F6

軌道シミュレーションを用いた静止軌道上物体の複数地点観測の有効性評価

Evaluation of multi-site observation of GEO objects by simulation

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（静止）軌道上物体に対する複数地点からの観測は、三角測量からの類推から軌道決定精度の向上が期待される。本検討では、IHI富岡事業所を基準として、緯度・経度が異なる日本国内および海外の観測地点を設定して複数地点での光学観測での軌道決定精度（6要素）の比較と瞬時の軌道上物体の位置測定精度を軌道シミュレーションにより作成したデータを使用して比較評価を行った。実際の観測データには観測誤差が含まれるため、シミュレーションデータには観測誤差相当を白色雑音として加えている。また、複数地点で観測時刻が異なる場合についてもその影響を評価した。

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5th Space Debris Workshop

EVALUATION OF MULTI-SITE OBSERVATION OF GEO OBJECTS BY SIMULATION =SUMMARY=

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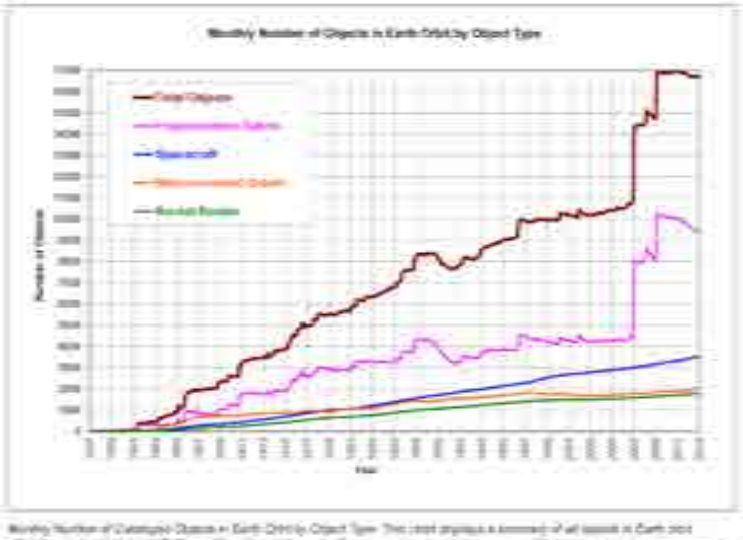
1. Introduction

- There exists **more than 16,000**※1 objects, not only active satellites but also inactive satellite and upper stage of launcher, fragments from those space systems on Earth orbit.
- It become appear that even the latest upper stage of launcher might be the cause of many on-orbit fragments, space debris, through Briz-M explosion on October 2012.
- Orbital Objects on GEO:

  1,557※2
  - Active satellites: 404
  - Fragments, etc: 378 (20※3)
- GEO is a unique, one and only orbit for many applications satellites, therefore it is most important topics to prevent debris generation due to collisions.



Ref.: NASA Orbital Debris Program Office, "Orbital Debris Quarterly News," Volume 17, Issue 1, January 2013

※1.: 2013年1月14日現在、米空軍が識別している軌道上物体は16,897個(SpaceTrack.org, "Satellite Situtation Report," January 14, 2013

※2: 2011年初期の時点。 V. Agapov, "Results of GEO and HEO space debris population research and asteroids study within the framework of ISON international project in 2011," 49th session of STSC of COUPUOS, 6-17 February 2012による。同時期に米空軍カタログでは、1016個。

※3: 米空軍のカタログに記載された個数。 出典は※2。

1. Introduction

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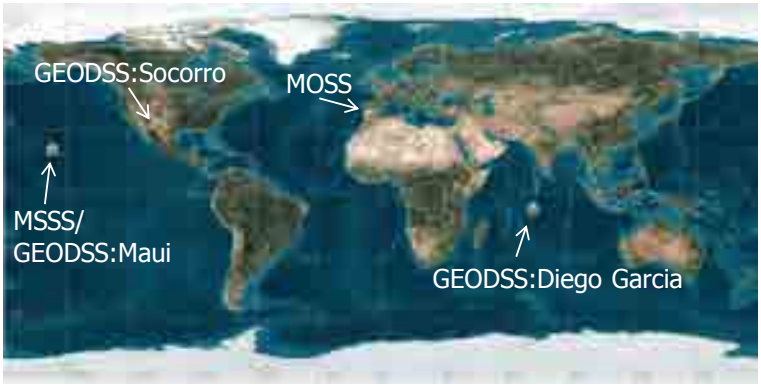
Space Situational Awareness on GEO regions is necessary for sustainable space utilization/GEO application.

- Orbital determination of the satellite around geo-stationary orbit is conducted by optically observed data.
  - Optical Observation Site of the US Space Surveillance Network: 4 sites

From the analogy of triangulation, it is supposed that the use of data observed from multiple sites give some advantages to improve the accuracy of orbit determination.



US Space Surveillance Network (SSN): Optical Site

Multi-site observation by small optical equipment might give comparable accuracies of orbital determination by large optical equipment on one site.

