# Experience of Formation of GEO Orbital Information Archive Based on Different Data Sources

**V.Agapov, Z.Khutorovskiy, V.Boykov,
N.Sbytov, A.Samotokhin**

*Space Informatics Analytical Systems (KIA Systems) JSC,
Keldysh Institute of Applied Mathematics RAS*

## GEO OBJECTS ORBITAL ARCHIVE

**GEO objects:**
$i \leq 30°$, $e \leq 0.2$, $0.7 \leq n \leq 1.3$ rev/day

- Special database was developed to provide collecting, storing, processing and analysis of various data for near-Earth objects including GEO
- Special software tools were developed
- The database and software development is a joint project of Space Informatics Analytical Systems JSC («KIA Systems») Russian company and the Keldysh Institute of Applied Mathematics of the RAS (KIAM RAS)

## ARCHIVE DEVELOPMENT ENVIRONMENT

- Oracle 8i RDBMS with current transition to Oracle 9 and an additional version using Linter RDBMS
- LINUX operational system
- QT library for graphical features design
- C++ programming language
- Apache HTTP-server

## INFORMATION FOR PROCESSING AND ANALYSIS

### *1. Input measurement information for processing:*

- state vectors $\{x, y, z, v_x, v_y, v_z\}$ derived from TLE sets or provided by satellite operators
- positional observations $\{\alpha, \delta\}$ obtained by optical stations
- Doppler VLBR measurements
- angles of direction measurements (e.g. azimuth, elevation)

***2. Additional information for orbital analysis and object identification:***

- UN Registry data
- ITU registration data
- NASA GSFC Satellite Situation Reports
- photometric data from observatories
- public information on launch and operations of GEO satellites
- satellite characteristics provided by owners, designers etc.

## GEO OBJECTS ARCHIVE MAINTENANCE TASKS

***1. Initial processing***

- preliminary processing of input measurement information
- orbital parameters estimation based on one set of raw measurements
- anomaly measurements selection
- correlation of measurements with catalogued objects

***2. Primary tracking process***

- search for possible unpredicted orbital parameters changes
- adaptation to measurements errors and orbital propagation model errors
- orbit determination based on measurement sets from different nights
- analysis and correction of automatic process decisions in questionable cases

***3. Detail processing and analysis***

- correlation of measurements for which a corresponding object was not found automatically
- preliminary tracking and analysis of newly discovered objects
- identification of unknown objects with specific launch or orbital event sequences based on the archive of general, orbital and photometric information
- obtaining comprehensive orbital parameter solutions based on the most accurate motion model
- calculation of polynomial coefficients for approximating the object's trajectory and trajectory errors over all the time of the object's existence in the GEO region

## ORBITAL PROPAGATION MODEL

A special semi-analytical model of GEO object's motion is used at stages of the initial processing and the primary tracking.

This model takes into account:

- Primary effects of $J_{m,n}$, $m,n \le 6$
- Short period recovery of the important effects of $J_{m,n}$ terms
- Lunar and solar gravity effects model
- Solar Radiation
- Precession and nutation of the Earth's equator

It provides improvement of the model used by the Russian Space Surveillance Center for GEO catalogue maintenance.

**A numerical model** is used at the detail processing and analysis stage. It takes into account the Earth gravity (all $J_{m,n}$, $m,n \leq 16$), lunar and solar gravity, and solar radiation. The equations of motion are formulated and integrated in J2000 reference frame.

## WHAT'S NEW?

New features of the general processing algorithm:

- calculation of updated orbits based on the joint processing of different nights of original measurements (instead of one-night set solutions as a general kind measurements), state vectors, and other measurements
- change of the method of the RMS-functional minimization (SVD-method is currently applied)
- new technique of initial orbit estimation construction and anomaly measurements selection based on a modified Gauss method with the use of the Lambert-Battin algorithm
- automatic determination of unpredicted orbital parameters changes
- adaptation to measurements errors and orbital propagation model errors
- high level of processing automation

## USING SVD METHOD IN MINIMIZATION

Minimization of the RMS-functional is not always possible with the usual methods, due to the bad condition of the task in the case of a small number of measurements or measurement intervals much less than the orbital period of the observed object (short track case).

**S**ingular **V**alue **D**ecomposition (SVD) method had been applied to provide higher reliability and stability of the minimization process.

## INITIAL ORBIT ESTIMATION

Laplace method is highly sensitive to anomalous measurements. Wrong solutions (distorted orbit) were possible.

A more complex and more reliable *algorithm based on Gauss method had been constructed*:

- minimum quantity of data (3 angular positions) is used
- orbit determination is based on the Lambert-Battin algorithm, which permits construction of a solution in the case of a long interval (up to 10 hours) between angular positions

- analysis of orbits obtained from different combinations of angular positions permits one to select anomalous measurements correctly, even in the case of 2:3 relation between anomalous and non-anomalous measurements in one night set.

