

RE-ENTRY PREDICTIONS FOR THE EARLY AMMONIA SERVICER [EAS]

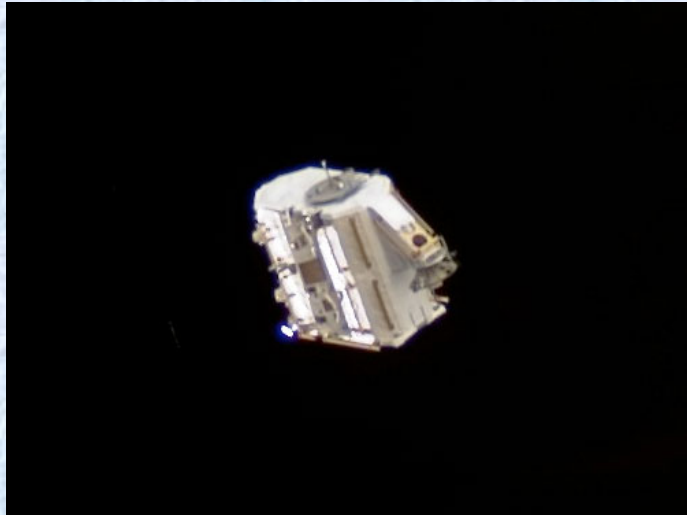
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Early Ammonia Servicer [EAS]

test object for the IADC reentry
prediction test campaign 2008



The Early Ammonia Servicer (EAS), was thrown overboard from
the International Space Station on July 23, 2007

COMMON NAME:	ISS DEB (EAS)
US SSN CATALOG NUMBER:	31928
COSPAR ID:	1998-067BA
MASS:	640 kg
DIMENSIONS:	2.5 m x 1.2 m x 1.7 m
REENTRY DATE:	3 November 2008

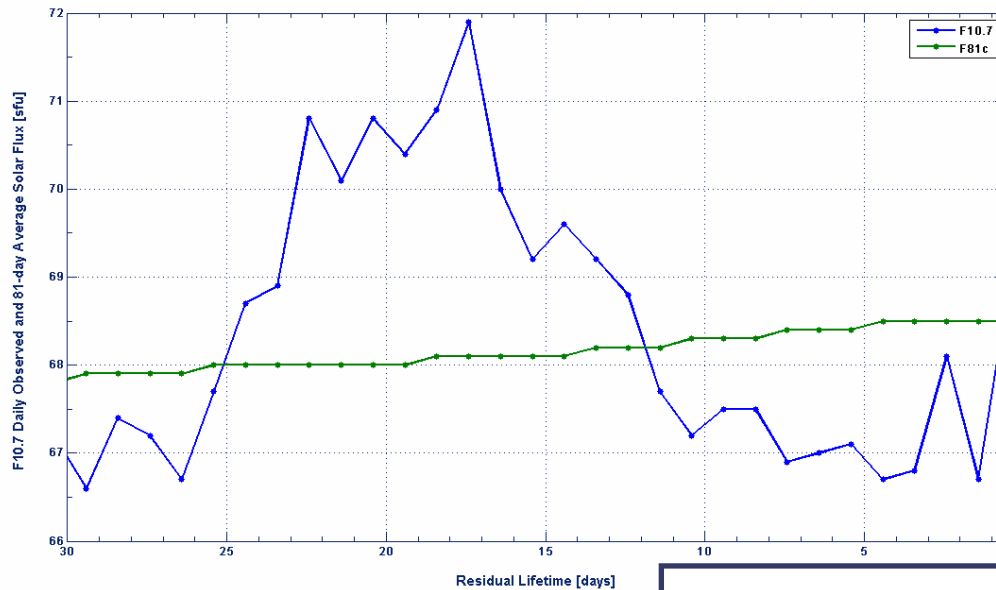
ISTI/CNR reentry campaign of EAS

The IADC reentry test campaign of EAS officially began on 22 October 2008

However,

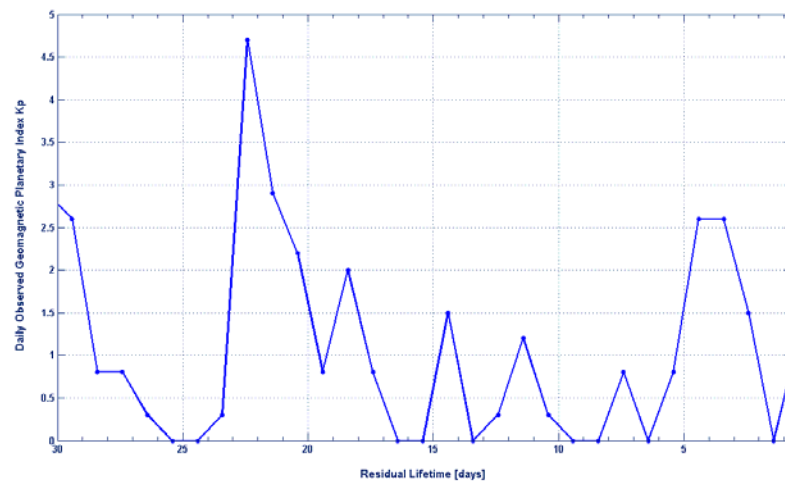
- reentry predictions of EAS were carried out at ISTI/CNR starting from 7 October 2008
- four atmospheric density models were used during the EAS reentry campaign:
 - JR-71, MSISE-90, NRLMSISE-00 (from 7 October 2008 to the EAS reentry date)
 - JB2006 (from 22 October 2008 to the EAS reentry date)
- 34 reentry predictions were carried out at ISTI from 7 October to 3 November 2008
- 28 reentry predictions were carried out at ISTI from 22 October to 3 November 2008.
 - of these, **24 predictions were uploaded to the IADC Common and Reentry Database**
- the 24 IADC reentry predictions (R.P.) were obtained using the following density models:
 - NRLMSISE-00 (R.P. 1 to 2)
 - JR-71 (R.P. 3 to 8)
 - JB2006 (R.P. 9 to 24)
- A post-reentry assessment was carried out using the last TLE available

Observed solar and geomagnetic activity during the EAS re-entry campaign



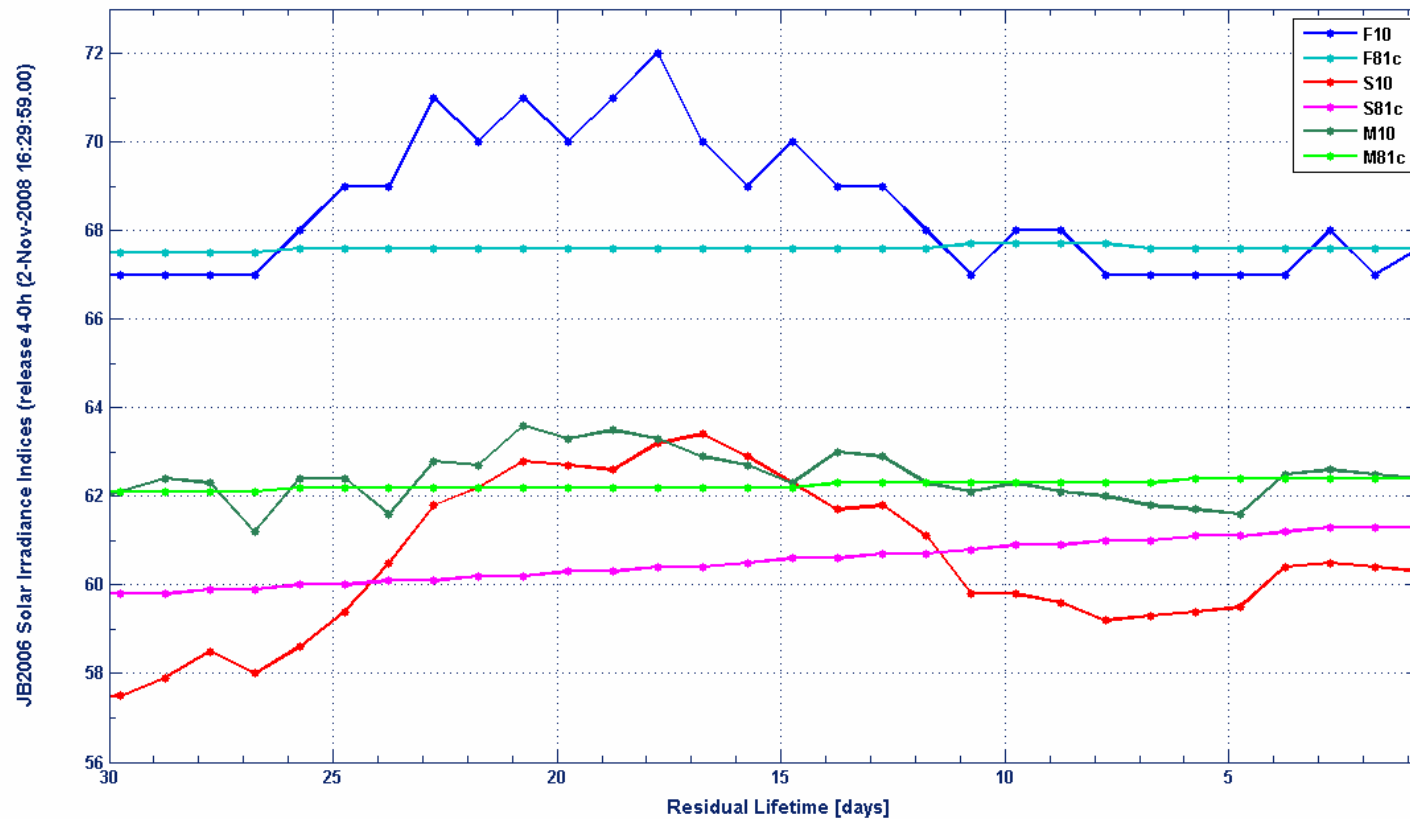
Used by the atmospheric density models:

- **JR-71**
- **MSISE-90**
- **NRLMSISE-00**



JB2006 indices during the EAS re-entry campaign

Used by the atmospheric density model JB2006



ISTI/CNR Re-entry Predictions of EAS Models and Assumptions

ORBIT PROPAGATION

The Satellite Re-entry Analysis Program SATRAP, developed at ISTI to predict the orbital decay of uncontrolled low Earth satellites, was used to propagate the trajectory

The principal orbit perturbations were modeled, namely the zonal and tesseral harmonics of the geopotential up to the 16th degree and order, luni-solar attraction, solar radiation pressure with eclipses, aerodynamic drag

ATMOSPHERIC DENSITY MODELS

Four atmospheric density models were considered: JR-71, MSISE-90, NRLMSISE-00, JB2006

SOLAR AND GEOMAGNETIC ACTIVITY INDICES

Daily observed values of A_p and $F_{10.7}$ from NOAA/NGDC (ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SOLAR_RADIO/FLUX; ftp://ftp.ngdc.noaa.gov/STP/GEOMAGNETIC_DATA/INDICES/KP_AP) and Jan Alvestad (<http://dxlc.com/solar>). Predicted values from NOAA/SEC (<http://sec.noaa.gov/ftplib/latest/45DF.txt>)

JB2006 indices from Space Environment Technologies (<http://www.spacewx.com>)

ORBITAL DATA

Two line elements from the IADC Common and Re-entry Database (<http://mas15.esoc.esa.de:8000/>) and Space Track database (<http://www.space-track.org/>)

RE-ENTRY ALTITUDE

Nearly 80 km up to 1 November, 2:30 UTC; about 10 km afterwards

RE-ENTRY WINDOW

Ballistic parameter $\pm 20\%$

ISTI/CNR Re-entry Predictions of EAS Calibration of the Ballistic Parameter

The ballistic parameter B , defined as

$$B = \frac{C_D A}{M}$$

where C_D , A and M are respectively the satellite drag coefficient, the cross-sectional area and mass, **was obtained by fitting, in a least squares sense, the semi-major axis decay described by the historical TLEs**

The semi-major axis root mean squares (rms) residuals (R) were computed according to the relation

$$R = \sqrt{\frac{\sum_{i=1}^N [a_{i_obs} - a_{i_com}]^2}{N}}$$

where a_{i_obs} and a_{i_com} are, respectively, the observed and the computed semi-major axis at the same epoch and N is the number of observations available, i.e. the number of TLE used in the fitting

ISTI/CNR Re-entry Predictions of EAS

The Re-entry Reference Epoch

“The U.S. Space Surveillance Network has assessed that EAS reached the atmospheric interface (~80 km altitude) at 04:51 UTC on 3 November 2008, at a location of 48°S, 151°E”

The corresponding 10 km interface is reached about 7 minutes later, i.e. at 04:58 UTC

The resulting epoch of 04:58 UTC on 03-Nov-2008 was used as reference re-entry date

ISTI/CNR Re-entry Predictions of EAS

Re-entry Predictions Errors

The reference re-entry date was assumed to be the actual re-entry date (T_{REF}) with which to compare the predicted re-entry time (T_{PRED})

The **PERCENTAGE ERROR IN THE ESTIMATION OF THE RESIDUAL LIFETIME** was computed as follows:

$$PE_{RL} = 100 \times \frac{(T_{PRED} - T_{REF})}{(T_{REF} - T_{IN})}$$

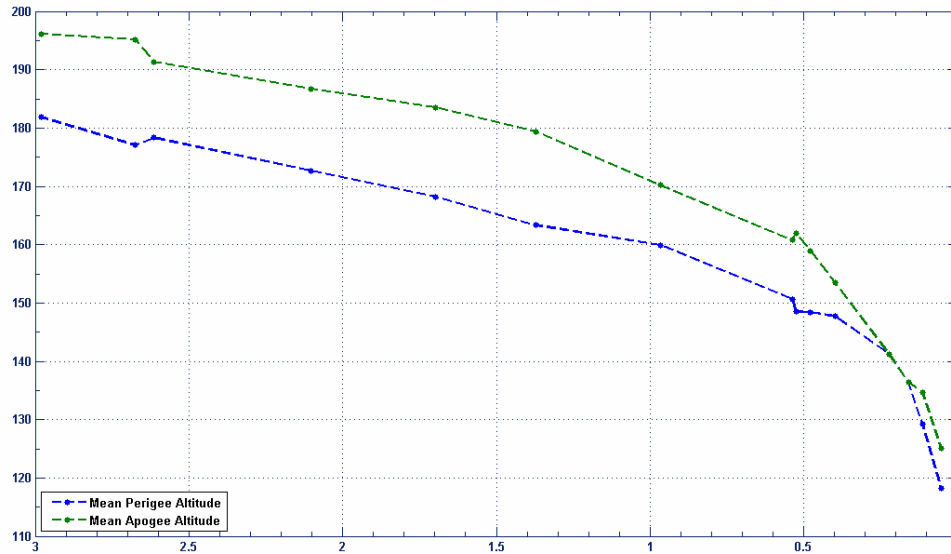
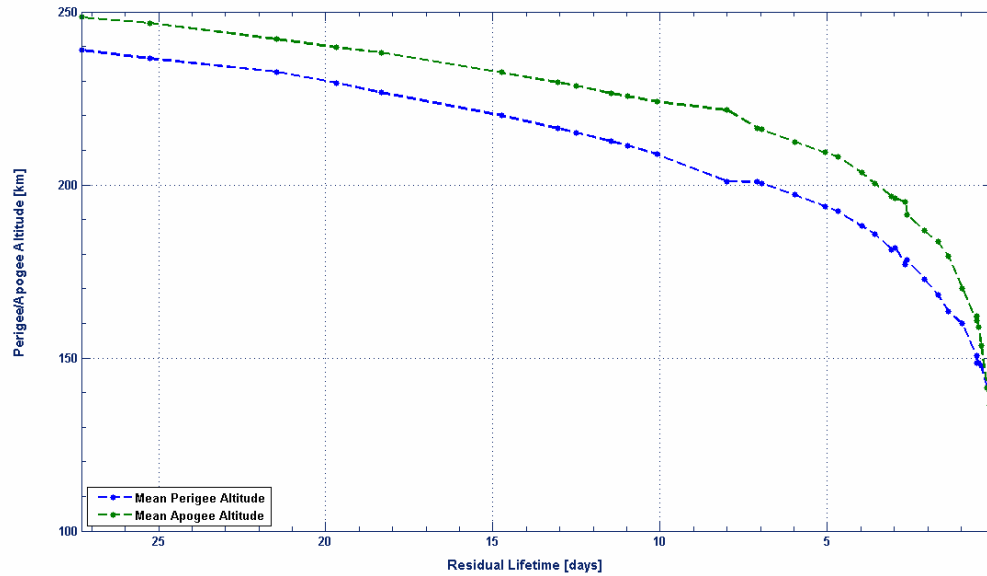
where T_{IN} is the time corresponding to the initial TLE propagated, and $(T_{REF} - T_{IN})$ indicates the residual lifetime (**RL**)