2. Assumptions

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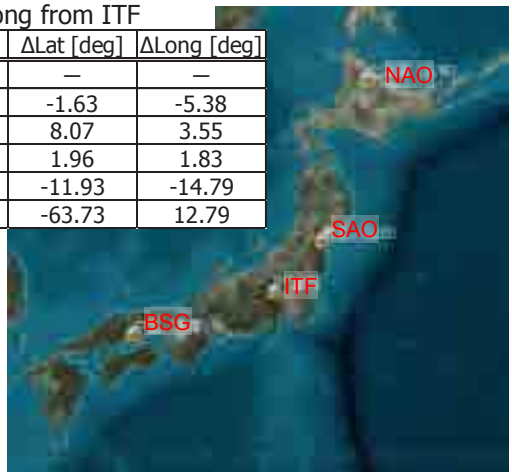
- Site Location:

Site		Lat. [deg]	Long. [deg]	Alt. [m]
IHI-Tomioka	ITF	36.2993	138.928	205
Bisei	BSG	34.6727	133.545	420
Hokkaido	NAO	44.3736	142.482	142
Sendai	SAO	38.2569	140.755	164
Okinawa	IAO	24.3736	124.140	176
Eastern Australia	QRO	-27.4333	151.717	400

Difference in Lat and long from ITF

Site		ΔLat [deg]	ΔLong [deg]
ITF		—	—
BSG		-1.63	-5.38
NAO		8.07	3.55
SAO		1.96	1.83
IAO		-11.93	-14.79
QRO		-63.73	12.79



2. Assumptions

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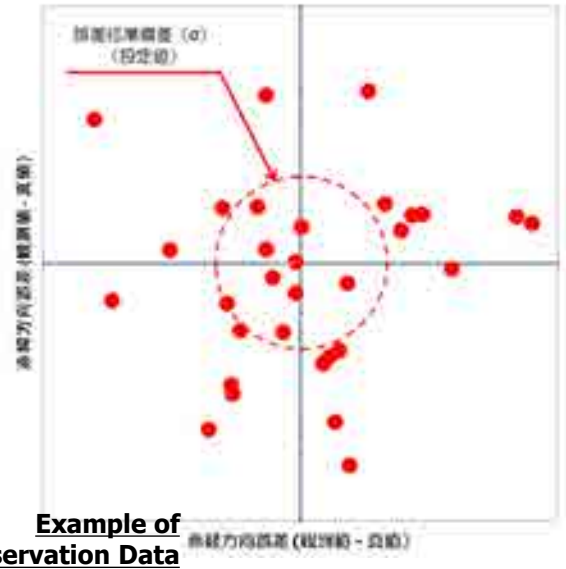
- Orbital Object to be observed:
  - Existing geo-stationary satellite was assumes for simulation.
    - NSS-6: TLE as follows。

      1 27603U 02057A 13010.45190851 .00000000 00000-0 10000-3 0 6205
      2 27603 0.0369 351.5205 0002994 296.6192 79.6083 1.00264833 36939

- Observation Data Generation:
  - 衛星軌道シミュレーションにより各観測拠点から各時刻での衛星方向を算出
  - 観測誤差は2変数（赤経・赤緯方向）正規分布すると仮定。
  - シミュレーションにより得られた方向に観測誤差を加えた値を、観測システムの分解能で離散化して観測データを算出。
    （観測誤差・分解能は小型望遠鏡相当を仮定）
  - Observation duration: 5 min/cycle
  - Data (image) sampling rate: 10 sec/data
  - Number of data (images): 31 data/cycle



Example of Observation Data

3. Simulation Results:

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3.1. Observation from Single site with interval

Two observation from single site with interval

- Site: IHI Tomioka (ITF)

	1st observation (UTC)	2nd observation (UTC)
Short duration (1 cyc)	2013/01/10 13:00～13:05	—
30 min interval	2013/01/10 13:00～13:05	2013/01/10 13:30～13:35
4 hour interval	2013/01/10 13:00～13:05	2013/01/10 17:00～17:05
24 hour interval	2013/01/10 13:00～13:05	2013/01/11 13:00～13:05

3. Simulation Results:

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3.1. Observation from Single site with interval

- Orbit determination (epoch: 2013/01/10 13:00:00)
  - ➢No determination of orbit for 24 hours interval case
  - ➢No valid result for observation with short duration(1 cycle of 5min)

		Short (1 cycle)	30m interval	4h interval	TLE
		ITF	ITF	ITF	
Result	Semi-major Axis (km)	-49,389.168	41,907.248	42,185.046	42,167.785
	Eccentricity	2.212463	0.005116	0.000099	0.000289
	Inclination (deg)	1.9475	0.1106	0.0975	0.0972
	RAAN (deg)	103.7830	46.9480	53.6280	53.3550
	Arg of Perigee (deg)	310.1164	153.7935	40.4848	241.6128
	True Anomaly (deg)	344.4558	199.2957	305.9146	105.0615
	Mean Anomaly (deg)	344.4558	199.4901	305.9238	105.0296
Error	Semi-major Axis (km)	-91,556.952	-260.537	17.261	
	Eccentricity	2.212174	0.004827	-0.000190	
	Inclination (deg)	1.850	0.013	0.000	
	RAAN (deg)	50.428	-6.407	0.273	
	Arg of Perigee (deg)	68.504	-87.819	-201.128	
	True Anomaly (deg)	239.394	94.234	200.853	
	Mean Anomaly (deg)	239.426	94.461	200.894	
Error(%)	Semi-major Axis (km)	-217.13%	-0.62%	0.04%	
	Eccentricity	766253.48%	1672.12%	-65.64%	
	Inclination (deg)	1903.60%	13.79%	0.31%	
	RAAN (deg)	94.51%	-12.01%	0.51%	
	Arg of Perigee (deg)	28.35%	-36.35%	-83.24%	
	True Anomaly (deg)	227.86%	89.69%	191.18%	
	Mean Anomaly (deg)	227.96%	89.94%	191.27%	