## UNPREDICTED ORBITAL PARAMETER CHANGES

Possible sources of unpredicted orbit changes:

1. Active GEO satellites:
   - implementing different station keeping strategy
   - specific station keeping and repositioning maneuvers are not known, as a rule, at the time of measurement processing
   - public orbital information is not available for some active satellites, so it is not always known whether the observed object is an active satellite or not
2. Fragmentations:
   - only 2 were recognized widely
   - hard to discover in contrast to LEO ones
3. Other events are possible (collisions, fuel remains venting, etc.)

A version of the general GEO catalogue maintenance algorithm was implemented in the Russian Space Surveillance Center:

- doesn't reveal unpredicted changes of orbital motion (maneuvers, collisions, fragmentations) automatically
- analyst has to make special investigations

As a result:

- no automatic analysis of GEO satellite orbital maneuvering is performed
- limited accuracy of orbits for active spacecrafts
- possibility of interruption of object tracking ('object loss') exists after a large maneuver, or fragmentation

*New algorithm* is similar to the one used in the LEO catalogue maintenance process at the Russian Space Surveillance Center.

Whole archive of state vectors for GEO objects (approx. 1.7 millions individual sets) had been reprocessed *to validate the algorithm* and determine maneuvers made by active spacecraft, as well as unpredicted changes in non-active, orbital motions of objects.

*Sensitivity of the algorithm* had been determined based on TLE data. Minimum automatically detectable values:

- 0.035 m/s in transversal velocity change (that is equal to change of ~3 seconds in orbital period)
- ~4 m/s in binormal velocity change (that is equal to change of inclination on 0.07°)

*Table 1. Major Unpredicted Orbital Parameter Changes(UOPC) For Non-Active Objects*

| Object number | COSPAR designation | Name | Date of UOPC | Orbital period change, min |
|---|---|---|---|---|
| 11623 | 1979-098C | Transtage 37 | 24 Mar 1980 | 0.15 |
| 05589 | 1971-095C | Transtage 21 | 04 Jun 1980 | 0.3 |
| 08751 | 1976-023E | Transtage 30 | 20 Nov 1980 | 0.13 |
| 11940 | 1973-040B | Transtage 24 | 07 Mar 1981 | 1.0 |
| 11436 | 1979-053C | Transtage 31 | 05 Nov 1982 | 0.15 |
| 13089 | 1982-019B | Transtage 38 | ~09 Apr 1983 | 0.3 |
| 02222 | 1966-053J | Transtage 11 | 03 Oct 1987 | 2.4 |
| 12635 | 1981-073A | FLTSATCOM 5 | 22 Aug 1990 | 0.2 |
| 12635 | 1981-073A | FLTSATCOM 5 | 17 Dec 1990 | 0.1 |
| 03432 | 1968-081E | Transtage 5 | 21 Feb 1992* | 0.8 |
| 06976 | 1973-100D | Transtage 26 | 10 Apr 1992 | 0.8 |
| 02868 | 1967-066G | Transtage 14 | 14 Feb 1994 | 3.1 |
| 13984 | 1983-030A | SATCOM 1R | 01 Oct 1997 | 0.1 |
| 11147 | 1978-113D | Transtage 36 | 17 Oct 1997 | 2.2 |
| 11147 | 1978-113D | Transtage 36 | 21 Feb 1998 | 0.3 |
| 15383 | 1984-113B | ANIK D2 | 09 Jul 1998 | 0.3 |
| 18570 | 1987-095A | TV-SAT 1 | 16 Aug 1999 | 3.5 |
| 08476 | 1975-117A | SATCOM 1 | 14 Sep 1999 | 0.15 |
| 21055 | 1991-003A | ITALSAT 1 | 04 Sep 2001 | 0.1 |
| 18952 | 1988-018B | TELECOM 1C | 19 Sep 2002 | 0.17 |

* - confirmed explosion

## ARCHIVE OF OPTICAL OBSERVATIONS OF GEO

- Covering period since 1975 till present
- Contains  about 250000 normal places
- Measurements were obtained by optical facilities operated by RAS (former USSR AS) and other research organizations, as well as by individual observers over the world within own programSince 1991 some facilities became property of other

independent states, but good science and research contacts continueOther optical facilities are welcome to cooperation

*Table 2. Observation facilities*

| Name | Long, °E | Lat, °N | Currently owned by | Current status |
|---|---|---|---|---|
| Uzhgorod | 22.30 | 48.63 | Ukraine | OPS held up |
| Pulkovo | 30.33 | 59.77 | Russia | Operational |
| Kiev | 30.50 | 50.37 | Ukraine | Operational |
| Simeiz | 34.00 | 44.40 | Ukraine/Russia | Operational |
| Nauchnyi | 34.02 | 44.73 | Ukraine/Russia | Operational |
| Zvenigorod | 36.76 | 55.69 | Russia | Operational |
| Zelenchukskaya | 41.43 | 43.66 | Russia | Operational |
| Terskol | 42.60 | 43.27 | Russia/Ukraine | Operational |
| Abastumani | 42.82 | 41.75 | Georgia | OPS held up |
| Ashkhabad | 57.88<br>58.10 | 37.92<br>37.94 | Turkmenistan | Dismantled<br>Limited OPS |
| Kourovka | 59.54 | 57.04 | Russia | Operational |
| Maidanak | 66.94 | 38.68 | Uzbekistan | Operational |
| Dushanbe | 68.68 | 38.49 | Tajikistan | OPS held up |
| Alma-Aty | 76.97 | 43.17 | Kazakhstan | Operational |
| Mondy | 100.92 | 51.62 | Russia | Operational |
| Yuzhno-Sakhalinsk | 142.73 | 46.95 | Russia | Dismantled |

