International Committee on
Global Navigation Satellite Systems

Relative Onboard Orbit Determination and Propagation for LEO Missions

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Introduction

Relative Orbit Determination and Propagation (RODP) algorithm estimates the relative orbit between two satellites (Target and Chaser) using GNSS measurements transmitted through Inter Satellite Link (ISL) based on reduced dynamic method.

GNSS measurements based relative orbit estimation

- Instantaneous estimation of relative LEO satellite's position and velocity using carrier phase - GNSS measurements of Target and Chaser satellites
- Extended Kalman Filter (EKF) based instantaneous relative orbit estimation in ECEF frame using common visible satellites (between Chaser and Target)
- Processed measurements and absolute estimated orbit with attitude and thruster firing information of the other S/c will be available through Inter Satellite Link (ISL – every second)

Merits:

- Eliminate the common errors (GNSS orbit, clock, ionospheric errors) through single difference for Inter Satellite Distance (ISD) - 5Km to 5m
- Carrier phase measurements used hence better accuracy
- Provides propagated O/p during ISL non-availability

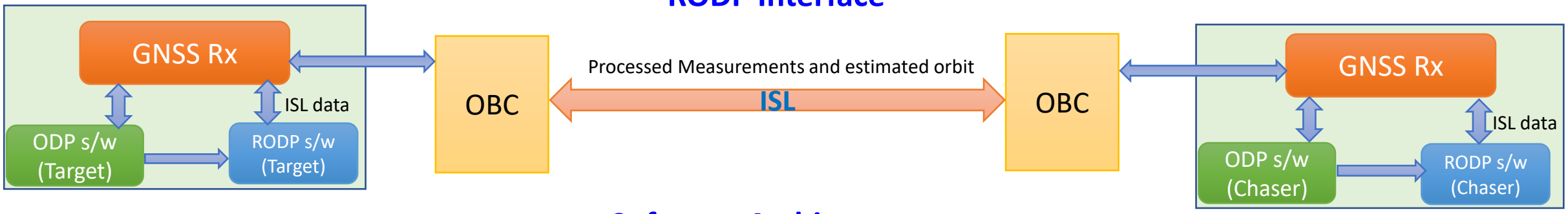
Targeted Accuracies for RODP

S.N	Algorithm	Instantaneous Estimation Accuracy (3σ)
1	**Absolute Position Difference (Uses Smoothened code and carrier measurements)**	**Position: 80cm; Velocity: <3mm/s**
2	**Relative Positioning using GNSS measurements**	**Position: 30cm; Velocity: <2mm/s**

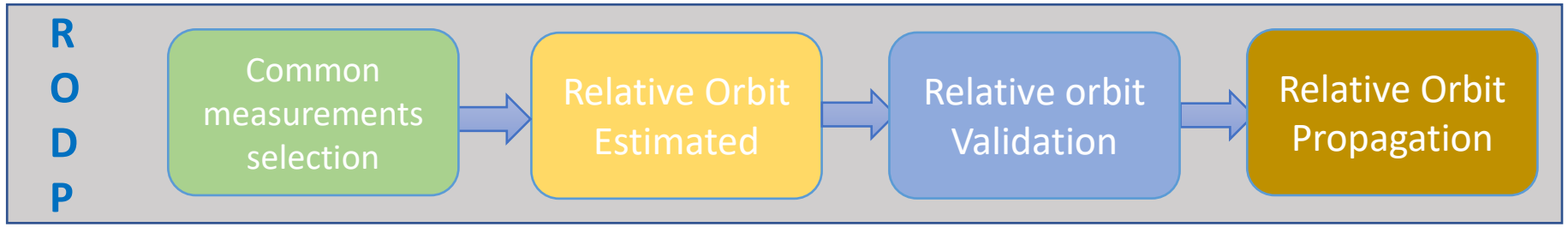
Architecture

A Relative Orbit Determination and Propagation (RODP) will be integrated with the existing onboard Orbit Determination & Propagation (ODP) s/w at GNSS receiver (Rx) and required inputs from ODP s/w of target and chaser are expected through ISL.

