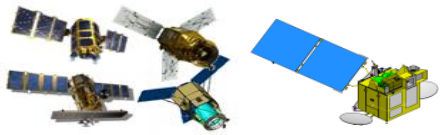


Enhancement Software Package for Collision Risk Mitigation in KARI

Jaedong Seong*, Okchul Jung, Deawon Chung

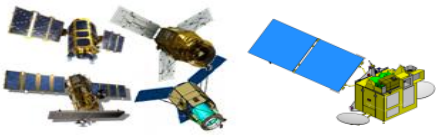
9 November 2018

21th IWLR, Canberra, Australia



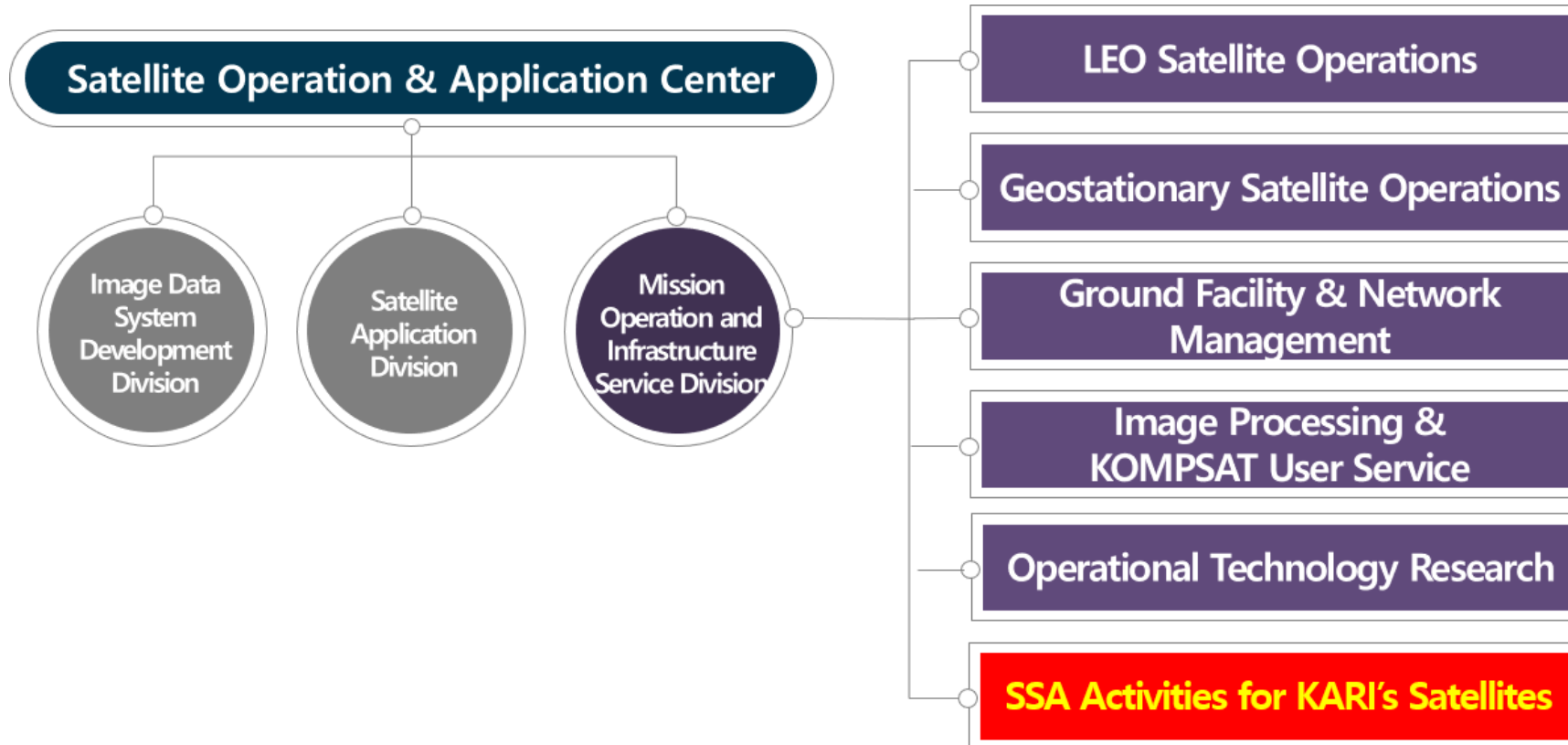
Background

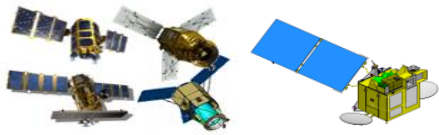
- 1. Satellite Operation & Application Center**
- 2. KARI's Role in SSA Activities**
- 3. KARI Satellite Operations**
- 4. Conjunction Assessment & Mitigation**



Satellite Operation & Application Center

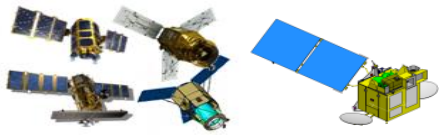
- Specialized national agency dedicated to satellite operations and satellite information applications
- Organizational Structure