3. Simulation Results:

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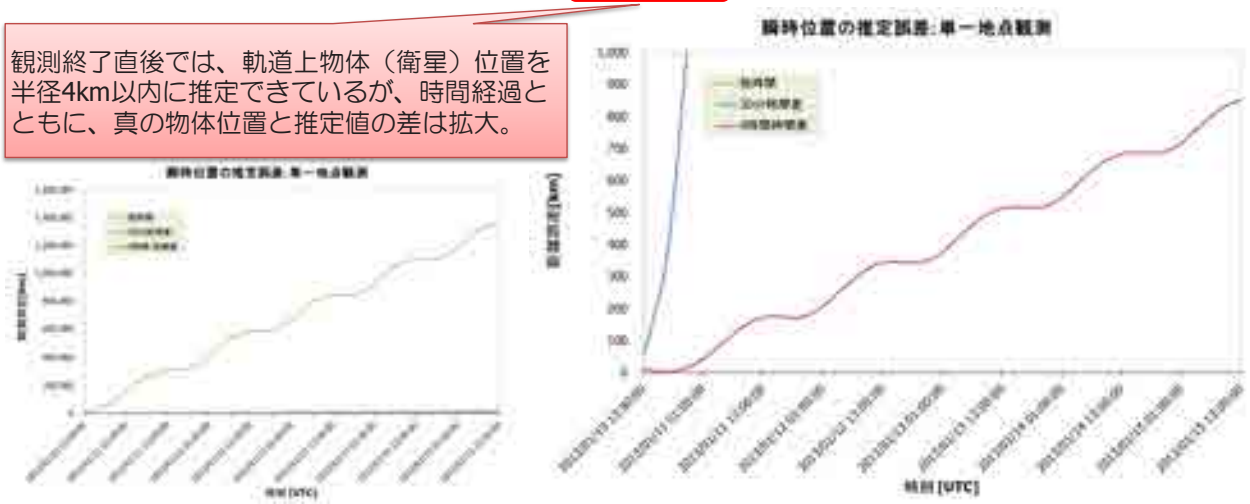
3.1. Observation from Single site with interval

衛星／宇宙デブリの衝突リスク評価には、瞬時の軌道上物体位置を正確に推定することが必要

- Position errors at time (Epoch: 2013/01/10 13:00:00)

		瞬時位置誤差[km]				
		元期	観測終了時	観測終了時刻[UTC]	最小値	観測終了時刻[UTC]
短時間観測	富岡	19,377.747	19,130.584	2013/01/10 13:05:00	17,779.719	2013/01/10 14:00:45
30分 時間差観測	富岡	62.067	77.242	2013/01/10 13:35:00	62.067	2013/01/10 13:00:00
4時間 時間差観測	富岡	11.725	3.566	2013/01/10 17:05:00	3.101	2013/01/10 17:47:55

観測終了直後では、軌道上物体（衛星）位置を半径4km以内に推定できているが、時間経過とともに、真の物体位置と推定値の差は拡大。



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3. Simulation Results:

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3.2. Two sites Observation

– Two sites observations with simultaneous or time interval

	IHI Tomioka (UTC)	Other (UTC)
Simultaneous	2013/01/10 13:00～13:05	2013/01/10 13:00～13:05
30 min interval	2013/01/10 13:00～13:05	2013/01/10 13:30～13:35
4 hour interval	2013/01/10 13:00～13:05	2013/01/10 17:00～17:05

3. Simulation Results:

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3.2. Two sites Observation

• Orbit determination (epoch: 2013/01/10 13:00:00)

		Short (1 cycle)	Simultaneous					TLE
		ITF	ITF-NAO	ITF-SAO	ITF-BSG	ITF-IAO	ITF-QRO	
Result	Semi-major Axis (km)	-49,389.168	43,233.631	42,692.849	43,310.970	42,046.325	42,108.172	42,167.785
	Eccentricity	2.212463	0.087270	0.043129	0.092687	0.014870	0.006915	0.000289
	Inclination (deg)	1.9475	0.6238	0.3578	0.6011	0.0342	0.1012	0.0972
	RAAN (deg)	103.7830	42.8970	44.8730	42.9340	77.5450	52.4080	53.3550
	Arg of Perigee (deg)	310.1164	76.7504	73.1702	76.7938	220.5947	245.0958	241.6128
	True Anomaly (deg)	344.4558	280.3736	281.9780	280.2926	101.8897	102.5252	105.0615
	Mean Anomaly (deg)	344.4558	290.0839	286.7789	290.6002	100.2185	101.7508	105.0296
Error	Semi-major Axis (km)	-91,556.952	1,065.846	525.065	1,143.185	-121.460	-59.613	
	Eccentricity	2.212174	0.086982	0.042840	0.092398	0.014582	0.006626	
	Inclination (deg)	1.850	0.527	0.261	0.504	-0.063	0.004	
	RAAN (deg)	50.428	-10.458	-8.482	-10.421	24.190	-0.947	
	Arg of Perigee (deg)	68.504	-164.862	-168.443	-164.819	-21.018	3.483	
	True Anomaly (deg)	239.394	175.312	176.917	175.231	-3.172	-2.536	
	Mean Anomaly (deg)	239.426	185.054	181.749	185.571	-4.811	-3.279	
Error(%)	Semi-major Axis (km)	-217.13%	2.53%	1.25%	2.71%	-0.29%	-0.14%	
	Eccentricity	766253.48%	30128.75%	14839.04%	32004.99%	5050.81%	2295.08%	
	Inclination (deg)	1903.60%	541.77%	268.11%	518.42%	-64.81%	4.12%	
	RAAN (deg)	94.51%	-19.60%	-15.90%	-19.53%	45.34%	-1.77%	
	Arg of Perigee (deg)	28.35%	-68.23%	-69.72%	-68.22%	-8.70%	1.44%	
	True Anomaly (deg)	227.86%	166.87%	168.39%	166.79%	-3.02%	-2.41%	
	Mean Anomaly (deg)	227.96%	176.19%	173.05%	176.68%	-4.58%	-3.12%	

