Assessment of an accuracy of orbits determination and prediction

For example, the calculations were carried out for SC"METEOR M1". As the initial data TLE were used taken from the Internet at "http://www.space-track.org". These data are presented below. It was received 41 sets at all. Recent elements are related to12 October 2009.

```
Space-Track - Object ID Query Results
Object ID Query Results
 1 35865U 09049A   09260.72535468 -.00000045  00000-0  00000+0 0    19
 2 35865 098.7998 310.8940 0003181 081.7658 278.3815 14.21921862    02
 1 35865U 09049A   09260.86609852  .00000176  00000-0  10000-3 0    23
 2 35865 098.8001 311.0403 0003574 080.8701 279.2896 14.21858330    20
 1 35865U 09049A   09260.93646957 +.00000176 +00000-0 +10000-3 0 00118
 2 35865 098.8073 311.0962 0003522 107.5299 252.6413 14.218318290000 36
 1 35865U 09049A   09261.85130047  .00000176  00000-0  10000-3 0    40
 2 35865 098.8004 312.0250 0003601 080.8898 279.2547 14.21823900   165
 1 35865U 09049A   09262.90688002 +.00000176 +00000-0 +10000-3 0 00080
 2 35865 098.8008 313.0781 0003592 078.1595 281.9966 14.218235990003 18
 1 35865U 09049A   09263.18836766  .00000176  00000-0  10000-3 0    50
 2 35865 098.8007 313.3591 0003564 077.3801 282.7795 14.21824067   353
 1 35865U 09049A   09263.68096973 +.00000176 +00000-0 +10000-3 0 00075
 2 35865 098.8007 313.8501 0003584 074.1254 286.0304 14.218242640004 28
 1 35865U 09049A   09264.66617459  .00000176  00000-0  10000-3 0    61
 2 35865 098.8010 314.8326 0003553 071.4378 288.7185 14.21824773   567
 1 35865U 09049A   09265.58100732 +.00000176 +00000-0 +10000-3 0 00097
 2 35865 098.8005 315.7444 0003490 068.8840 291.2717 14.218252380006 97
 1 35865U 09049A   09266.00323756  .00000176  00000-0  10000-3 0    76
 2 35865 098.8004 316.1656 0003476 067.7453 292.4070 14.21825238   750
 1 35865U 09049A   09266.77732717 +.00000176 +00000-0 +10000-3 0 00105
 2 35865 098.8003 316.9374 0003459 066.1413 294.0126 14.218254590008 61
 1 35865U 09049A   09267.76253122  .00000176  00000-0  10000-3 0    80
 2 35865 098.8003 317.9196 0003392 063.6114 296.5400 14.21825734  1005
 1 35865U 09049A   09268.74773547 +.00000176 +00000-0 +10000-3 0 00111
 2 35865 098.8001 318.9020 0003361 059.7753 300.3748 14.218260200011 44
 1 35865U 09049A   09269.16996577  .00000176  00000-0  10000-3 0    95
 2 35865 098.8001 319.3232 0003363 059.2873 300.8625 14.21826147  1200
 1 35865U 09049A   09269.73293961 +.00000176 +00000-0 +10000-3 0 00118
 2 35865 098.8000 319.8845 0003341 057.1100 303.0398 14.218263380012 82
 1 35865U 09049A   09270.64777175  .00000176  00000-0  10000-3 0   103
 2 35865 098.7999 320.7967 0003335 054.0891 306.0582 14.21826594  1417
 1 35865U 09049A   09270.71814367 +.00000176 +00000-0 +10000-3 0 00117
 2 35865 098.7999 320.8669 0003331 053.9950 306.1535 14.218266180014 24
 1 35865U 09049A   09271.70334727  .00000176  00000-0  10000-3 0   114
 2 35865 098.7999 321.8492 0003297 051.8181 308.3273 14.21826881  1563
 1 35865U 09049A   09272.68855112 +.00000176 +00000-0 +10000-3 0 00141
 2 35865 098.7998 322.8315 0003244 049.1824 310.9608 14.218271130017 09
 1 35865U 09049A   09273.11078140  .00000176  00000-0  10000-3 0   126
 2 35865 098.7998 323.2526 0003240 050.3367 309.8063 14.21827182  1764
 1 35865U 09049A   09273.67375518 +.00000176 +00000-0 +10000-3 0 00148
 2 35865 098.7998 323.8140 0003213 047.3155 312.8270 14.218273360018 47
 1 35865U 09049A   09274.16635696  .00000176  00000-0  10000-3 0   138
 2 35865 098.7998 324.3052 0003207 049.6494 310.4916 14.21827409  1919
