantly to meet growing needs**
  - Approach centred around database of processed CDMs
  - Automation of CDM mixed CDM/OO processing (needed due to large number of CDMs)
  - "minicat": flexibility, manoeuvre support with short turn-around times for small delta-v
  - Web-based interfaces for visualisation/coordination (Space Debris experts and FCT/FDT)
  - Support tools for specific analysis in back-end
    - Improved/expanded risk assessment and avoidance manoeuvre planning
  - Maintain capability to acquire dedicated tracking
- **Statistics show that the challenges differ over time and for each orbit type**
  - Feedback to operational procedures

Thank you!

Database of conjunction events

- **Central DB** for all automatic and manual processing
- Grouping by conjunction event ID: unambiguous description by 2 conjunction partners and TCA
- DB content
    - **CDM data** obtained from JSpOC
        - Augmented by collision risk and other analyses results/sources
        - Automated insertion and standard analysis
    - **"Mini-Catalogue"** screening results against 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

SCARF - Event view

- Core event data (objects, TCA, CDMs)
- Trend plots or tabular view
- Status (ownership, escalation level)
- Single CDMs display
- E-mail / screening trigger
- Reporting: statistics on high risk events
- CAMOS results (plots)

Event: 212673

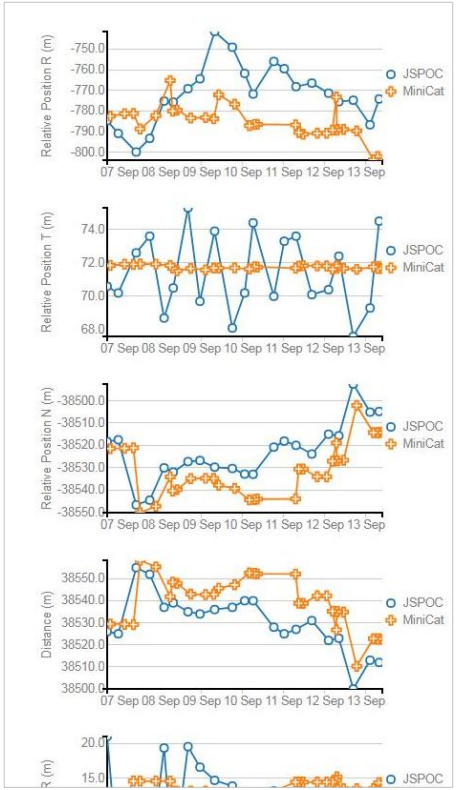
Status: Assigned

Owner: presentation

Chaser: Fengyun 1C debris (1999-025CWH)

Target: CRYOSAT 2 (2010-013A)

TCA: 2018-11-03 18:37:18.063



TCA	Creation Date	Distance (m)	R_Pos (m)	T_Pos (m)	N_Pos (m)	P_{coll}	P_{max}	T σ_R (m)	T σ_T (m)	T σ_N (m)	C σ_R (
2018-09-13 13:14:46.097	2018-09-13 09:38:45	38522.55	-803.76	71.66	-38514.09	1.000e-30	3.6250e-8	14.33	108.67	13.68	
2018-09-13 13:14:46.081	2018-09-13 07:49:31	38512.00	-774.20	74.50	-38504.80	1.000e-30	3.4620e-8	8.09	18.37	3.09	
2018-09-13 13:14:46.096	2018-09-13 07:29:26	38522.73	-803.85	71.79	-38514.27	1.000e-30	3.6250e-8	14.33	108.67	13.68	
2018-09-13 13:14:46.094	2018-09-13 06:58:28	38522.71	-802.07	71.66	-38514.29	1.000e-30	3.6880e-8	13.18	114.22	14.25	
2018-09-13 13:14:46.095	2018-09-13 04:25:27	38522.78	-803.69	71.76	-38514.33	1.000e-30	3.3160e-8	13.48	504.27	13.43	
2018-09-13 13:14:46.082	2018-09-13 02:29:02	38513.00	-786.70	69.30	-38505.10	1.000e-30	3.4660e-8	7.98	19.92	2.86	
2018-09-13 13:14:46.098	2018-09-12 18:38:31	38510.25	-789.69	71.61	-38502.08	1.000e-30	3.4160e-8	13.48	504.25	13.43	
2018-09-13 13:14:46.087	2018-09-12 16:39:24	38500.00	-774.80	67.60	-38492.50	1.000e-30	4.0950e-8	2.84	15.38	2.79	
2018-09-13 13:14:46.116	2018-09-12 11:01:53	38534.86	-788.91	71.67	-38526.71	1.000e-30	3.4820e-8	13.48	504.27	13.43	

SCARF – future enhancements

- Multi-mission dashboard view
- Event group view, for connected events (i. e. repeating conjunctions)
- Add activity triggers: configure and launch CORAM runs

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.