RODP Interface



Software Architecture



Common Measurements

Select the common visible GNSS satellites with valid measurements between both Target and Chaser

Relative Orbit Estimation

EKF based relative orbit estimation using the valid common GNSS satellites measurements with respected to targets satellite

Relative Orbit Validation

Estimated Relative orbit and the difference ODP output will be within bounds.

Relative Orbit Propagation

Relative acceleration with RK4 methods (Geopotential 5X5) and the analytical state transition matrix computation.

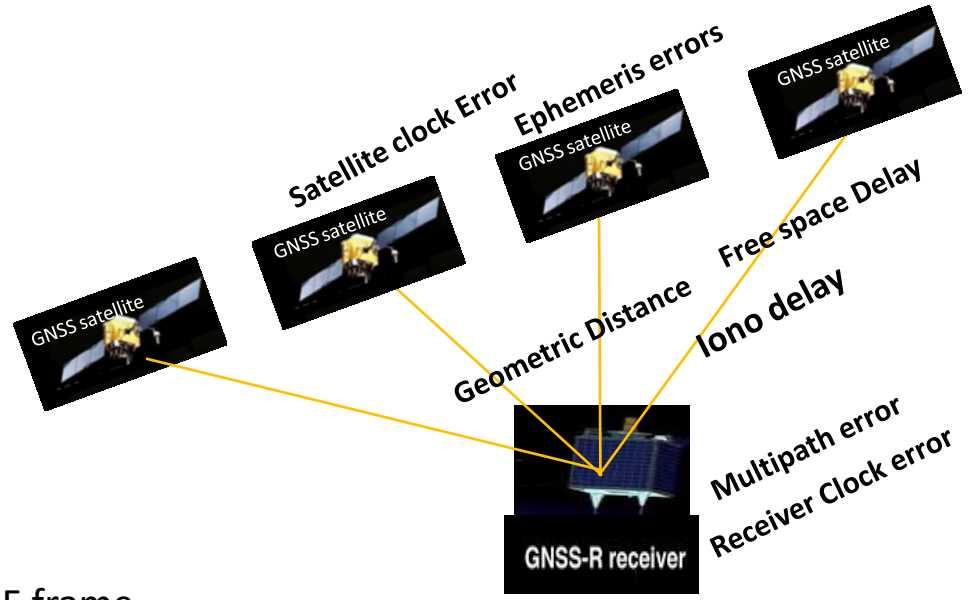
Features

Pre-requisites

- Precise antenna phase center co-ordinates of both the antenna's position known
- Attitude information values - available all the time
- During thruster firing, the accuracy values are applicable after filter settling (based on delta-v availability and accuracy)
- Availability of ISL data – every 1 second
- Minimum of 4 common GNSS S/c to be visible between chaser and target at every instant.
- Both chaser and target measurements are time stamped at every 1 sec (integer) with a time stamping accuracy <1micro sec

Input

- GNSS C/A Code, Carrier, Doppler and SNR on L1 frequency from Chaser and Target
- GNSS Broadcast (Nav) Parameters (from GNSS receiver)
- Thruster firing epoch and validated delta-v – accumulated for every 1 second
- Absolute LEO SV from ODP for both Target and Chaser
- Filter Configuration parameters (from Tele-Command (TC))



Output

- Relative LEO SV (position and velocity) for current epoch (every 1 sec) in ECEF frame

Methodology

Data processing

- *Outlier detection of range measurements*
- *Cycle Slip detection using rate of L4 & L6 measurements*
- *Dual - Compute P3 and L3 Iono error free combination*
- *Single – Compute Iono error free combination (P1+L1)/2*
- *Smoothening of P3*

Estimation

Estimated parameters (states -X) are

- *Relative LEO Satellites Position*
- *Relative LEO Satellites Velocity*
- *Relative LEO Satellites Clock Bias*
- *Relative Integer ambiguities (at every Line of Sight (LOS))*

Details of Orbit Model	
Reference Coordinate System	ECEF
Earth Gravity	EGM 2008
Third Body Perturbation	Sun, Moon Empiricial Formula
Drag Model	Harris-Priester
Solar Radiation Pressure	Empirical SRP model
Relativistic	Mathematical formulation
Numerical Integration	Runge-Kutta (4^{th} order)
Additional Forces	Coriolis, Centrifugal