The **MEAN PREDICTION ERROR** was estimated as follows:

$$MPE = \sum_{n=1}^{N_p} \frac{|PE_{RL}|}{N_p}$$

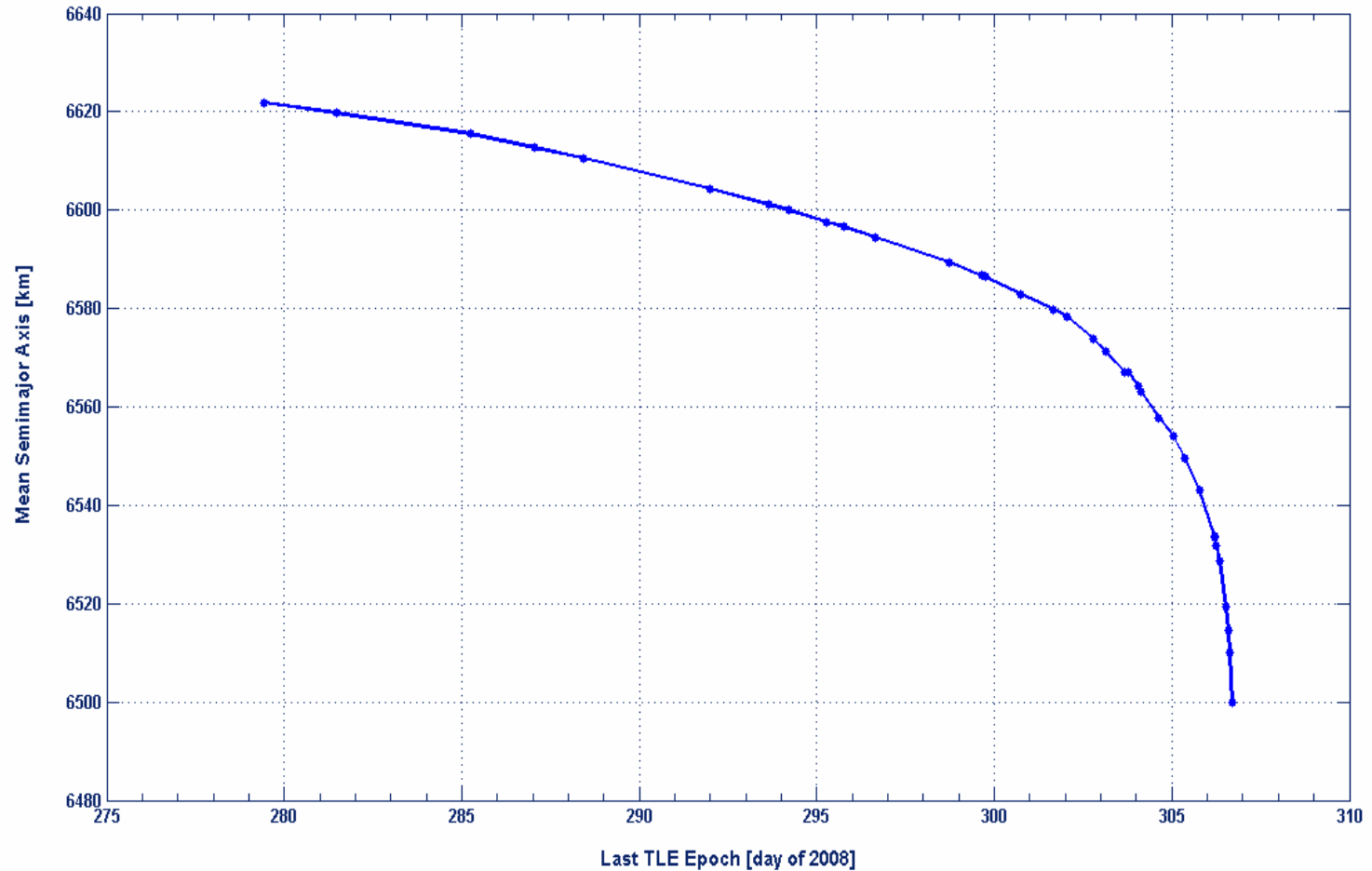
where N_p is the number of predictions between the current residual lifetime (**RL**) and the reference re-entry epoch

EAS Perigee/Apogee Altitude



Residual Lifetime [days]	Perigee Altitude [km]	Apogee Altitude [km]
27.31	238.9	248.4
25.26	236.5	246.8
21.48	232.6	242.1
19.69	229.5	239.7
18.32	226.7	238.2
14.74	220.0	232.4
13.07	216.3	229.6
12.52	215.1	228.7
11.47	212.5	226.4
10.97	211.4	225.6
10.09	208.8	223.9
7.99	201.0	221.6
7.09	200.9	216.4
6.97	200.5	216.0
5.99	197.1	212.5
5.06	193.8	209.4
4.69	192.3	208.2
3.96	188.0	203.5
3.59	185.8	200.3
3.08	181.3	196.7
2.98	181.8	196.1
2.67	177.1	195.1
2.61	178.3	191.4
2.10	172.6	186.7
1.69	168.2	183.5
1.37	163.3	179.4
0.96	159.9	170.2
0.54	150.7	160.8
0.53	148.5	162.0
0.48	148.4	158.9
0.40	147.7	153.5
0.22	141.2	141.2
0.16	136.4	136.4
0.11	129.2	134.7

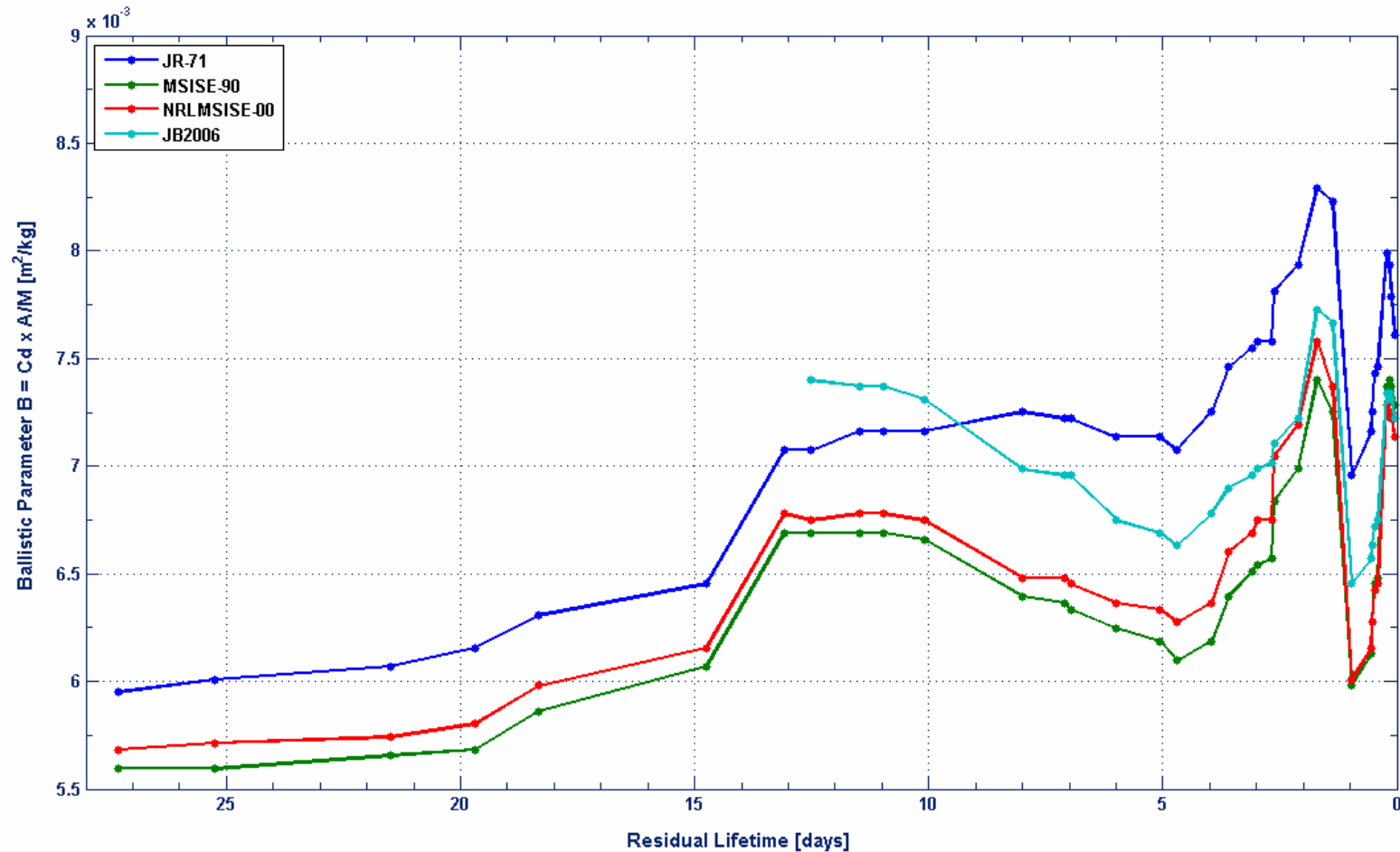
EAS Semimajor axis decay



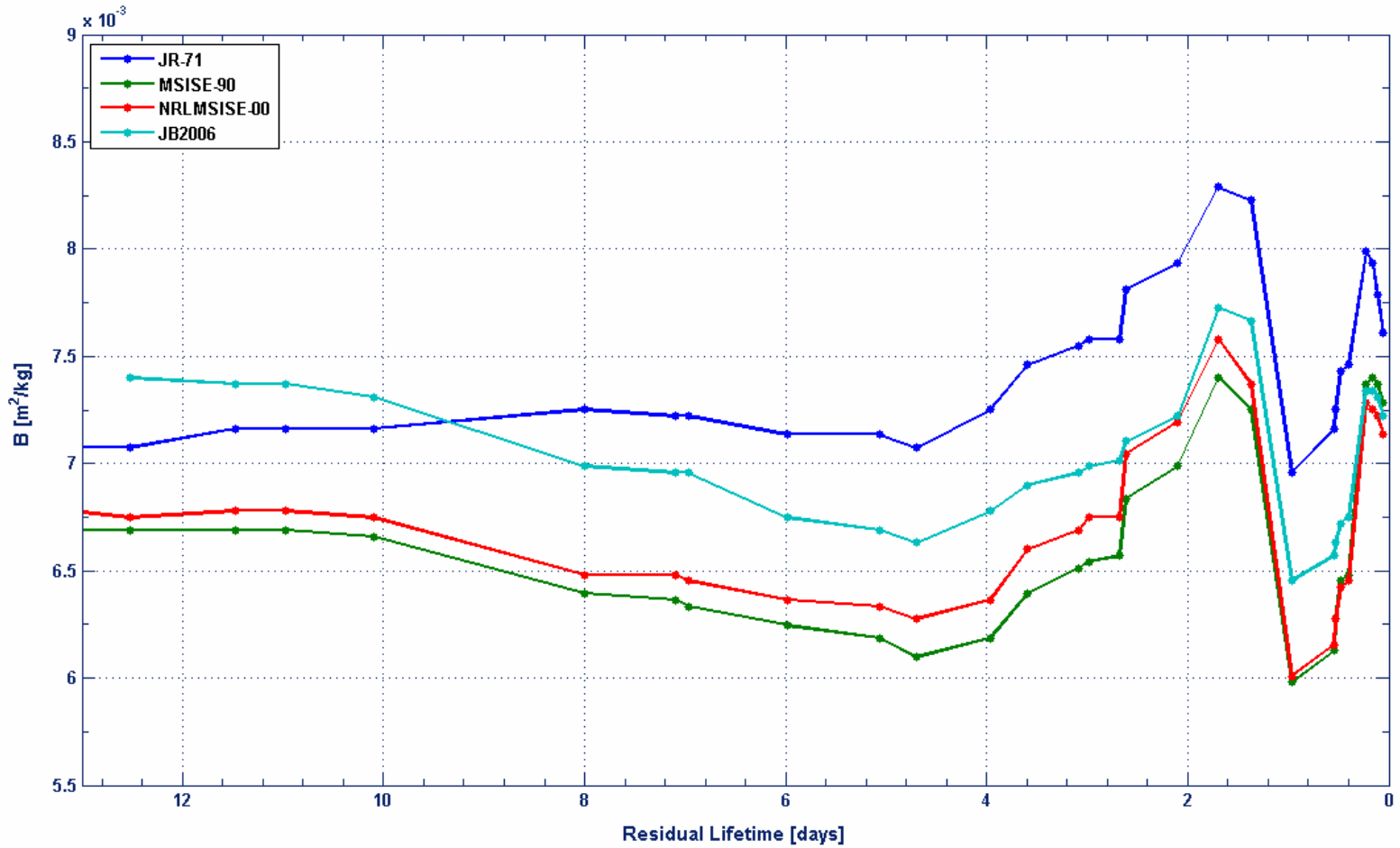
EAS BALLISTIC PARAMETER

Residual Lifetime [days]	Number of TLE over which B was retro-fitted	BALLISTIC PARAMETER B [m ² /kg]			
		JR-71	MSISE-90	NRLMSISE-00	JB2006
27.30763	81 (~ 30 days)	0.005950	0.005594	0.005683	
25.26180	85 (~ 30 days)	0.006009	0.005594	0.005713	
21.48194	88 (~ 30 days)	0.006068	0.005654	0.005742	
19.68680	73 (~ 24 days)	0.006157	0.005683	0.005802	
18.32500	65 (~ 20 days)	0.006305	0.005861	0.005979	
14.74027	68 (~ 21 days)	0.006453	0.006068	0.006157	
13.07291	24 (8.6 days)	0.007074	0.006690	0.006778	
12.51736	31 (9.2 days)	0.007074	0.006690	0.006749	0.007400
11.46875	28 (10.3 days)	0.007163	0.006690	0.006778	0.007370
10.97500	29 (10.7 days)	0.007163	0.006690	0.006778	0.007370
10.09166	33 (11.6 days)	0.007163	0.006660	0.006749	0.007311
8.00000	27 (8.1 days)	0.007252	0.006394	0.006482	0.006986
7.09444	29 (9.6 days)	0.007222	0.006364	0.006482	0.006956
6.97152	31 (9.7 days)	0.007222	0.006334	0.006453	0.006956
5.98750	28 (8.1 days)	0.007134	0.006246	0.006364	0.006749
5.06597	29 (7.4 days)	0.007134	0.006186	0.006334	0.006690
4.69722	28 (6.8 days)	0.007074	0.006098	0.006275	0.006630
3.96111	30 (7.0 days)	0.007252	0.006186	0.006364	0.006778
3.59305	18 (3.5 days)	0.007459	0.006394	0.006601	0.006897
3.08194	20 (4.0 days)	0.007548	0.006512	0.006690	0.006956
2.98055	21 (4.1 days)	0.007578	0.006542	0.006749	0.006986
2.67430	22 (4.4 days)	0.007578	0.006571	0.006749	0.007015
2.61319	15 (3.0 days)	0.007814	0.006838	0.007045	0.007104
2.10277	17 (3.5 days)	0.007933	0.006986	0.007193	0.007222
1.69652	12 (1.88 days)	0.008288	0.007400	0.007578	0.007726
1.37291	9 (1.30 days)	0.008229	0.007252	0.007370	0.007666
0.96458	7 (0.49 days)	0.006956	0.005979	0.006009	0.006453
0.53819	8 (0.91 days)	0.007163	0.006127	0.006157	0.006571
0.52569	9 (0.93 days)	0.007252	0.006275	0.006275	0.006630
0.47777	8 (0.78 days)	0.007430	0.006453	0.006423	0.006719
0.39930	9 (0.86 days)	0.007459	0.006482	0.006453	0.006749
0.22291	8 (0.30 days)	0.007992	0.007370	0.007282	0.007341
0.15972	9 (0.38 days)	0.007933	0.007400	0.007252	0.007341
0.11388	10 (0.45 days)	0.007785	0.007370	0.007222	0.007311

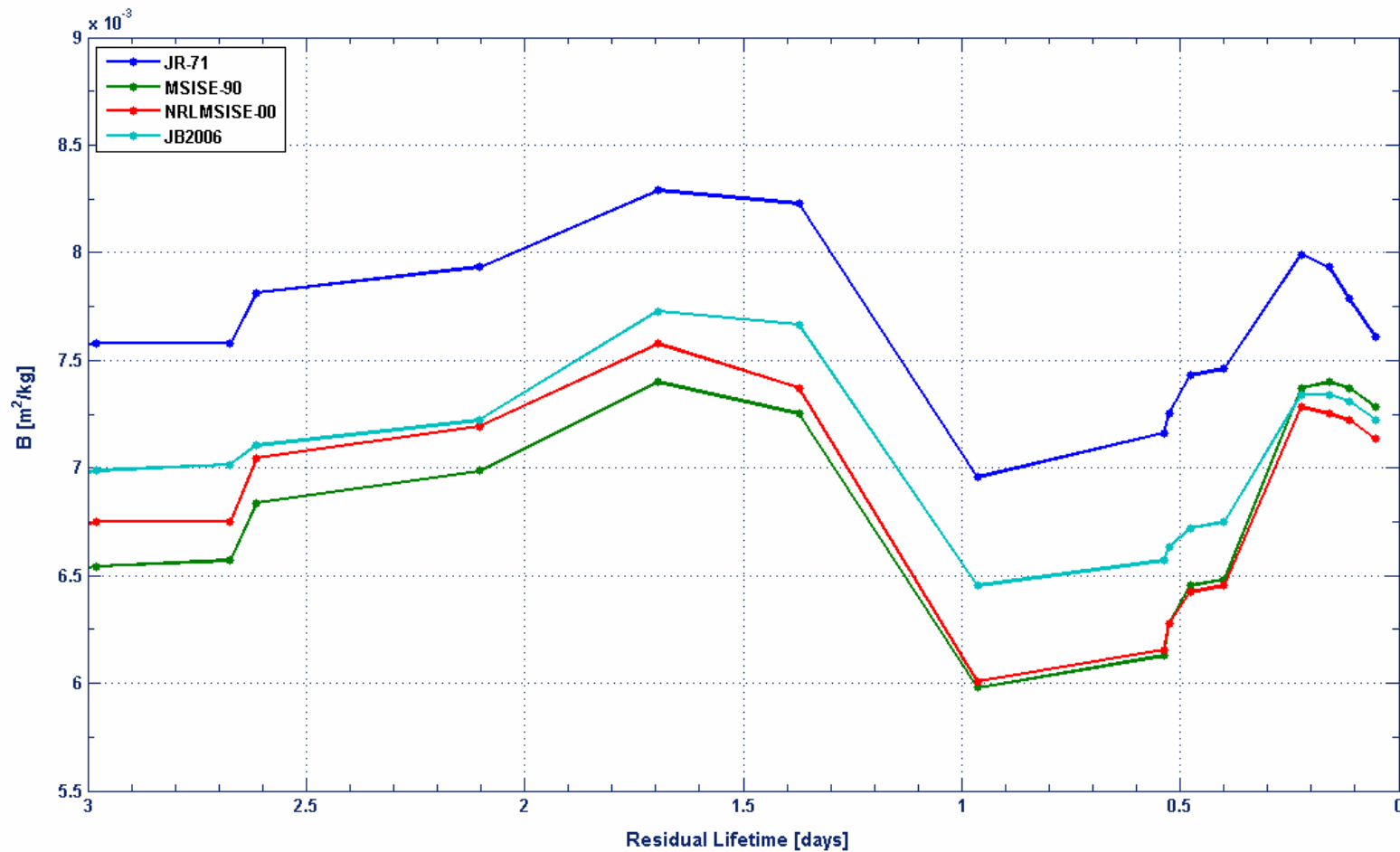
EVOLUTION OF THE EAS BALLISTIC PARAMETER