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3. Simulation Results:

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3.2. Two sites Observation

- Orbit determination (epoch: 2013/01/10 13:00:00)

		30m interval	30 min interval					TLE
		ITF	ITF-NAO	ITF-SAO	ITF-BSG	ITF-IAO	ITF-QRO	
Result	Semi-major Axis (km)	41,907.248	41,417.968	40,586.117	42,018.916	42,338.270	42,288.962	42,167.785
	Eccentricity	0.005116	0.014057	0.029110	0.002826	0.002954	0.004352	0.000289
	Inclination (deg)	0.1106	0.1545	0.1432	0.1007	0.1097	0.1401	0.0972
	RAAN (deg)	46.9480	39.2940	27.0040	49.7850	54.3490	51.0810	53.3550
	Arg of Perigee (deg)	153.7935	170.8230	190.5481	168.1641	347.3979	53.9015	241.6128
	True Anomaly (deg)	199.2957	189.9354	182.5282	182.0844	358.2764	295.0418	105.0615
	Mean Anomaly (deg)	199.4901	190.2163	182.6786	182.0962	358.2865	295.4930	105.0296
Error	Semi-major Axis (km)	-260.537	-749.817	-1,581.668	-148.869	170.485	121.177	
	Eccentricity	0.004827	0.013768	0.028821	0.002537	0.002665	0.004063	
	Inclination (deg)	0.013	0.057	0.046	0.004	0.013	0.043	
	RAAN (deg)	-6.407	-14.061	-26.351	-3.570	0.994	-2.274	
	Arg of Perigee (deg)	-87.819	-70.790	-51.065	-73.449	105.785	-187.711	
	True Anomaly (deg)	94.234	84.874	77.467	77.023	253.215	189.980	
	Mean Anomaly (deg)	94.461	85.187	77.649	77.067	253.257	190.465	
Error(%)	Semi-major Axis (km)	-0.62%	-1.78%	-3.75%	-0.35%	0.40%	0.29%	
	Eccentricity	1672.12%	4768.96%	9982.96%	878.73%	923.24%	1407.45%	
	Inclination (deg)	13.79%	58.95%	47.33%	3.60%	12.86%	44.14%	
	RAAN (deg)	-12.01%	-26.35%	-49.39%	-6.69%	1.86%	-4.26%	
	Arg of Perigee (deg)	-36.35%	-29.30%	-21.13%	-30.40%	43.78%	-77.69%	
	True Anomaly (deg)	89.69%	80.78%	73.73%	73.31%	241.02%	180.83%	
	Mean Anomaly (deg)	89.94%	81.11%	73.93%	73.38%	241.13%	181.34%	

3. Simulation Results:

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3.2. Two sites Observation

- Orbit determination (epoch: 2013/01/10 13:00:00)

		4h interval	4 hr interval					TLE
		ITF	ITF-NAO	ITF-SAO	ITF-BSG	ITF-IAO	ITF-QRO	
Result	Semi-major Axis (km)	42,185.046	42,334.080	42,106.381	42,106.605	42,290.343	42,284.773	42,167.785
	Eccentricity	0.000099	0.002865	0.001446	0.001445	0.002061	0.001925	0.000289
	Inclination (deg)	0.0975	0.0915	0.1012	0.1005	0.0953	0.1056	0.0972
	RAAN (deg)	53.6280	57.8650	51.9030	52.0030	56.1040	54.6590	53.3550
	Arg of Perigee (deg)	40.4848	4.8094	179.3346	178.5361	5.6788	9.6171	241.6128
	True Anomaly (deg)	305.9146	337.3481	168.7925	169.4903	338.2416	335.7479	105.0615
	Mean Anomaly (deg)	305.9238	337.4743	168.7603	169.4601	338.3291	335.8384	105.0296
Error	Semi-major Axis (km)	17.261	166.295	-61.404	-61.179	122.558	116.988	
	Eccentricity	-0.000190	0.002577	0.001157	0.001157	0.001772	0.001636	
	Inclination (deg)	0.000	-0.006	0.004	0.003	-0.002	0.008	
	RAAN (deg)	0.273	4.510	-1.452	-1.352	2.749	1.304	
	Arg of Perigee (deg)	-201.128	-236.803	-62.278	-63.077	-235.934	-231.996	
	True Anomaly (deg)	200.853	232.287	63.731	64.429	233.180	230.686	
	Mean Anomaly (deg)	200.894	232.445	63.731	64.431	233.300	230.809	
Error(%)	Semi-major Axis (km)	0.04%	0.39%	-0.15%	-0.15%	0.29%	0.28%	
	Eccentricity	-65.64%	892.48%	400.87%	400.66%	613.89%	566.68%	
	Inclination (deg)	0.31%	-5.86%	4.12%	3.40%	-1.95%	8.64%	
	RAAN (deg)	0.51%	8.45%	-2.72%	-2.53%	5.15%	2.44%	
	Arg of Perigee (deg)	-83.24%	-98.01%	-25.78%	-26.11%	-97.65%	-96.02%	
	True Anomaly (deg)	191.18%	221.10%	60.66%	61.32%	221.95%	219.57%	
	Mean Anomaly (deg)	191.27%	221.31%	60.68%	61.35%	222.13%	219.76%	

3. Simulation Results:

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3.2. Two sites Observation

- Position errors at time (Epoch: 2013/01/10 13:00:00)

