Development Status of GPS-Based Precise Orbit Determination System for Japanese Ocean Surface Topography Mission（COMPIRA）

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Introduction

Japan Aerospace Exploration Agency (JAXA) has proposed the first ocean surface topography mission in Japan, named COMPIRA [1]. In the mission, JAXA will deliver near real time products to users within 6 to 12 hours (TBD), as well as precise products which require a radial orbit accuracy of 3 cm RMS within 60 days (TBD). In order to meet these requirements, JAXA has developed a GPS-based Precise Orbit Determination (POD) software, which can estimate orbits of Low Earth Orbit (LEO) satellites with an accuracy of a few centimeters. This poster provides a brief overview of the POD software and accuracy evaluation results of the existing LEO satellite missions.

COMPIRA Mission

There are three main purposes of the COMPIRA mission: ocean currents forecast for various human activities in the ocean including ship navigation; fishery for estimating fishing places; and scientific outcomes including ocean sub-mesoscale phenomena, sea-level rise phenomena, and improvement of Tsunami forecast model.

To obtain sea surface height data over the coastal region, wide-swath measurement is effective. COMPIRA will carry a wide-swath altimeter with two synthetic aperture radar antennas, named SHIOSAI (SAR Height Imaging Oceanic Sensor with Advanced Interferometry), having 80 km swath in both left and right sides (80km x 2).

COMPIRA Level-2 products

COMPIRA standard (Level-2) products consist of the following three types, depending on latency:

1) **Near-real-time products**
2) **General products**
3) **High-precision products**

Products	Latency	Accuracy
Near-real-time	6-12 hours	5.4 cm (relative) 12.2 cm (absolute)
General	3 days	7.5 cm (absolute)
High-precision	60 days	6.9 cm (absolute)

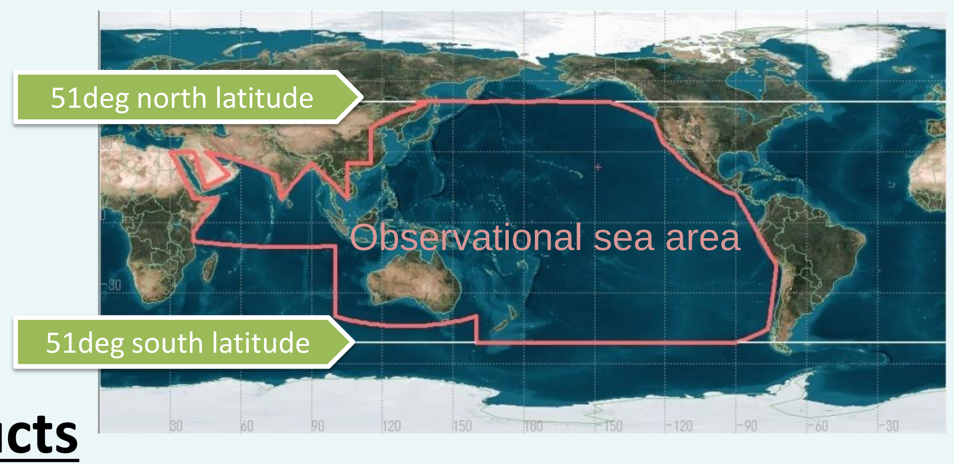
Corrected Sea Level Anomaly (SLA)/ Absolute Dynamic Topography (ADT), and SLA/ ADT/ Geostrophic Current maps are produced from Geophysical Data Records (GDR)

Requirements of COMPIRA Orbit Products

To meet the accuracy requirement of sea surface height, the orbit accuracy and the latency in shown the following table are required in COMPIRA mission. Near real time products and precise products will be generated using GPS-based POD software developed by JAXA. In addition to GPS measurements, Satellite Laser Ranging (SLR) observations are used to calibrate biases of GPS-determined orbits and to obtain combined precise orbits from SLR/GPS measurements with the cooperation of ILRS (International Laser Ranging Service) stations.

