Collision Avoidance Operations at DLR/GSOC

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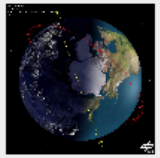
Introduction

- GSOC collision avoidance system (COLA) operational since 2009
- Monitoring satellites 5 in LEO, 2 in GEO:
  TerraSAR-X and TanDEM-X (514 km), GRACE-1&2 (460 km), PRISMA (750 km)
- Input: **TLE** and **C**onjunction **S**ummary **M**essage from JSpOC
- Daily proximity prediction using TLEs (for 7 days) running in automated process
- Automated warning and analysis process available

COLA FD Web



General

- FD Ops Home
- Overview

Available Products

- GRACE-1

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DLR                                                                                                  German Space Operations Center
Program  COLA  run on 2011/02/22  02:01
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PREDICTION FROM: 2011/02/22  02:01:47.000
           TO  : 2011/03/01  02:01:47.000

REL.DIST     <    10.0  [km]
RADIAL_DIST  <     3.0  [km]

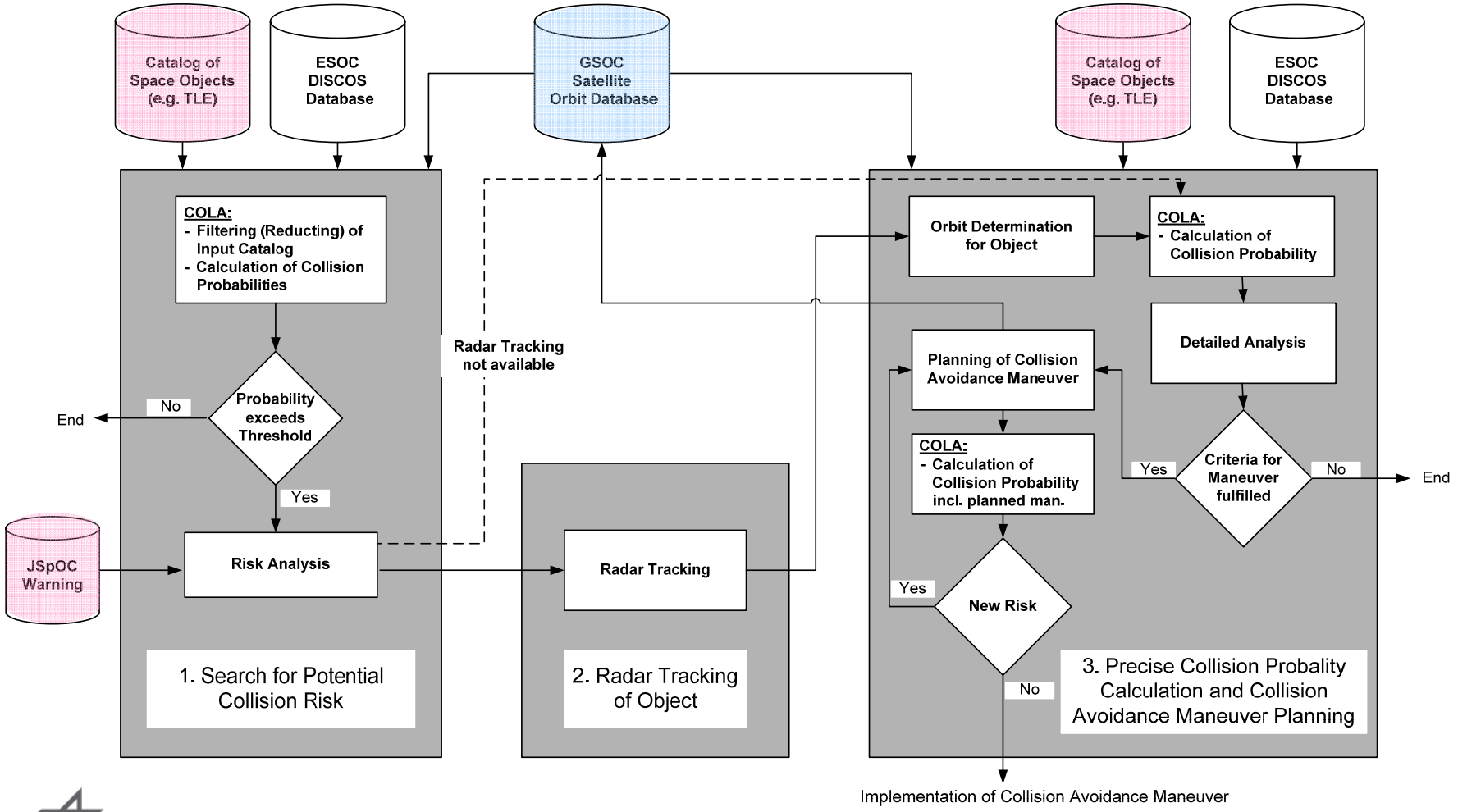
TARGET_R :        2.60  [m]
OBJECT_R :        2.00  [m]   (Default)