		瞬時位置誤差[km]				
		元期	観測終了時	観測終了時刻[UTC]	最小値	観測終了時刻[UTC]
短時間観測（１地点）	富岡	19,377.747	19,130.584	2013/01/10 13:05:00	17,779.719	2013/01/10 14:00:45
２地点同時観測	富岡-名寄	70.212	9.199	2013/01/10 13:05:00	1.178	2013/01/10 13:04:25
	富岡-仙台	64.971	25.792	2013/01/10 13:05:00	1.267	2013/01/10 13:08:17
	富岡-美星	68.954	15.221	2013/01/10 13:05:00	0.878	2013/01/10 13:04:06
	富岡-石垣	4.875	8.542	2013/01/10 13:05:00	0.873	2013/01/10 13:01:48
	富岡-豪州	1.653	4.546	2013/01/10 13:05:00	0.664	2013/01/10 13:01:16
30分 時間差観測（１地点）	富岡	62.067	77.242	2013/01/10 13:35:00	62.067	2013/01/10 13:00:00
２地点時間差(30m)観測	富岡-名寄	181.425	206.293	2013/01/10 13:35:00	181.425	2013/01/10 13:00:00
	富岡-仙台	408.326	433.496	2013/01/10 13:35:00	408.326	2013/01/10 13:00:00
	富岡-美星	33.734	37.526	2013/01/10 13:35:00	33.734	2013/01/10 13:00:00
	富岡-石垣	42.665	41.674	2013/01/10 13:35:00	41.629	2013/01/10 13:29:02
	富岡-豪州	39.764	13.600	2013/01/10 13:35:00	4.380	2013/01/10 13:52:17
4時間 時間差観測（１地点）	富岡	11.725	3.566	2013/01/10 17:05:00	3.101	2013/01/10 17:47:55
２地点時間差(4h)観測	富岡-名寄	51.540	61.502	2013/01/10 17:05:00	38.069	2013/01/10 14:48:10
	富岡-仙台	4.989	33.680	2013/01/10 17:05:00	4.989	2013/01/10 13:00:45
	富岡-美星	4.654	33.995	2013/01/10 17:05:00	4.654	2013/01/10 13:00:00
	富岡-石垣	38.716	44.948	2013/01/10 17:05:00	28.183	2013/01/10 14:51:34
	富岡-豪州	39.904	42.100	2013/01/10 17:05:00	28.123	2013/01/10 15:01:34

- IHI富岡-豪州での２地点同時観測では、軌道上物体（衛星）位置を半径4km以内に推定可能。
- 他のケースは、推定位置誤差は安定しない。

⇒ 時間経過とともに、位置誤差が拡大

- ２地点観測により、瞬時位置の推定精度が向上するわけではない（時間差による誤差の影響の方が大きい）

3. Simulation Results:

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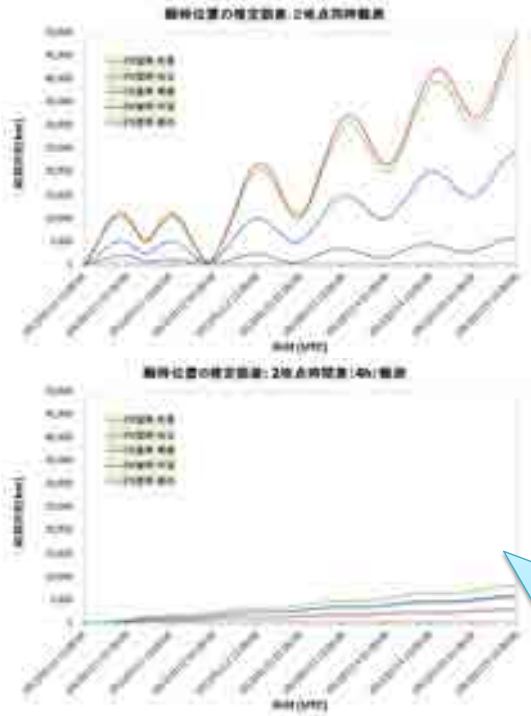
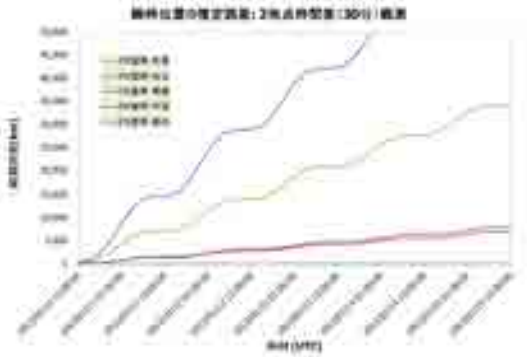
3.2. Two sites Observation

- Position errors at time (Epoch: 2013/01/10 13:00:00)





- 4時間差２地点観測では、
  - ➢瞬時の軌道上物体の位置は、他のケースが推定精度が良くなる場合があるが、
  - ➢時間差により軌道力学的考慮が加わるため、時間経過に伴う推定位置誤差の拡大を抑制可能。

3. Simulation Results:

IHI Realize your dreams

3.3. Three sites Observation

– Three sites observations with simultaneous or time interval

	IHI Tomioka (UTC)	IAO	QRO(UTC)
Simultaneous	2013/01/10 13:00～13:05	2013/01/10 13:00～13:05	2013/01/10 13:00～13:05
30 min interval	2013/01/10 13:00～13:05	2013/01/10 13:00～13:05	2013/01/10 13:30～13:35
4 hour interval	2013/01/10 13:00～13:05	2013/01/10 13:30～13:35	2013/01/10 17:00～17:05