 1 35865U 09049A   09274.72933162 +.00000176 +00000-0 +10000-3 0 00151
 2 35865 098.7997 324.8666 0003235 045.7514 314.3923 14.218275000019 96
 1 35865U 09049A   09275.50342050  .00000176  00000-0  10000-3 0   147
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2 35865 098.7994 325.6382 0003133 043.4994 316.6423 14.21827494  2107
1 35865U 09049A   09275.71453548 +.00000176 +00000-0 +10000-3 0 00156
2 35865 098.7994 325.8489 0003222 041.2417 318.8963 14.21827447002136
1 35865U 09049A   09276.62936828  .00000176  00000-0  10000-3 0   154
2 35865 098.7988 326.7607 0003204 036.8601 323.2764 14.21827496  2263
1 35865U 09049A   09276.91085537 +.00000176 +00000-0 +10000-3 0 00169
2 35865 098.7989 327.0415 0003204 035.7401 324.3972 14.21827547002306
1 35865U 09049A   09277.75531651  .00000176  00000-0  10000-3 0   165
2 35865 098.7985 327.8837 0003177 033.6125 326.5204 14.21827375  2421
1 35865U 09049A   09278.88126537 +.00000176 +00000-0 +10000-3 0 00208
2 35865 098.7984 329.0063 0002850 036.9325 323.2048 14.21827274002585
1 35865U 09049A   09279.16275187  .00000176  00000-0  10000-3 0   172
2 35865 098.7982 329.2871 0002653 041.9542 318.1796 14.21827152  2623
1 35865U 09049A   09279.72572576 +.00000176 +00000-0 +10000-3 0 00198
2 35865 098.7982 329.8484 0002804 034.8855 325.2456 14.21827199002707
1 35865U 09049A   09280.42944343  .00000176  00000-0  10000-3 0   181
2 35865 098.7979 330.5500 0002634 036.7103 323.4238 14.21827279  2807
1 35865U 09049A   09280.64055863 +.00000176 +00000-0 +10000-3 0 00196
2 35865 098.7977 330.7604 0002769 032.5468 327.5843 14.21827231002837
1 35865U 09049A   09281.76650640  .00000176  00000-0  10000-3 0   194
2 35865 098.7975 331.8829 0002899 027.2485 332.8774 14.21827137  2994
1 35865U 09049A   09282.75171110 +.00000176 +00000-0 +10000-3 0 00228
2 35865 098.7972 332.8650 0002964 022.9024 337.2232 14.21827175003135
1 35865U 09049A   09283.10357027  .00000176  00000-0  10000-3 0   209
2 35865 098.7972 333.2159 0002903 023.4149 336.7138 14.21827220  3186
1 35865U 09049A   09283.94803124 +.00000176 +00000-0 +10000-3 0 00238
2 35865 098.7971 334.0578 0003012 019.4902 340.6374 14.21827274003302
1 35865U 09049A   09284.22951805  .00000176  00000-0  10000-3 0   218
2 35865 098.7969 334.3383 0002920 020.3403 339.7864 14.21827243  3343
1 35865U 09049A   09284.86286414 +.00000176 +00000-0 +10000-3 0 00237
2 35865 098.7970 334.9699 0003006 018.0496 342.0763 14.21827135003438
1 35865U 09049A   09285.42583840  .00000176  00000-0  10000-3 0   222
2 35865 098.7967 335.5311 0002835 020.0781 340.0484 14.21826973  3517
1 35865U 09049A   09285.70732540 +.00000176 +00000-0 +10000-3 0 00237
2 35865 098.7967 335.8117 0002718 019.1738 340.9512 14.21826840003553
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Processing of these data was performed in two stages:

1. Recalculation of TLE into components of the state vector (tRV) in Earth-Centered Inertial (ECI) coordinate system at the time of TLE “binding”. This recalculation was implemented by using SGP4 model, which adapted to use TLE as initial data (ID).
2. Determination of ID by processing the source data in the form of (tRV) using Least Square Technique (LST) and prediction of motion in “future" data in the same form. 7 (tRV) sets were processed on fit span. Prediction of motion was performed on 4 "future" dataset in the form of (tRV). Three components of prediction errors were calculated: in radial, along-track (time) and cross-track directions. Thus, all source data handled consistently. The number of possible determinations and prediction consist of 42-7-4 = 31.