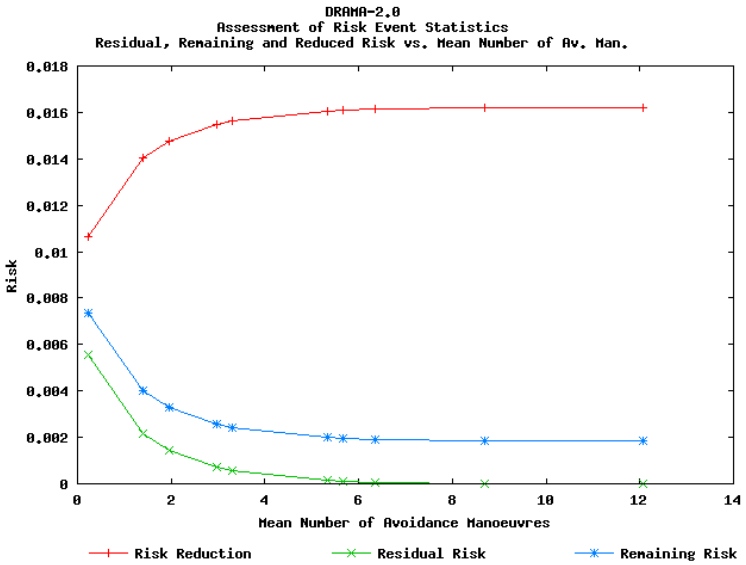
OSCAR
Orbital Spacecraft Active Removal:
Analyze disposal manoeuvres of spacecraft and compliance with ESA's mitigation requirements.

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
- Flux based on MASTER-2009
- Results **statistical**, based on "average encounters"
- Four functionalities:
  - Annual collision probability
  - Manoeuvre rate, false alarm rates, risks as a function of accepted collision probability level (ACPL)
  - Estimate DV to perform CAMs
  - Estimate propellant mass for CAMs



Risk reduction: risk actually removed by manoeuvres

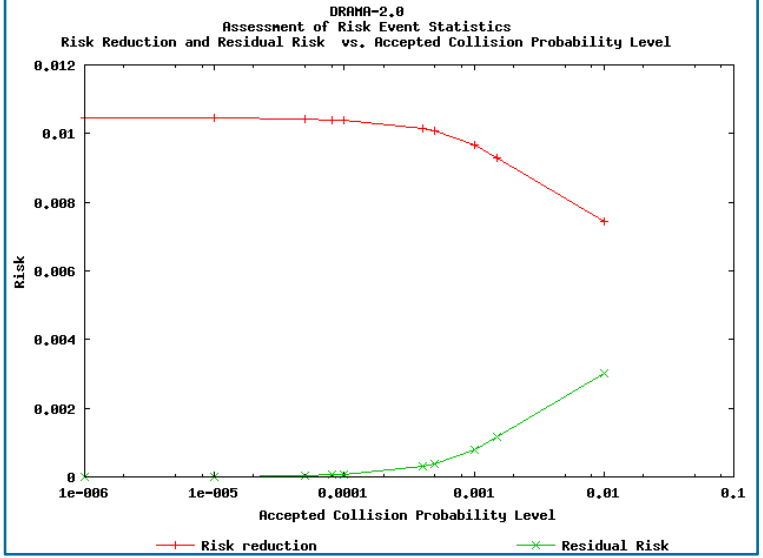
Residual risk: risk not intended to be reduced (although it would be possible)