COMPIRA orbit parameters

- Recurrent Period: 10days
- Altitude: 937.49 km
- Inclination: 51.2 deg



Requirements of orbit products

Products	Latency	Orbit Accuracy(radial)	Measurements
Near-real-time	6-12 hours	10 cm (RMS)*	GPS
General	Nominal:1 day with orbit control:3 days	4 cm (RMS)	GPS (+SLR)
High-precision	60 days	3 cm (RMS)	GPS + SLR

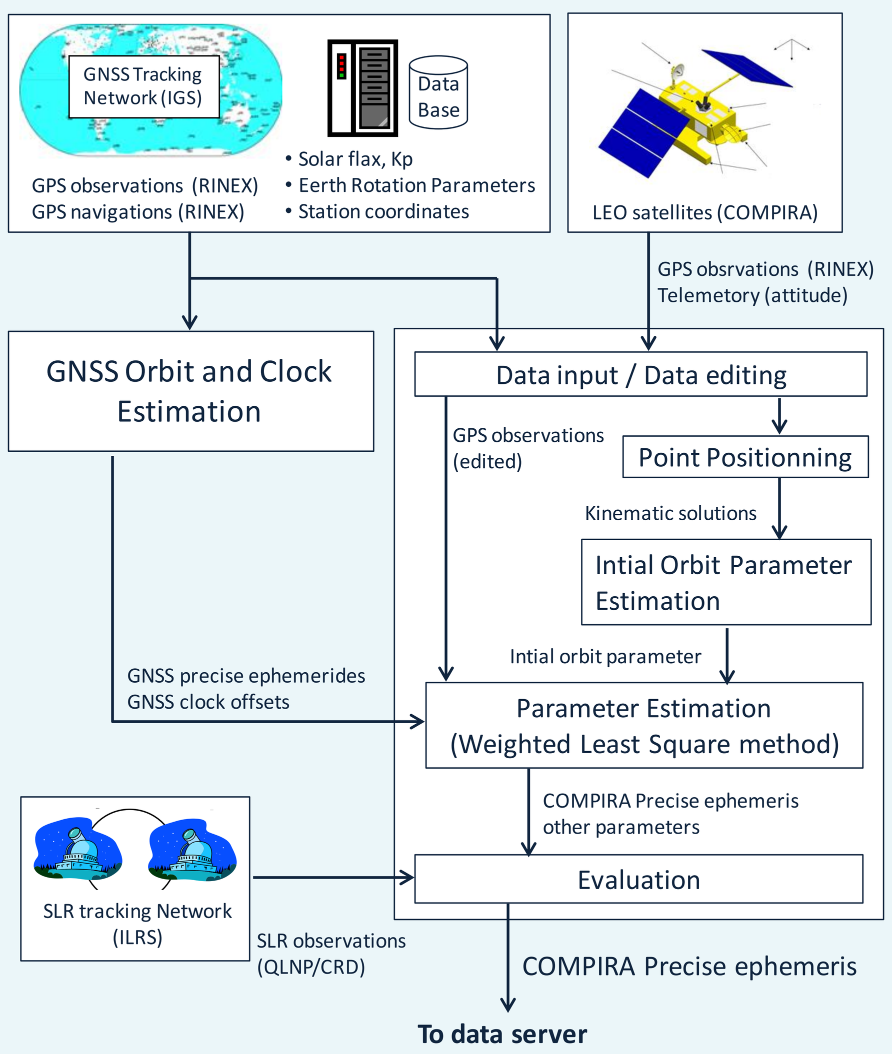
* orbit accuracy will be measured with regard to the High-precision ephemeris

POD Software Development

JAXA developed the GNSS precise orbit and clock estimation software, “MADOCA” in 2011 and 2012, which can estimate GNSS orbits with accuracy of a few centimeters [2]. In order to above requirements of COMPIRA orbit products, JAXA has developed a new POD software by expanding the capabilities of MADOCA to cover both GNSS and LEO satellites making use of the measurement and dynamic model, as well as the parameter estimation algorithm that were already implemented to MADOCA.

The key functions of the POD software are as follows,

1) **Orbit determination for GNSS**
2) **Orbit determination for LEO satellites**
3) **Integer carrier-phase ambiguity resolution**
4) **Phase Center Variation (PCV) estimation for GPS receiver antennas**
5) **SLR residual evaluation**



POD Strategy and Procedure

There are 2 steps to generate the COMPIRA orbit products.