EVOLUTION OF THE EAS BALLISTIC PARAMETER



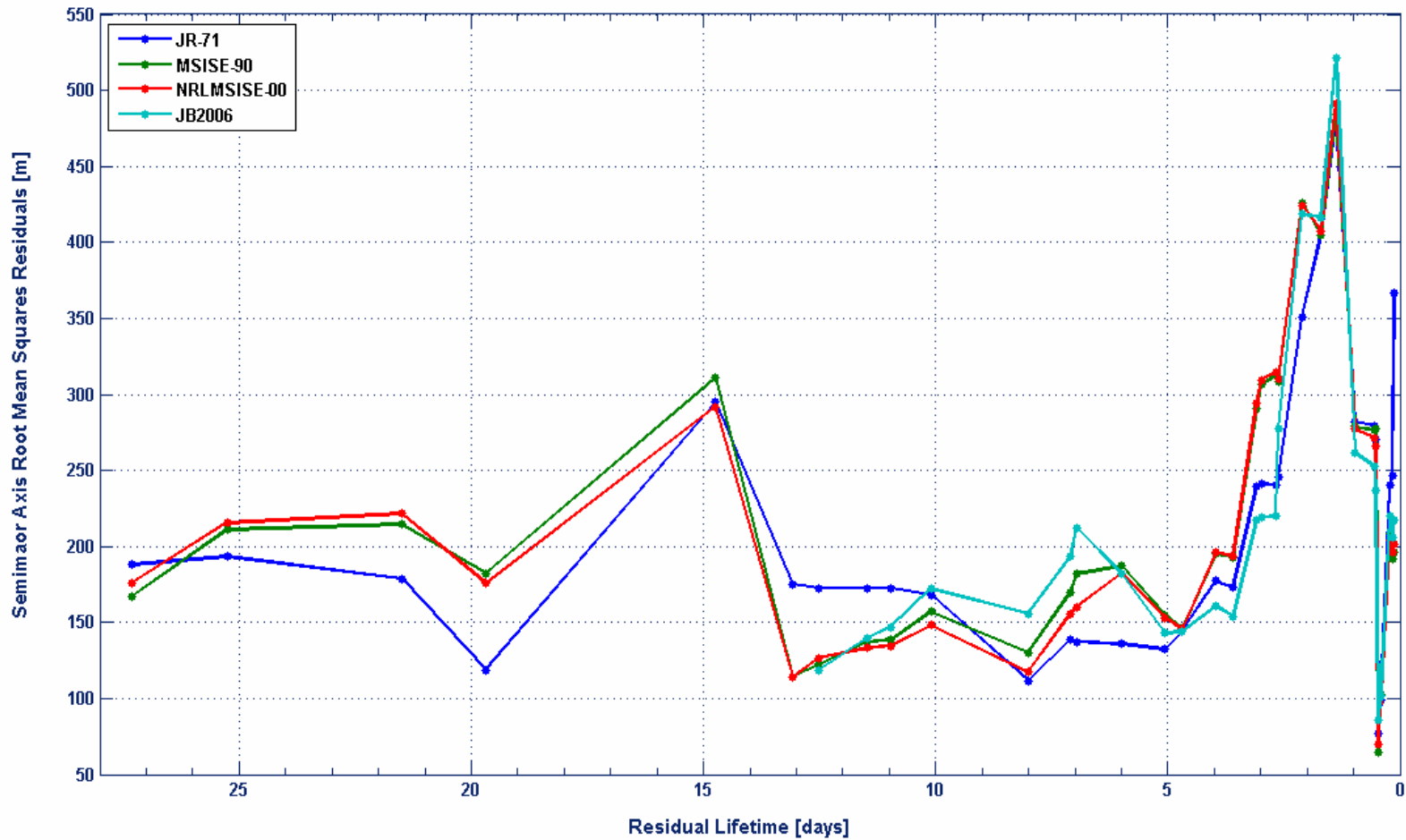
EVOLUTION OF THE EAS BALLISTIC PARAMETER



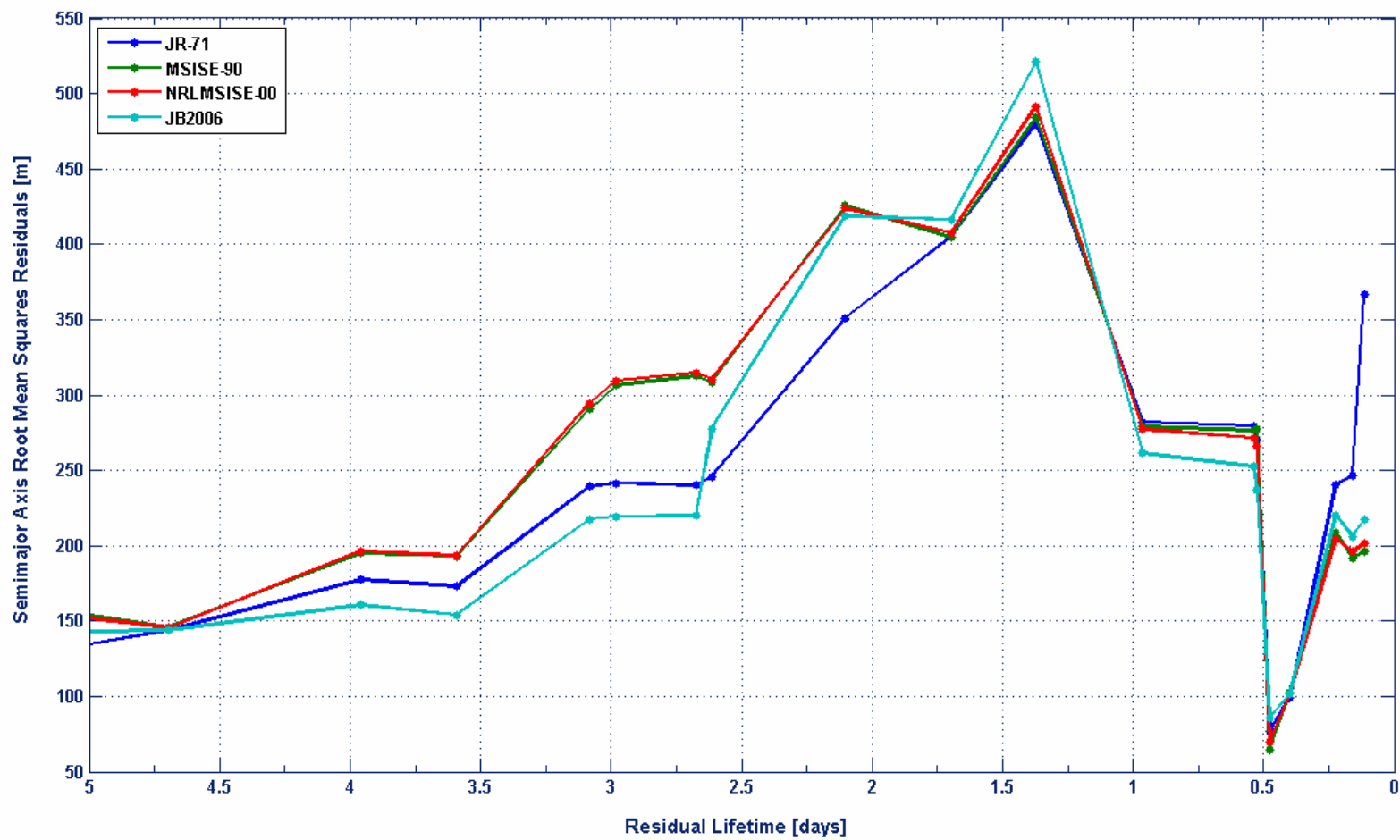
**SEMI-MAJOR AXIS
ROOT MEAN
SQUARES RESIDUALS**

Residual Lifetime [days]	SEMIMAJOR AXIS ROOT MEAN SQUARES RESIDUALS [m]			
	JR-71	MSISE-90	NRLMSISE-00	JB2006
27.30763	188.2	167.2	176.3	
25.26180	193.5	211.1	215.6	
21.48194	178.7	214.6	221.5	
19.68680	118.9	182.5	175.7	
14.74027	294.9	310.9	291.7	
13.07291	175.0	114.2	113.9	
12.51736	172.4	122.5	126.6	118.6
11.46875	172.7	137.2	133.3	140.1
10.97500	172.7	138.4	134.6	147.1
10.09166	168.1	157.2	148.4	172.3
8.00000	111.8	130.2	117.3	155.8
7.09444	139.2	170.0	155.7	193.4
6.97152	137.4	182.0	160.4	212.4
5.98750	135.9	187.3	182.2	181.9
5.06597	132.3	155.1	153.0	142.9
4.69722	143.8	146.0	145.7	143.9
3.96111	177.4	195.1	196.3	160.6
3.59305	173.0	192.9	193.5	153.8
3.08194	239.3	290.4	294.3	217.5
2.98055	241.5	306.3	309.7	219.2
2.67430	240.2	312.7	315.0	219.7
2.61319	245.9	308.7	310.5	277.6
2.10277	350.9	425.6	423.8	418.8
1.69652	404.7	404.6	407.7	416.4
1.37291	479.9	483.9	491.3	520.9
0.96458	282.2	278.8	277.1	261.4
0.53819	279.4	276.5	271.6	252.5
0.52569	270.0	277.6	265.7	236.7
0.47777	76.9	64.8	69.7	86.0
0.39930	99.2	103.0	101.9	101.4
0.22291	240.4	208.8	204.2	220.1
0.15972	246.3	191.4	196.1	206.2
0.11388	366.4	196.6	201.3	217.4

SEMI-MAJOR AXIS ROOT MEAN SQUARES RESIDUALS



SEMI-MAJOR AXIS ROOT MEAN SQUARES RESIDUALS



Predicted Re-entry Epoch (T_{PRED})

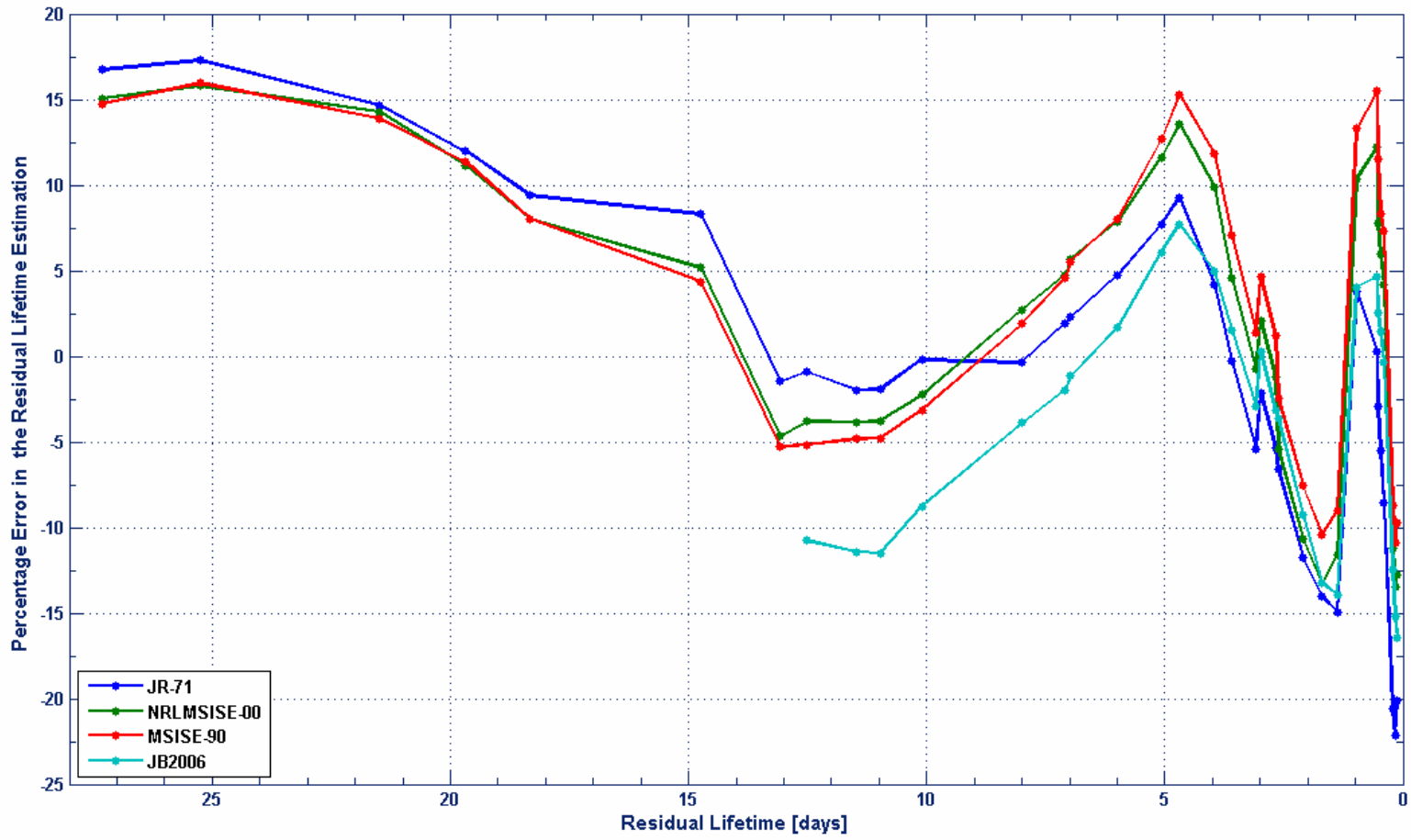
“black”: reentry altitude ~80 km
 “blue”: reentry altitude ~10 km
 “red”: post-reentry assessment
 using the last TLE available

EPOCH OF ORBIT DATA		COIW EPOCH							
		JR-71	MSISE-90	NRLMSISE-00	JB2006				
20081006	213500	20071107	183500	20081107	053500	20081107	073500		
20081008	224100	20081107	134100	20081107	054100	20081107	044100		
20081012	172400	20081106	082400	20081106	042400	20081106	062400		
20081014	122900	20081105	132900	20081105	102900	20081105	092900		
20081015	211000	20081104	221000	20081104	161000	20081104	161000		
20081019	111200	20081104	101200	20081103	201200	20081103	231200		
20081021	031300	20081103	001300	20081102	121300	20081102	141300		
20081021	163300	20081103	020900	20081102	132100	20081102	172100	20081101	203300
20081022	174300	20081102	232500	20081102	153700	20081102	181300	20081101	212500
20081023	053400	20081102	234600	20081102	161600	20081102	185200	20081101	223400
20081024	024600	20081103	042200	20081102	211600	20081102	232200	20081102	073400
20081026	045800	20081103	041000	20081103	082800	20081103	100400	20081102	212200
20081027	024200	20081103	080600	20081103	123600	20081103	125400	20081103	013000
20081027	053900	20081103	083900	20081103	140300	20081103	142100	20081103	025700
20081028	051600	20081103	114000	20081103	162200	20081103	161000	20081103	071600
20081029	032300	20081103	141000	20081103	201500	20081103	185900	20081103	121400
20081029	121400	20081103	151900	20081103	220500	20081103	200900	20081103	133400
20081030	055400	20081103	085000	20081103	160400	20081103	141500	20081103	093300
20081030	144400	20081103	043500	20081103	105500	20081103	084600	20081103	060900
20081031	030000	20081103	005100	20081103	055100	20081103	041800	20081103	024000
20081031	052600	20081103	032000	20081103	081100	20081103	062100	20081103	050300
20081031	124700	20081103	012400	20081103	053800	20081103	040500	20081103	024800
20081031	141500	20081103	004200	20081103	031800	20081103	012700	20081103	023400
20081101	023000	20081102	225600	20081103	010200	20081102	232900	20081103	001100
20081101	121500	20081102	231500	20081103	004400	20081102	233400	20081102	233400
20081101	200100	20081103	000300	20081103	020000	20081103	010800	20081103	002300
20081102	054900	20081103	055100	20081103	080300	20081103	072200	20081103	055400
20081102	160300	20081103	050000	20081103	065800	20081103	063300	20081103	053400
20081102	162100	20081103	043600	20081103	062500	20081103	055700	20081103	051700
20081102	173000	20081103	042000	20081103	055500	20081103	053900	20081103	050800
20081102	192300	20081103	040900	20081103	054000	20081103	052200	20081103	045600
20081102	233700	20081103	035200	20081103	043000	20081103	042200	20081103	041800
20081103	010800	20081103	040700	20081103	043300	20081103	042700	20081103	042300
20081103	021400	20081103	042500	20081103	044200	20081103	043700	20081103	043100
20081103	034100	20081103	044300	20081103	045100	20081103	044700	20081103	044200