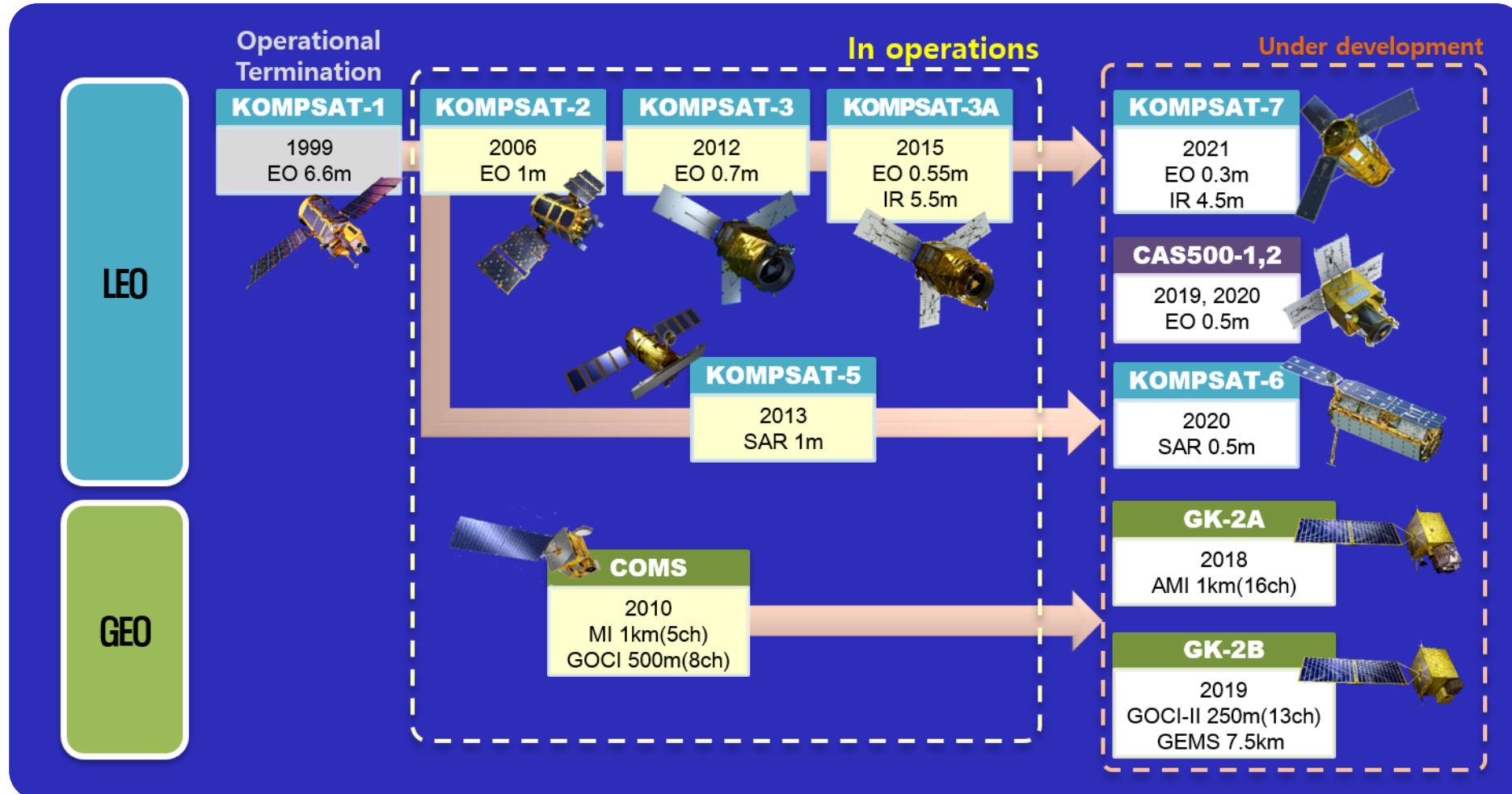
KARI's Role in SSA Activities

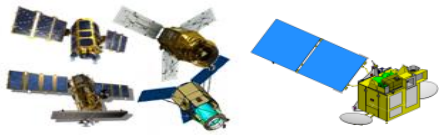
- **SSA Activities is in KARI's Articles of Association**
 - **Collision Risk Managements for National Space Assets (Satellites, Launch Vehicles)**
 - **Development of Space Debris Risk Mitigation Technologies**
- **Documentation**
 - The government (Ministry of Science, ICT and Future Planning) has released the document, 'Manual for Space Hazards'
 - In accordance with government document, the KARI also revised the operational manual
 - **Doc. ID: KMO-QP-740-001**
 - **Doc. Title: Operational Manual against the Conjunction Events**
 - **Doc. Version: Rev. 4**
 - **The first version was released in 2010**
 - **The document is being updated as required**
 - **The revision 4 includes the comprehensive instructions with respect to the detail activities against the conjunction events**



KARI Satellite Operations

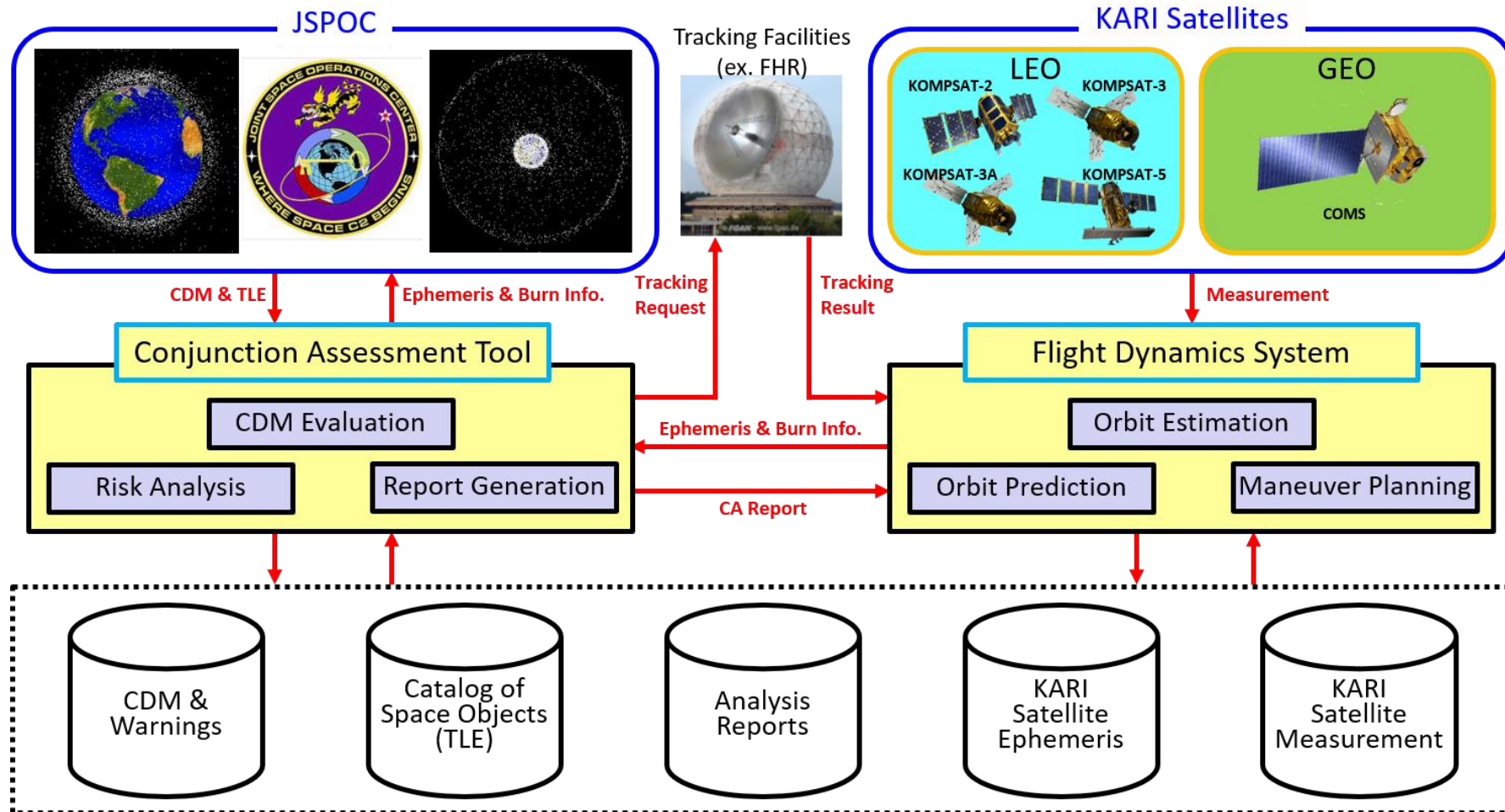
- KARI Satellites in Operation (As of 2018)

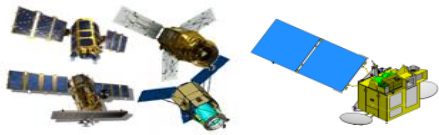




Conjunction Assessment & Mitigation (1/3)