Range Modelling

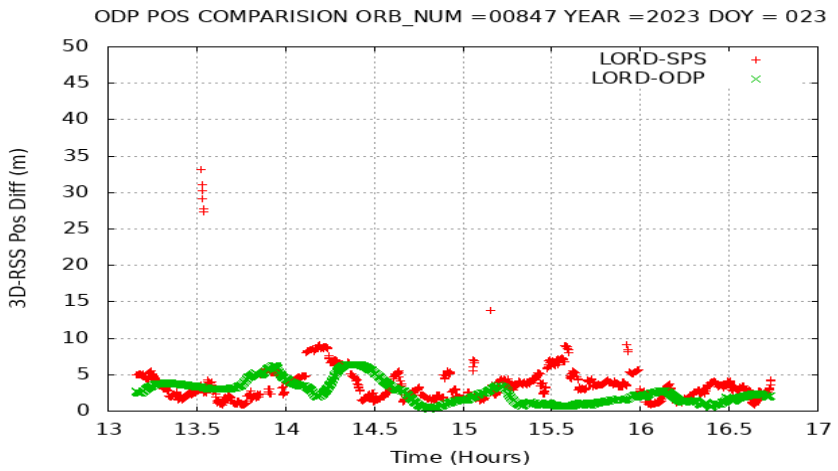
Modelled Receiver related, Satellite related and Transmission related errors, viz.,

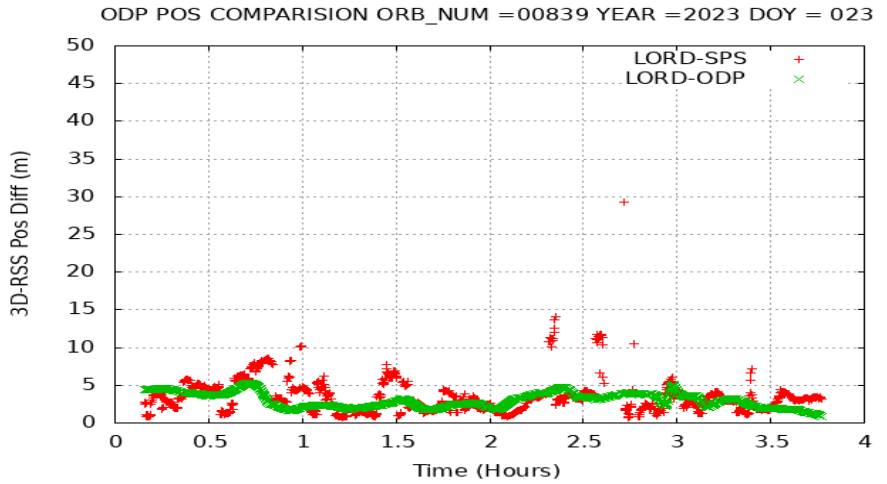
- ✓ *Relativistic errors due to Earth and satellite motion (Sagnac Effect)*
- ✓ *Satellite and receiver clock offsets*
- ✓ *Antenna phase centre offsets, variations and biases*

Oceansat-3 Results

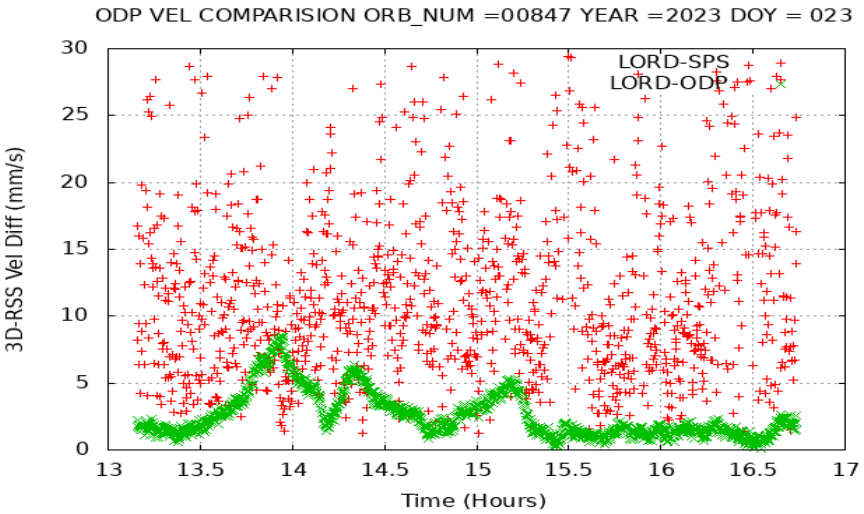
EOS06 (OS-3) satellite has been flown with stand alone ODP software for the first time and the onboard performance achieved is shown below.