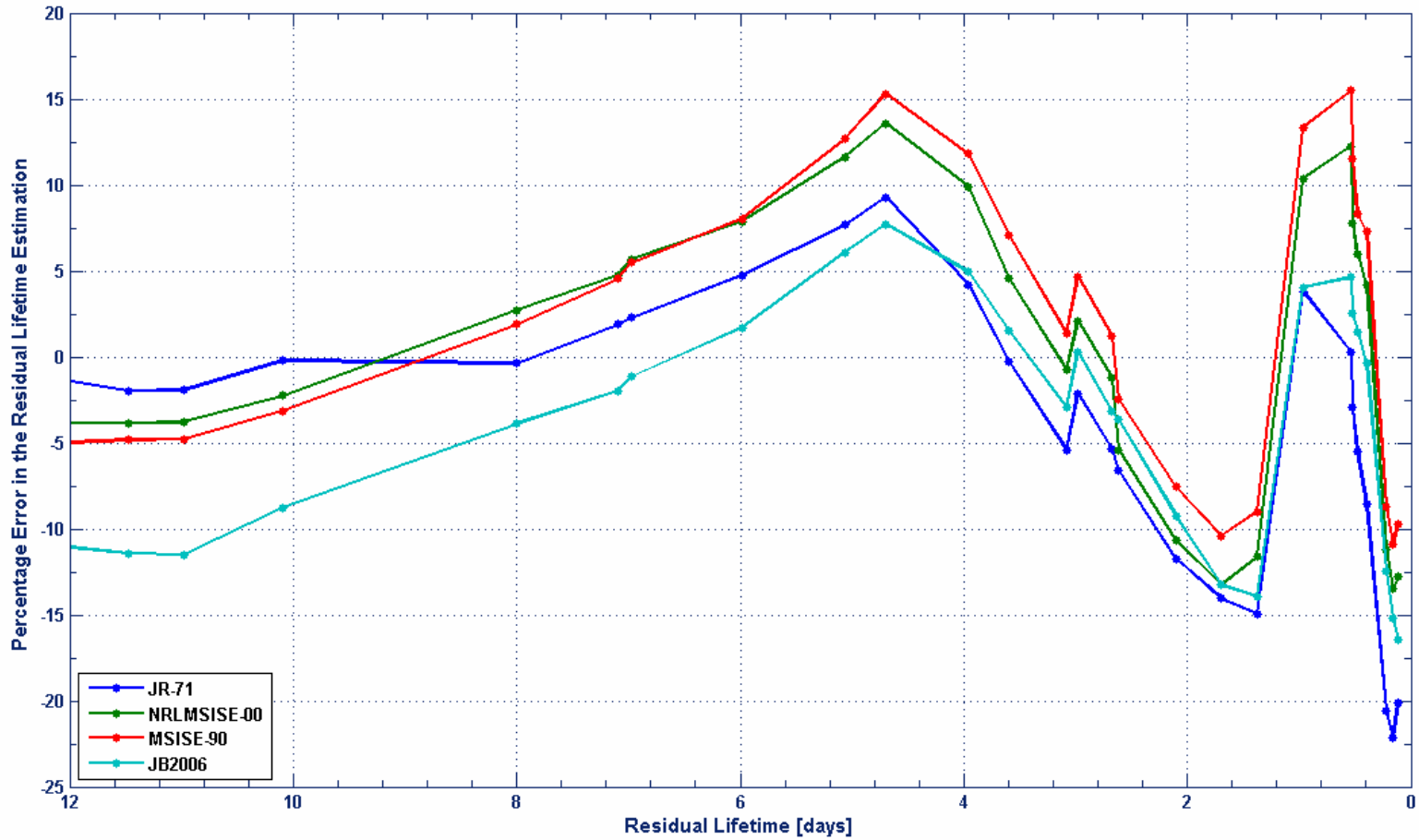
PERCENTAGE ERROR IN THE ESTIMATION OF THE RESIDUAL LIFETIME

Residual Lifetime [days]	PERCENTAGE ERROR IN THE ESTIMATION OF THE RESIDUAL LIFETIME			
	JR-71	MSISE-90	NRLMSISE-00	JB2006
27.308	16.743	14.760	15.065	
25.262	17.291	15.972	15.807	
21.482	14.654	13.878	14.266	
19.687	11.986	11.351	11.140	
18.325	9.394	8.030	8.030	
14.740	8.296	4.339	5.187	
13.073	-1.477	-5.301	-4.664	
12.517	-0.899	-5.160	-3.828	-10.752
11.469	-1.974	-4.808	-3.863	-11.420
10.975	-1.930	-4.777	-3.790	-11.497
10.092	-0.200	-3.131	-2.264	-8.788
8.000	-0.356	1.884	2.717	-3.898
7.094	1.909	4.552	4.728	-1.968
6.972	2.271	5.499	5.678	-1.136
5.987	4.744	8.014	7.875	1.682
5.066	7.663	12.666	11.624	6.073
4.697	9.284	15.287	13.572	7.732
3.961	4.190	11.799	9.888	4.944
3.593	-0.309	7.035	4.542	1.508
3.082	-5.408	1.352	-0.744	-2.952
2.981	-2.120	4.660	2.097	0.280
2.674	-5.375	1.220	-1.194	-3.194
2.613	-6.617	-2.471	-5.421	-3.641
2.103	-11.724	-7.563	-10.634	-9.247
1.697	-14.040	-10.397	-13.262	-13.262
1.373	-14.922	-9.004	-11.634	-13.910
0.965	3.816	13.319	10.367	4.032
0.538	0.258	15.484	12.258	4.645
0.526	-2.906	11.493	7.794	2.510
0.478	-5.523	8.285	5.959	1.453
0.399	-8.522	7.304	4.174	-0.348
0.223	-20.561	-8.723	-11.215	-12.461
0.160	-22.174	-10.870	-13.478	-15.217
0.114	-20.122	-9.756	-12.805	-16.463

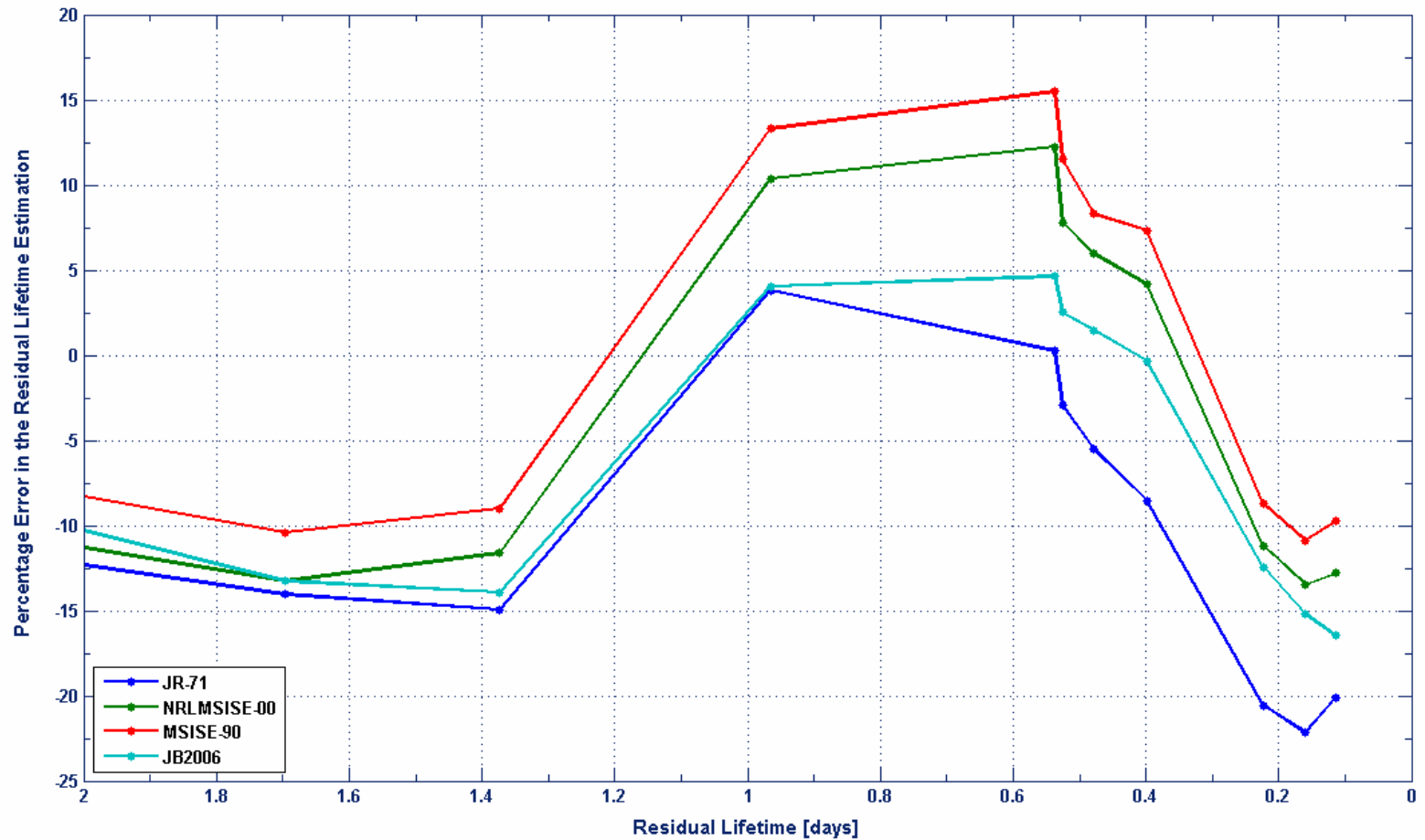
PERCENTAGE ERROR IN THE ESTIMATION OF THE RESIDUAL LIFETIME



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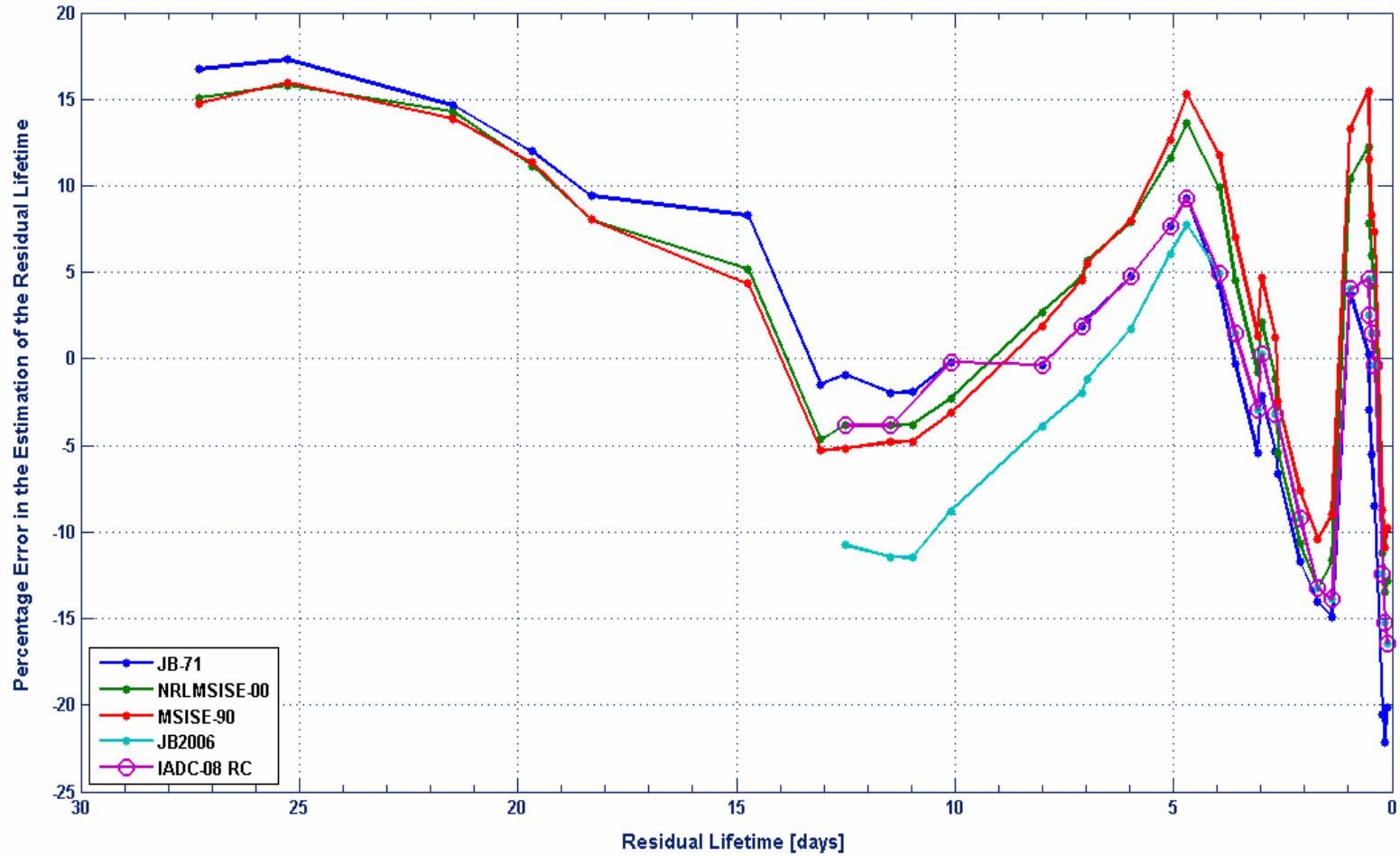