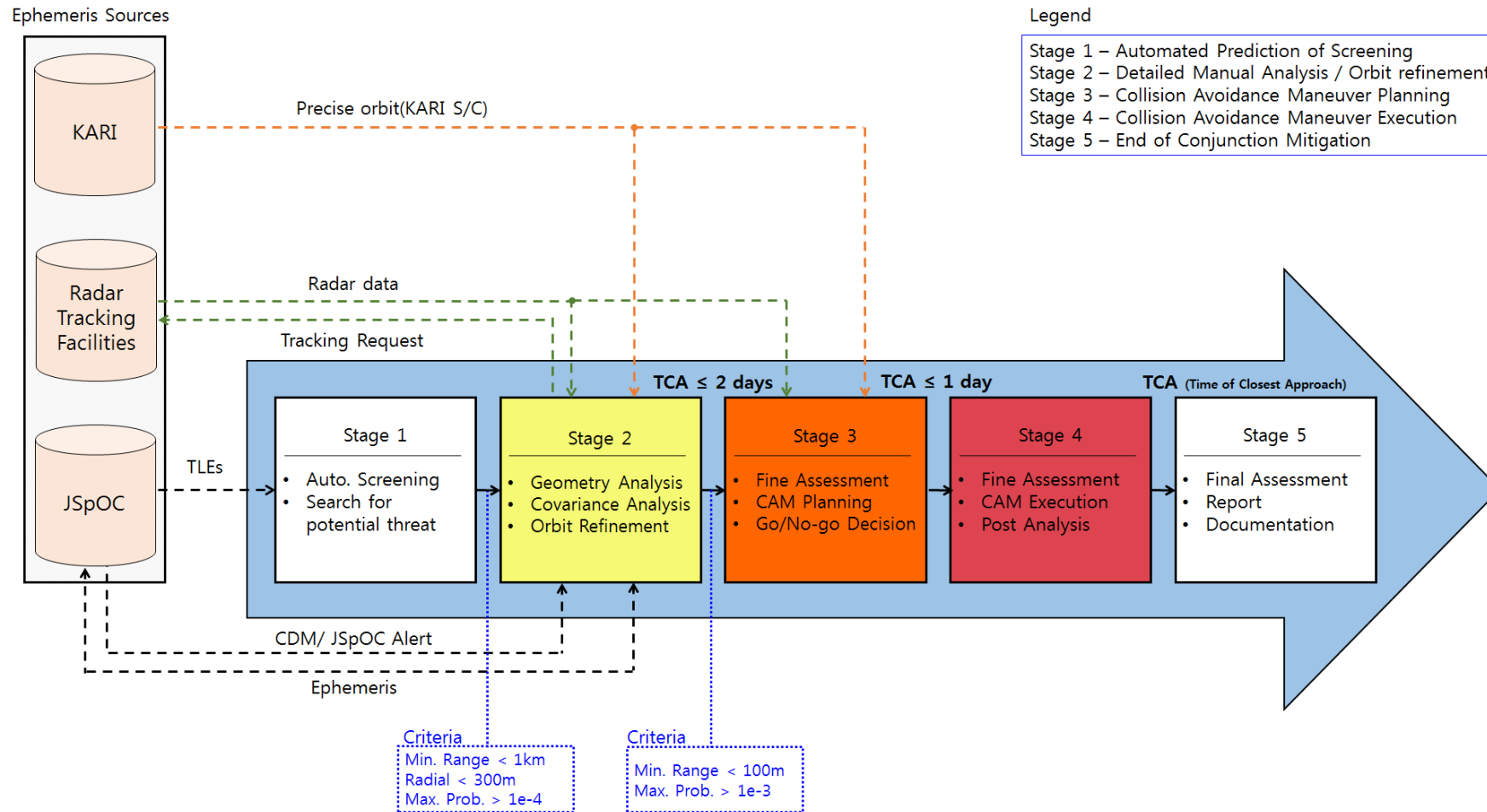
- Overview of KARI Activities for SSA

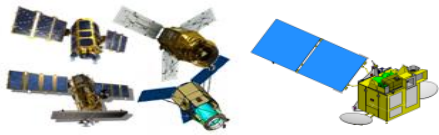




Conjunction Assessment & Mitigation (2/3)

Operational Procedure





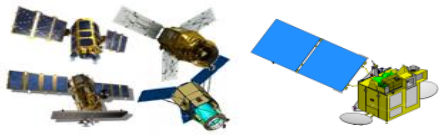
Conjunction Assessment & Mitigation (3/3)

• CA Criteria & Results

Action	Data	Time to TCA (day)	Orbit	Min Range (m)	Radial Dist (m)	Coll. Probability
Weekly & Monthly Report	TLE, CDM	7	LEO	1000	300	1.00E-04
			GEO	5000		
Fine Assessment	CDM	3	LEO	500		
			GEO	3000		
JSpOC EPH Transfer	CDM	3	LEO	300		
			GEO	2000		
COLA	CDM, Other	2	LEO	100		1.00E-03
			GEO	3000		

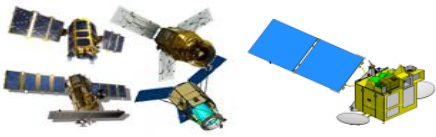
Action	KOMPSAT-1	KOMPSAT-2	KOMPSAT-3	KOMPSAT-5	KOMPSAT-3A	COMS	TOTAL
Weekly & Monthly Report	2	12	13	22	15	3	67
Fine Assessment	0	5	6	8	6	0	25
JSpOC EPH Transfer	0	4	5	8	2	0	19
COLA	0	0	0	1	0	0	1
TOTAL	2	21	24	39	23	3	112

CA Results (1 Jan 2018 ~ 31 Aug 2018)



Issues

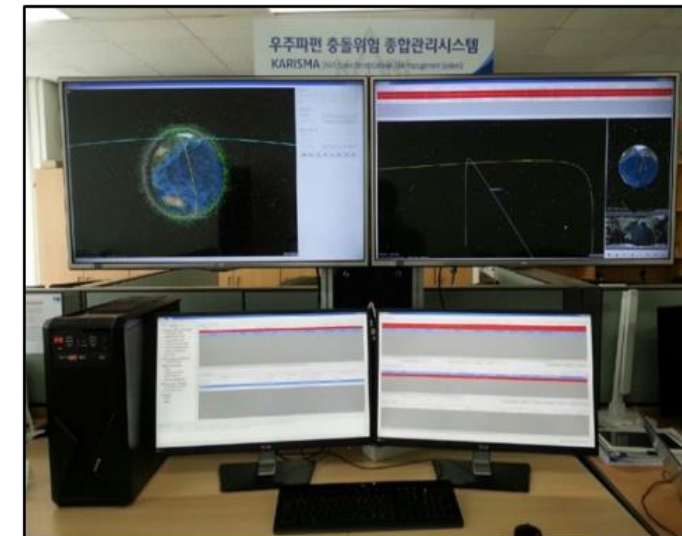
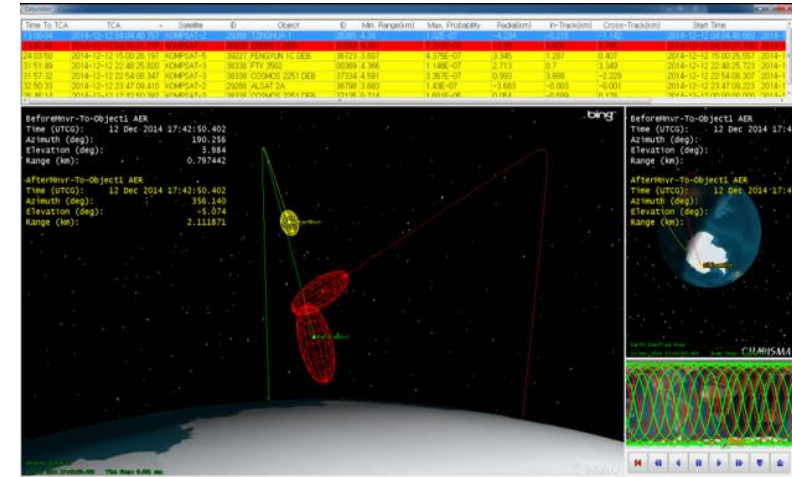
- 1. Existing CA Tool: KARISMA**
- 2. KOMPSAT-5 vs. FENGYUN 1-C DEB**
- 3. Normal Maneuver & Conjunction Risk**
- 4. Etc.**

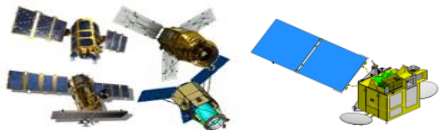


Existing CA Tool: KARISMA

- **Tool : KARISMA (KARI Space Debris Collision Risk Management System)**

- 24/7 Operational (Automated) SINCE August 2014
- COTS based conjunction assessment tool (AGI/STK)
- Major Functions
 - **Conjunction Assessment**
(Coarse using TLE, Fine using CDM)
 - **Optimized Collision Avoidance Maneuver Planning**
 - **Precise Orbit Determination & Prediction**
- Data Sources
 - **JSPOC TLE (download twice a day)**
 - **JSPOC CDM (download every 2 hours)**
 - **Precise Ephemeris (In-house ephemeris of KARI satellite)**
 - **Radar Tracking Data**
(External Sources-FHR[Germany], if necessary)