3. Simulation Results:

IHI Realize your dreams

3.3. Three sites Observation

• Orbit determination (epoch: 2013/01/10 13:00:00)

		4h interval	Simul	30 min interval	4 hr interval	TLE
		ITF	ITF-IAO-QRO	ITF-IAO-QRO	ITF-IAO-QRO	
Result	Semi-major Axis (km)	42,185.046	42,131.900	42,183.516	42,202.023	42,167.785
	Eccentricity	0.000099	0.004273	0.001854	0.000502	0.000289
	Inclination (deg)	0.0975	0.0834	0.0930	0.0998	0.0972
	RAAN (deg)	53.6280	54.9110	53.7830	53.2120	53.3550
	Arg of Perigee (deg)	40.4848	242.2422	73.0761	336.1926	241.6128
	True Anomaly (deg)	305.9146	102.8756	273.1687	10.6228	105.0615
	Mean Anomaly (deg)	305.9238	102.3979	273.3808	10.6122	105.0296
Error	Semi-major Axis (km)	17.261	-35.885	15.731	34.238	
	Eccentricity	-0.000190	0.003984	0.001565	0.000214	
	Inclination (deg)	0.000	-0.014	-0.004	0.003	
	RAAN (deg)	0.273	1.556	0.428	-0.143	
	Arg of Perigee (deg)	-201.128	0.629	-168.537	94.580	
	True Anomaly (deg)	200.853	-2.186	168.107	-94.439	
	Mean Anomaly (deg)	200.894	-2.632	168.351	-94.417	
Error(%)	Semi-major Axis (km)	0.04%	-0.09%	0.04%	0.08%	
	Eccentricity	-65.64%	1380.08%	→ 542.15%	→ 73.99%	
	Inclination (deg)	0.31%	-14.20%	-4.32%	2.67%	
	RAAN (deg)	0.51%	2.92%	0.80%	-0.27%	
	Arg of Perigee (deg)	-83.24%	0.26%	-69.75%	39.15%	
	True Anomaly (deg)	191.18%	-2.08%	160.01%	-89.89%	
	Mean Anomaly (deg)	191.27%	-2.51%	160.29%	-89.90%	

3. Simulation Results:

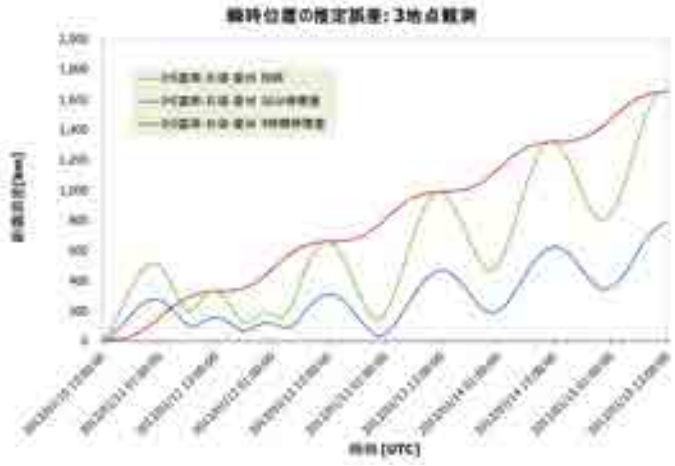
IHI Realize your dreams

3.3. Three sites Observation

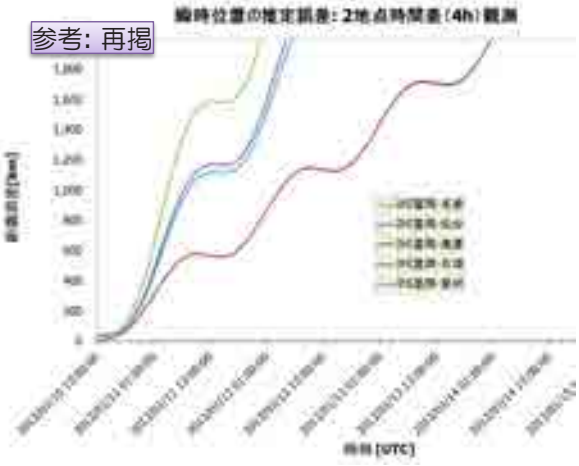
- Position errors at time (Epoch: 2013/01/10 13:00:00)

		瞬時位置誤差[km]				
		元期	観測終了時	観測終了時刻[UTC]	最小値	観測終了時刻[UTC]
3地点同時観測	富岡-石垣-豪州	0.951	4.075	2013/01/10 13:05:00	0.951	2013/01/10 13:00:00
	富岡-石垣-豪州	8.178	5.513	2013/01/10 13:35:00	1.068	2013/01/10 13:21:00
	富岡-石垣-豪州	10.327	21.039	2013/01/10 17:35:00	9.165	2013/01/10 14:09:27