PERCENTAGE ERROR IN THE ESTIMATION OF THE RESIDUAL LIFETIME



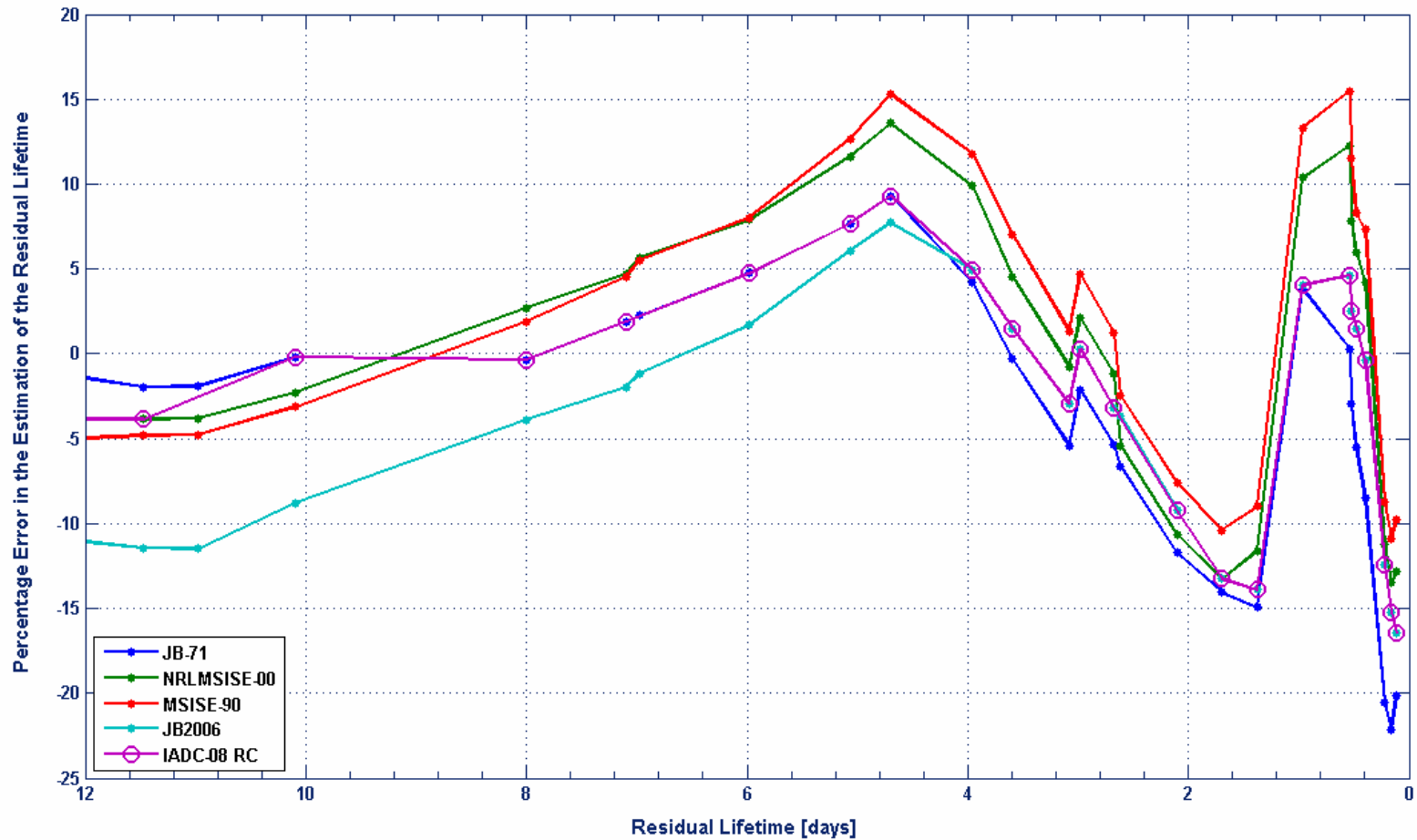
PERCENTAGE ERROR IN THE ESTIMATION OF THE RESIDUAL LIFETIME

including the reentry predictions uploaded to the IADC database: IADC-08 RC



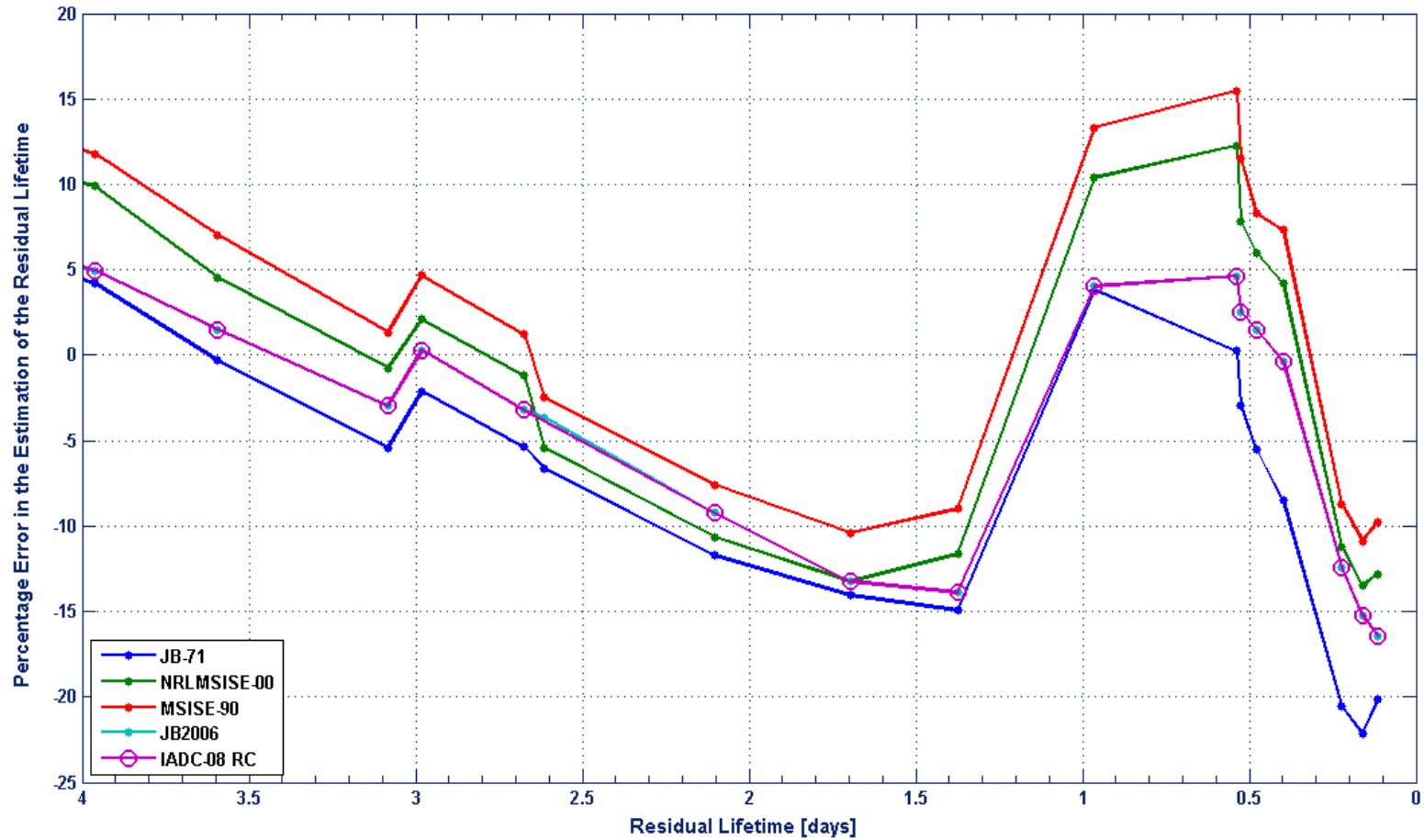
PERCENTAGE ERROR IN THE ESTIMATION OF THE RESIDUAL LIFETIME

including the reentry predictions uploaded to the IADC database: IADC-08 RC



PERCENTAGE ERROR IN THE ESTIMATION OF THE RESIDUAL LIFETIME

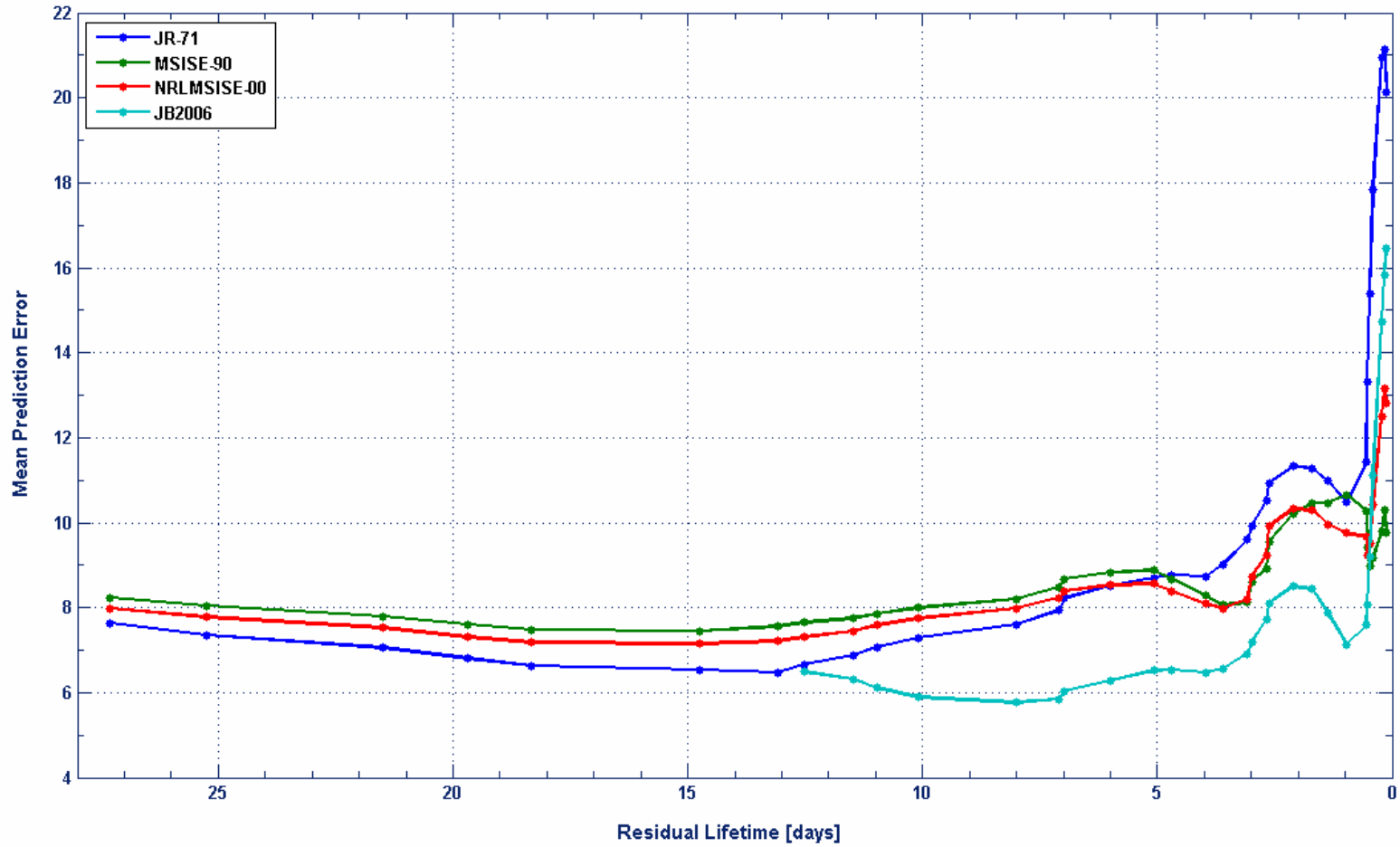
including the reentry predictions uploaded to the IADC database: IADC-08 RC



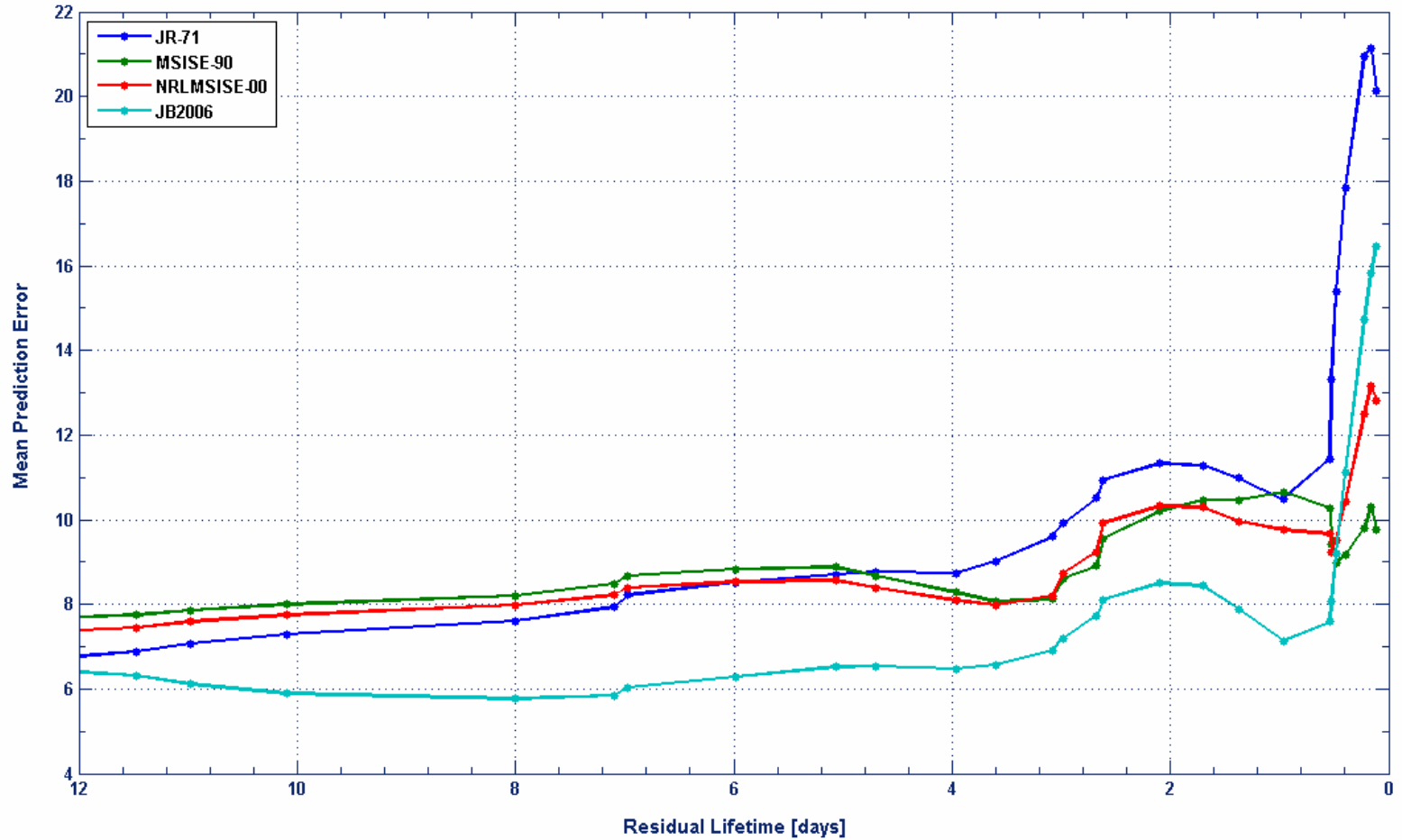
Mean Prediction Error

Residual Lifetime [days]	MEAN PREDICTION ERROR			
	JR-71	MSISE-90	NRLMSISE-00	JB2006
27.308	7.630	8.240	7.987	
25.262	7.361	8.042	7.773	
21.482	7.051	7.794	7.522	
19.687	6.805	7.598	7.304	
18.325	6.633	7.473	7.176	
14.740	6.538	7.454	7.147	
13.073	6.475	7.565	7.217	
12.517	6.660	7.649	7.311	6.482
11.469	6.881	7.744	7.445	6.318
10.975	7.078	7.862	7.589	6.114
10.092	7.292	7.990	7.747	5.889
8.000	7.601	8.202	7.985	5.763
7.094	7.930	8.489	8.225	5.848
6.972	8.217	8.676	8.391	6.033
5.987	8.514	8.835	8.527	6.278
5.066	8.712	8.878	8.561	6.520
4.697	8.771	8.668	8.391	6.544
3.961	8.740	8.279	8.086	6.475
3.593	9.025	8.058	7.974	6.570
3.082	9.606	8.127	8.202	6.908
2.981	9.906	8.611	8.735	7.190
2.674	10.505	8.915	9.246	7.722
2.613	10.932	9.556	9.917	8.099
2.103	11.324	10.200	10.325	8.504
1.697	11.284	10.463	10.295	8.430
1.373	10.978	10.471	9.965	7.893
0.965	10.485	10.654	9.756	7.141
0.538	11.438	10.274	9.669	7.585
0.526	13.301	9.405	9.237	8.075
0.478	15.380	8.988	9.526	9.188
0.399	17.845	9.163	10.418	11.122
0.223	20.952	9.783	12.499	14.714
0.160	21.148	10.313	13.142	15.840
0.114	20.122	9.756	12.805	16.463