Table 1. Initial data in form of (tRV)

№	Date	Rev	Time	x	y	z	Vx	Vy	Vz
1	17.09	1	18887.72535595	4713.2880522	-5442.3198163	-0.0002860	-0.8666811335	-0.7373685038	7.3550584594
2	17.09	3	18887.86609822	4727.2564888	-5430.3677712	0.0000520	-0.8650073663	-0.7393880079	7.3550253713
3	17.09	4	18887.93646664	4733.3812298	-5426.7038957	-0.0000511	-0.8647530838	-0.7408080397	7.3536393355
4	18.09	17	18888.85130320	4819.9579809	-5348.4103001	0.0000511	-0.8522081806	-0.7541495459	7.3549623310
5	19.09	32	18889.90688039	4917.3609222	-5258.8339983	-0.0001061	-0.8382345694	-0.7697547273	7.3550766032
6	20.08	36	18890.18836726	4943.0712786	-5234.6314676	0.0000576	-0.8344244195	-0.7738712463	7.3551099824
7	20.09	43	18890.68097000	4987.6468331	-5191.9745947	-0.0000834	-0.8277628287	-0.7810258651	7.3552586507
8	21.09	57	18891.66617459	5075.8628076	-5105.6099739	0.0000002	-0.8142469402	-0.7951857364	7.3553643669
9	22.09	70	18892.58100718	5156.4008170	-5024.1257133	0.0000114	-0.8013952278	-0.8080652004	7.3554678494
10	23.09	76	18893.00323800	5193.1645462	-4986.0544126	-0.0000844	-0.7954082512	-0.8139501955	7.3555133072
11	23.09	87	18893.77732718	5259.8117861	-4915.6088770	-0.0000516	-0.7843406949	-0.8246153089	7.3555764274
12	24.09	101	18894.76253144	5343.2428040	-4824.6712391	-0.0000622	-0.7700293963	-0.8380106454	7.3556565965
13	25.09	115	18895.74773564	5425.0771915	-4732.2630210	-0.0000558	-0.7554698351	-0.8511521222	7.3557965155
14	26.09	121	18896.16996597	5459.7043678	-4692.2416726	-0.0000560	-0.7491870842	-0.8566912293	7.3558156259
15	26.09	129	18896.73293962	5505.3557504	-4638.4860696	-0.0000511	-0.7407086705	-0.8640292189	7.3558889681
16	27.09	142	18897.64777201	5578.4241467	-4550.1867692	0.0000014	-0.7268012280	-0.8757636375	7.3559956242
17	27.09	143	18897.71814368	5583.9937076	-4543.3475871	0.0000001	-0.7257241092	-0.8766566888	7.3559971913
18	28.09	157	18898.70334766	5661.0163258	-4446.9145234	0.0000061	-0.7105338009	-0.8890239070	7.3560563513
19	29.09	171	18899.68855163	5736.3725197	-4349.1750427	0.0000134	-0.6951053109	-0.9011330043	7.3561192125
20	30.09	177	18900.11078204	5768.2119342	-4306.9204129	0.0000125	-0.6884834309	-0.9061951622	7.3560807859
21	30.09	185	18900.67375562	5810.0704625	-4250.1490131	0.0000148	-0.6794993147	-0.9129657964	7.3561620639
22	01.10	192	18901.16635788	5846.3525482	-4200.2258803	0.0000190	-0.6716904557	-0.9187124843	7.3560873132
23	01.10	200	18901.72933172	5887.1196253	-4142.6660895	0.0000045	-0.6625838682	-0.9253103297	7.3562224168
24	02.10	211	18902.50342063	5942.3643851	-4063.0051796	0.0000061	-0.6499435529	-0.9341862968	7.3562394791
25	02.10	214	18902.71453626	5957.1762935	-4041.0646488	0.0000507	-0.6464933534	-0.9365977826	7.3563498171
26	03.10	227	18903.62936890	6020.6438027	-3945.6995535	0.0000516	-0.6313479552	-0.9467984335	7.3564652003
27	03.10	231	18903.91085572	6039.8863542	-3916.1312639	0.0000310	-0.6266779832	-0.9499159770	7.3564905424
28	04.10	243	18904.75531747	6096.7687839	-3826.9131884	0.0000895	-0.6125521747	-0.9590300992	7.3565313297
29	05.10	259	18905.88126537	6170.8019515	-3706.8685056	-0.0000511	-0.5935876968	-0.9708179110	7.3562625703
30	06.10	263	18906.16275269	6189.0838797	-3676.6939931	0.0000061	-0.5888310288	-0.9736401389	7.3560418648
31	0.10	271	18906.72572673	6224.6016623	-3615.7687409	0.0000474	-0.5791739972	-0.9794575160	7.3562824814
32	07.10	281	18907.42944375	6268.5277587	-3539.3445711	0.0000079	-0.5670887872	-0.9864345317	7.3561498356
33	07.10	284	18907.64055934	6281.3430544	-3516.2235033	0.0000380	-0.5634073607	-0.9885408385	7.3563173771
34	08.10	300	18908.76650776	6348.8668686	-3392.4145168	0.0001148	-0.5438280435	-0.9994469792	7.3564999488
35	09.10	314	18909.75171213	6405.9824124	-3283.0462025	0.0001071	-0.5264928304	-1.0086616327	7.3566184230
36	10.10	319	18910.10357070	6426.0112162	-3243.7738646	0.0000407	-0.5203022270	-1.0118603733	7.3565696417