SatID  Name                   Days since    Time of approach        Max.Prob                    Obj.R        1 Sigma in RTN
                                                                                                              [km]
                                                                  Min.Range      Rel.Vel  OrbPl.Angl
                                                                       [km]       [km/s]       [deg]

                                                                          R           T           N
                                                                       [km]        [km]        [km]

                                                                  OrbArcDist TimFromNode DstFromNode
                                                                       [km]        [sec]        [km]
--------------------------------------------------------------------------------------------------------------------------------
31698  TerraSAR-X              0.528 S:2011/02/22  06:32:46.429    2.73E-07                 DEFAULT     0.002     0.124     0.001
27134  PSLV DEB                1.537   2011/02/22  06:32:46.792       8.436       14.796      152.91     0.204     2.315     0.385
                               0.188 E:2011/02/22  06:32:47.155       1.476       -1.945      -8.074
                                                                      1.427        2.338      17.728
```

GSOC Collision Avoidance Process Overview



Automated Warning

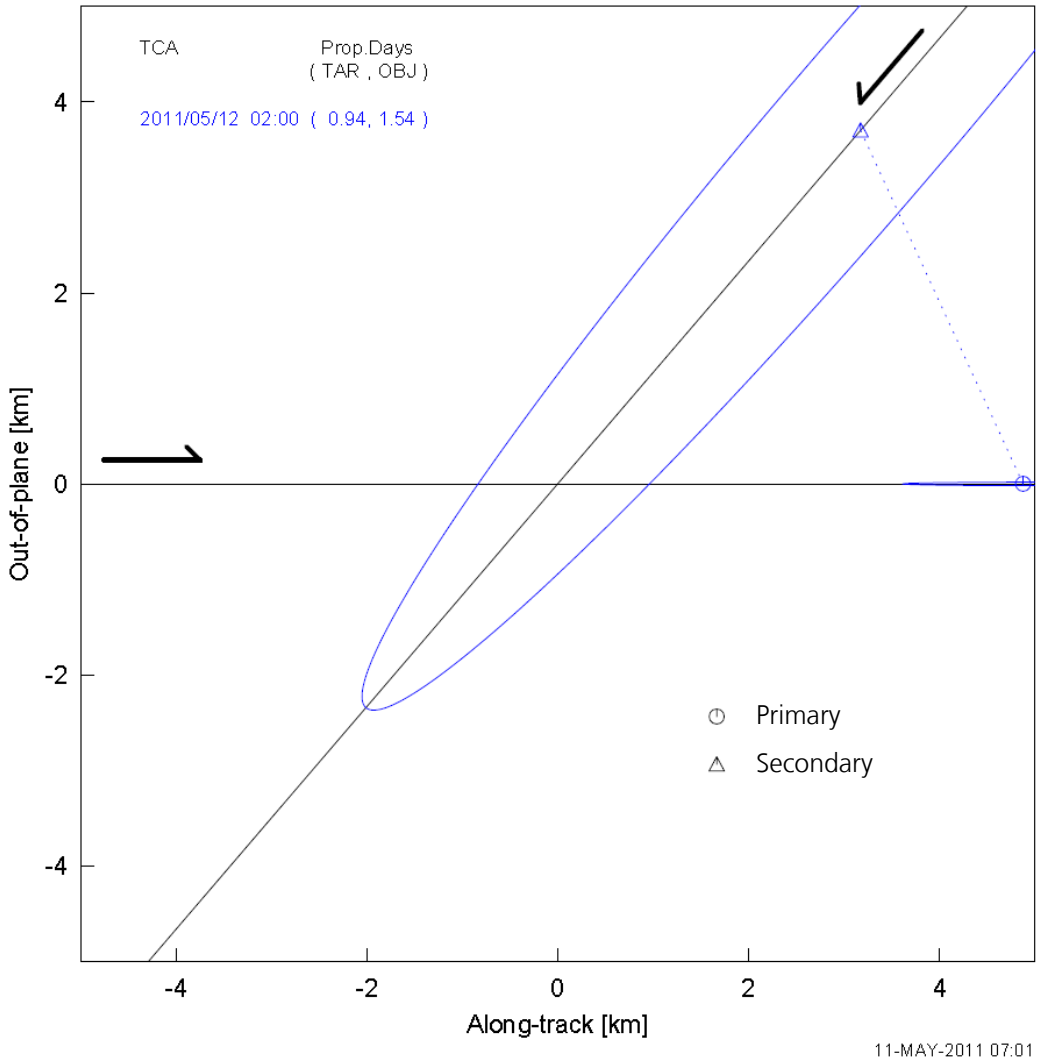
Automated warning based on

- Daily prediction using TLEs (maximum probability > 10E-04 and radial distance < 300 m)
- Notification from JSpOC

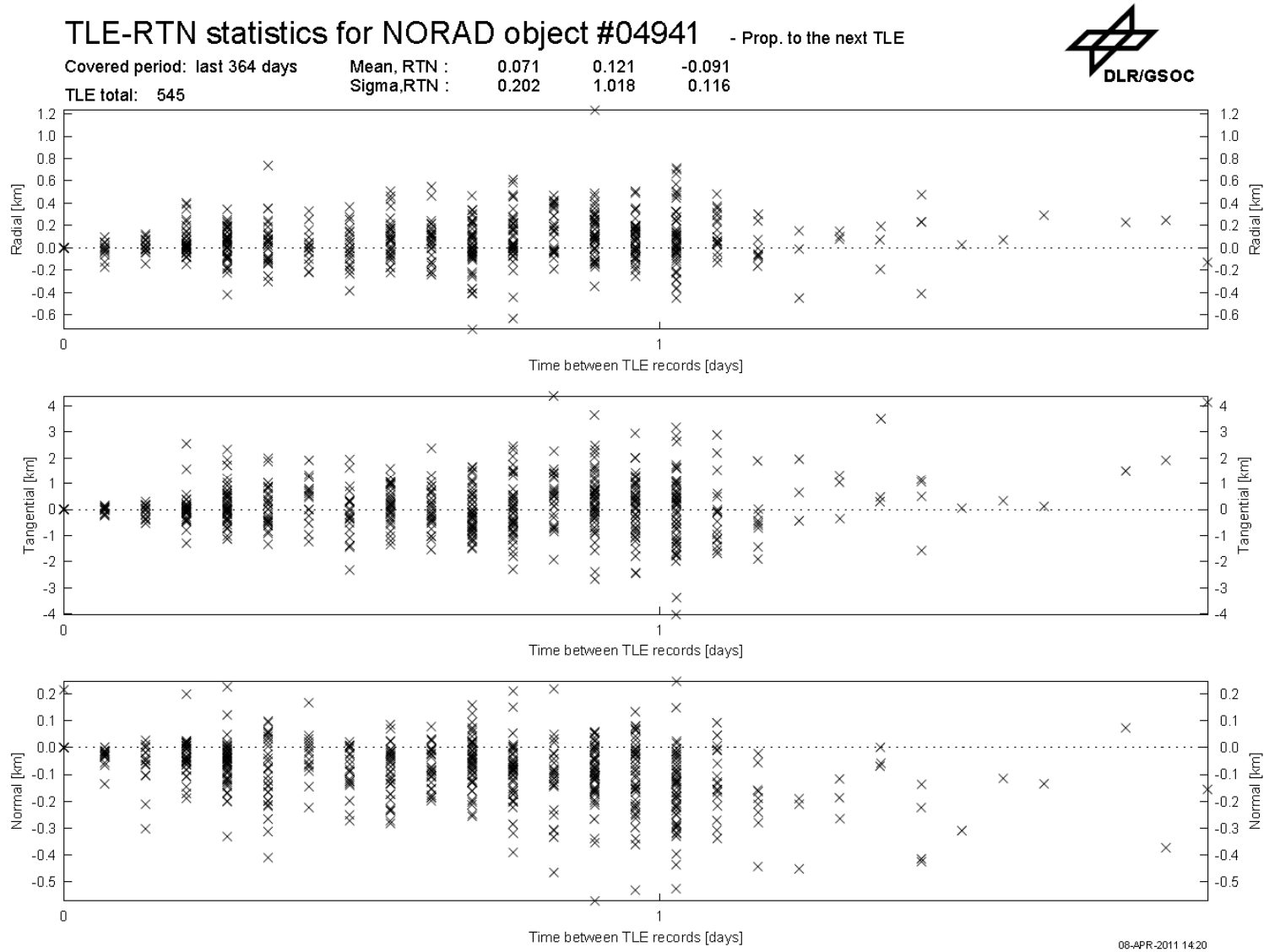
The latest COLA prediction results are sent to FD staff per E-mail

- Prediction summary (current and history)
- CSM summary (in case of JSpOC notification)
- First analysis results
  - Close approach geometry (example see next slide)
  - TLE statistics of the secondary object (subsequent 2 slides)

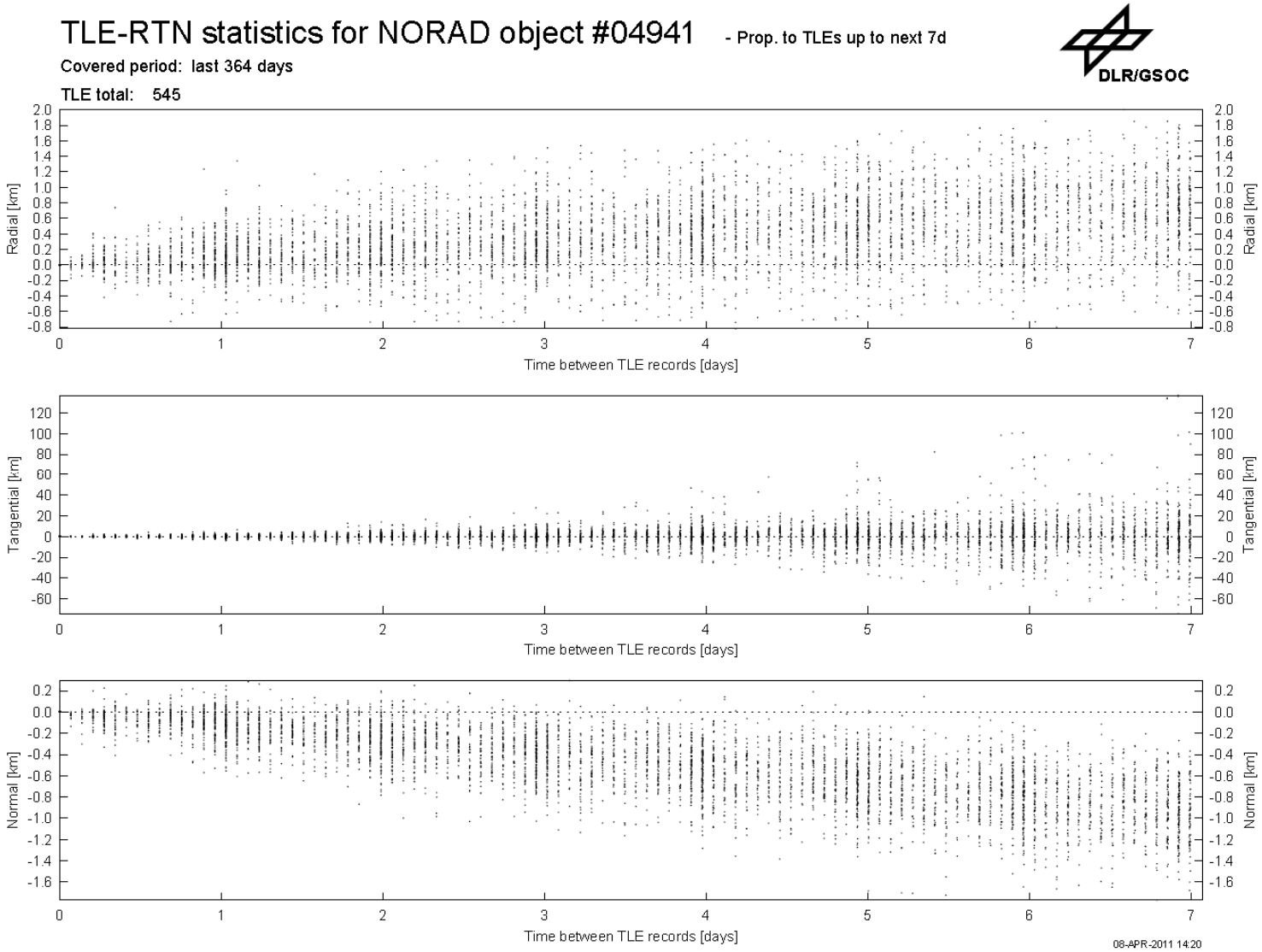
Example of Close Approach Geometry



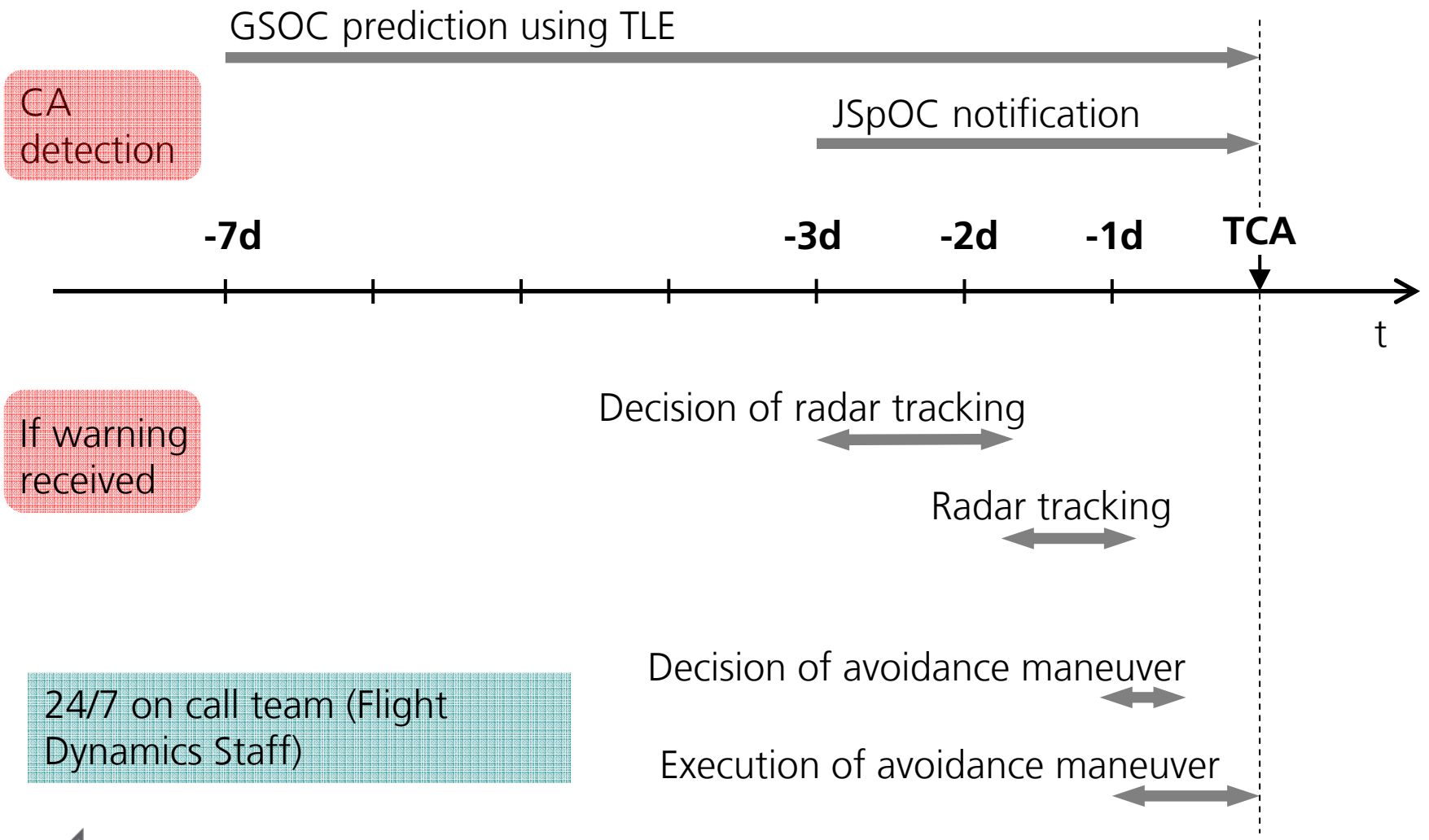
Example of TLE Statistics (1/2)



Example of TLE Statistics (2/2)



Conjunction Avoidance Timeline



Maneuver Strategy for TerraSAR-X and TanDEM-X (1/3)

Mission Characteristics