## CURRENT STATUS OF GEO ARCHIVE

- As of Jun 1, 2003 there were a total of 1045 GEO objects in our database
- For 38 identified objects, orbital data have not been updated for more than several years, due to the absence of measurements
- 34 objects have enough measurements, but they are not identified yet (so called uncorrelated targets, UCTs)
- 57 objects (including operational debris) are known to have entered GEO, but have never been observed or identified among UCTs

# SOME RESULTS OF MEASUREMENTS ARCHIVE PROCESSING

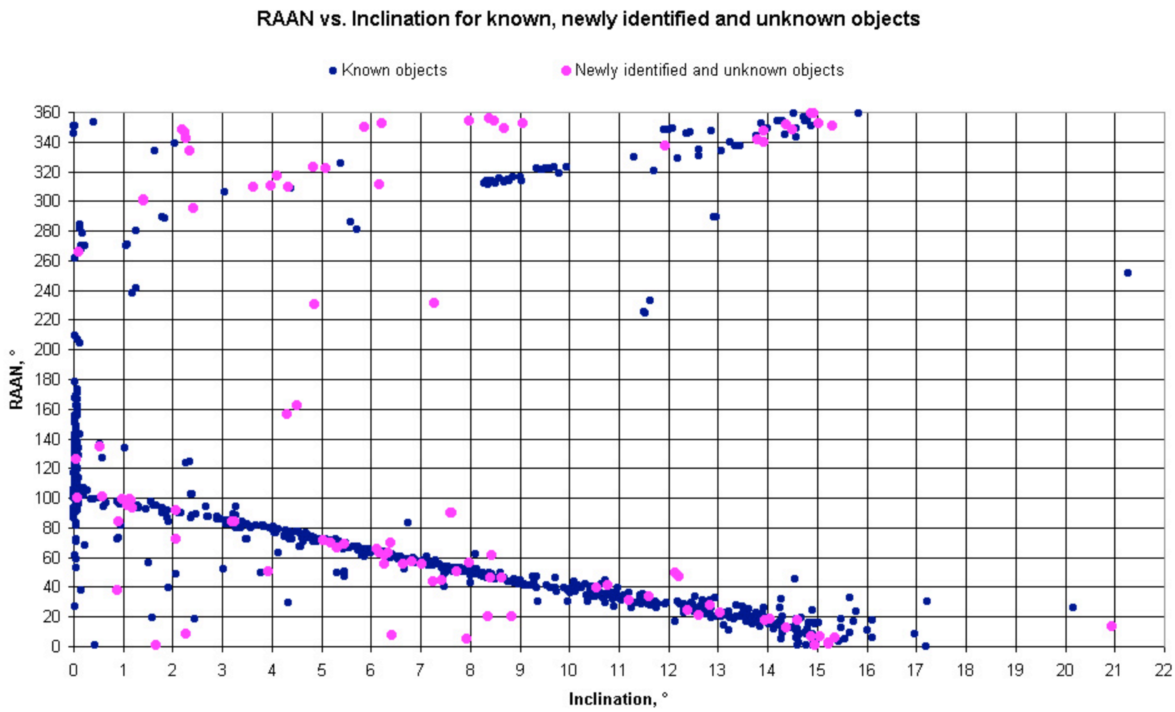



*Fig. 1.*

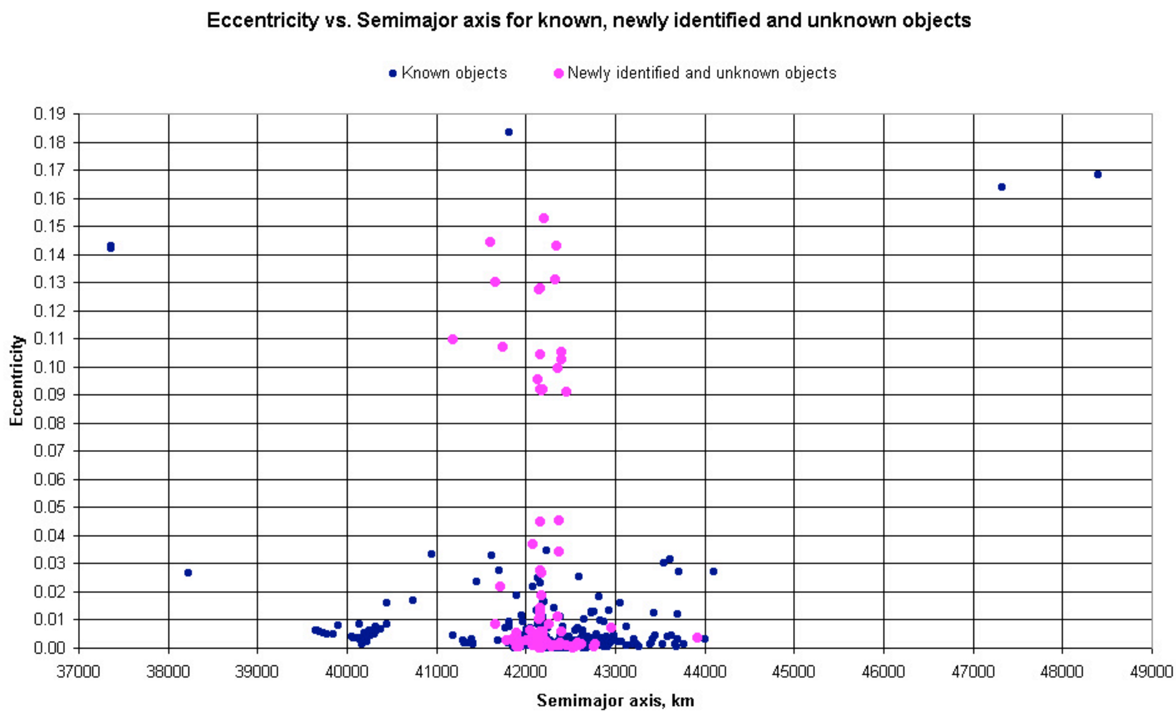
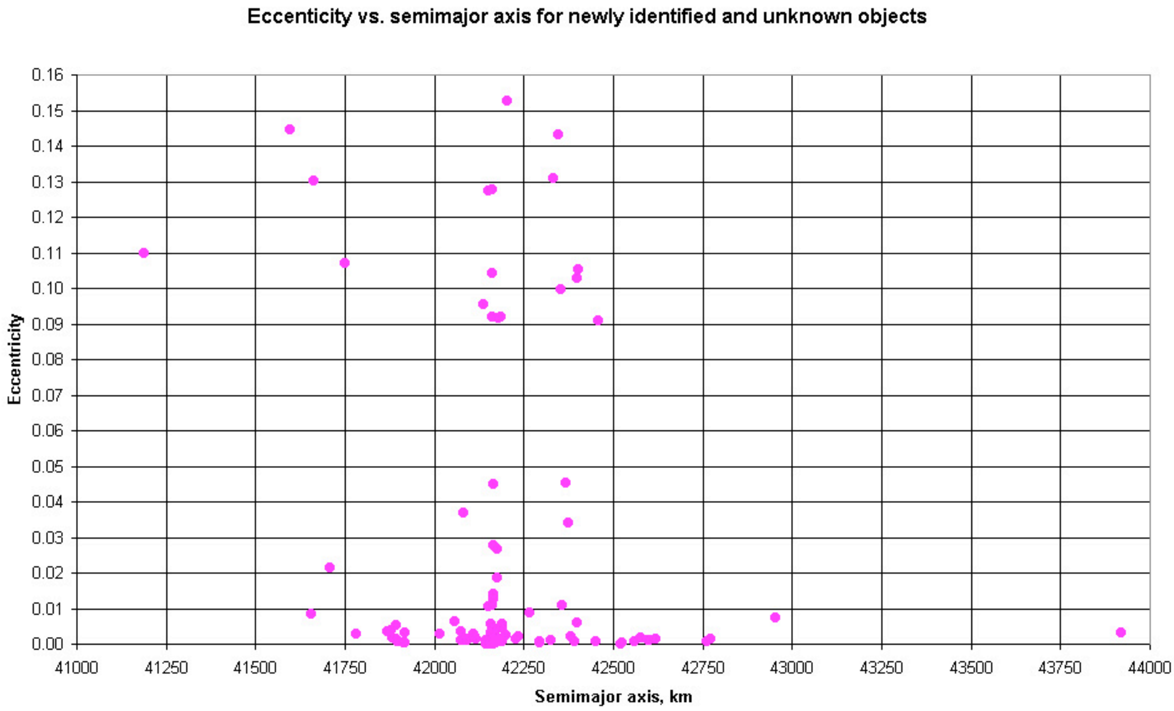