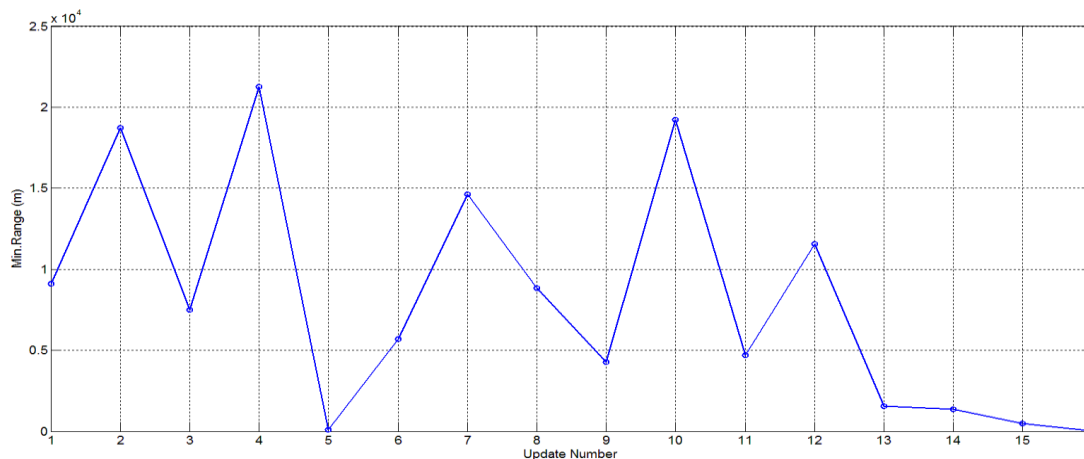




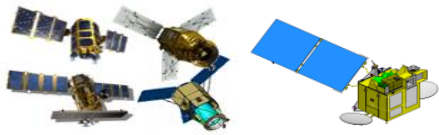
KOMPSAT-5 vs. FENGYUN 1-C DEB

- Conjunction event at 3 Mar 2018 04:28:51 (UTC) over North Pole
- FENGYUN 1-C DEB was small object (RCS = 0.02m²)
- Total 16 CDM were provided from JSpOC (Latest CDM arrived 2 hours before TCA)
- Min. range of CDM was changed dramatically (11,553m > 1,546m > 1,380m > 475m > **17m (TCA - 2Hr)**)
- There was not enough time for collision avoidance maneuver planning and execution

- Maneuver planning
- Conjunction assessment
- Generate maneuver command
- Contact and upload command
- Execution maneuver



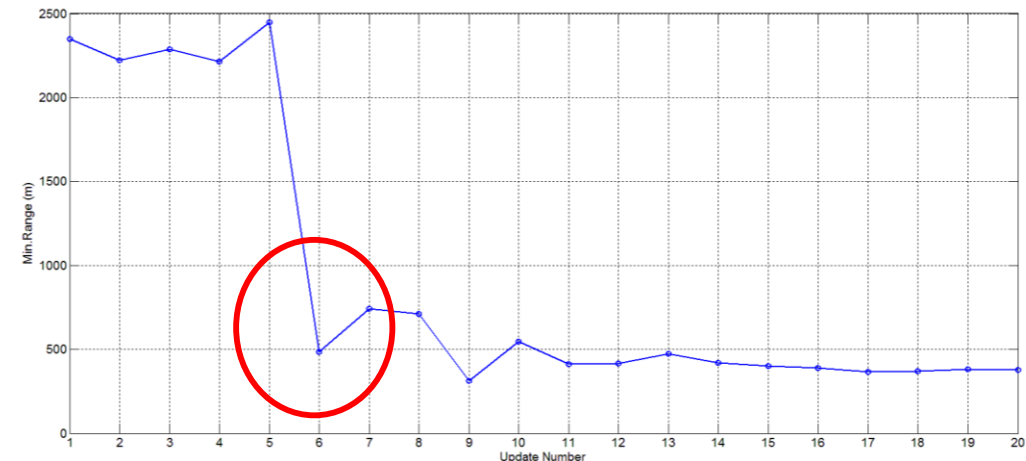
Minimum Distance at TCA w.r.t Updated CDM



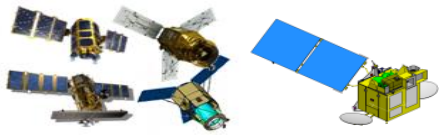
Normal Maneuver & Conjunction Risk

Mane. (2017/11/16 23:00:00, Alt. +10m)		Before Mane.	After Mane.
COSMOS 2251 DEB	Min. Range	43m	1,491m
	Coll. Probability	5.2E-03	1.0E-06
FENGYUN 1-C DEB	Min. Range	2,448m	377m
	Coll. Probability	1.0E-06	1.5E-05

- KOMPSAT-5 performs regular maneuver for InSAR mission twice a month .
- After maneuver, conjunction risk of COSMOS 2251 DEB was decreased but another object (FUNGYUN 1-C DEB) was much closer than before.

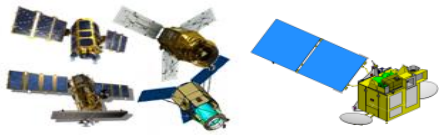


→ **KARI shares the maneuver plan with JSpOC,**
JSpOC reflects the information in conjunction assessment



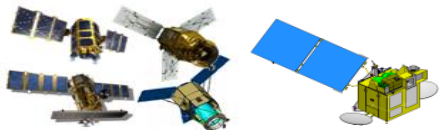
Etc.

- Automated documentation
- Trend analysis
- Browsing object information
- GEO station keeping box monitoring
- Statistics



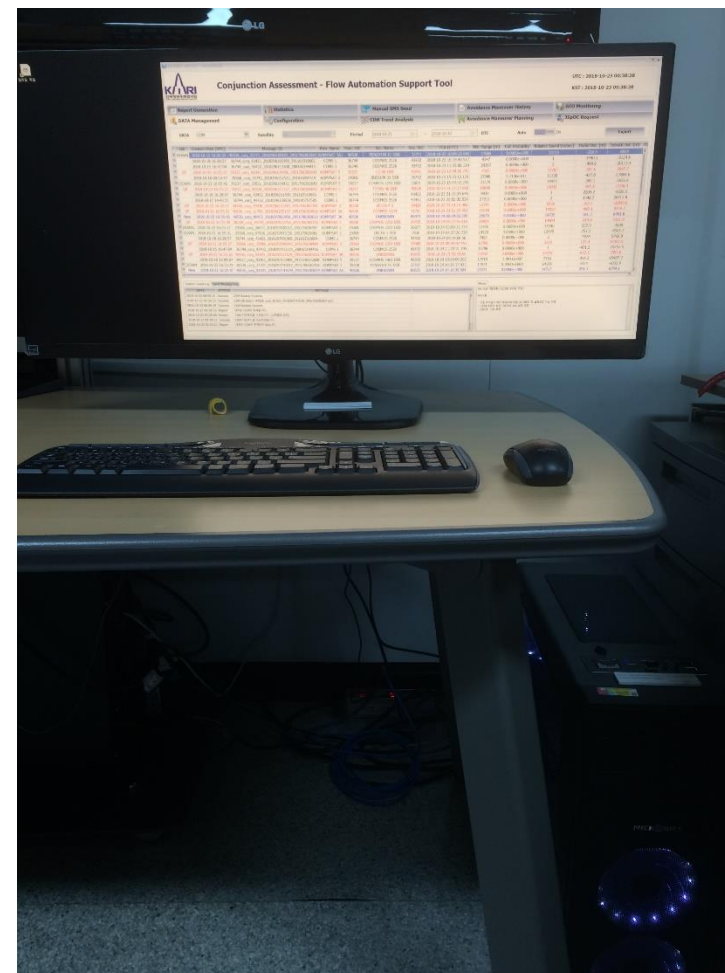
Enhancement Software Package: CA-FAST

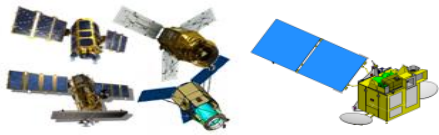
1. CA-FAST
2. Data management
3. CDM trend analysis
4. Avoidance maneuver planning
5. JSpOC Interface
6. Report generation
7. GEO monitoring



- **Conjunction Assessment Flow Automation Support Tool**

- 24/7 Operational (Automated) SINCE October 2016
- COTS based conjunction assessment tool (AGI/STK)
- 1 Desktop PC
 - **Window 10 (64bit), I7 8700k, 32GB RAM, SSD storage**
- Development language: C#, MATLAB
- Functions
 - **Data management**
 - **CDM trend analysis**
 - **Avoidance maneuver planning**
 - **JSpOC Interface**
 - **Report generation**
 - **GEO monitoring**
 - **Statistic**