37	10.10	331	18910.94803155	6472.8660305	-3148.9485283	0.0000363	-0.5052819986	-1.0194509695	7.3567006991
38	11.10	335	18911.22951856	6488.2704915	-3117.2537004	0.0000531	-0.5002757213	-1.0218756335	7.3566299435
39	11.10	344	18911.86286462	6522.1607039	-3045.5059236	0.0000571	-0.4889357257	-1.0273785300	7.3567161117
40	12.10	352	18912.42583885	6551.8059044	-2981.5361323	0.0000431	-0.4788526725	-1.0320499769	7.3565780608
41	12.10	356	18912.70732597	6566.3922649	-2949.4421187	0.0000470	-0.4737334182	-1.0343973413	7.3565075115

Table 2. Results of orbits determination in form of (tRV)

N	Time	x	y	z	Vx	Vy	Vz
76	18893.0032380	5193.3425300	-4986.0091752	-0.037096	-0.79541867044	-0.81396033230	7.35539987039
87	18893.7773272	5259.9849070	-4915.5273959	-0.031457	-0.78435273544	-0.82464472934	7.35548816945
101	18894.7625314	5343.4370204	-4824.5388444	-0.113148	-0.76998268772	-0.83808394522	7.35558595588
115	18895.7477356	5425.2937045	-4732.1508850	-0.108479	-0.75544461859	-0.85121712505	7.35568903739
121	18896.1699660	5459.8607472	-4692.1538740	-0.084579	-0.74915408292	-0.85675361432	7.35573865319
129	18896.7329396	5505.5176784	-4638.4130177	-0.122584	-0.74064594460	-0.86410545069	7.35579732652
142	18897.6477720	5578.6066619	-4550.1258179	-0.053942	-0.72678872072	-0.87579398845	7.35587710230
143	18897.7181437	5584.1229792	-4543.3088501	-0.037730	-0.72571454512	-0.87667822878	7.35590773489
157	18898.7033477	5661.1465993	-4446.8454764	-0.020741	-0.71052350281	-0.88903956128	7.35598471133
171	18899.6885516	5736.5068647	-4349.0800219	0.008911	-0.69512897918	-0.90112922831	7.35605765674
177	18900.1107820	5768.2752012	-4306.8122038	0.066297	-0.68851200228	-0.90619362117	7.35608532538
185	18900.6737556	5810.1642244	-4250.0662413	-0.001189	-0.67950082714	-0.91296955851	7.35612600314
192	18901.1663579	5846.3534838	-4200.1143179	0.126204	-0.67173410913	-0.91869919838	7.35614508227
200	18901.7293317	5887.1997023	-4142.6202390	0.134921	-0.66267464699	-0.92525563934	7.35617326185
211	18902.5034206	5942.4533213	-4062.9106775	0.060787	-0.65002757531	-0.93417721035	7.35620543444
214	18902.7145363	5957.2973936	-4041.0720501	0.178999	-0.64667466474	-0.93649580918	7.35623116192
227	18903.6293689	6020.8473786	-3945.6706072	0.113634	-0.63154284370	-0.94675234766	7.35628673270
231	18903.9108557	6040.0676742	-3916.1072835	-0.025822	-0.62673257187	-0.94992992477	7.35633275177
243	18904.7553175	6096.9068488	-3826.9232216	0.240016	-0.61285295952	-0.95892573189	7.35638629815
259	18905.8812654	6170.7263187	-3706.6768778	0.033822	-0.59364341890	-0.97090569440	7.35641198509
263	18906.1627527	6188.8248577	-3676.4572566	0.103437	-0.58891060282	-0.97374468574	7.35637555959
271	18906.7257267	6224.5509140	-3615.6469557	0.054125	-0.57923941820	-0.97950141514	7.35637577858
281	18907.4294437	6268.4118037	-3539.1375410	-0.207069	-0.56689674255	-0.98665471315	7.35634161034
284	18907.6405593	6281.3736597	-3516.1430656	0.003944	-0.56344099820	-0.98860529566	7.35631344784
300	18908.7665078	6349.0577450	-3392.4129837	0.184933	-0.54403160539	-0.99938825094	7.35631127490
314	18909.7517121	6406.2952451	-3283.0404544	-0.011909	-0.52654515536	-1.00868176785	7.35631730070
319	18910.1035707	6426.2408788	-3243.7484998	-0.072359	-0.52026128353	-1.01191773792	7.35635602222
331	18910.9480316	6473.1409847	-3148.9325704	-0.109099	-0.50520301365	-1.01950948256	7.35644060071

One can see from above TLE data that 3 sets were obtained in first day after SC launch. The analysis showed that these data have elevated errors. On this account first three sets were not used. Further the TLE were obtained with lower frequency: every 15 hours on average. Thus, 31-3 = 28 determinations and predictions were performed. The average duration of fit span equals 15 * (7-1) = 90 hours (3.75 days).