*Fig. 2.*


Eccenticity vs. semimajor axis for newly identified and unknown objects
Eccentricity
Semimajor axis, km
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
41000
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41500
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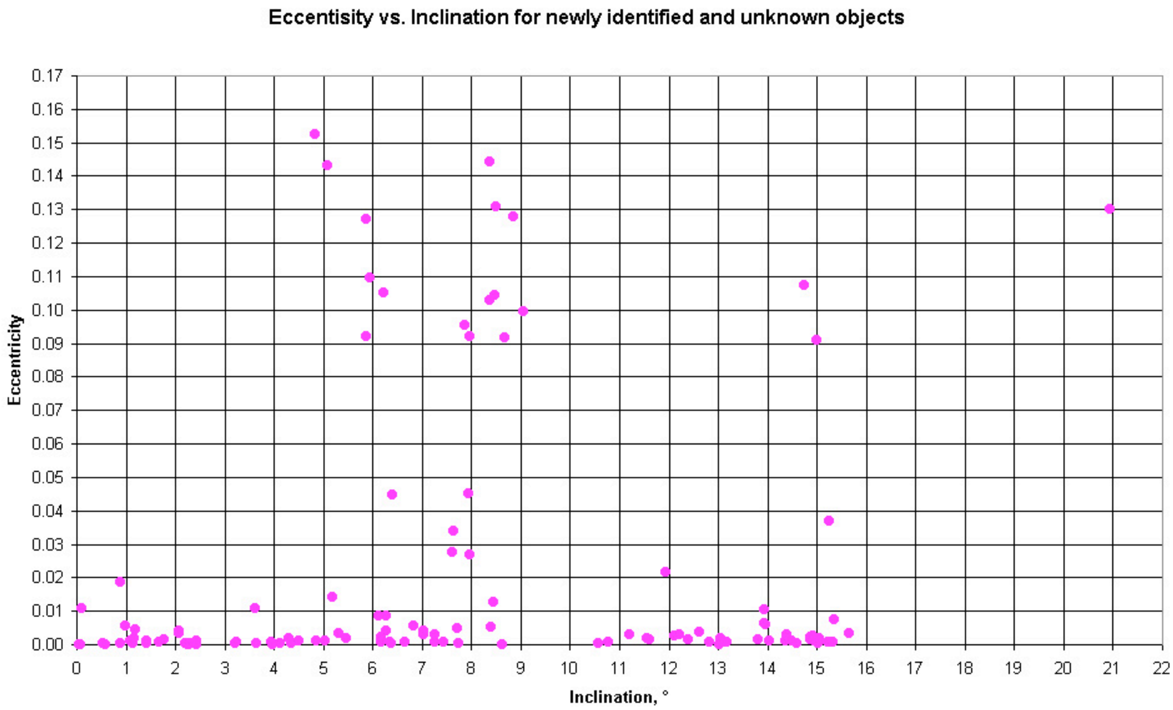
43250
43500
43750
44000


Eccentisity vs. Inclination for newly identified and unknown objects
Eccentricity
Inclination, °
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
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0.02
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*Fig. 4.*

## ANALYSIS OF ARCHIVE TLE ACCURACY

Adaptation to measurement and motion model errors revealed a significant difference in TLE accuracy depending on the epoch. Statistics had been accumulated for each object over the whole time span of it's existence in the GEO region.

***<u>Average accuracy (RMS value) of TLE</u>*** sets for GEO objects at present is within following limits:

**7-15 km in along track (normal) direction**

**5-10 km in radial direction**

**1-5 km in binormal direction**

The following charts present residuals in normal, radial, and binormal directions for object 14194 over the time span 1996-2002 as an example.