- TerraSAR-X (TSX, launch 2007), TanDEM-X (TDX, launch 2010)
- Radar Satellites flying in a close formation (with TSX as Reference)
- TSX is controlled against a reference orbit inside a tube of 250 m radius
- TDX is flying in a close formation with TSX in a relative distance < 500 m
- Tube control currently requires 1 orbit control maneuver (~ 2 cm/s) per day (planned for TSX and duplicated with TDX)
- Number of Tube control maneuvers is increasing with higher solar activity
- Formation control requires 2 maneuvers (~ 4 mm/s) per day executed by TDX only

Maneuver Strategy for TerraSAR-X and TanDEM-X (2/3)

TSX/TDX Collision Avoidance Process

- Tube and formation flight requirements shall be violated to a minimum (tight 3 years measurement schedule)
- Investigation of scenarios for shifting planned maneuvers to avoid additional maneuvers
- Analysis of these scenarios with respect to
  - Safe collision avoidance
  - Compliance of tube and formation keeping requirements
  - Compliance with observation plan (in strong coordination with mission planning and mission operations)
  - Compliance with ground station availability (for uploading of maneuver commands)
- Implementation of the selected scenario (including modified observation plan, if necessary)
- In case of violation of tube and formation requirements a recovery operations is to plan and implement after execution of collision avoidance maneuver

Maneuver Strategy for TerraSAR-X and TanDEM-X (3/3)

TSX/TDX Collision Avoidance Maneuver Strategy

- TSX collision avoidance
  - Change execution time/size of regular maneuver, TDX replicates the maneuver
  - TSX perform two maneuvers (for collision avoidance and for re-acquisition of reference orbit)
    - TDX replicates the maneuvers (fuel-expensive)
    - TDX remains passive → formation has to be re-acquired afterwards (time-consuming)
- TDX collision avoidance
  - TDX performs several maneuvers for collision avoidance and formation re-acquisition
  - TSX remains passive

TerraSAR-X Close Approach to Pegasus Debris (1/3)

TCA	[UTC]	2010/08/07 13:19:35
Object		Pegasus debris (ID 24978)
Estimated size		~10 cm (RCS: 0.010 m^2)
Perigee/apogee of object	[km]	464 / 1181 (*e*:0.044, *i*: 81.5°)
Relative velocity	[km/s]	15.1
Orbital plane angle	[deg]	160

- Warning from JSpOC, TCA-1.5 days