Table 1 presents the results of TLE recalculation into source data in a form of (tRV), while table 2 lists all results (28) of orbit determinations in the same form. Residual discrepancies for each of the components of initial vectors were calculated for each of determinations. These discrepancies were recalculated into time discrepancies and then averaged under all determinations. Below, table 3 presents RMS of time discrepancies for each of 7 measurements that were used on fit span.

Table 3. RMS of time discrepancies, sec.

№ of measurement on fit span						
1	2	3	4	5	6	7
0.0148	0.0139	0.0144	0.0158	0.0153	0.0127	0.0143

These data shows that the level of residual discrepancies is sufficiently low. It corresponds to known a priori data about accuracy of TLE. RMS range is 0.014-0.015 sec, which corresponds to position error of ≈ 110 m. No abnormal measurement has been among the 28 performed determinations.

During the process of the orbit determination, the diagonal weight matrix is used. The weights are selected individually for each of the components of discrepancies on the position and velocity. These components were projected on the axis of satellite coordinate system (RSW). Weights were chosen so that the average ratio of the square of discrepancies the variance of the little differed from 1. Table 4 shows the obtained estimates of RMS for TLE.

Table 4. RMS of TLE errors in satellite coordinate system (km, km/sec)

Position			Velocity		
R	S	W	R	S	W
0.102	0.105	0.091	1.04e-4	1.04e-4	0.36e-4

During motion prediction to 4 "future" points, time intervals have various values because time intervals between initial data were unequal. Therefore, the discrete grid with step of 0.5 days is applied in averaging of prediction errors. The mean value (M), root mean square (RMS) and standard deviation (σ) of errors were calculated during averaging. The results for time and radial errors are presented in table 5.

Table 5. Statistical characteristics of prediction errors

Time, days	time, secк			radius, km			Number of cases
	RMS	M	σ	RMS	M	σ	
0.0 – 05	0.023	0.000	0.023	0.1410	-0.0534	0.1305	28
0.5 - 1.0	0.026	0.009	0.024	0.1733	-0.0020	0.1733	12

1.0 - 1.5	0.036	-0.003	0.036	0.1716	-0.1174	0.1252	28
1.5 - 2.0	0.053	0.003	0.053	0.1897	-0.0334	0.1867	17
2.0 - 2.5	0.056	-0.009	0.055	0.1893	-0.1298	0.1378	24

Although the number of implementations in statistical processing of prediction results is relatively small, data of table 4 gives the sufficiently objective understanding of errors.

Table 6 shows the results of orbit determination, which differ from the data of table 2 so that they are "bound" to the Equator (z = 0) and time (TU) is given in the traditional calendar form.

Further analysis, involving the comparison of mentioned results with corresponding results of TLE use as initial data, was conducted for evaluation the accuracy of determination and prediction of orbital parameters.

During use the TLE, the motion prediction was performed by SGP4 model that best suited to the use of TLE. Figure 1 shows the standard time errors (σ) as function of interval of forecast for two considered methods.

