# NASDA'S PRECISE ORBIT DETERMINATION SYSTEM

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## Abstract

In order to meet the scientific mission requirements for precise orbit determination strongly required by future earth observationmissions in the 2000's, NASDA has started the study of Precise orbit determination using onboard GPS (Global Positioning System) data and SLR (Satellite Laser Ranging) data from 1995. In this research, we performed high accuracy orbit determination experiment using SLR. As a result of this experiment, we achieved ten-hold accuracy than the RARR method. (Reported on Space Flight Dynamics 1997 and 1998)

To based on this result, the NASDA's precise orbit determination system with GPS and SLR is now being developed at the NASDA/TACC (Tracking and Control Center). This system, which is called GUTS (Global and high accUracy Trajectory determination System) will use on-board GPS data , global ground GPS data and SLR data to determine satellite orbit. GUTS will be used to demonstrate precise orbit determination with ADEOS-II (Advanced Earth Observing Satellite II), set for a 2000 launch.

This paper presents an overview of the GUTS and its experimental plans.

*Key words:* Precise orbit determination, GPS, SLR, ADEOS-II, ALOS

## GUTS System design

The system overview of GUTS is shown in figure1. GUTS consists of 7 subsystems, GPS ground station subsystem, GPS ground station control subsystem, SLR ground station subsystem, SLR ground station control subsystem, Master Control and Operation Planning subsystem (COPs), Orbit Determination subsystem and Data Transfer subsystem.

In this section, we introduce about these subsystems' outline and its function.

### GPS ground stations subsystem

GUTS will have 5 GPS ground stations. (3sites will be located in Japan and 2 sites will be located overseas.) One of these stations will be located at Tsukuba space center in JAPAN. This station will be constructed in FY1999.

These GPS antennas will be about 2.5 meter tall with doom to protect antenna from rain and snow and with plate to detect reflection. GPS stations can receive L1 and L2 carrier phase signals from GPS satellites.

GPS ground station will receive GPS data all of the day, and will send these data to GPS station control subsystem.

### GPS Station Control subsystem

GPS station control subsystem controls remote GPS ground stations subsystem. This system collects GPS raw data from GPS ground stations, convert to RINEX format. RINEX data and raw data are sent to Data archive part (a part of Orbit Determination subsystem) once per day. RINEX data and raw data will accumlate there.

### SLR ground station subsystem

SLR ground station subsystem comprises SLR station. GUTS uses not only GPS data also SLR data. We will gather SLR data from CDDIS (Crustal Data Information System) data server and SLR stations in JAPAN (CRL/Koganei and Shimosato etc.). We are planning to construct SLR station for ALOS operation.

### SLR Station Control subsystem

SLR station control subsystem will conduct operation of SLR station.