1) **GNSS orbit/clock estimation**
2) **COMPIRA orbit estimation**

The GNSS precise ephemeris and clock offsets derived in STEP1 are fixed during the COMPIRA orbit estimation process (STEP2). The modeling of gravitational and non-gravitational forces within the POD software are shown in the following tables. A reduced dynamic strategy [3], which complements imperfect dynamics of LEO satellites with empirical accelerations, is applied to the COMPIRA orbit determination process.

POD Strategy

- ■GPS station coordinates： EST
- ■Tropospheric delay: EST
- ■Earth Rotation Parameters: EST
- ■Carrier Phase Ambiguity: EST

Dynamic model for LEO GNSS satellite

Item	Description
Gravity Field	EGM2008 etc.
Tide	Rate, Solid earth tide, Ocean tide, pole tide corrections by IERS 2010
Atmospheric Drag	satellite model: Spherical/multi-surface Atmosphere Density: NRL MSIS-E00/JB2008
Solar Radiation Pressure	SRP model: Spherical/CODE/DYB-axis etc. Shadow model: Earth and Moon
Third-body Gravity	Sun, Moon, Jupiter and Venus Planetary ephemeris by JPL DE405/421

Parameter Estimation (GNSS/COMPIRA)

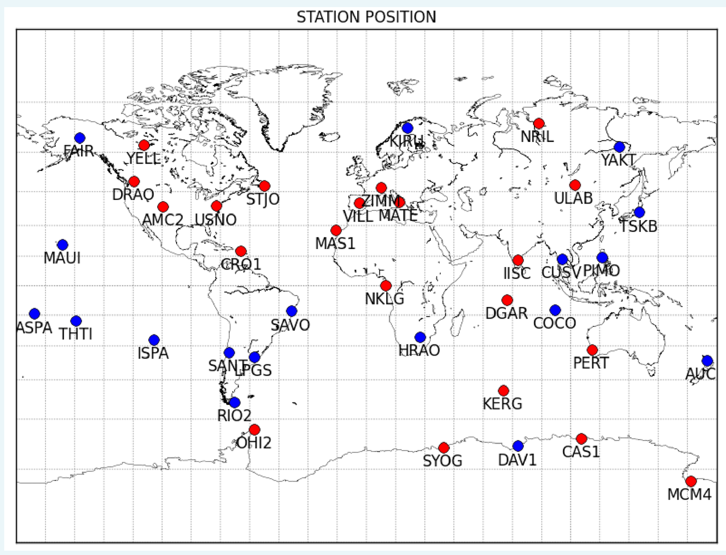
STEP1. GNSS orbit/clock estimation
- GPS orbit: EST
- GPS clock offset: EST
- Air drag: neglect
- SRP model: DYB-axis (9 parameters)
- Emperical Acc: EST (piece-wise const)

STEP2. COMPIRA orbit estimation
- GPS orbit: FIX
- GPS clock offset: FIX
- Air drag: Spherical model
- SRP model: Spherical model
- Empirical Acc: EST* (piece-wise const)

* Reduced dynamics orbit determination

Evaluation Results

In order to evaluate the POD software for COMPIRA, orbit determination tests were conducted using GPS observations received in GRACE-A satellite (NASA/JPL)[4]. The GNSS precise ephemeris and clock offsets were fixed to the IGS final orbit and IGS high-rate clock products [5], respectively. Moreover, the ground GPS observations in 40 IGS (International GNSS Service) stations shown in the figure on the right were processed with integer carrier-phase ambiguity fixing procedure.