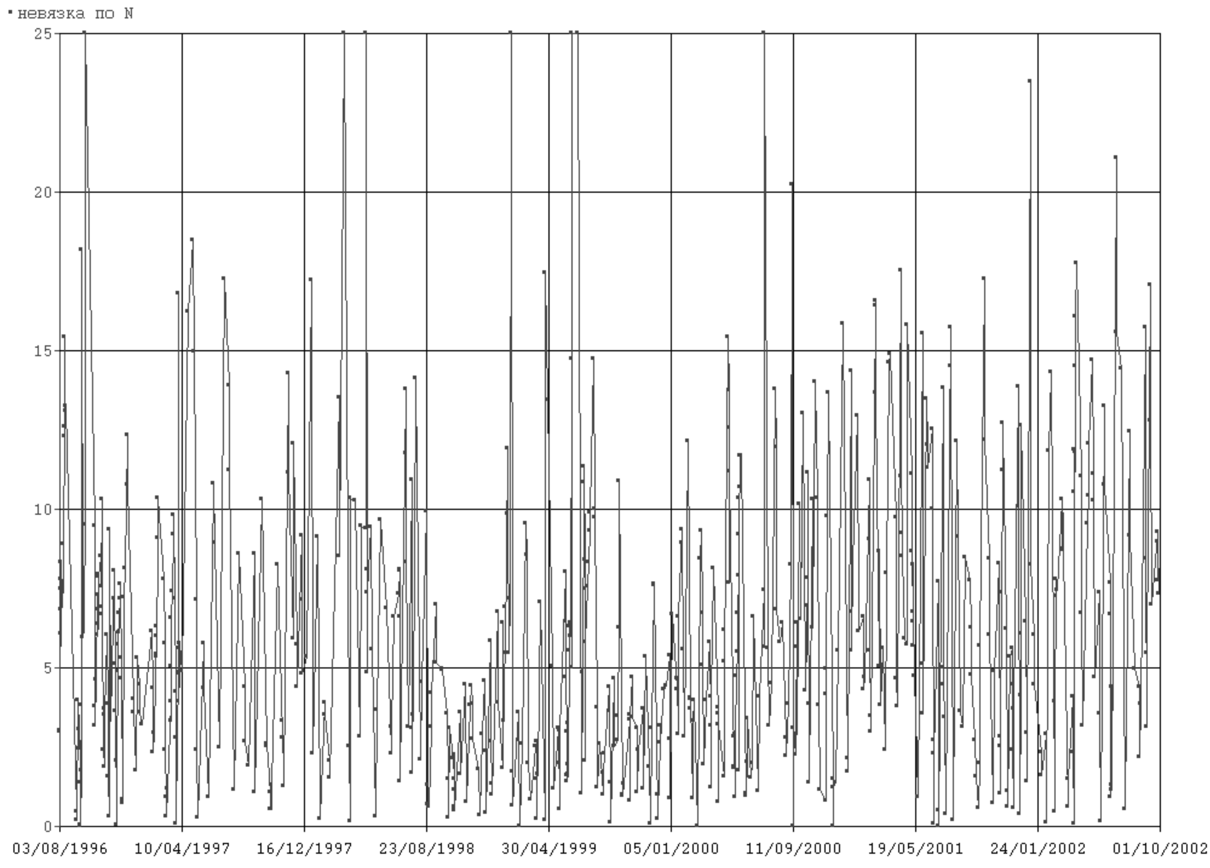
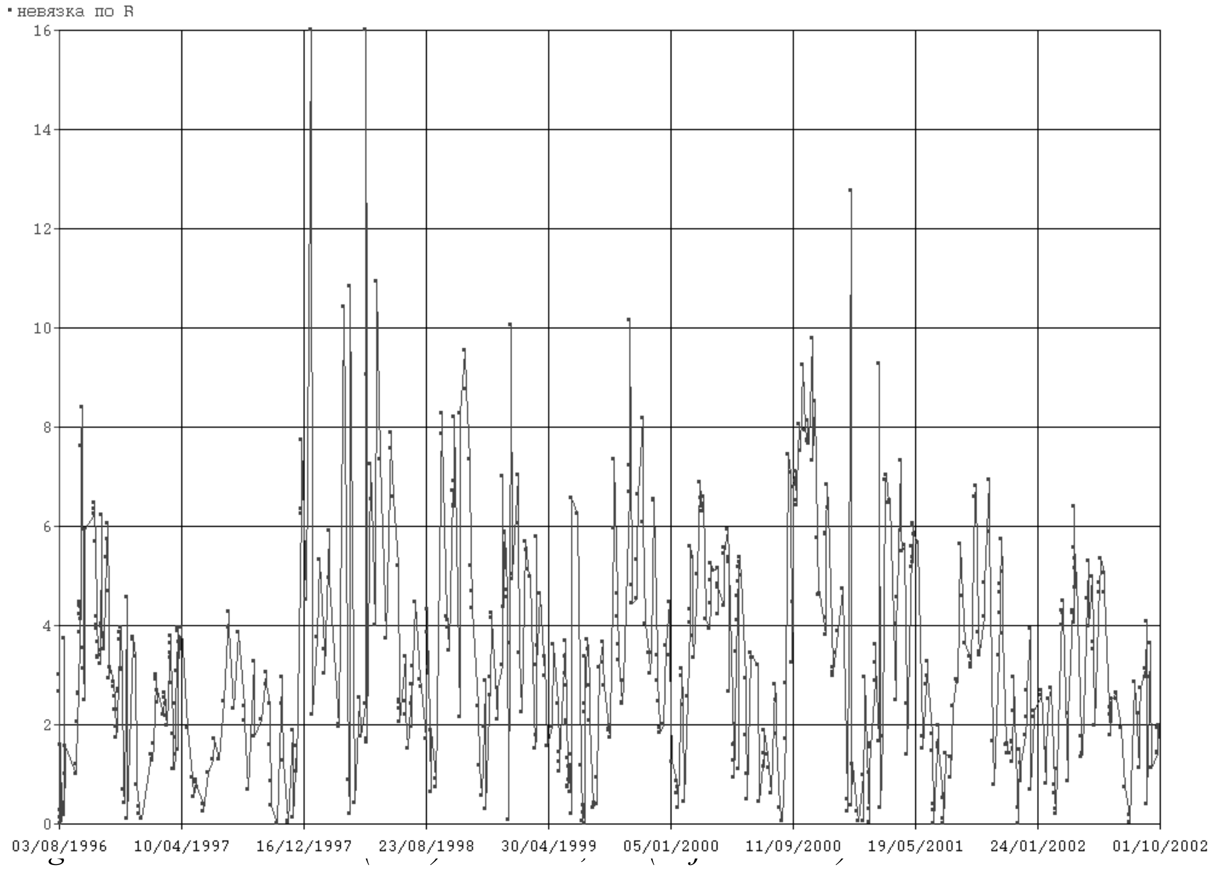