Data management

- JSpOC CDM are mainly used automatically (updated every 30 min.)
- E-mail and SMS Alarm available when risk event reaches specific criteria

CA-FAST ver 2.3 2018/09/30

Conjunction Assessment - Flow Automation Support Tool

UTC : 2018-10-22 12:28:12
KST : 2018-10-22 21:28:12

Report Generation | Statistics | Manual SMS Send | Avoidance Maneuver History | GEO Monitoring
 DATA Management | Configuration | CDM Trend Analysis | Avoidance Maneuver Planning | JSpOC Request

DATA: CDM | Satellite: ALL | Period: 2018-10-22 ~ 2018-10-29 | UTC | Auto: On | Export

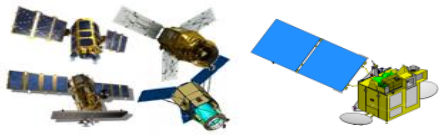
risk	Creation Date (UTC)	Message ID	Prim. Name	Prim. SSC	Sec. Name	Sec. SSC	TCA (UTC)	Min. Range ... Δ	Col. Probability	Relative Speed (m/sec)	Radial Dist. (m)	Intrack Dist. (m)	Cro
New	2018-10-22 07:18:06	38338_conj_81451_2018300182551_2950731082385	KOMPSAT 3	38338	UNKNOWN	81451	2018-10-27 18:25:51.431	1594	0.0000e+000	4049	-344	1499.1	
New	2018-10-18 16:28:57	36744_conj_43432_2018297215327_291163310605	COMS 1	36744	COSMOS 2526	43432	2018-10-24 21:53:27.71	1841	0.0000e+000	1	1755.8	-512.8	
New	2018-10-22 07:17:06	29268_conj_35856_2018299235547_295073108469	KOMPSAT 2	29268	IRIDIUM 33 DEB	35856	2018-10-26 23:55:47.221	3278	4.2149e-005	14569	69.4	786	
New	2018-10-22 07:18:12	29268_conj_82438_2018296004219_295073108474	KOMPSAT 2	29268	UNKNOWN	82438	2018-10-23 00:42:19.043	4109	0.0000e+000	14778	-152.4	706.9	
New	2018-10-18 16:28:57	36744_conj_43432_2018296101940_291163310602	COMS 1	36744	COSMOS 2526	43432	2018-10-23 10:19:40.517	4347	0.0000e+000	1	-3440.3	-2124.6	
New	2018-10-22 07:16:24	39227_conj_31539_2018301132754_2950731082673	KOMPSAT 5	39227	FENGYUN 1C DEB	31539	2018-10-28 13:27:54.78	4447	9.0013e-007	14970	356.1	-722.1	
New	2018-10-22 07:15:44	40536_conj_12904_2018300061840_2950731083040	KOMPSAT 3A	40536	SL-3 R/B	12904	2018-10-27 06:18:40.088	5053	0.0000e+000	15085	-76	-490.8	
New	2018-10-22 07:17:09	29268_conj_36599_2018301134046_295073108471	KOMPSAT 2	29268	PRISMA (MANGO)	36599	2018-10-28 13:40:46.907	5339	0.0000e+000	5077	136.5	-5027.3	
New	2018-10-22 07:16:24	39227_conj_31539_2018301115204_2950731082672	KOMPSAT 5	39227	FENGYUN 1C DEB	31539	2018-10-28 11:52:04.962	5371	7.5194e-009	14971	403.9	875.3	
New	2018-10-22 07:17:33	39227_conj_41041_2018296124456_2950731082679	KOMPSAT 5	39227	CZ-4B DEB	41041	2018-10-23 12:44:56.774	7185	0.0000e+000	13767	-390.9	3011.7	
New	2018-10-18 16:28:57	36744_conj_43432_2018297091908_291163310604	COMS 1	36744	COSMOS 2526	43432	2018-10-24 09:19:08.56	7493	0.0000e+000	1	-4224	5763.9	
New	2018-10-20 23:23:57	38338_conj_35627_2018299175713_2932345142334	KOMPSAT 3	38338	IRIDIUM 33 DEB	35627	2018-10-23 17:57:13.469	7565	0.0000e+000	15007	-494.9	524.1	
New	2018-10-18 16:28:58	36744_conj_43432_2018298221812_291163310607	COMS 1	36744	COSMOS 2526	43432	2018-10-23 17:57:13.469	9023	0.0000e+000	1	1402.6	8646.2	
New	2018-10-22 07:18:16	29268_conj_85042_2018299222724_295073108475	KOMPSAT 2	29268	UNIDENTIFIED	85042	2018-10-27 22:27:24.924	9098	0.0000e+000	4410	-333.7	8689.1	
New	2018-10-22 07:15:55	39227_conj_20666_2018299044753_2950731082667	KOMPSAT 5	39227	SL-3 R/B	20666	2018-10-27 04:47:53.161	9746	0.0000e+000	14881	464.2	1909.1	
New	2018-10-19 23:56:01	39227_conj_23232_2018298085952_2930008342628	KOMPSAT 5	39227	ARIAN 5	23232	2018-10-28 08:59:52.788	9829	3.6866e-010	13141	382.5	-6783.1	
New	2018-10-18 16:28:57	36744_conj_43432_2018296211539_291163310603	COMS 1	36744	COSMOS 2526	43432	2018-10-23 12:44:56.774	9939	0.0000e+000	1	2209.2	-9326.5	
New	2018-10-22 07:17:31	39227_conj_40528_2018296211537_2950731082678	KOMPSAT 5	39227	TITAN	40528	2018-10-27 21:15:37.691	10614	0.0000e+000	14933	-398.1	-1956.8	
New	2018-10-15 16:47:04	36744_conj_43432_2018298111156_288165144417	COMS 1	36744	COSMOS 2526	43432	2018-10-23 11:11:56.095	11417	0.0000e+000	1	-432.5	-11387.3	
New	2018-10-22 07:18:03	40536_conj_81035_2018297123529_2950731083045	KOMPSAT 3A	40536	UNKNOWN	81035	2018-10-24 12:35:29.913	11758	2.9279e-019	14724	-469.9	2907.2	
New	2018-10-22 07:17:08	29268_conj_36077_2018297030012_295073108470	KOMPSAT 2	29268	COSMOS 2251 DEB	36077	2018-10-24 03:00:12.739	12476	0.0000e+000	14340	359.4	-3603.6	
New	2018-10-22 07:17:23	38338_conj_39438_2018296231415_2950731082382	KOMPSAT 3	38338	VELOX-P 2	39438	2018-10-23 23:14:15.488	12722	0.0000e+000	9236	160.2	-9993.8	

System Event Log | Send Message Log

DATE	STATUS	MESSAGE
2018-10-22 20:50:23	Success	TLE Screening 작업이 수행되었습니다.
2018-10-22 20:50:23	Success	새로운 TLE Screening 결과가 경신되었습니다.
2018-10-22 20:50:25	Success	TLE Screening 결과를 정상적으로 DB에 추가하였습니다.
2018-10-22 20:50:25	Success	TLE Screening 결과를 성공적으로 백업하였습니다.
2018-10-22 21:00:00	Report	CDM 다운로드를 시작합니다. (스케줄링 동작)
2018-10-22 21:00:35	Success	CDM 다운로드를 성공하였습니다.
2018-10-22 21:00:46	Report	새로운 CDM이 존재하지 않습니다.