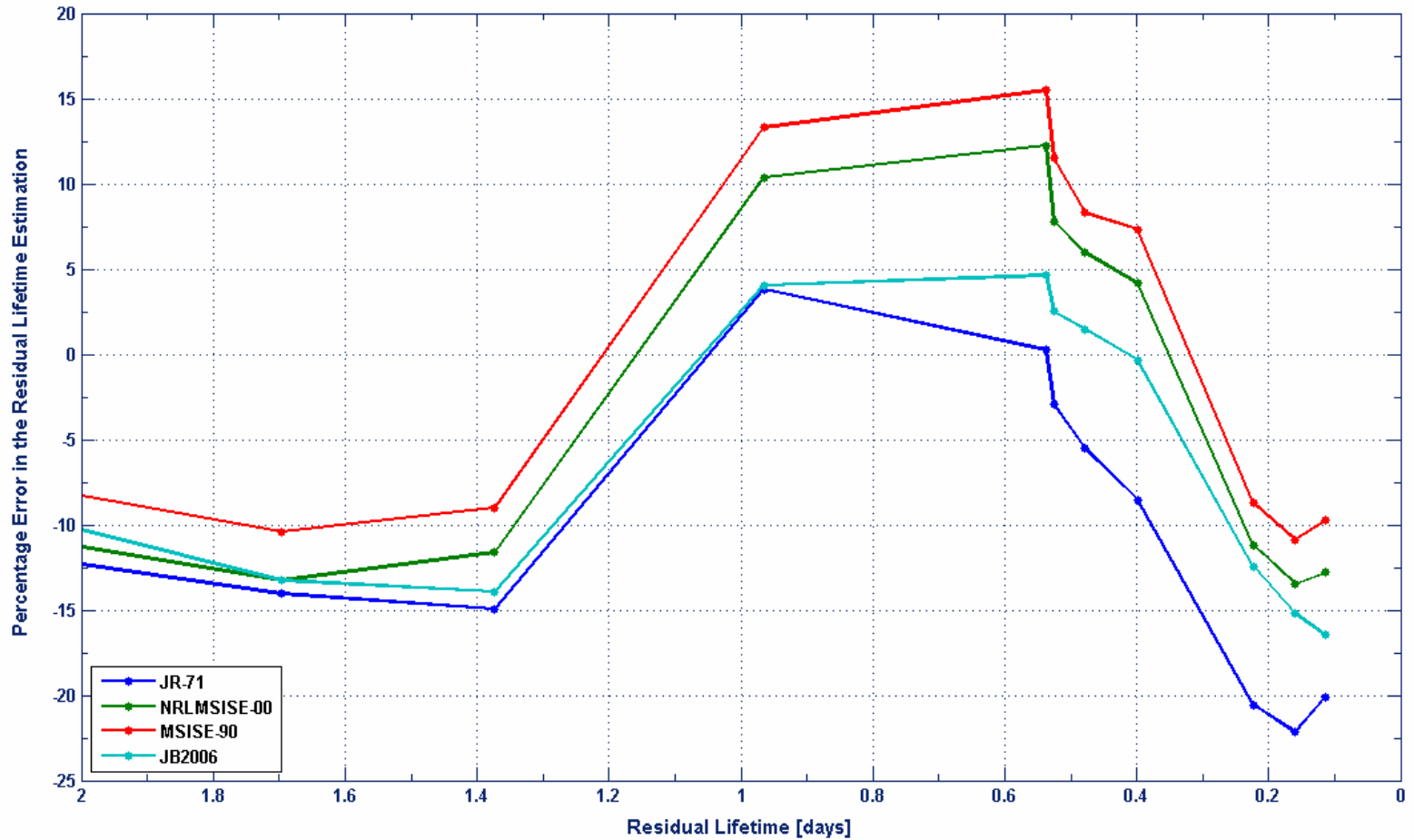
Mean Prediction Error



Mean Prediction Error

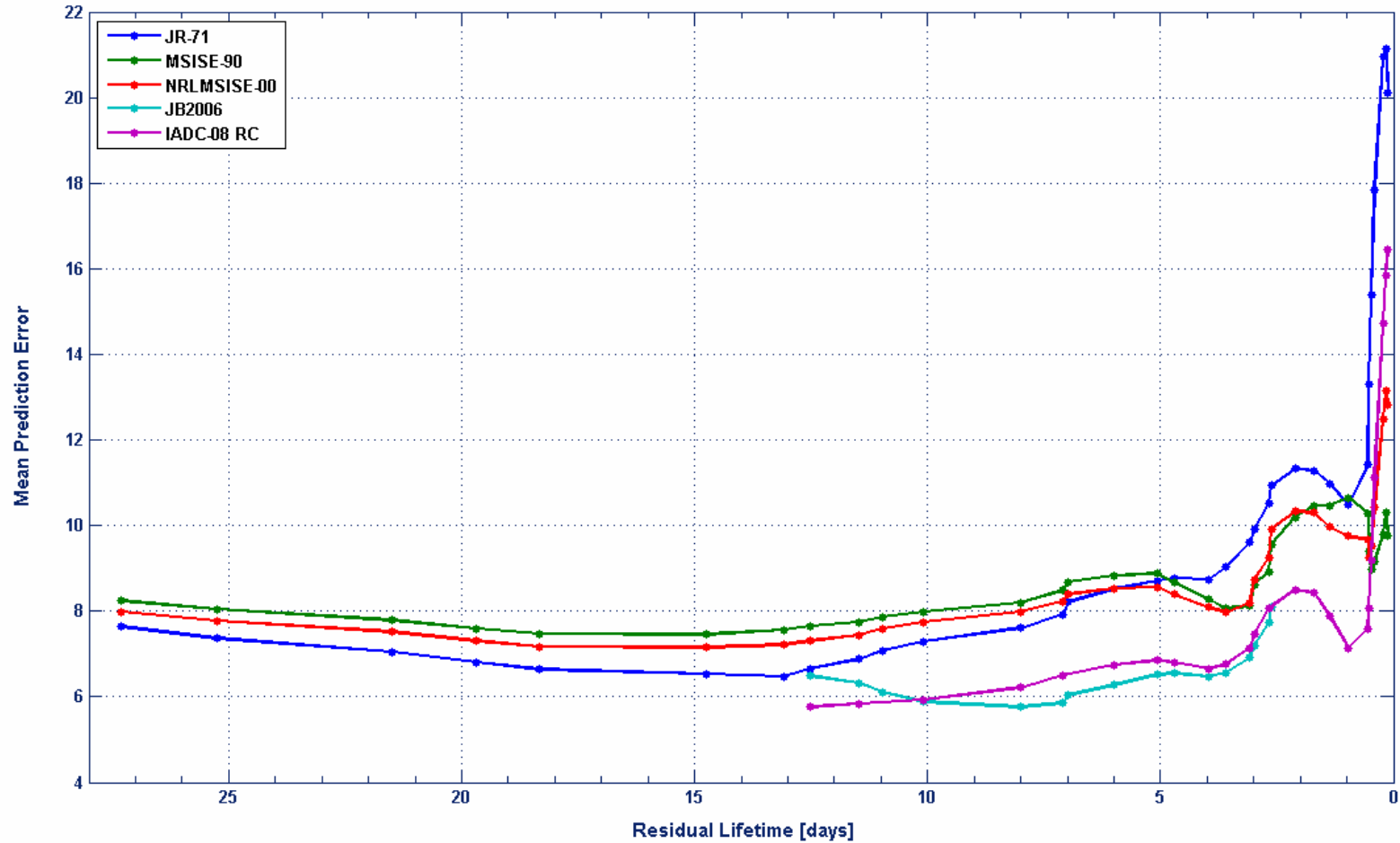


Mean Prediction Error



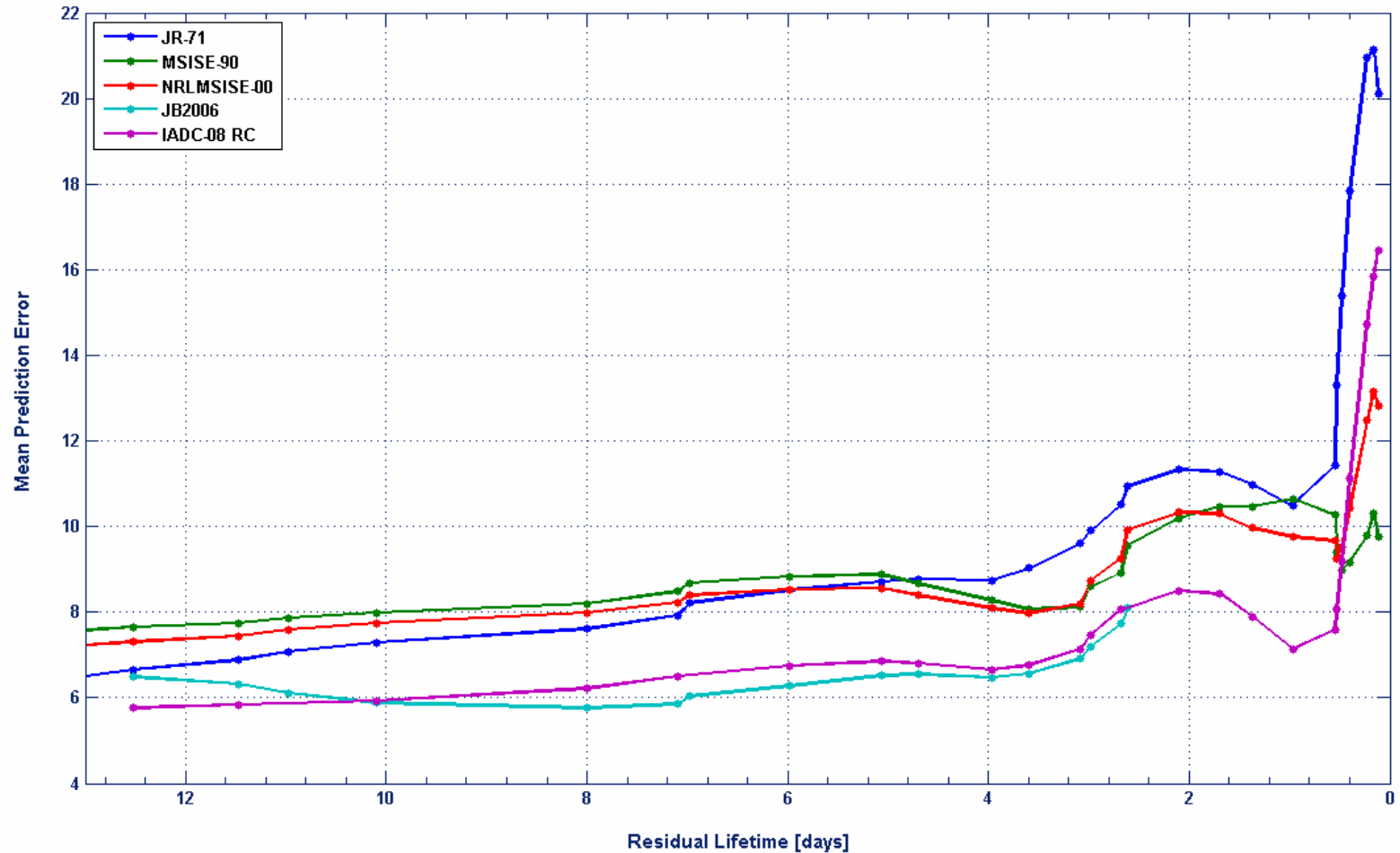
Mean Prediction Error

including the reentry predictions uploaded to the IADC database: IADC-08 RC



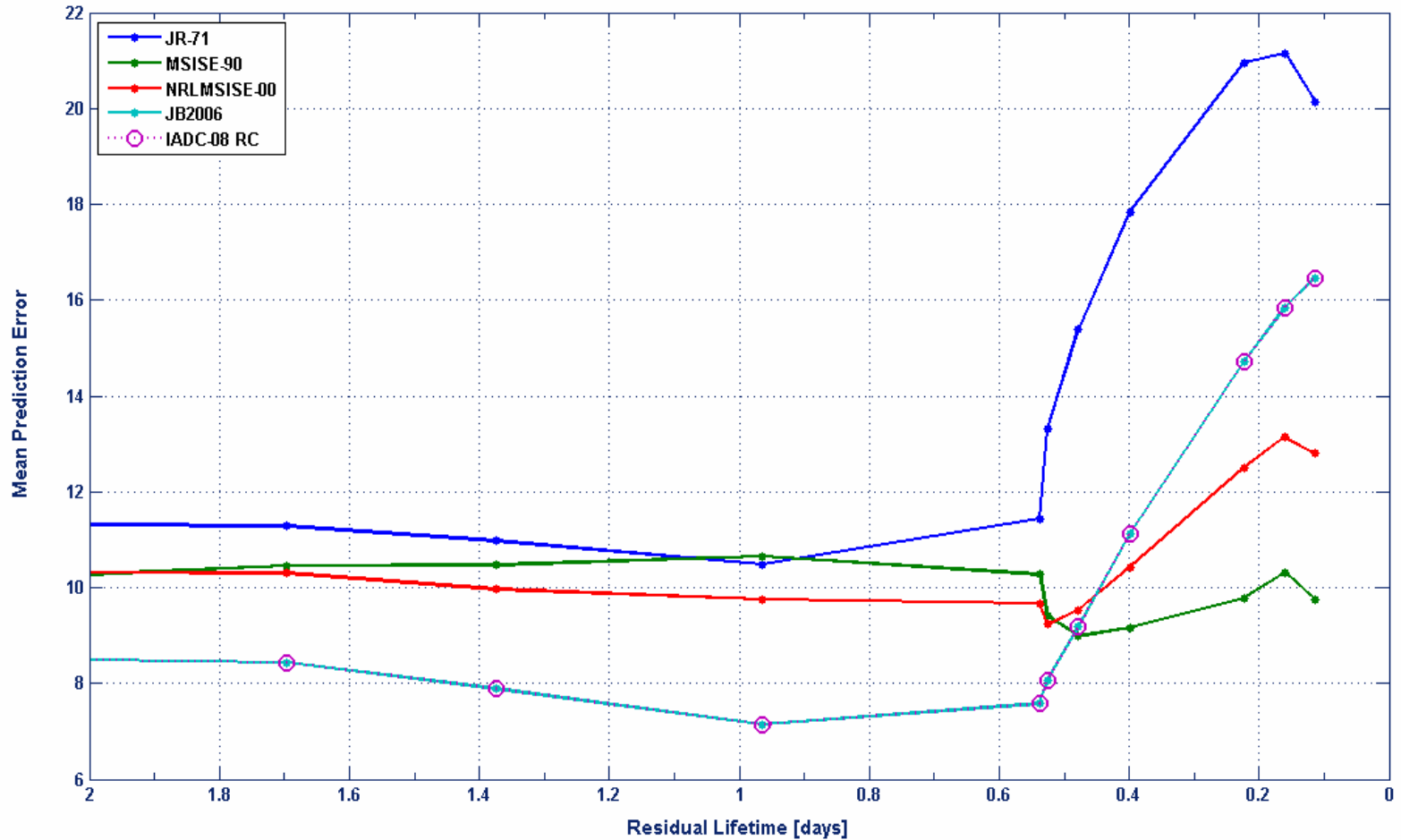
Mean Prediction Error

including the reentry predictions uploaded to the IADC database: IADC-08 RC

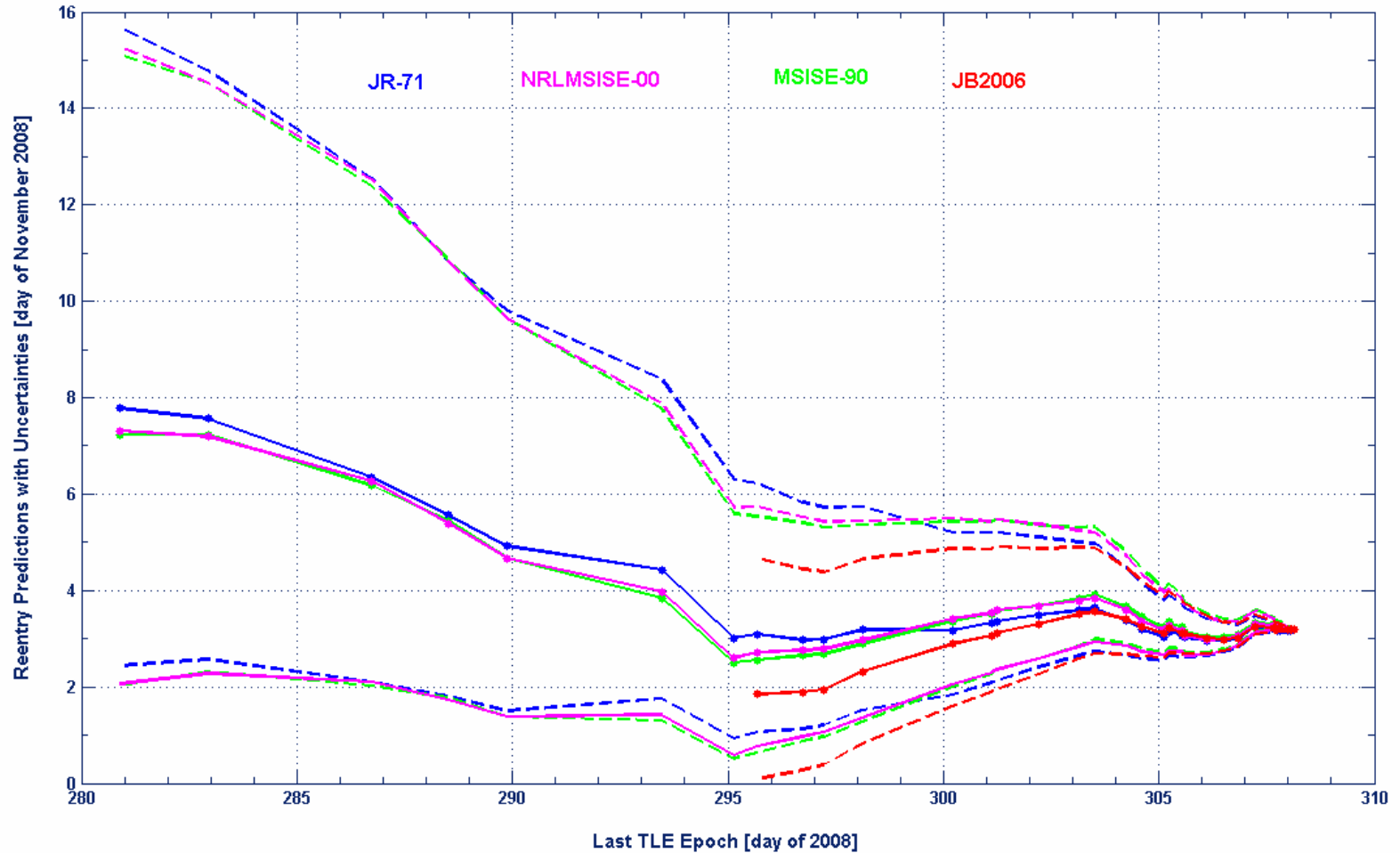


Mean Prediction Error

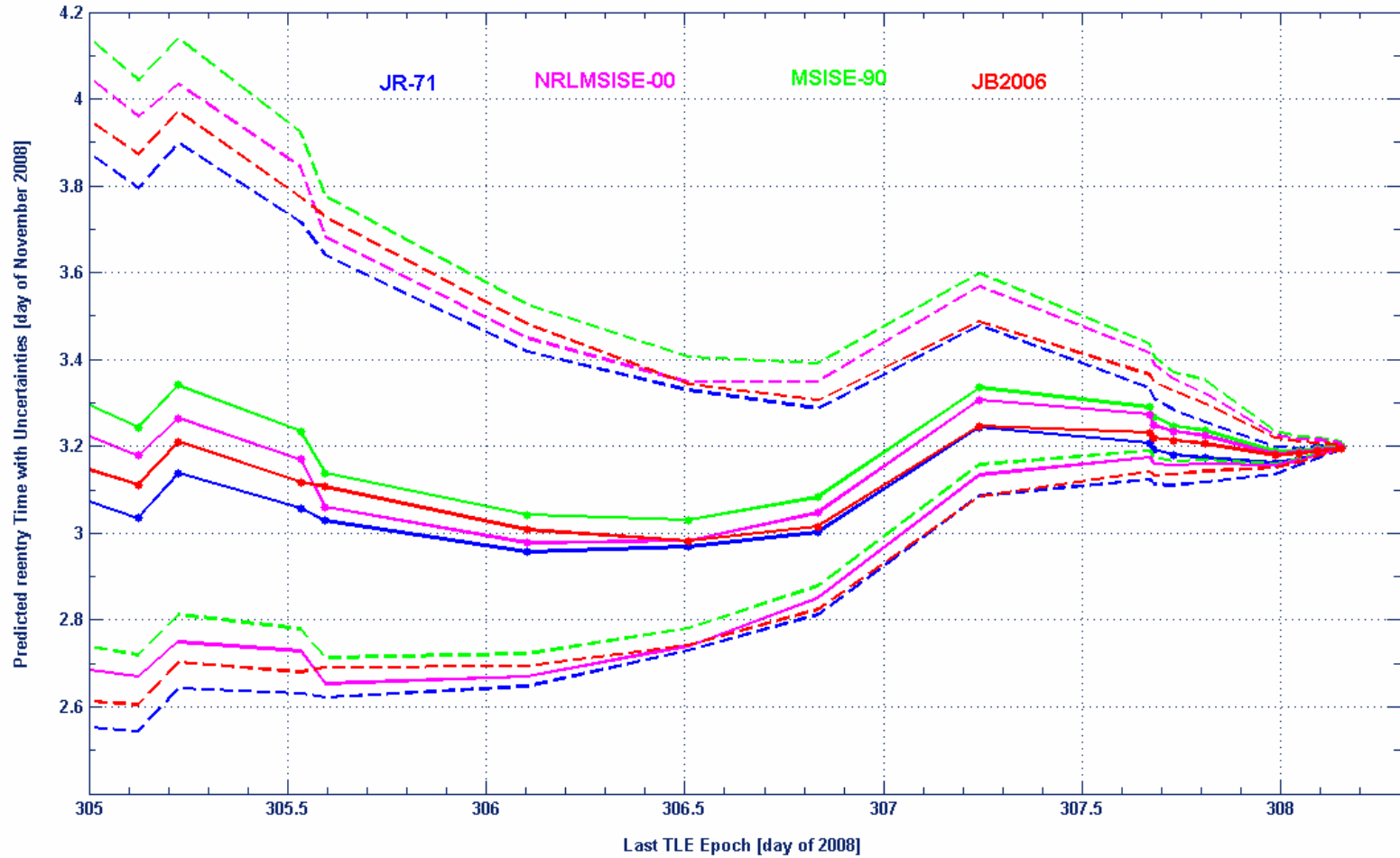
including the reentry predictions uploaded to the IADC database: IADC-08 RC