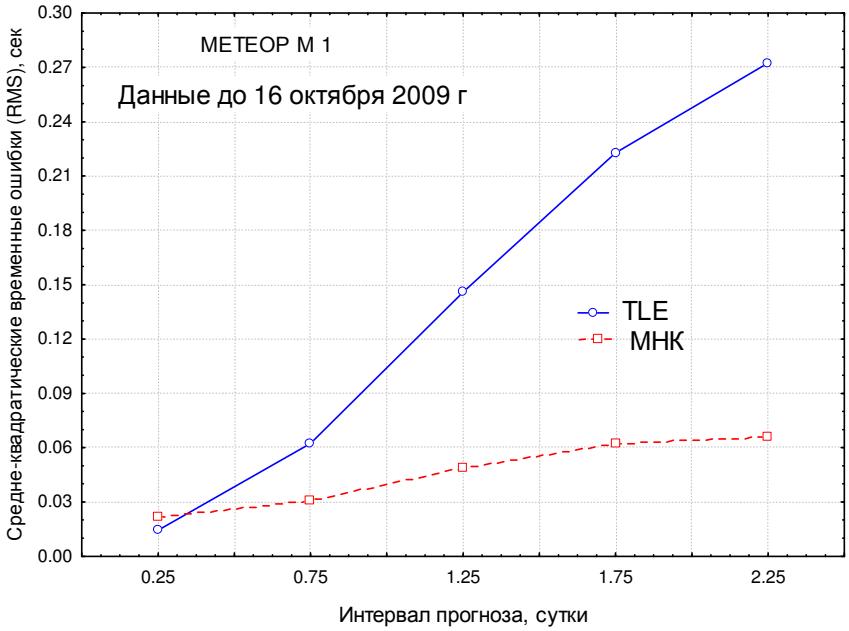


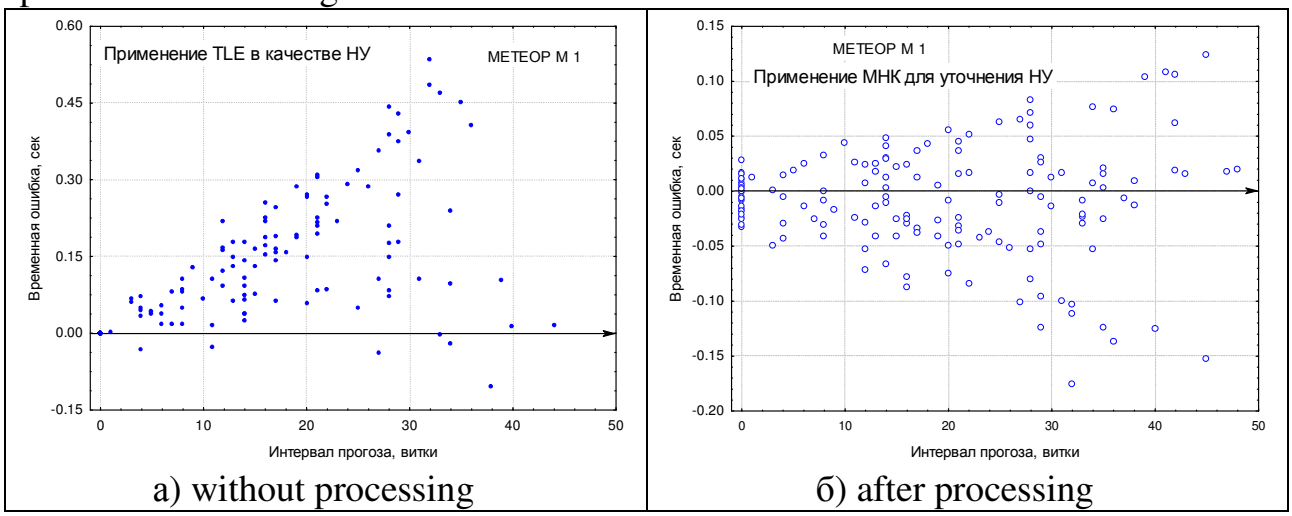
Figure1. Standard deviation of time errors vs. prediction interval (days)

It is shown from these data that the direct use of TLE as ID leads to significantly high forecast errors in comparison with results of ID determination using LST. During forecast on 2 days with direct use of TLE as ID, the prediction errors are founded four times more. This effect is caused for several reasons. One of them is the use of numerical motion model during the TLE processing with LST and for the forecast of orbits. Another reason is the best accuracy of the results of LST use in comparison with proper errors of TLE. The data about this is presented below.