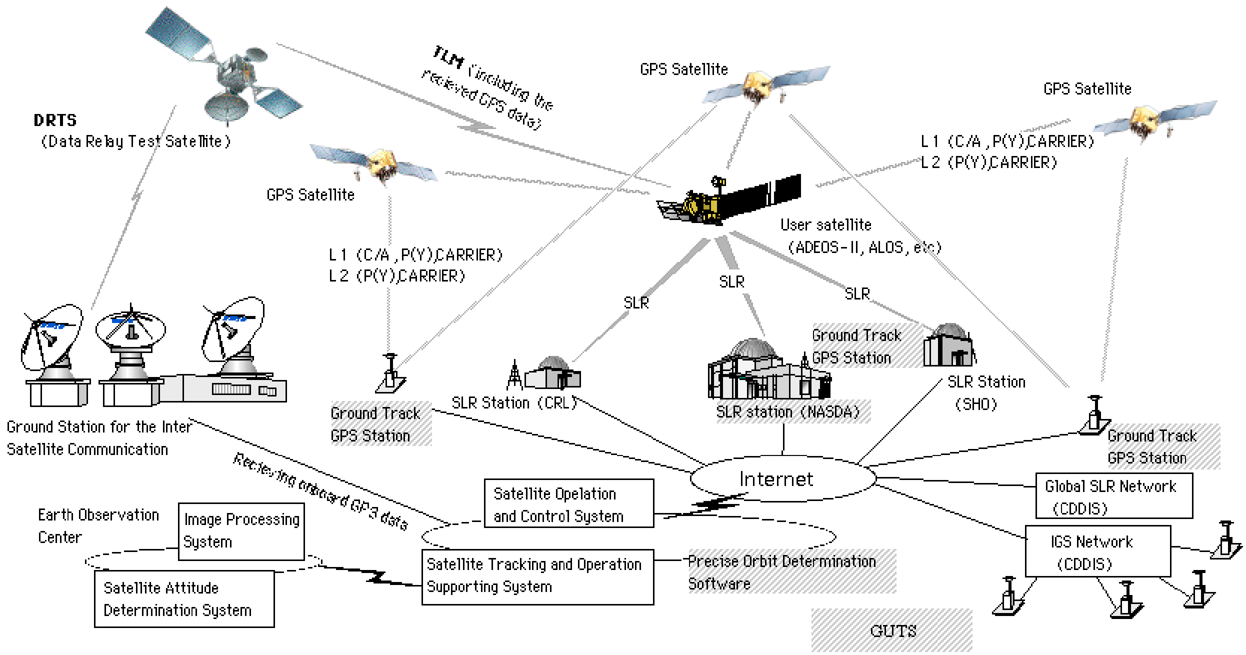



Figure.1: The overview of GUTS

SLR station control subsystem makes satellite-tracking information of telescope by TIRV (Tuned Interrange Vector). SLR station control subsystem will receive operation plan of SLR station from COPs and will operate SLR station on the basis of COPs' plan. SLR data will be sent to Data archive part after the pass operation and used for orbit determination. SLR data obtained by NASDA SLR station will be sent to CDDIS data server and these data will be made good use of geodetic science.

SLR station control subsystem is also under the conceptual design for ALOS operational phase.

**Master Control and Operation Planning subsystem**

Master Control and Operation Planning subsystem (COPs) will control all of operations of GUTS. Operators input operation plan to COPs and manage GUTS operation. COPs plans total operation schedule of GUTS (Orbit Determination/ GPS stations/ Data transfer…) and instructs operation plan to each subsystem.

Operation plan consists from some tasks. And each subsystem carries out operation on the basis of operation plan received from COPs. And after finished operation, they return the result of the solution to COPs.

**Precise Orbit Determination subsystem**

Precise Orbit determination subsystem is divided into two parts. One is Orbit determination calculation part, the other is Data archive part.

Orbit determination calculation part is the main part of GUTS. This part performs precise orbit determination using GPS and/or SLR data and evaluates orbit accuracy.

Data archive part is to accumulate and administer all of the data using orbit determination.

Data archive part will collect

- -Onboard GPSR data from the Satellite Operation and Control System
- -On-orbit satellite condition (on-board attitude, tempreture data and so on.)
- -GPS and SLR data from each ground site(GPS and SLR data from IGS and CDDIS global sites)
- -Astronomical data (earth rotation parameters, solar flux and geomagnetic, etc.)

Force and observation models using GUTS is shown in table 1. Force models include once and twice per revolution empirical acceleration model in addition to the JGM-3 (70,70) and the latest gravity models, atmospheric drag, thermal radiation pressure and so on.

Measurement models include Marini-Murray troposphere correction model for SLR data, Saastamoinen, Lanyi models for GPS data, center of mass, antenna phase correction model and so on.

Batch sequential filters and smoothers are adopted for estimation method. We generate and deliver precise satellite ephemeris to earth observation mission users.