- Detected also by the daily (TLE) monitoring since TCA-7days (max Prob. >1.0E-04)

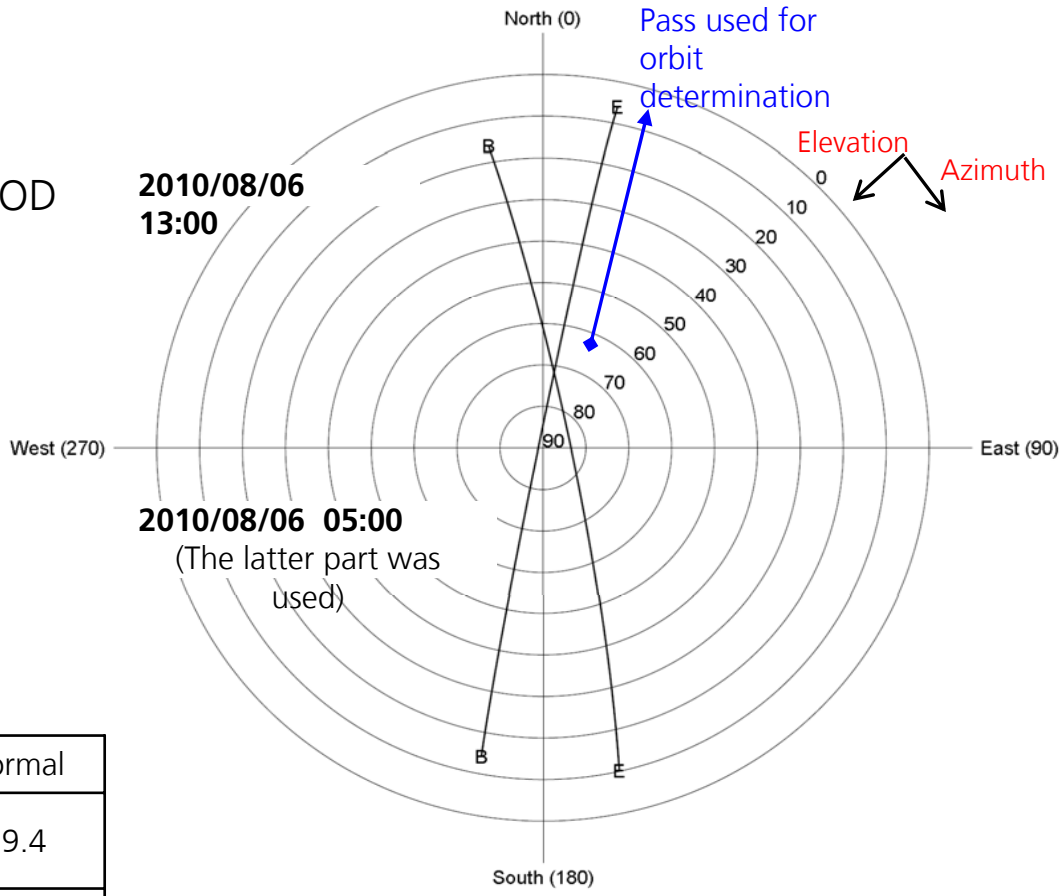
Close Approach Prediction

	JSpOC warning (TCA-1.5d)	GSOC analysis (TCA-1.5d)	Daily prediction (TCA-1d)
TSX orbit	JSpOC	TSX precise	TSX precise
Debris orbit	JSpOC	JSpOC	TLE
Probability	N/A	3.4E-04	1.4E-05
Min.distance [m]	90	**81**	1064
Rel.distance (RTN) [m]	(69; -7; -58)	(**71**; 5; 39)	(166; -184; -1035)

TerraSAR-X Close Approach to Pegasus Debris (2/3)

Orbit refinement using TIRA radar

- 1.5-1.0 day before TCA
- Data arc of ~10 hours was used for OD
- Accuracy improvement, especially in radial direction of 2.5 m



Orbit Error at TCA (1-sigma, in [m])

	Radial	Along-track	Normal
Radar tracking (TCA - 1.0 d)	2.5	16.3	29.4
JSpOC (TCA - 1.5 d)	12	135	18

TerraSAR-X Close Approach to Pegasus Debris (3/3)

After the radar tracking, a collision avoidance maneuver was decided

- Increase of radial separation ~150 m
- 2 maneuvers, for collision avoidance and coming back a half orbit before/after TCA
- Each maneuver was ~5 cm/s and ~64 g hydrazine was used in total

Latest Prediction with / without Maneuver