- 3地点観測により瞬時位置の推定精度は向上する。
- 時間経過に伴う推定位置誤差の拡大も抑制（２地点観測と比較して）



参考: 再掲



3. Simulation Results: (Summary: cases of QRO)

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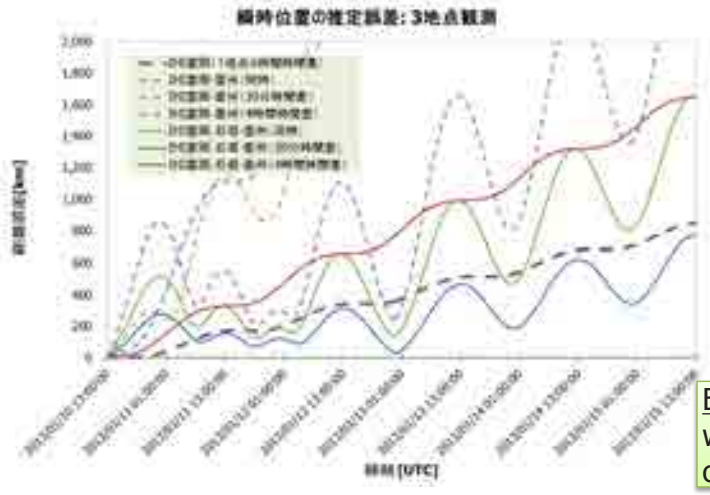
			Two-sites			Three-sites			
		4h interval	Simul	30min interval	4h interval	Simul	30 min interval	4 hr interval	TLE
		ITF	ITF-QRO	ITF-QRO	ITF-QRO	ITF-IAO-QRO	ITF-IAO-QRO	ITF-IAO-QRO	
Result	Semi-major Axis (km)	42,185.046	42,108.172	42,288.962	42,284.773	42,131.900	42,183.516	42,202.023	42,167.785
	Eccentricity	0.000099	0.006915	0.004352	0.001925	0.004273	0.001854	0.000502	0.000289
	Inclination (deg)	0.0975	0.1012	0.1401	0.1056	0.0834	0.0930	0.0998	0.0972
	RAAN (deg)	53.6280	52.4080	51.0810	54.6590	54.9110	53.7830	53.2120	53.3550
	Arg of Perigee (deg)	40.4848	245.0958	53.9015	9.6171	242.2422	73.0761	336.1926	241.6128
	True Anomaly (deg)	305.9146	102.5252	295.0418	335.7479	102.8756	273.1687	10.6228	105.0615
	Mean Anomaly (deg)	305.9238	101.7508	295.4930	335.8384	102.3979	273.3808	10.6122	105.0296
Error	Semi-major Axis (km)	17.261	-59.613	121.177	116.988	-35.885	15.731	34.238	
	Eccentricity	-0.000190	0.006626	0.004063	0.001636	0.003984	0.001565	0.000214	
	Inclination (deg)	0.000	0.004	0.043	0.008	-0.014	-0.004	0.003	
	RAAN (deg)	0.273	-0.947	-2.274	1.304	1.556	0.428	-0.143	
	Arg of Perigee (deg)	-201.128	3.483	-187.711	-231.996	0.629	-168.537	94.580	
	True Anomaly (deg)	200.853	-2.536	189.980	230.686	-2.186	168.107	-94.439	
	Mean Anomaly (deg)	200.894	-3.279	190.463	230.809	-2.632	168.351	-94.417	
Error(%)	Semi-major Axis (km)	0.04%	-0.14%	0.29%	0.28%	-0.09%	0.04%	0.08%	
	Eccentricity	-65.64%	2295.08%	1407.45%	566.68%	1380.08%	542.15%	73.99%	
	Inclination (deg)	0.31%	4.12%	44.14%	8.64%	-14.20%	-4.32%	2.67%	
	RAAN (deg)	0.51%	-1.77%	-4.26%	2.44%	2.92%	0.80%	-0.27%	
	Arg of Perigee (deg)	-83.24%	1.44%	-77.69%	-96.02%	0.26%	-69.75%	39.15%	
	True Anomaly (deg)	191.18%	-2.41%	180.83%	219.57%	-2.08%	160.01%	-89.89%	
	Mean Anomaly (deg)	191.27%	-3.12%	181.34%	219.76%	-2.51%	160.29%	-89.90%	

3. Simulation Results: (Summary: cases of QRO)

IHI Realize your dreams

- Position errors at time (Epoch: 2013/01/10 13:00:00)

			瞬時位置誤差[km]				
			元期	観測終了時	観測終了時刻[UTC]	最小値	観測終了時刻[UTC]
時間差観測(4h後)	富岡	n04_itf_04	11.725	3.566	2013/01/10 17:05:00	3.101	2013/01/10 17:47:55
２地点同時観測	富岡-豪州	n10_qro_00	1.653	4.546	2013/01/10 13:05:00	0.664	2013/01/10 13:01:16
２地点時間差(30m)観測	富岡-豪州	n15_qro_hf	39.764	13.600	2013/01/10 13:35:00	4.380	2013/01/10 13:52:17
２地点時間差(4h)観測	富岡-豪州	n20_qro_04	39.904	42.100	2013/01/10 17:05:00	28.123	2013/01/10 15:01:34
３地点同時観測	富岡-石垣-豪州	n21_iao_qro_00	0.951	4.075	2013/01/10 13:05:00	0.951	2013/01/10 13:00:00
	富岡-石垣-豪州	n22_iao_00_qro_hf	8.178	5.513	2013/01/10 13:35:00	1.068	2013/01/10 13:21:00
	富岡-石垣-豪州	n23_iao_hf_qro_04	10.327	21.039	2013/01/10 17:35:00	9.165	2013/01/10 14:09:27



=Conclusion=
- (Multi-sites)Simultaneous observation give good estimation of positions
- Long interval of observation cycle improve eccentricity

Proposed observation strategy:
- Good position estimation
  ⇒ (Multi-sites) simul. observation
- Improvement of eccentricity/orbit shape estimation
  ⇒ Observation with Long interval

Expectation of fine orbit determination with two-sites simultaneous & time interval observation using minimal facility and time.