Table.1: Software models of NOCS2 and GUTS

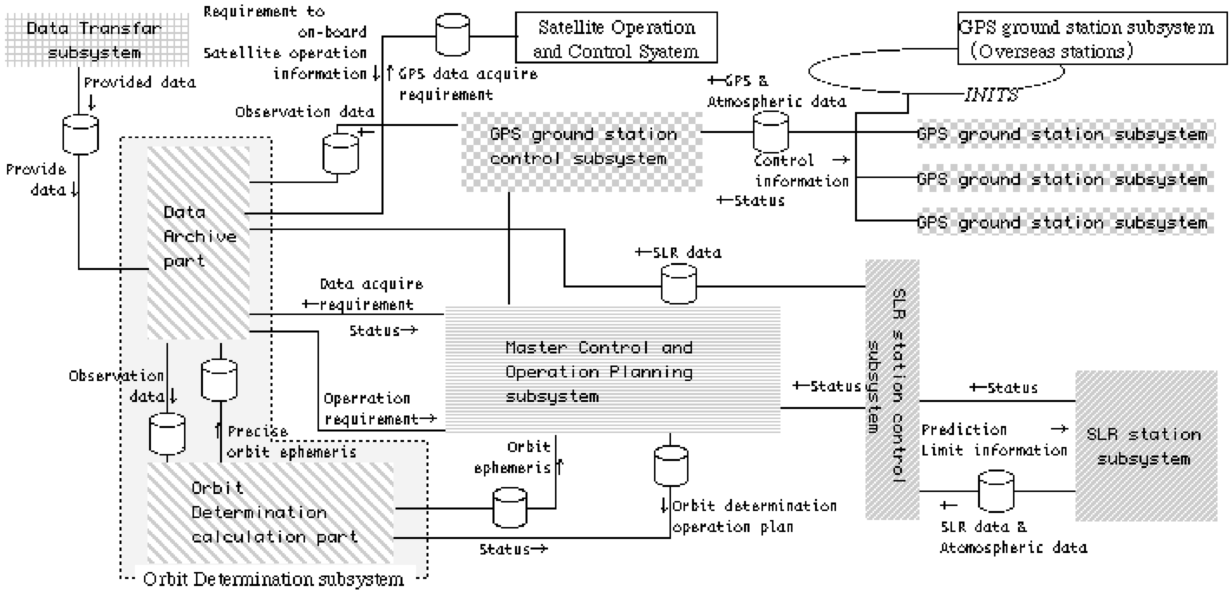
| | NOCS2(using RARR data) | GUTS(using GPS/SLR data) |
|---|---|---|
| Earth gravity model | • GEM-10B | • JGM-3(7070)<br>• J2, rate of C21,S21<br>• Considering Rotational Deformation |
| Tidal effect by Earth | • LOVE Model | • IERS1996 standard |
| Gravity model | • MOON and SUN<br>• JPL-DE200 | • Planet (not only Sun and Moon)<br>• 22 Lunar gravity model<br>• JPL-DE403 |
| Solar radiation pressure model | • Board model | • Introducing GPS satellite model<br>• Improvement of satellite shape model<br>• Improvement of eclipse model (conical model) |
| Earth radiation pressure model,<br>Satellite model | • board model | • Improvement of satellite shape model (Attitude and data)<br>• Considering thermal radiation |
| Air drag model | • Board model | • Improvement of satellite shape model (Attitude and data) |
| Effect of relativity | • Not considered | • IERS1996 standaed |
| empirical acceleration | • Not considered | • Considered |

## Data Transfer subsystem

Data transfer subsystem is the interface point between GUTS and other organization. This system gathers solar flax data, polar motion data etc, ground GPS data (from IGS), global SLR data (from CDDIS), SLR data from CRL and JHD, and other necessary data for orbit determination.

The other important function of this subsystem is to deliver information generated by GUTS. For example, precise orbit ephemeris, SLR prediction data (TIRV), SLR data evaluation report, SLR/GPS data obtained by NASDA stations and so on. These data interface are via INTERNET (ftp/SMTP).

The block diagram of GUTS is shown in figure 2.




Figuer.2: Block diagram of GUTS

**GUTS development and integration schedule**

The figure 3 shows the planned schedule of GUTS development and experiments, which will be performed the following steps.