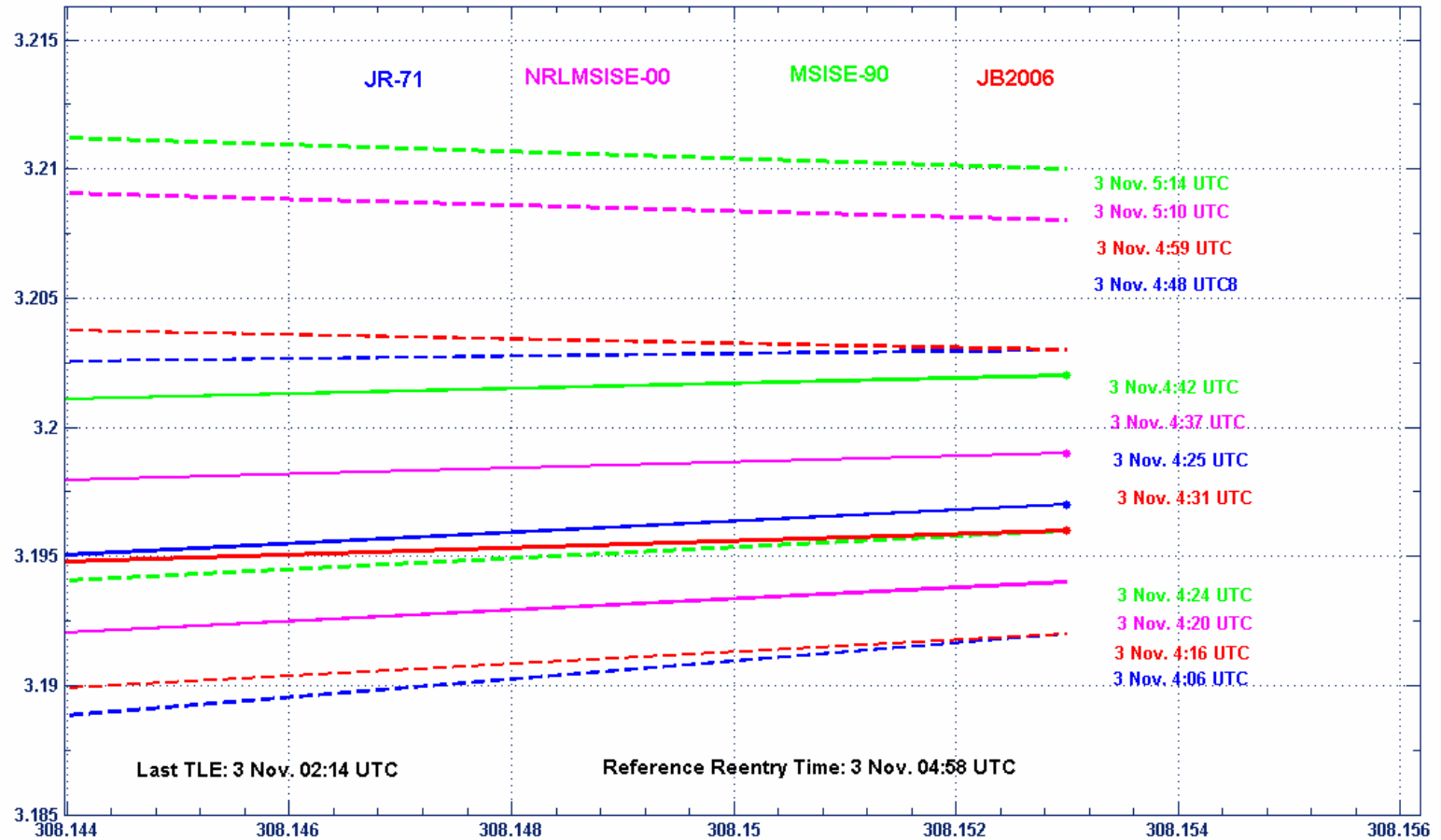
Predicted reentry time with uncertainties



Predicted reentry time with uncertainties

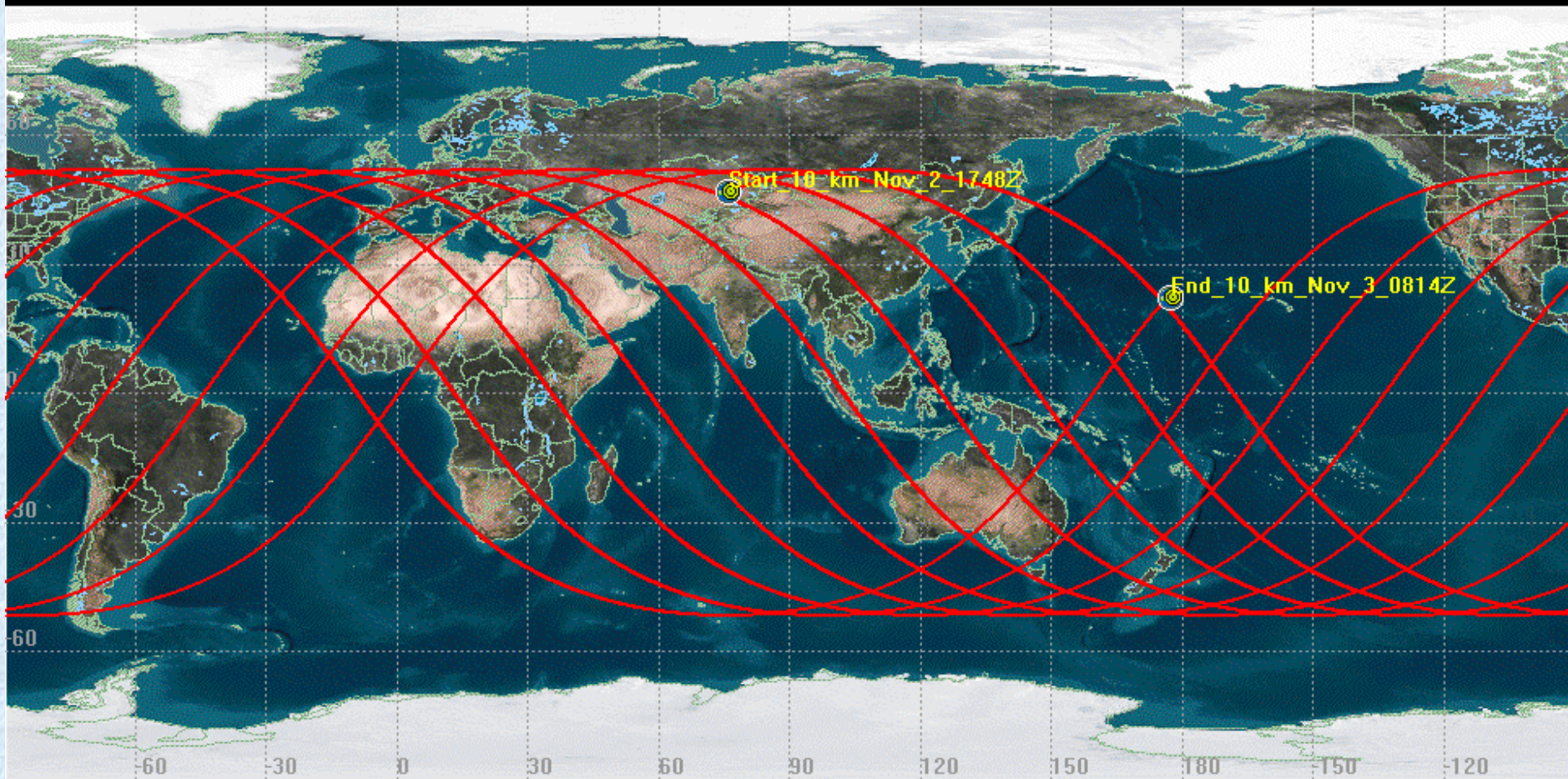


Predicted reentry time with uncertainties



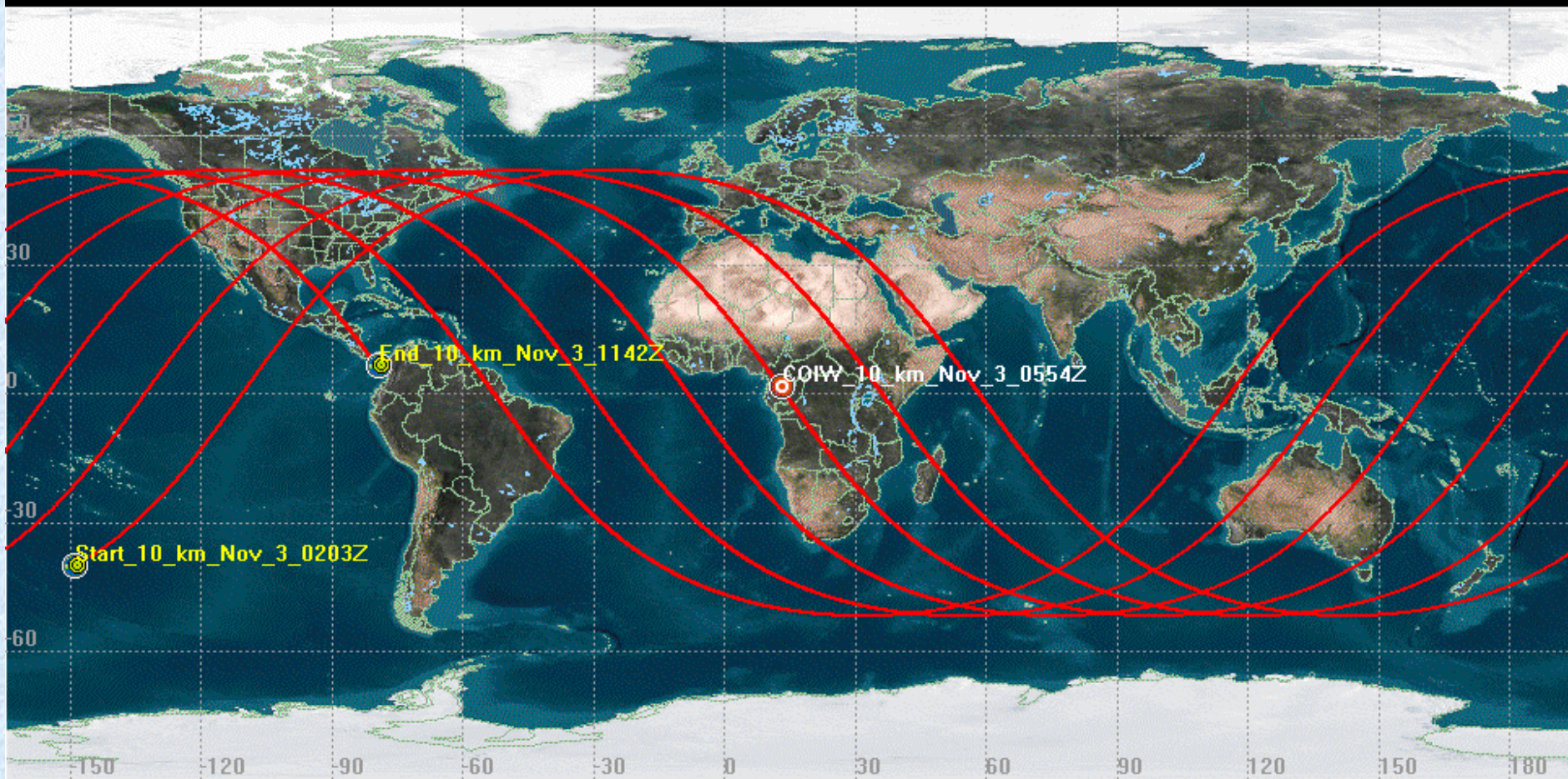
Re-entry window based on TLE of 1 November, 12:15 UTC

JB2006 atmospheric density model



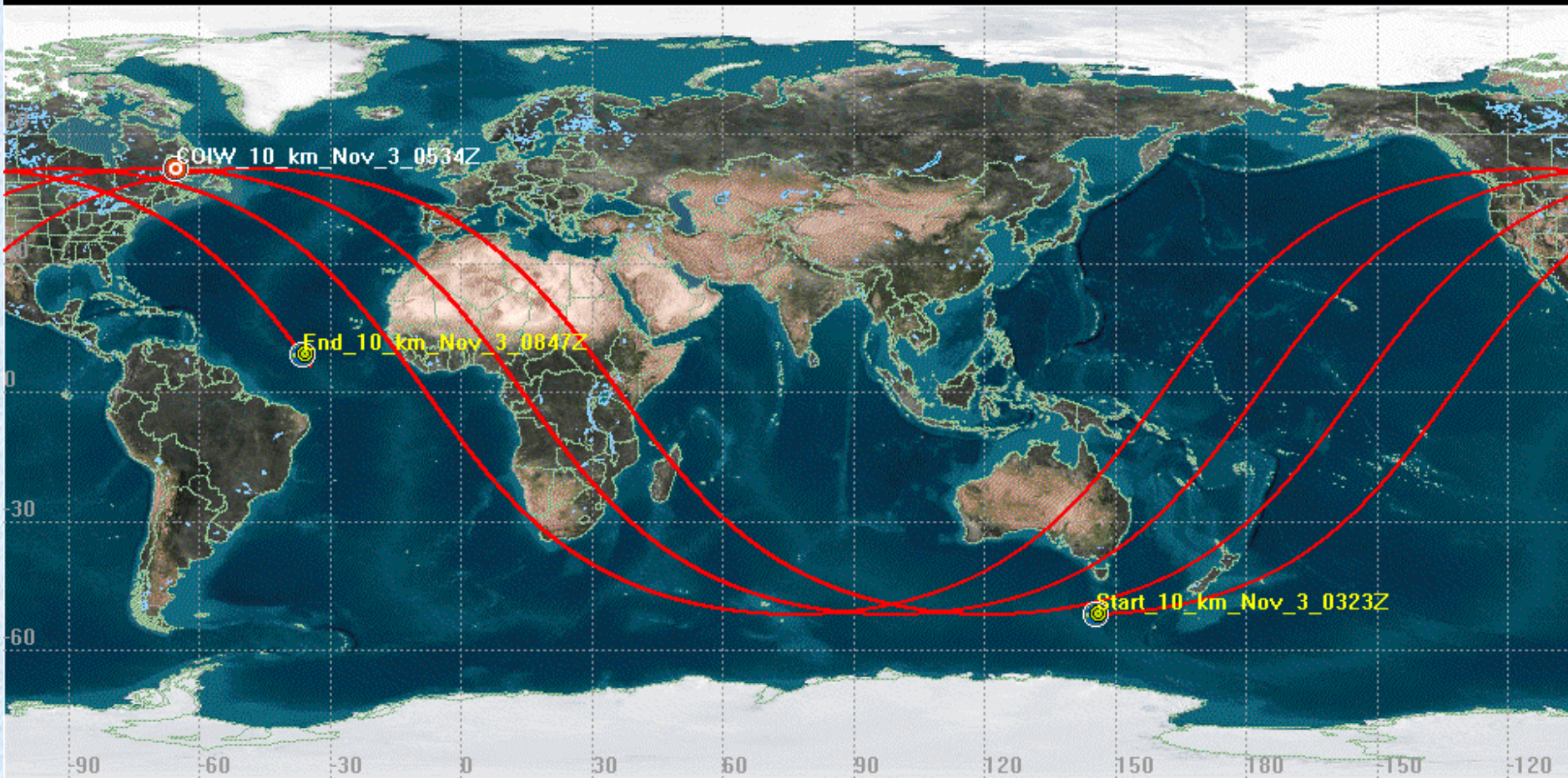
Re-entry window based on TLE of 2 November, 05:49 UTC

JB2006 atmospheric density model



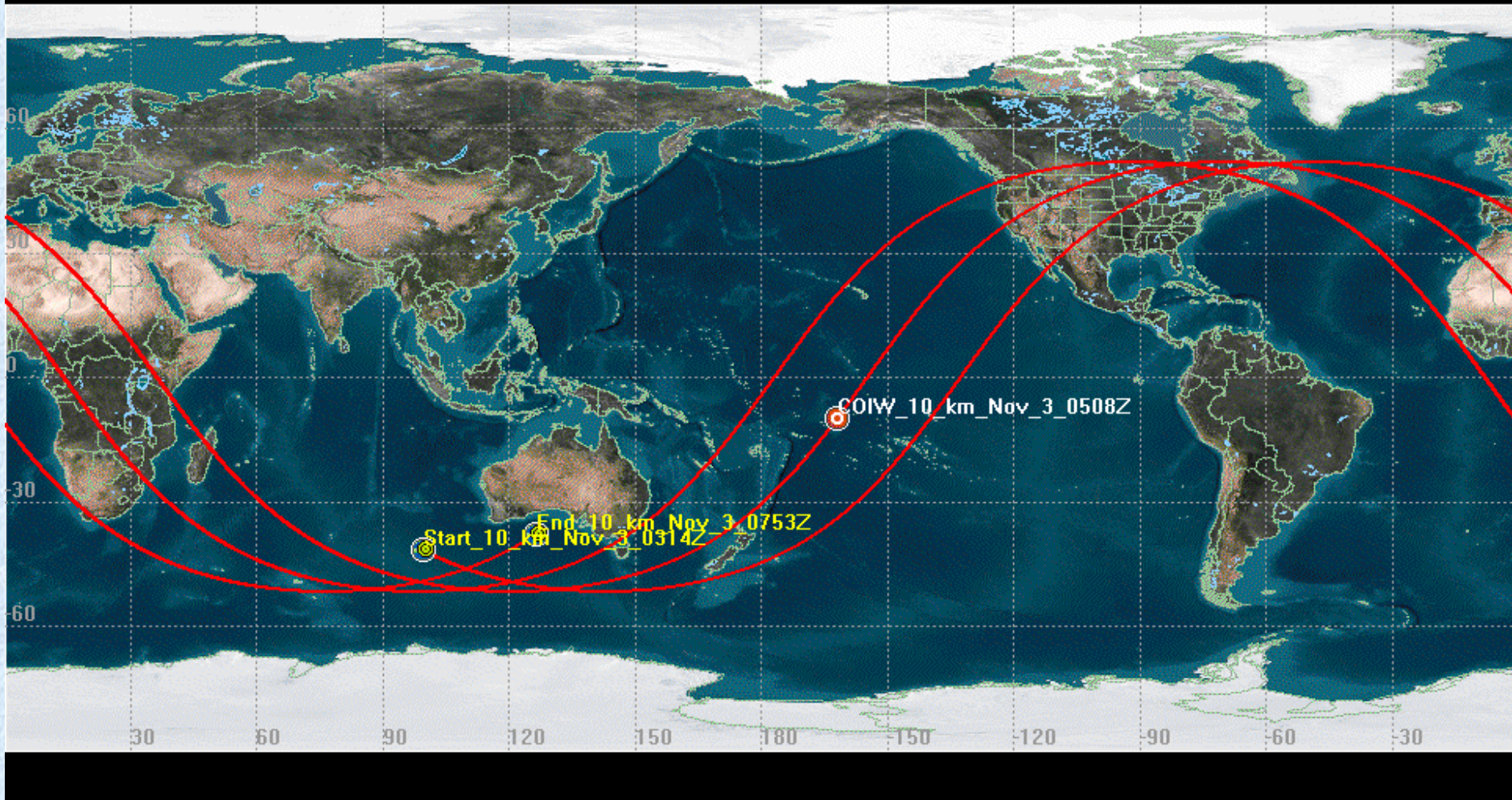
Re-entry window based on TLE of 2 November, 16:03 UTC