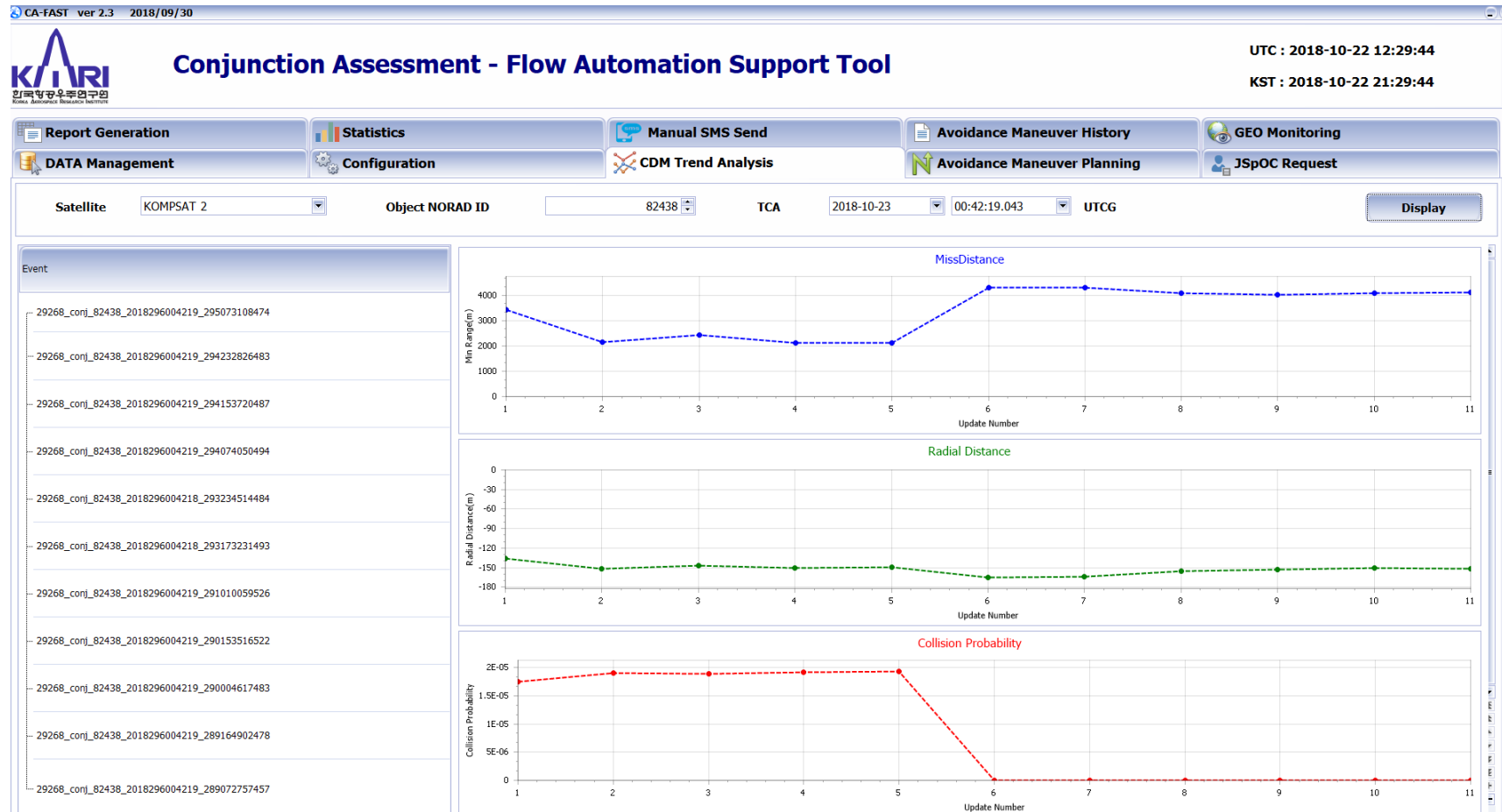
Memo

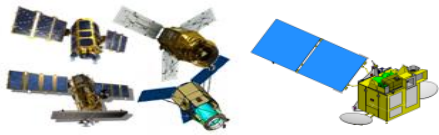
- <2016.12.12 Update>
- 1. KARISMA Result DB Insert Fail 예외처리
=> MessageBox(메시박스) 통합
- 2. KARISMA Result Backup시 과거 DATA 삭제
- 3. 그래프 10분 : SatCat Histogram X축 최대값 및 Step 설정 가능 컨트롤
- 4. Data Management, 데이터에서 DATA CDM 또는 KARISMA 설정되어 있는 경우에 따라 업데이트 표시
- 5. Trend Analysis : 그래프 색깔 및 X 축 1부터 시작 수정



CDM trend analysis

- CDM trend analysis from multiple CDM of specific conjunction event
- Min. Range, Radial Distance, Collision Probability (Foster's method)





Avoidance maneuver planning (1/2)

- Conjunction assessment for various maneuver cases in a short time
- Precise orbit prediction with maneuver using engine modeling and BC* estimation

CA-FAST ver 2.3 2018/09/30

Conjunction Assessment - Flow Automation Support Tool

UTC : 2018-10-22 12:57:09
KST : 2018-10-22 21:57:09

Report Generation | Statistics | Manual SMS Send | Avoidance Maneuver History | GEO Monitoring
 DATA Management | Configuration | CDM Trend Analysis | Avoidance Maneuver Planning | JSpOC Request

SETUP

General | Physical Properties | COLA

TCA: 2017-06-10 05:31:16.850

Searching Mode: On

Burn Start Time: 2017-06-09 23:20:00.000 Step: 0.5 hr Iter: 10

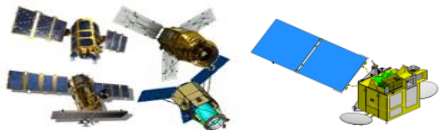
Burn Duration: -5 sec Step: 1 sec Iter: 10