*Fig. 5. Along track (normal) direction (O-C) residuals, km (object 14194)*



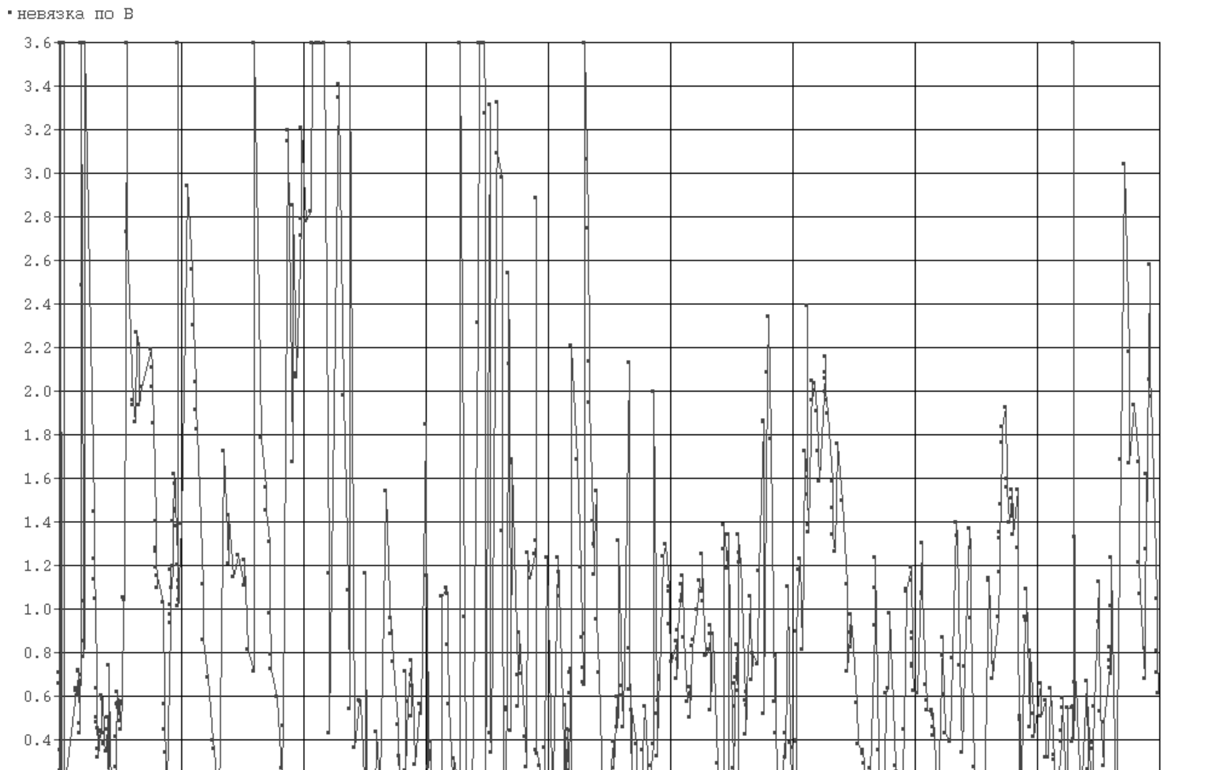




*Fig. 7. Binormal direction (O-C) residuals, km (object 14194)*

## HOW ACCURATE ORBIT DETERMINATION AND PROPAGATION MODEL IS?

Special tests have been performed to compare the orbit determination and propagation model with the numerical one for different objects.

The difference between the two propagation models was in the perturbation values. The numerical propagator takes into account the full 16x16 Earth gravity field. Lunar and solar gravity effects are taken into account using the DE405 ephemeris.

In general, both models give very close results. Special cases are is the  librating orbits. It was revealed that for some GEO objects on such orbits the difference is significant.

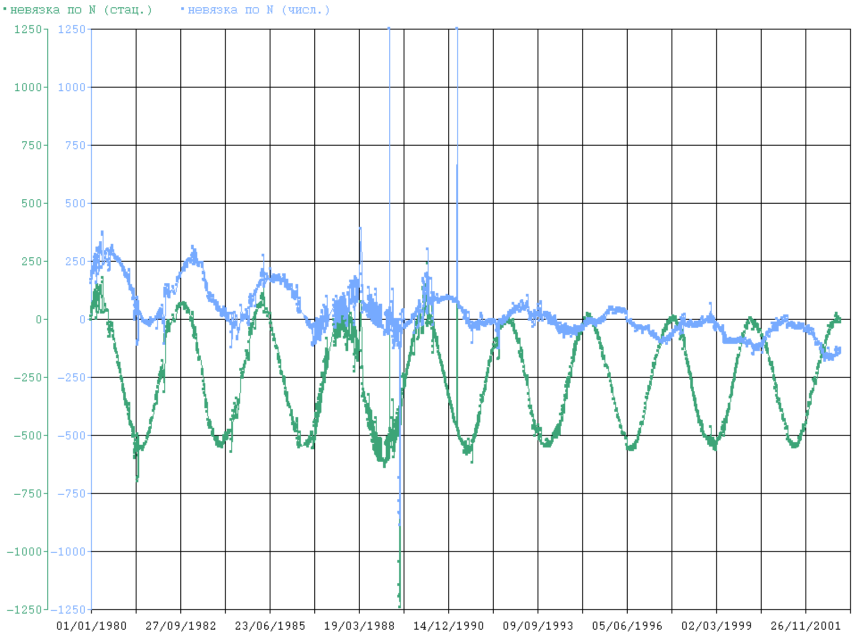



*Fig. 8.  Along track residuals obtained by propagation of 730-day span solution with two models - semi-analytical and numerical (object 5587)*