Table 6. Results of ID determination in form (tRV) on equathor

N	D	m	Год	H	M	S	x	y	z	Vx	Vy	Vz
76	23	9	2009	0	4	39.768	5193.3385789	-4986.0133382	0.0	-0.79544668172	-0.81393342064	7.35539978342
87	23	9	2009	18	39	21.071	5259.9816131	-4915.5309792	0.0	-0.78437679508	-0.82462222703	7.35548808333
101	24	9	2009	18	18	2.731	5343.4252346	-4824.5517891	0.0	-0.77007060747	-0.83800454585	7.35558587362
115	25	9	2009	17	56	44.376	5425.2826218	-4732.1634891	0.0	-0.75553020500	-0.85114245642	7.35568895672
121	26	9	2009	4	4	45.071	5459.8521900	-4692.1637742	0.0	-0.74922123839	-0.85669588542	7.35573857498
129	26	9	2009	17	35	26.000	5505.5053914	-4638.4274646	0.0	-0.74074408933	-0.86402274779	7.35579725072
142	27	9	2009	15	32	47.510	5578.6013886	-4550.1322862	0.0	-0.72683248361	-0.87575827859	7.35587702659
143	27	9	2009	17	14	7.618	5584.1193121	-4543.3133913	0.0	-0.72574518291	-0.87665328678	7.35590766106
157	28	9	2009	16	52	49.240	5661.1446505	-4446.8480257	0.0	-0.71054057733	-0.88902613509	7.35598463963
171	29	9	2009	16	31	30.861	5736.5077601	-4349.0789707	0.0	-0.69512154507	-0.90113485100	7.35605758767
177	30	9	2009	2	39	31.559	5768.2814581	-4306.8040753	0.0	-0.68845638315	-0.90623513560	7.35608525930
185	30	9	2009	16	10	12.485	5810.1641650	-4250.0664260	0.0	-0.67950183220	-0.91296881101	7.35612593891
192	1	10	2009	3	59	33.302	5846.3650565	-4200.0985911	0.0	-0.67162679722	-0.91877628106	7.35614502243
200	1	10	2009	17	30	14.244	5887.2119027	-4142.6033016	0.0	-0.66255912217	-0.92533691883	7.35617320486
211	2	10	2009	12	4	55.534	5942.4587373	-4062.9029889	0.0	-0.64997503880	-0.93421311960	7.35620537940
214	2	10	2009	17	8	55.909	5957.3131689	-4041.0492892	0.0	-0.64651956893	-0.93660100675	7.35623111311
227	3	10	2009	15	6	17.458	6020.8571722	-3945.6560076	0.0	-0.63144333474	-0.94681755009	7.35628668495
231	3	10	2009	21	51	37.939	6040.0655111	-3916.1106418	0.0	-0.62675525698	-0.94991520811	7.35633270480
243	4	10	2009	18	7	39.397	6096.9268747	-3826.8919538	0.0	-0.61264011645	-0.95905932112	7.35638625961
259	5	10	2009	21	9	1.323	6170.7290819	-3706.6724340	0.0	-0.59361306309	-0.97092392128	7.35641194394
263	6	10	2009	3	54	21.819	6188.8331718	-3676.4435846	0.0	-0.58881749271	-0.97379999020	7.35637552037
271	6	10	2009	17	25	2.781	6224.5552109	-3615.6397695	0.0	-0.57919041725	-0.97952987084	7.35637573767
281	7	10	2009	10	18	23.968	6268.3958810	-3539.1653334	0.0	-0.56708553155	-0.98654811500	7.35634157030
284	7	10	2009	15	22	24.327	6281.3740002	-3516.1425572	0.0	-0.56343739484	-0.98860730489	7.35631340367
300	8	10	2009	18	23	46.246	6349.0714593	-3392.3878800	0.0	-0.54386083340	-0.99947948887	7.35631123172
314	9	10	2009	18	2	27.929	6406.2944319	-3283.0421071	0.0	-0.52655625273	-1.00867607275	7.35631725451
319	10	10	2009	2	29	8.519	6426.2358012	-3243.7584734	0.0	-0.52032891723	-1.01188359046	7.35635597510
331	10	10	2009	22	45	9.941	6473.1335322	-3148.9477094	0.0	-0.50530573286	-1.01945950541	7.35644055430
335	11	10	2009	5	30	30.414	6488.4292398	-3117.2118467	0.0	-0.50027341940	-1.02191900879	7.35648730078
344	11	10	2009	20	42	31.485	6522.3220651	-3045.4931194	0.0	-0.48891128754	-1.02739677963	7.35656157014
352	12	10	2009	10	13	12.446	6551.8109905	-2981.4529544	0.0	-0.47877801212	-1.03214251697	7.35659462781
356	12	10	2009	16	58	32.943	6566.3293613	-2949.3421068	0.0	-0.47369729478	-1.03446779925	7.35659645532
368	13	10	2009	13	14	34.378	6608.9935505	-2852.5427813	0.0	-0.45838725109	-1.04132394965	7.35656299296
373	13	10	2009	21	41	14.973	6626.3516959	-2812.0462909	0.0	-0.45198323818	-1.04409929645	7.35654072489
385	14	10	2009	17	57	16.392	6667.0126788	-2714.3962210	0.0	-0.43653554229	-1.05062901880	7.35648082733
404	16	10	2009	2	2	38.644	6728.4208826	-2558.5650141	0.0	-0.41187771724	-1.06051904757	7.35641809470

Data of figures 2 is the addition to the above estimates. *All* prediction errors are presented in these figures.