COLA RESULT PLOT

Filled Contour Plot - Maximum Collision Probability

COLA MANEUVER and CA RESULT

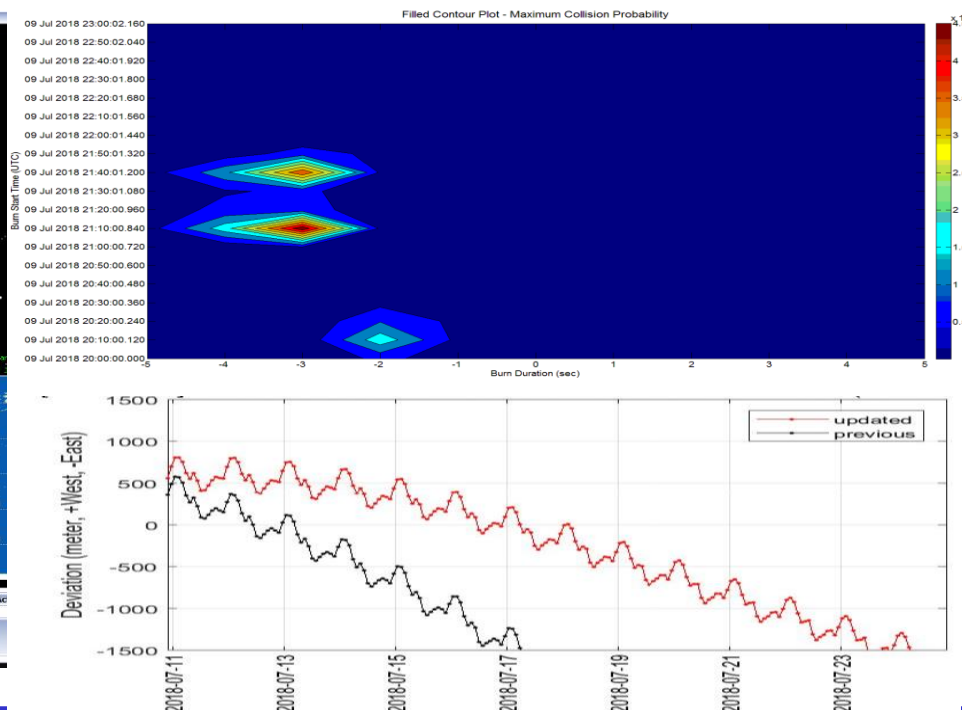
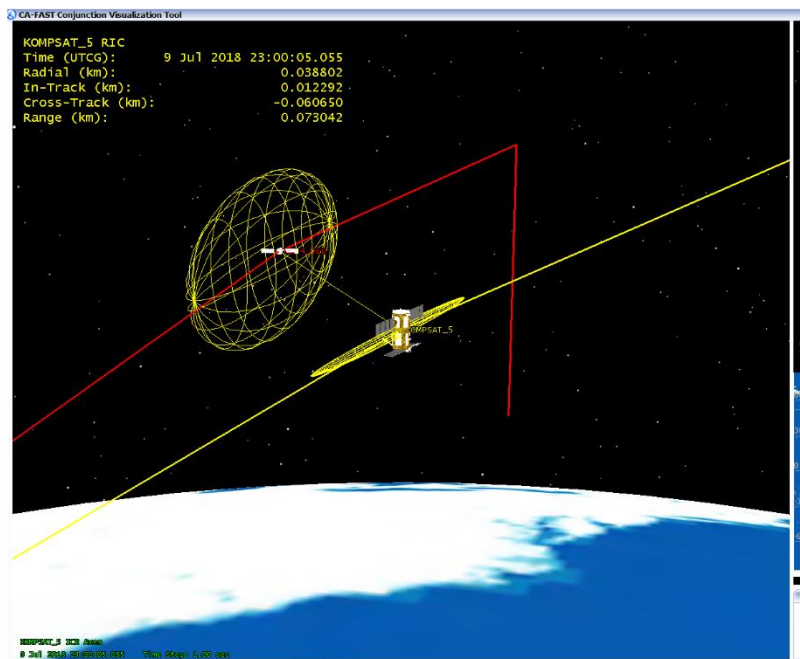
Maneuver Start Time (UTC)	Burn Duration (sec)	Pitch Angle (deg)	TCA (UTC)	Range (km)	Radial (km)	Intrack (km)	Crosstrack (km)	Max Probability	Analytic Probability	Numeric Probability	Patera Probability
09 Jun 2017 23:20:00.000	5	-90	10 Jun 2017 05:31:16.727	1.816	-0.19797	-1.4015	-1.1378	3.0851E-05	1E-305	0	4.1413E-19
09 Jun 2017 23:20:00.000	4	-90	10 Jun 2017 05:31:16.756	1.4763	-0.19908	-1.1357	-0.92194	4.6674E-05	1E-305	0	4.1413E-19
09 Jun 2017 23:20:00.000	3	-90	10 Jun 2017 05:31:16.784	1.1398	-0.20011	-0.8711	-0.70737	7.8274E-05	1E-305	0	3.7962E-19
09 Jun 2017 23:20:00.000	2	-90	10 Jun 2017 05:31:16.814	0.80234	-0.20146	-0.60289	-0.48957	0.00015785	1E-305	0	-2.0707E-19
09 Jun 2017 23:20:00.000	1	-90	10 Jun 2017 05:31:16.843	0.47908	-0.20259	-0.33701	-0.27368	0.00044147	1E-305	0	6.0395E-20
09 Jun 2017 23:20:00.000	0	90	10 Jun 2017 05:31:16.872	0.22414	-0.20363	-0.072673	-0.059086	0.0019858	1E-305	1.974E-309	3.0197E-20
09 Jun 2017 23:20:00.000	1	90	10 Jun 2017 05:31:16.901	0.32403	-0.20498	0.19482	0.15818	0.00096002	1E-305	0	3.0197E-19
09 Jun 2017 23:20:00.000	2	90	10 Jun 2017 05:31:16.930	0.6284	-0.2062	0.46081	0.37419	0.00025707	1E-305	0	-2.4158E-19
09 Jun 2017 23:20:00.000	3	90	10 Jun 2017 05:31:16.959	0.95567	-0.20719	0.72423	0.58809	0.00011131	1E-305	0	2.2432E-19
09 Jun 2017 23:20:00.000	4	90	10 Jun 2017 05:31:16.988	1.294	-0.20858	0.99135	0.805	6.075E-05	1E-305	0	3.4511E-19
09 Jun 2017 23:50:00.000	5	-90	10 Jun 2017 05:31:16.737	1.6899	-0.099631	-1.3097	-1.0633	3.5626E-05	1E-305	0	1.5875E-18
09 Jun 2017 23:50:00.000	4	-90	10 Jun 2017 05:31:16.764	1.374	-0.12046	-1.0626	-0.86281	5.3878E-05	1E-305	0	1.1734E-18
09 Jun 2017 23:50:00.000	3	-90	10 Jun 2017 05:31:16.791	1.059	-0.14143	-0.81469	-0.66158	9.0675E-05	1E-305	0	8.6278E-19

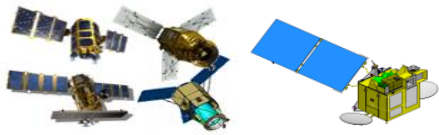


Avoidance maneuver planning (2/2)

- **Recent High-Risk Conjunction for KOMPSAT-5**

- Conjunction Event between KOMPSAT 5 and CZ-4 DEB (9 Jul 2018 23:00:05)
- Min. Range = 44m, Max. Probability = 2.8E-03
- Perigee Increasing Burn (TCA – 1 Hr) while maintaining the ground track boundary
- After avoidance maneuver, Max. Probability decreased to 7.17E-04





JSpOC Interface

- Orbit prediction data transfer after maneuver planning (normal and COLA)
- KARI-JSpOC(Space-track.org) interface through the API using cURL

CA-FAST ver 2.3 2018/09/30

KARI 한국항공우주연구원

Conjunction Assessment - Flow Automation Support Tool

UTC : 2018-10-22 12:58:45
KST : 2018-10-22 21:58:45

Report Generation | Statistics | Manual SMS Send | Avoidance Maneuver History | GEO Monitoring
DATA Management | Configuration | CDM Trend Analysis | Avoidance Maneuver Planning | JSpOC Request

User ID: Folder ID:
Password: EPH Folder:

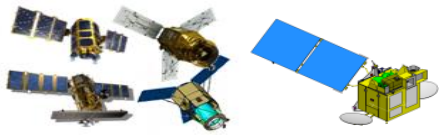
JSpOC Ephemeris Upload and Delete

File Name	Creation Time	Size
DIGITALGLOBE_GE0120170406.opm	2017-11-11 오후 2:43:53	654
International Conjunction Assessment Workshop 2017 CNES Pari...	2017-11-11 오후 2:43:53	15962
MEME_28474_GPS_1880000_operational_SVN61-DV_unclassifie...	2017-11-11 오후 2:43:53	1320136
MEME_29268_KOMPSAT2_0862300_operational_Unclassified.txt	2017-11-11 오후 2:43:53	25631
MEME_29268_KOMPSAT2_1270900_operational_Unclassified.txt	2017-11-11 오후 2:43:53	25733
MEME_29268_KOMPSAT2_1350600_operational_Unclassified.txt	2017-11-11 오후 2:43:53	25631
MEME_37393_Yahsat1A_1220000_OP_E_unclassified.txt	2017-11-11 오후 2:43:53	180736
MEME_37393_Yahsat1A_1690000_OP_I_unclassified.txt	2017-11-11 오후 2:43:53	204800
MEME_37393_Yahsat1A_1710000_OP_E_unclassified.txt	2017-11-11 오후 2:43:53	192768
MEME_38338_KOMPSAT3_0451700_operational_Unclassified.txt	2018-02-13 오후 1:26:10	25671
MEME_38338_KOMPSAT3_0871400_operational_Unclassified.txt	2017-11-11 오후 2:43:53	25704
MEME_38338_KOMPSAT3_1290800_operational_Unclassified.txt	2017-11-11 오후 2:43:53	25732
MEME_39227_KOMPSAT5_1310000_operational_Unclassified.txt	2017-11-11 오후 2:43:53	25684
MEME_39227_KOMPSAT5_1882100_spec_burn01_unclassified.txt	2018-07-09 오전 1:17:25	306697
MEME_39227_KOMPSAT5_1892300_operational_Unclassified.txt	2018-07-10 오전 2:14:58	306612
MEME_39227_KOMPSAT5_1892300_operational_Unclassified_...	2018-07-08 오전 8:04:31	306612
MEME_39227_KOMPSAT5_2160600_operational_Unclassified.txt	2017-11-11 오후 2:43:53	25638
MEME_40536_KOMPSAT3A_0260100_operational_Unclassified.txt	2017-11-11 오후 2:43:53	25675