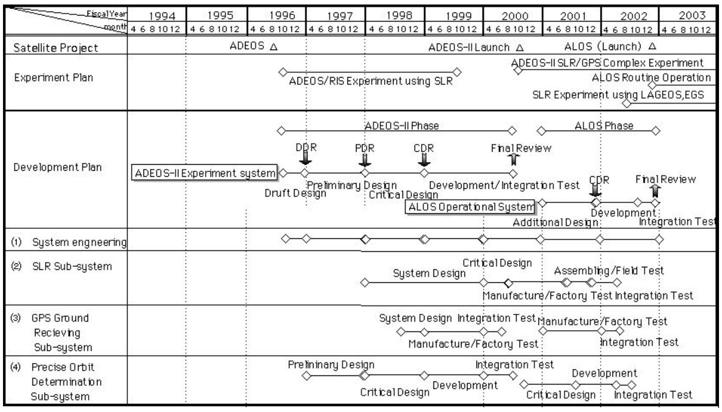


Figure.3: GUTS development and experiment schedule

**ADEOS/RIS**

In advance of this system integration, we started ADEOS/RIS experiments on 1996. This experiment used laser reflector onboard ADEOS (launched in 1995) called RIS (Retro reflector In Space). As a result of this experiment, by using SLR (Satellite Laser Ranging), we achieved 100-hold of orbit determination accuracy and 10-hold of orbit prediction accuracy. The detail of the ADEOS/RIS POD experiments is descried in OGAWA *et al.* (SFD 1998) and MAEDA *et al.* (SFD 1997).

**ADEOS-II experiments**

ADEOS-II(Advanced Earth Observing Satellite II) is being developed to serve as a post-ADEOS Earth observation satellite. It is scheduled for lift-off in 2000.

ADEOS-II will carry sensors such as AMSR developed by NASDA, NASA's Sea Winds, CNES's POLDER, laser retroreflectors and also six-channel, single-frequency (L1) GPS receiver(GPSR).

The GPSR is capable to measure C/A code pseudorange and L1 carrier phase data every 2 or 4 seconds. The differential GPS tracking using data from ADEOS-II onboard GPSR and from a global network of ground GPS receivers, which was successfully performed by NASA/JPL for the TOPEX/POSEIDON mission, are adopted for ADEOS-II POD on an experimental basis. We obtain on-board GPS data over ADEOS-II orbit using DRTS (Data Relay Test Satellite) space network system. We also obtained worldwide ground GPS data from IGS (International GPS Service) data server via Internet.

On the other hands, SLR data will be used for evaluating the GPS tracking and improving the gravity model for ADEOS-II orbits. Errors in modeling the signal propagation delay due to the ionosphere and errors caused by multipath will be significant because of the lack of L2 frequency data and the placement of the GPSR antenna, so that 2~3m orbit position accuracy is set when GPS data is used.

**ALOS operation**

Next, a development of the ALOS (Advanced Land Observing Satellite) operational system will be done taking into consideration the results of ADEOS-II experiments, and its operation will start from 2003.

ALOS will carry out high-resolution observation of the earth's surface to help in the process of compiling maps of Japan and the Asia-Pacific region. ALOS scientific mission requires the precise orbit information with position accuracy to 1m to analyze obtained sensor data. ALOS will carry 12 channel, dual-frequency (L1/L2) GPS receivers and laser retroreflectors. Measuring carrier phase data of both frequencies is effective to accurately calibrate the ionosphere delay, so that ALOS precise orbit over the whole revolution is estimated from the combined GPS tracking data and SLR data with a reduced dynamic solution, and position accuracy to 25cm is expected after testing measurement devices and orbit determination software.

Table.3: The goal of orbit accuracy

| Satellite | orbit type | altitude | The goal of orbit accuracy (3-D position) using GPS | using SLR |
|---|---|---|---|---|
| ADEOS (1996) | circular polar | 800km | - | 1m |
| ADEOS-II (2000) | circular polar | 800km | 2-3m | 40cm |
| ALOS (2003) | circular polar | 700km | from 1m to 25cm | 20cm |

**ETS-VIII experiment**

ETS-VIII (Engineering Test Satellite-VIII) is planned for launch in 2002. ETS-VIII will carry an atomic clock and will make a high accuracy satellite-ground clock synchronous experiment with the onboard atomic clock.

For this experiment, we will build ground experimental system based on GUTS. This experiment will be related to future technology.

## SUMMARY

For about five years, we have focused on researches in precise orbit determination, and this work led to a scheme of ADEOS-II POD experiment and the GUTS system. The aim of the experiment is to assess differential GPS tracking in NASDA, including performances of onboard GPSR, GUTS measurement devices and data processing software to cope with the next targets, ALOS and future earth observation missions.

Furthermore, making use of the GUTS components, a development of the ground segment for the NASDA's space-based positioning missions is now being planned.