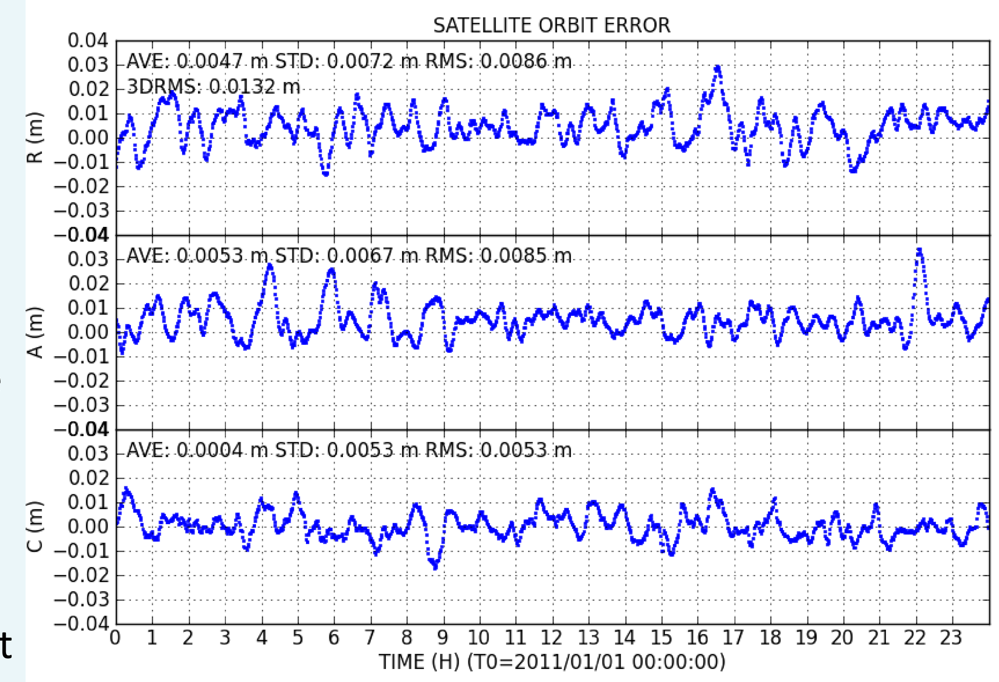


IGS Tracking Network (40 stations)

The figure on the right shows the GRACE-A orbit error with regards to the precise ephemeris derived form JPL level-1B products[4]. The statistical results during the estimation period (7-days) are summarized in the table in the bottom, which includes the SLR residuals.

According to the table, GRACE-A orbit differences between JAXA and JPL are 1.4 cm (3DRMS) and SLR residuals are also about 1.5 cm (RMS). In other words, the POD software can estimate orbit of GRACE-A satellite with higher accuracy of than 2.0 cm (RMS). This results indicate that the POD software developed by JAXA will meet the requirements of COMPIRA precise orbit products.

GRACE-A orbit determination
- ✓Estimation date: 2011-01-01 ~ 01-07 (7 days)
- ✓Estimation span: 24 hours (1 day)
- ✓Estimation interval: 60 sec



GRACE-A orbit differences @ 1th Jan, 2011 (JAXA-JPL)

upper: Radial, middle: Along-track bottom: Cross-track

AR-ON	JAXA-JPL [cm] rms				SLR Residuals [cm] rms
	R	A	C	3D	
2011-01-01	0.9	0.9	0.5	1.3	1.1
2011-01-02	0.9	0.9	0.6	1.4	3.0
2011-01-03	0.9	0.9	0.6	1.4	0.6
2011-01-04	0.9	1.0	0.6	1.5	0.4
2011-01-05	0.9	0.9	0.7	1.5	1.5
2011-01-06	0.8	0.9	0.7	1.4	2.0
2011-01-07	0.7	0.8	0.8	1.4	1.9
Mean	0.9	0.9	0.6	1.4	1.5

GRACE-A orbit estimation summary

References

[1] A. Uematsu, R. Nakamura, Y. Nakajima, and the JAXA COMPIRA team: X-band interferometric SAR sensor for the Japanese altimetry mission, COMPIRA, in Proc. IGARSS, Melbourne, July 2013.
[2] M. Miyoshi, S. Kogure, K. Kawate, H. Soga, Y. Hirahara, A. Yasuda and T. Takasu: The orbit and clock estimation result of GPS, GLONASS and QZSS by MADOCA, ISSFD, 2012.
[3] O. Montenbruck, T. Helleputte, R. Kroes and and E. Gill: Reduced dynamic orbit determination using GPS code and carrier measurements, Aerospace Science and Technology, 9, 261-271, 2005.
[4] K. Case, G. Kruizinga and S. Wu: GRACE level 1B data product user handbook, JPL Publication D-22027, Jet Propulsion Laboratory, Pasadena, 2002.
[5] J. Kouba: A guide to using international gnss service (igs) products, 2009.

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