	FHR tracking (TCA-1d)	Incl. maneuver (TCA-0.8d)
TSX orbit	TSX precise	TSX precise
Debris orbit	Radar tracking	Radar tracking
Probability	1.1E-03	1.7E-05
Min.distance [m]	216	337
Rel.distance (RTN) [m]	(-19; -31; -213)	(-165; -46; -291)
Orbital arc distance [m]	13	174

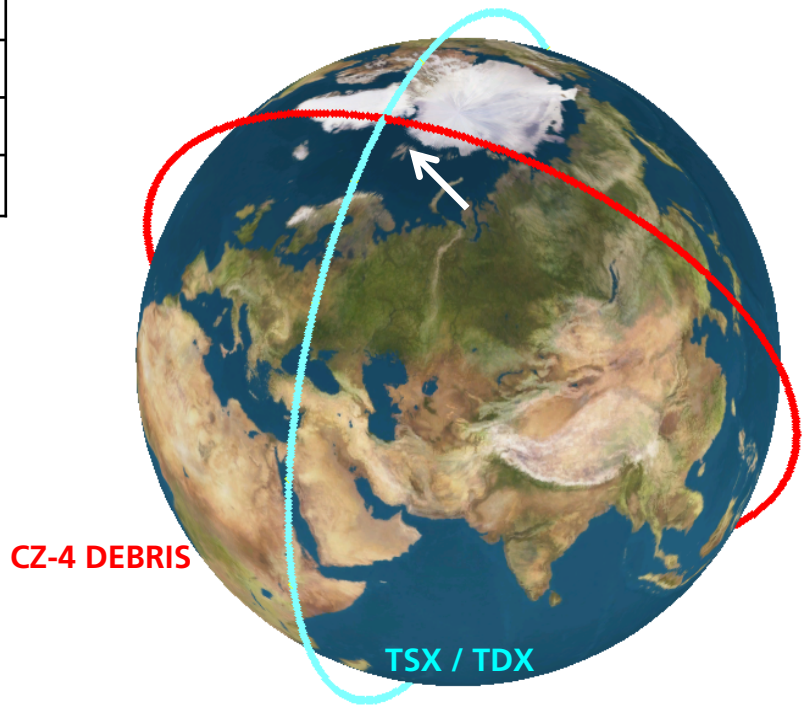
TSX/TDX Close Approach to CZ-4 Debris (1/4)

TCA	[UTC]	2011/03/25 15:08:11
Object		CZ-4 debris (ID 26278)
Estimated size		~15 cm from RCS
Perigee/apogee of object	[km]	490 / 506 (*e*:0.001, *i*: 98.5°)
Relative velocity	[km/s]	10.8
Orbital plane angle	[deg]	90

First critical CA,
since TSX-TDX formation was achieved

- Warnings from JSpOC, TCA-3 days and -0.5 day
- No Pre-warning from TLEs
- Radar tracking was not available

	TDX	**TSX**
Primary orbit	TDX precise	TSX precise
Secondary orbit	JSpOC	JSpOC
Probability	2.8E-05	6.8E-06
Min.distance [m]	**88**	186
Rel.distance (RTN) [m]	(**-87**; -9; -9)	(173; -50; -50)
1-sigma primary [m]	(**6**; 191; 5)	(2; 69; 1)
1-sigma secondary [m]	(**20**; 876; 11)	(20; 876; 11)



Prediction results by GSOC

TSX/TDX Close Approach to CZ-4 Debris (2/4)

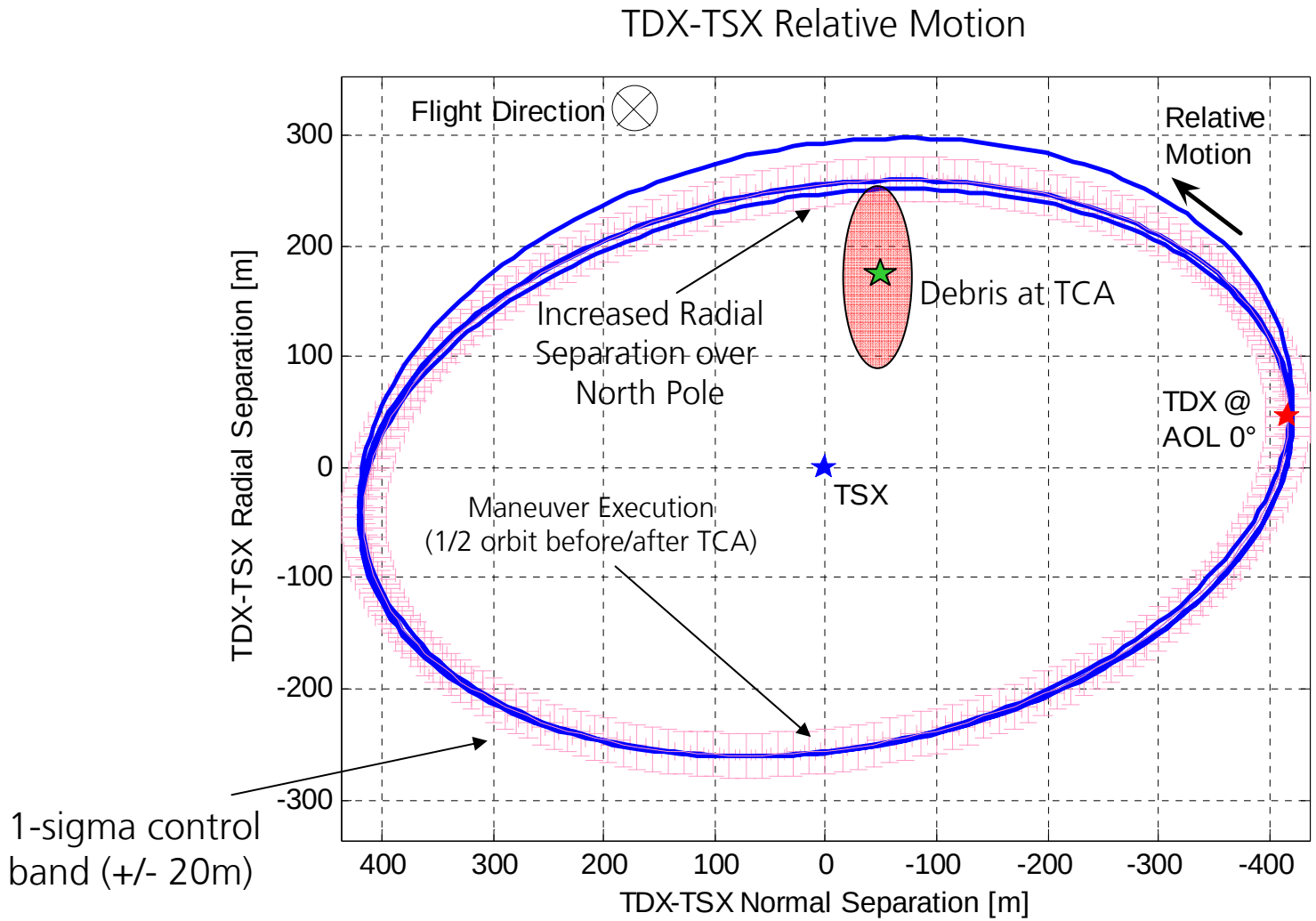