JB2006 atmospheric density model



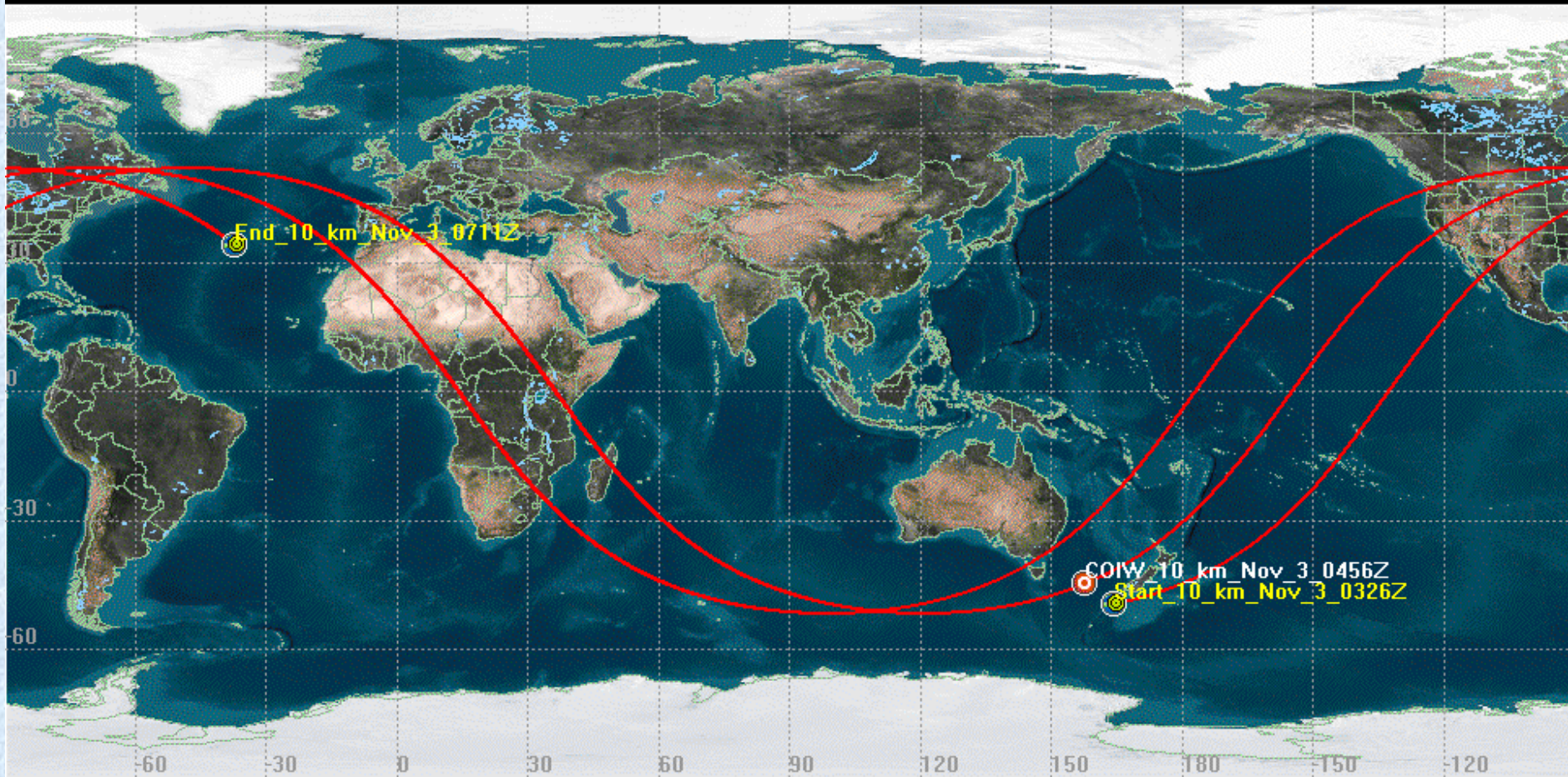
Re-entry window based on TLE of 2 November, 17:30 UTC

JB2006 atmospheric density model



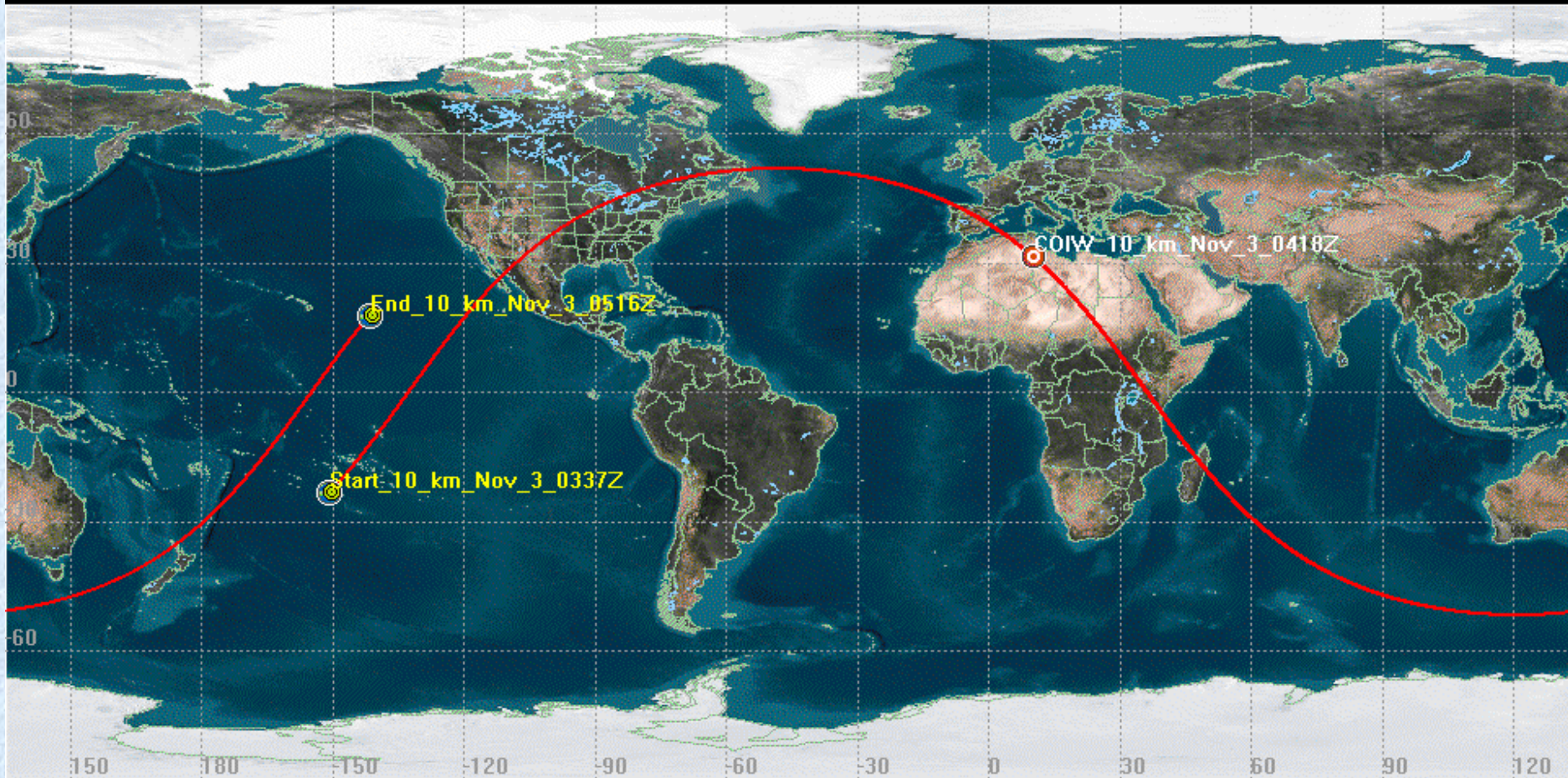
Re-entry window based on TLE of 2 November, 19:23 UTC

JB2006 atmospheric density model

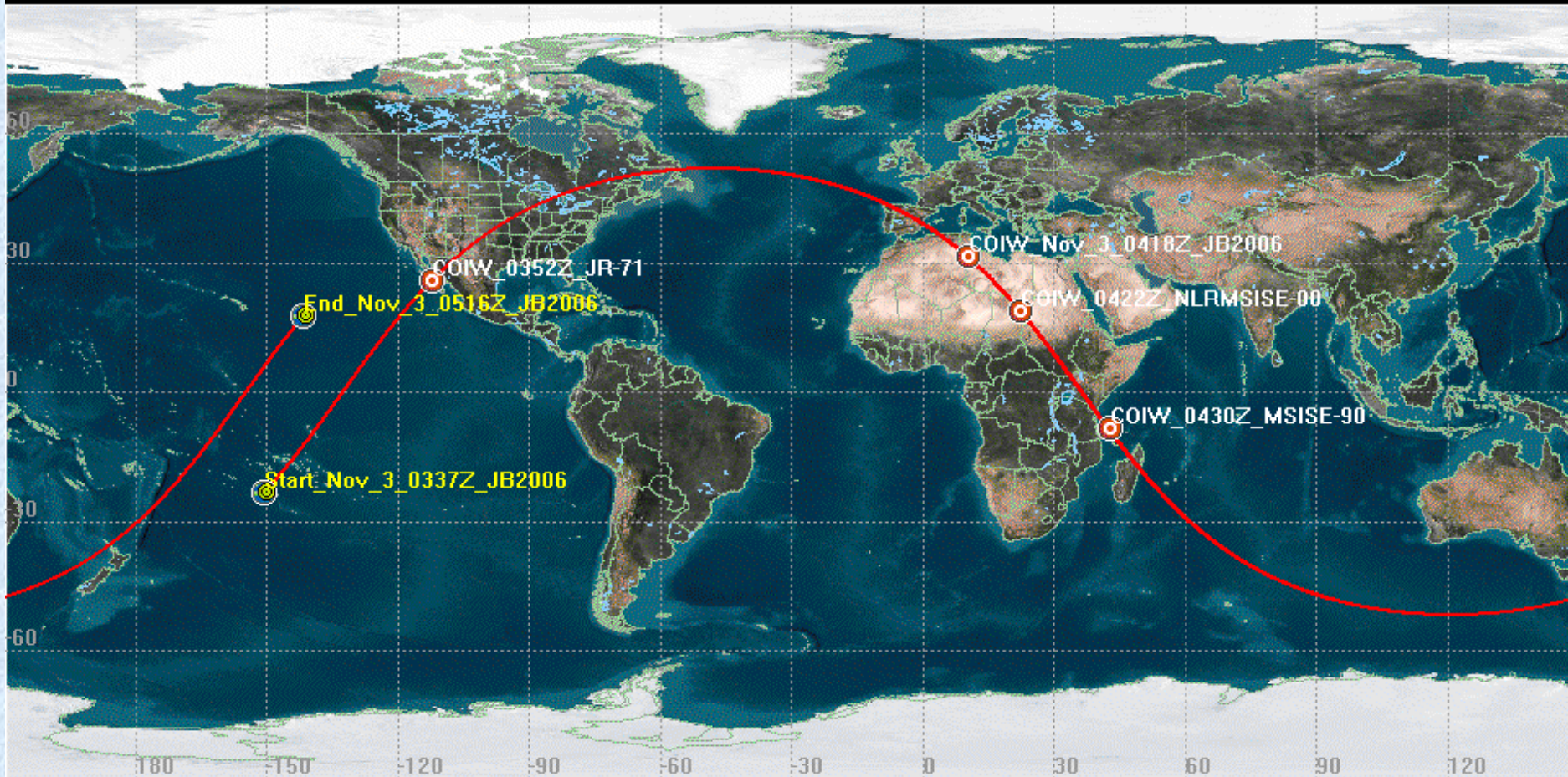


Re-entry window based on TLE of 2 November, 23:37 UTC

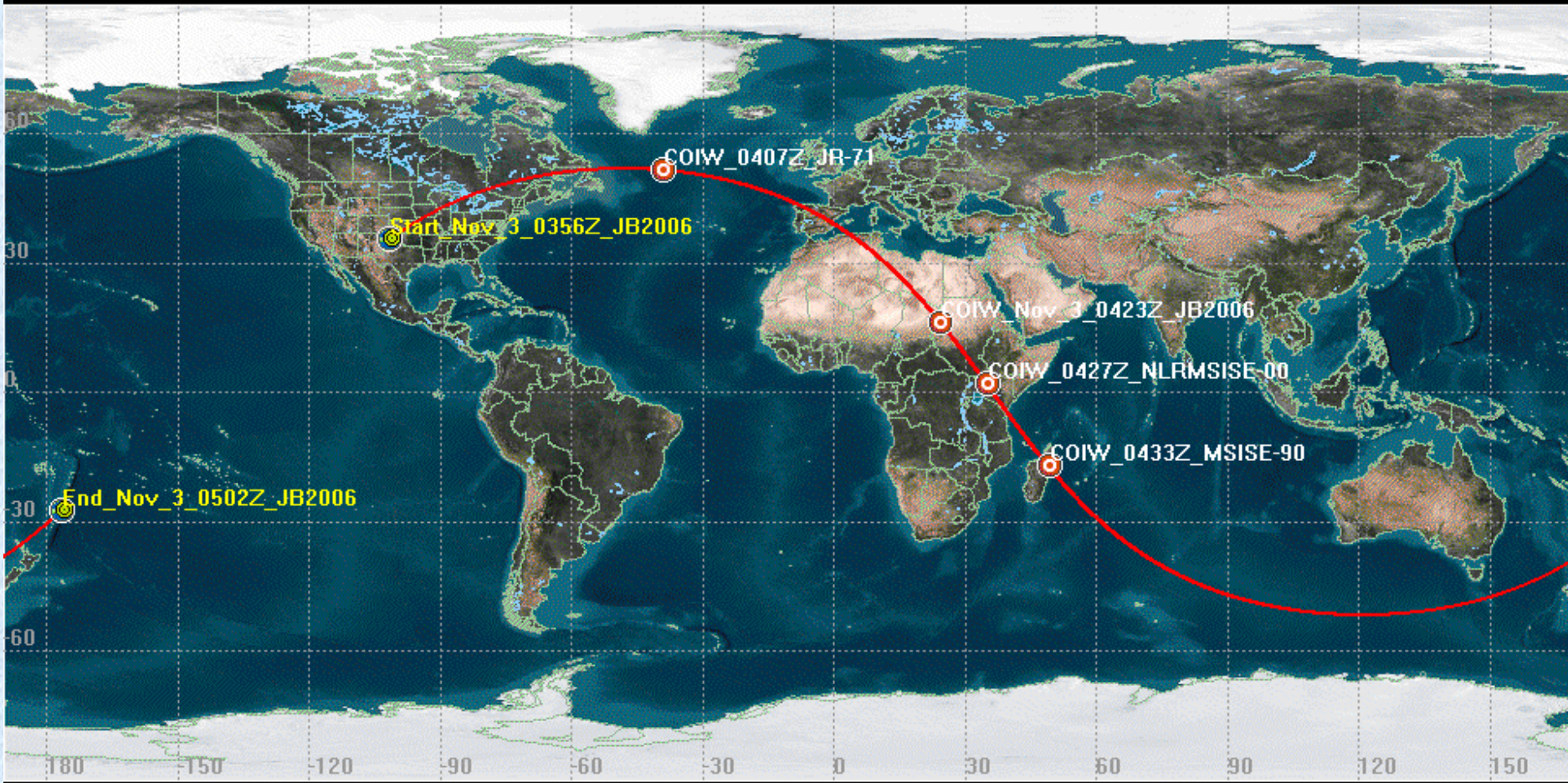
JB2006 atmospheric density model



Re-entry window based on TLE of 2 November, 23:37 UTC at 10 km with 4 atmospheric density models



Re-entry window based on TLE of 3 November, 01:18 UTC at 10 km with 4 atmospheric density models



Re-entry window based on TLE of 3 November, 02:14 UTC at 10 km with 4 atmospheric density models



Acknowledgments

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