JSpOC Response: **Good**

JSpOC Server

File Name	Uploaded Time	File ID	Size
/announcements_documents/2018 workshop FINAL.pdf	2018-08-05 22:30:11	499407	588660



Report generation

- Weekly and Monthly conjunction assessment summary
- Fine assessment report (Before TCA)
 - Outline
 - Trend analysis using CDM
 - Covariance analysis using CDM
 - Conjunction analysis (Primary: OP, Secondary: CDM)
- Post analysis report (After TCA)
 - Outline
 - Trend analysis using CDM
 - Trend analysis using TLE
 - Covariance analysis using CDM
 - CDM accuracy analysis for Primary object
 - Conjunction analysis (Primary: POD, Secondary: CDM)

문서번호 : CA-18-003-K5 작성일 : 2018-03-02 (금) 한국항공우주연구원 위성운영실

우주물체 충돌예측 상세분석 결과

○ 개 요

- 우주물체가 아리랑위성 5호 (S/C ID : 39227)에 가까이 접근함
 - 물체 종류 : FENGYUN 1C DEB (Catalog ID : 31785)
 - 근접 예상 시간 : 2018년 2월 27일 22:14:37 (UTC)
 - 근접 예상 위치 : 북극 상공

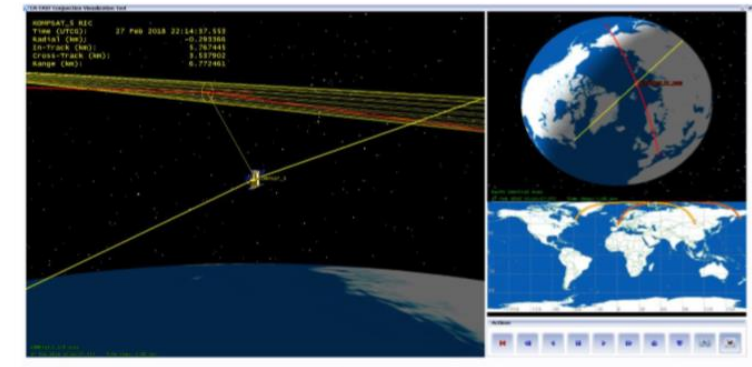
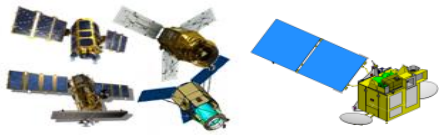


그림 1 3D Graphics(북극 상공)

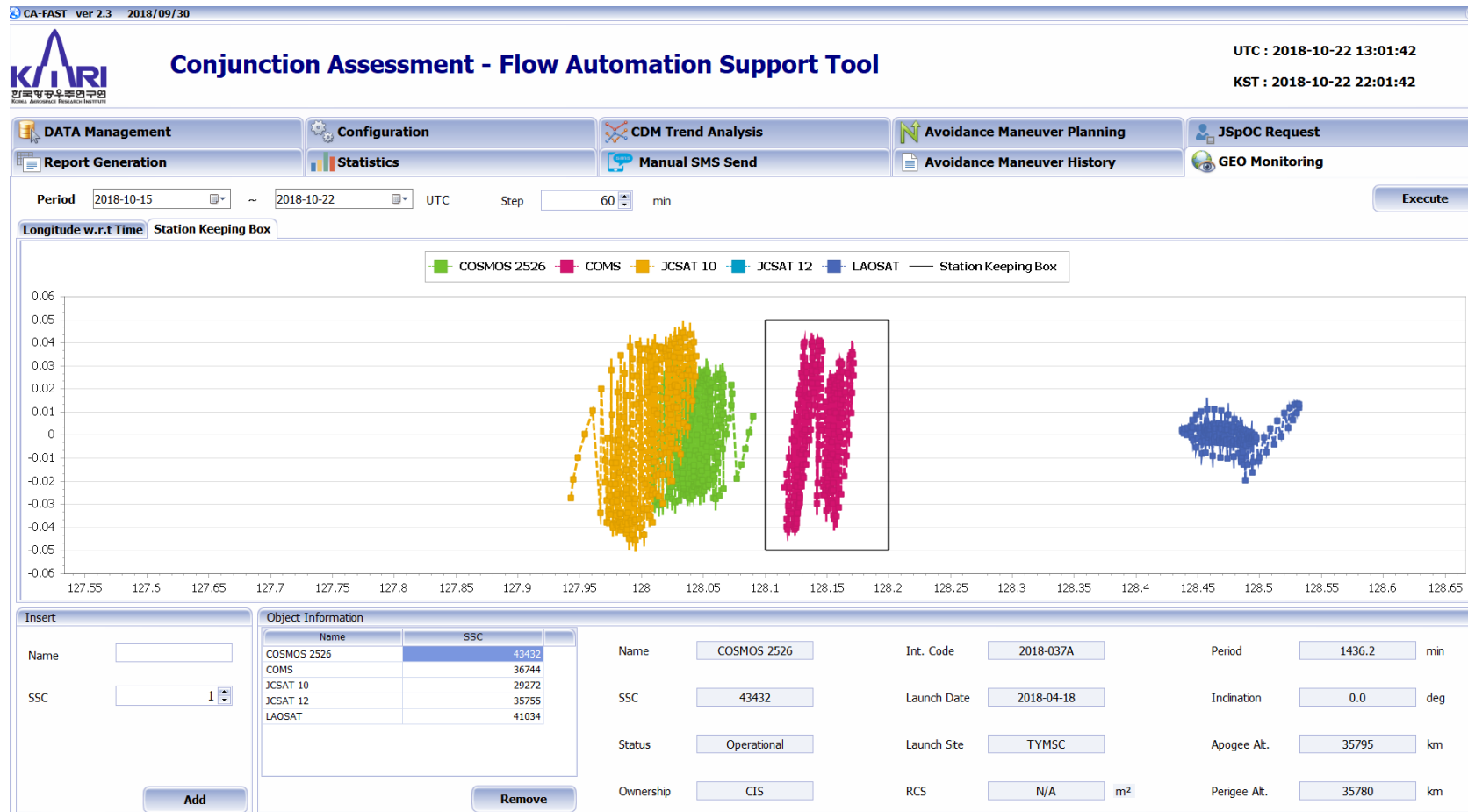
소유국	PRC	발사일	1999-05-10
궤도 장반경 (km)	6914	원지점 고도 (km)	562.4
궤도경사각 (deg)	96.5	근지점 고도 (km)	525.3
궤도 주기 (min)	95.4	RCS (m ²)	0.0087 (small)
상세 정보	해당 물체는 2007년 중국의 위성요격실험으로 발생한 폭발 파편이다.		

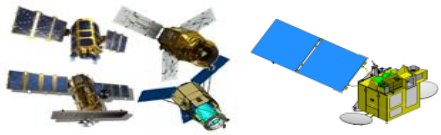
표 1 근접물체 정보



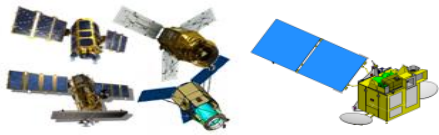
GEO monitoring

- GEO station keeping box monitoring around COMS using multiple TLE
- Identification potential risky objects, which intrudes station keeping box



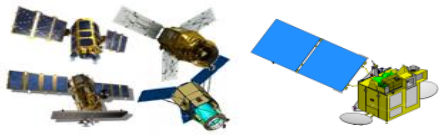


Summary



Summary

- **Enhanced software ‘CA-FAST’ developed to supplement existing CA tool**
- **Successful 2 years operation including collision avoidance maneuver planning**
- **Continuous update required to satisfy the varying operational environment**
- **Future work**
 - More automated and immediate system according to multiple satellites and complexity of satellite operations
 - External interface and data standardization with other group in preparation for Space Traffic Management



Thank You!