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

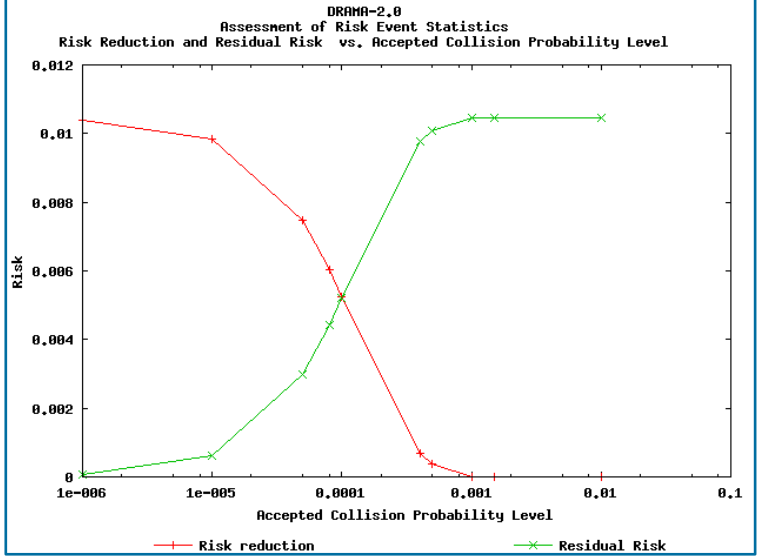
ARES example

Envisat-like: 780 km altitude polar, 26 m diameter, chaser limit size 10 cm

Catalogue covariance as per CDM



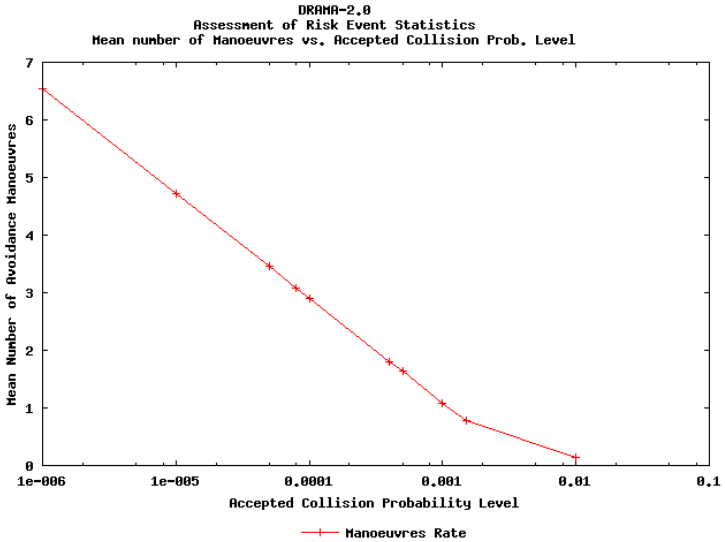
Catalogue covariance as per TLE



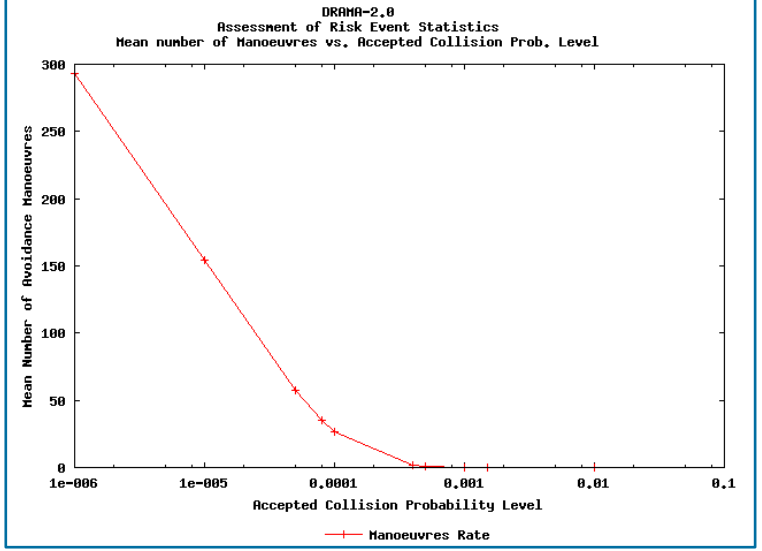
Higher risk reduction for same ACPL, in particular for 10^{-4} almost all risk reduced with CDM accuracy, only half the risk with TLE accuracy

ARES example - manoeuvres

Catalogue covariance as per CDM



Catalogue covariance as per TLE



With TLE accuracies: Much higher number of manoeuvres for same ACPL.

Risk reduction 50 % at ACPL of 10^{-4} at cost of approx. 30 manoeuvres!