A collision avoidance maneuver was decided for TanDEM-X

- Increase of radial separation ~40 m
- 2 maneuvers, for collision avoidance and coming back a half orbit before/after TCA
- Each maneuver was ~1 cm/s and ~14 g hydrazine was used in total

Latest Prediction with / without maneuver

	without maneuver (TCA-0.4d)	Incl. maneuver (TCA-0.4d)
TSX orbit	TDX precise	TDX precise
Debris orbit	JSpOC	JSpOC
Probability	2.8E-05	1.3E-05
Min.distance [m]	88	136
Rel.distance (RTN) [m]	(-87; -9; -9)	(-125; 38; 38)
Orbital arc distance [m]	87	125

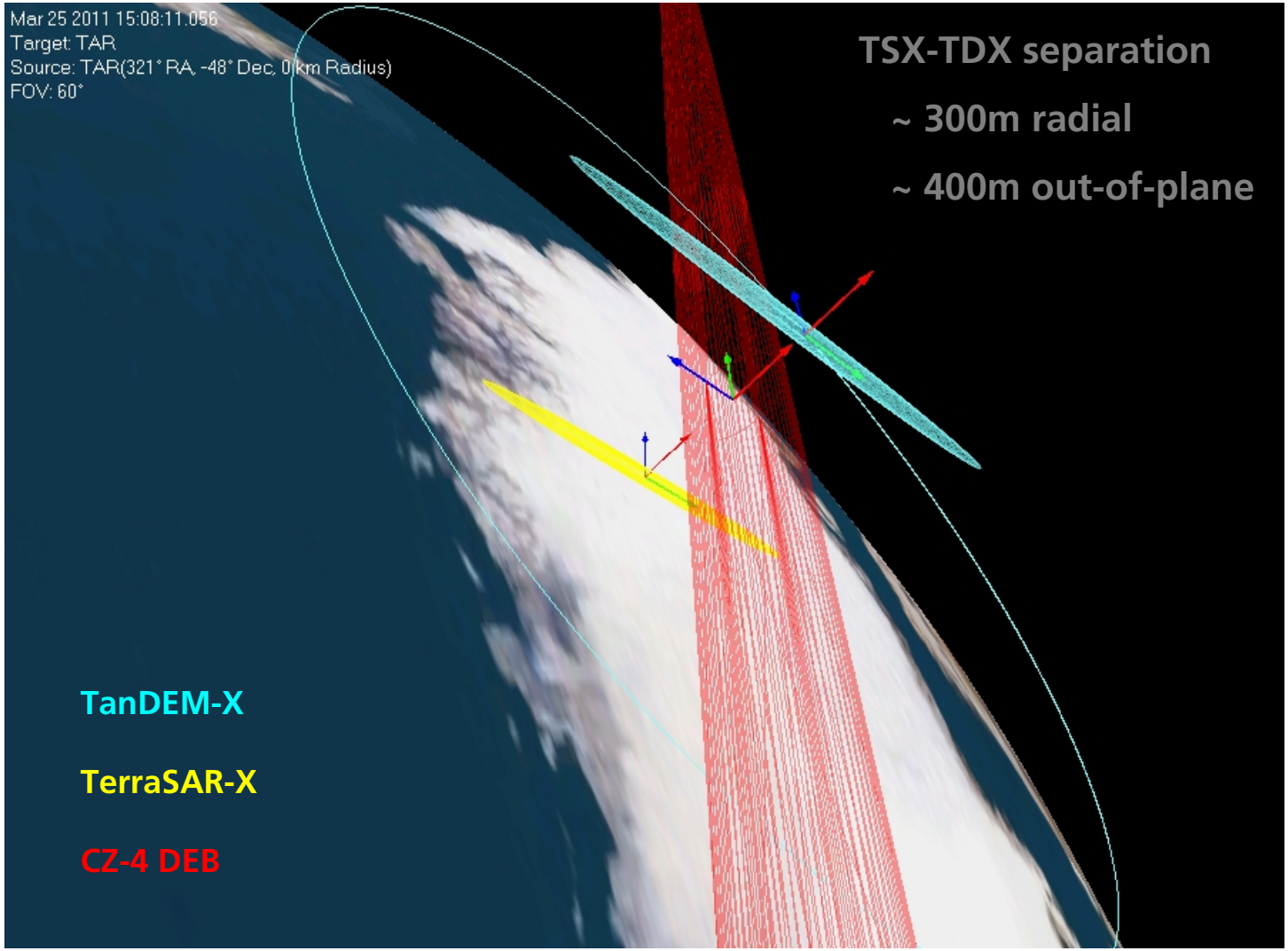
TSX/TDX Close Approach to CZ-4 Debris (3/4)



SAR instrument operation

→ not affected

TSX/TDX Close Approach to CZ-4 Debris (4/4)



Statistics of Events

Number of Handled Close Approaches (as of January 2011)

	Altitude	Record since	Analyzed	JSpOC warning	Maneuver
TerraSAR-X	514 km	Aug. 2009-	12	5	3
TanDEM-X	514 km	Jun. 2010-	7	3	2
GRACE-1	460 km	Nov. 2009-	3	3	0
GRACE-2	460 km	Nov. 2009-	0	0	0
PRISMA	750 km	Mar. 2011-	2	2	0

Future Work

Enhancement of the System

- Further Analysis Tools
- Further Automation of Process
- Geostationary Missions (Orbit Determination based on Optical Measurements)