а) without processing б) after processing

Figure 2. Prediction errors for direct use of TLE as ID and for its processing using LST

It is shown from these data that the errors of direct use of TLE as ID have significant offset their average values from 0 and significantly more variations from average values.

Finally, let's compare the standard deviations of ID errors for the direct use of TLE and for ID determination using LST. Standard deviations of TLE errors were determined using technique described in the notes to table 4. Standard deviations of LST results were determined on the basis of relevant components of the calculated correlation matrix. Acceptable reliability of these estimates is supported by adjustment of components of weighting matrix, as mentioned above. All these data are presented in table 7.

Table 7. Standard deviations of ID errors in satellite coordinate system

ID	Position, km			Velocity, km/sec		
	R	S	W	R	S	W
TLE	0.102	0.105	0.091	1.04e-4	1.04e-4	0.36e-4
LST	0.029	0.052	0.033	0.637e-4	0.303e-4	0.140e-4
Paper	0.101	0.300	0.174	-	-	-
	0.105	0.370	0.186	-	-	-
	0.097	0.299	0.131	-	-	-
	0.110	2.852	0.240	-	-	-
	0.118	0.310	0.101	-	-	-

Furthermore, the Standard deviations of TLE errors from article “Improving ESA's Collision Risk Estimates by an Assessment of the TLE Orbit Errors of the US SSN Catalogue”, *T. Flohrer, H. Krag, H. Klinkrad et al. Fifth European Conference on Space Debris, 30 March – 2 April 2009, ESOC, Darmstadt, Germany* are presented in the last lines. Such values "bounded" to specific SC.

The fragment from mentioned article is presented in figure 3. Those objects, those orbital characteristics are close to corresponding “MONITOR M1 data, are marked by blue color.

Satellite (km)	Source (-)	a (km)	e	i	σ_U	σ_V	σ_W
65032A	CPF	7492	0.025	41.2	0.077	0.215	0.265
75010A	CPF	7339	0.020	49.8	0.153	0.416	0.319
76039A	CPF	12273	0.004	109.9	0.075	0.302	0.174
86061A	CPF	7864	0.002	50.0	0.101	0.300	0.186
92070B	CPF	12159	0.014	52.6	0.178	0.443	0.437
93061B	CPF	7169	0.001	98.4	0.105	0.370	0.135
95021A	CPF	7154	0.001	98.6	0.097	0.299	0.131
00039B	CPF	6706	0.001	87.2	0.219	0.909	0.104
01055A	CPF	7715	0.001	66.0	0.141	0.412	0.189
01056A	CPF	7388	0.003	99.4	0.110	2.852	0.240
02009A	CPF	7159	0.001	98.5	0.118	0.311	0.101
02012A	CPF	6834	0.004	89.0	0.249	0.760	0.133
02012B	CPF	6833	0.004	89.0	0.248	0.720	0.145
03042G	CPF	7060	0.002	98.0	0.113	0.275	0.088
06055F	CPF	6677	0.002	51.7	0.240	1.463	0.173
07026A	CPF	6892	0.002	97.4	0.136	0.550	0.128
71114B	Radar	7143	0.002	74.0	0.295	0.864	0.409
78105A	Radar	7160	0.003	74.1	0.443	1.285	0.474
82051A	Radar	7158	0.002	74.0	0.317	0.783	0.316
83063B	Radar	7146	0.004	82.1	0.202	0.833	0.270
83079A	Radar	7157	0.002	74.0	0.380	0.912	0.438
85006A	Radar	7154	0.002	74.0	0.350	0.894	0.318
85006B	Radar	7150	0.003	74.1	0.317	0.816	0.214
94083B	Radar	7159	0.001	74.0	0.312	0.891	0.511
98053H	Radar	7175	0.001	45.0	0.231	0.682	0.595

Figure3. Fragment of article

Table 7 shows the following:

- Standard deviations of LST results in 2-3 times less corresponding "optimistic" values of TLE.
- According to the mentioned article, standard deviations of TLE errors not less than corresponding our values presented in tables 4 and 7. Standard deviations for radial direction are agreed well, but for the rest directions the values from mentioned article are more in multiple times.