3. Simulation Results:

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3.4. Two sites Simultaneous and time interval observation
– 4hr time interval is assumed

	IHI Tomika (UTC)	Australia (UTC)
Case 1: Time interval observation conducted at one site	2013/01/10 13:00～13:05 2013/01/10 17:00～17:05	2013/01/10 13:00～13:05
Case 2: Both site conduct time interval observation	2013/01/10 13:00～13:05 2013/01/10 17:00～17:05	2013/01/10 13:00～13:05 2013/01/10 17:00～17:05

3. Simulation Results:

IHI Realize your dreams

3.4. Two sites Simultaneous and time interval observation

- Orbit determination (epoch: 2013/01/10 13:00:00)

		4h interval	Case 1:Simul. +4 hr int	Case 2:Simul. +4 hr int	TLE
		ITF	ITF-QRO	ITF-QRO	
Result	Semi-major Axis (km)	42,185.046	42,167.248	42,162.962	42,167.785
	Eccentricity	0.000099	0.000307	0.000350	0.000289
	Inclination (deg)	0.0975	0.0966	0.0970	0.0972
	RAAN (deg)	53.6280	52.9620	52.9180	53.3550
	Arg of Perigee (deg)	40.4848	233.3355	217.2941	241.6128
	True Anomaly (deg)	305.9146	113.7308	129.8164	105.0615
	Mean Anomaly (deg)	305.9238	113.6986	129.7857	105.0296
Error	Semi-major Axis (km)	17.261	-0.537	-4.823	
	Eccentricity	-0.000190	0.000018	0.000061	
	Inclination (deg)	0.000	-0.001	-0.000	
	RAAN (deg)	0.273	-0.393	-0.437	
	Arg of Perigee (deg)	-201.128	-8.277	-24.319	
	True Anomaly (deg)	200.853	8.669	24.755	
	Mean Anomaly (deg)	200.894	8.669	24.756	
Error(%)	Semi-major Axis (km)	0.04%	0.00%	-0.01%	
	Eccentricity	-65.64%	6.30%	21.16%	
	Inclination (deg)	0.31%	-0.62%	-0.21%	
	RAAN (deg)	0.51%	-0.74%	-0.82%	
	Arg of Perigee (deg)	-83.24%	-3.43%	-10.07%	
	True Anomaly (deg)	191.18%	8.25%	23.56%	
	Mean Anomaly (deg)	191.27%	8.25%	23.57%	

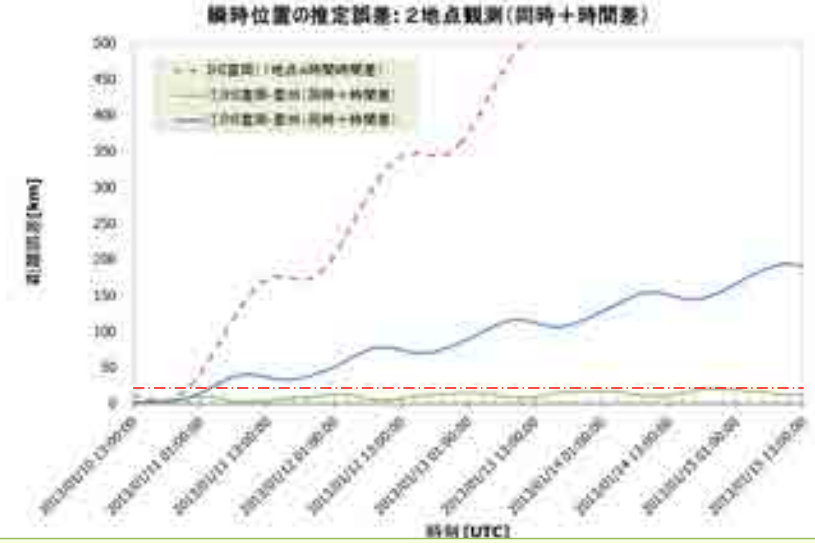
3. Simulation Results:

IHI Realize your dreams

3.4. Two sites Simultaneous and time interval observation

- Position errors at time (Epoch: 2013/01/10 13:00:00)

			瞬時位置誤差[km]				
			元期	観測終了時	観測終了時刻[UTC]	最小値	観測終了時刻[UTC]
時間差観測(4h後)	富岡	IHI富岡（1地点4時間時間差）	11.725	3.566	2013/01/10 17:05:00	3.101	2013/01/10 17:47:55
2地点観測(同時+4h後単独)	富岡-豪州	①IHI富岡-豪州（同時+時間差）	1.716	3.192	2013/01/10 17:05:00	1.716	2013/01/10 13:00:00
2地点観測(同時+4h後同時)	富岡-豪州	①IHI富岡-豪州（同時+時間差）	1.662	3.207	2013/01/10 17:05:00	1.662	2013/01/10 13:00:00



"Two sites Simultaneous and time interval observation" can provide fine orbit determination within short period of observation.

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4. Conclusion

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- Effectiveness of multi-site observation is evaluated using virtual observation data generated by orbit simulation considering influence of observation errors /resolutions

- Multi(two or three) sites observation with time interval may not improve accuracy of estimated orbit due to error associated with different observation time (errors due to orbit propagation)
  - ➢Depend on observation error and time interval (propagation error)
- Multi-site simultaneous observation improve position estimation of on-orbit object.

- Propose observation strategy and scenario for orbital object in GEO region using minimal asset and short period of observation
  - ➢At **two sites** far from each other(ex. IHI tomioka-Australia), (1) simultaneous observation(5 min), after that, (2) re-observation with appropriate time interval(5 min after 4 hr interval) provide fine orbital determination.

◆ Only one scenario was evaluated in this study. It is necessary to evaluate this proposed observation strategy with some other cases.