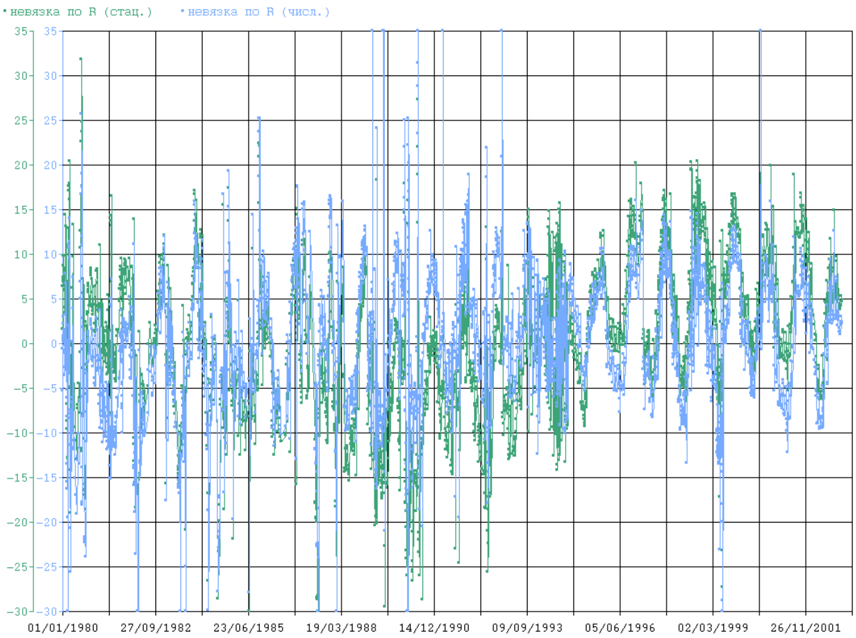


*Fig. 9. Radial direction residuals obtained by propagation of 730-day span solution with two models - semi-analytical and numerical (object 5587)*

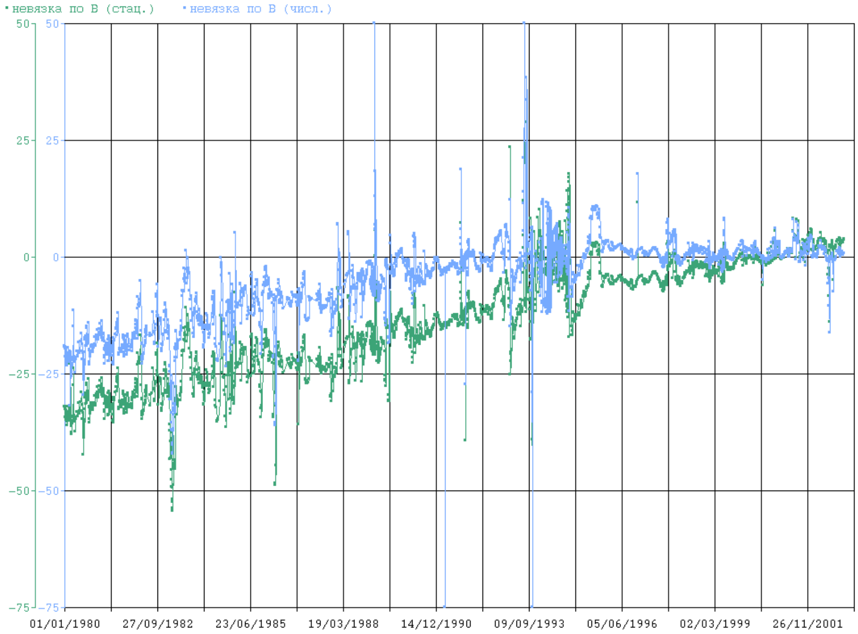



*Fig. 10. Binormal direction residuals obtained by propagation of 730-day span solution with two models - semi-analytical and numerical (object 5587)*

## FURTHER DEVELOPMENTS

We're planning ***to print a public version*** of the GEO catalogue by the end of this year.

At present preparation is jointly by

- Space Informatics Analytical Systems JSC
- Central (Pulkovo) Astronomical Observatory RAS
- Keldysh Institute of Applied Mathematics RAS

*All observers and researchers are welcome to participate in validation of the data and improvement of the orbits for GEO objects.*

## CONCLUSIONS

1. A new *highly efficient tool with a high level of automation* has been *developed and implemented* in the GEO trajectory information archive maintenance process.
2. The algorithms and methods used in the new version of the GEO catalogue significantly *increased the reliability ofthe data and the stability of the operation process*.
3. A large volume of the measurement data have been processed. *Estimations of the TLE sets real accuracy* has been obtained.
4. *Unpredicted changes* of non-active objects' orbits have been *revealed*.

5. Tuning of the motion model is needed for some kinds of GEO orbits.
6. *Public version* of the GEO catalogue is *under preparation*