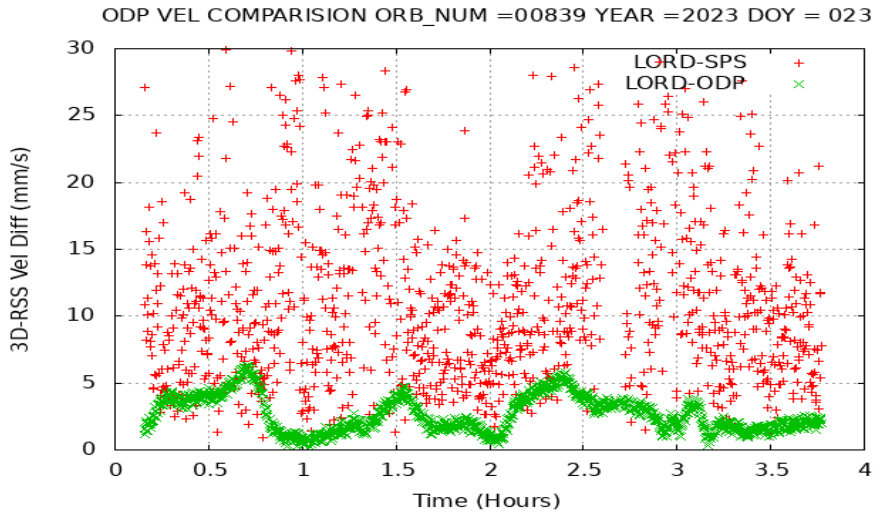
Position Difference





Velocity Difference





- ODP(Onboard Orbit Determination & Propagation) – EKF based onboard estimated orbit
- SPS(Standard Positioning System)- onboard single point positioning orbit
- LORD(LEO Orbit Determination) –Ground Batch Least Square technique based on PB data
- Position & Velocity accuracies are plotted in RSS (Root Sum Square) domain, w.r.t different estimated solution

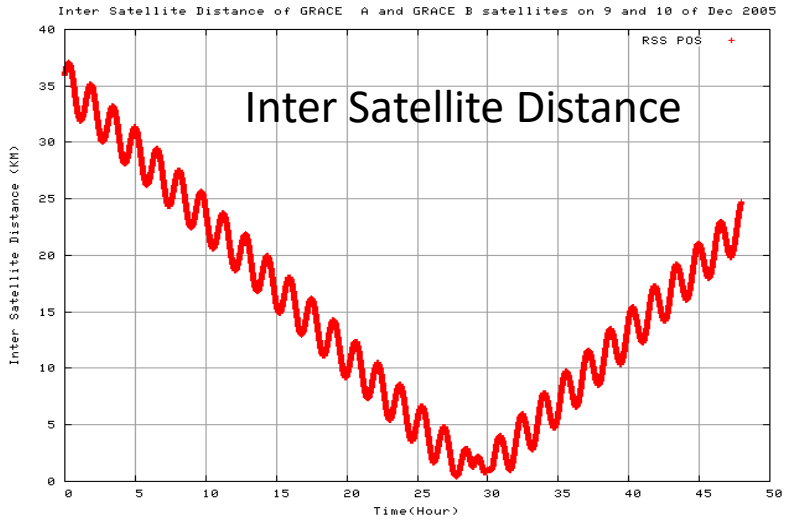
GRACE (A&B) satellites Results

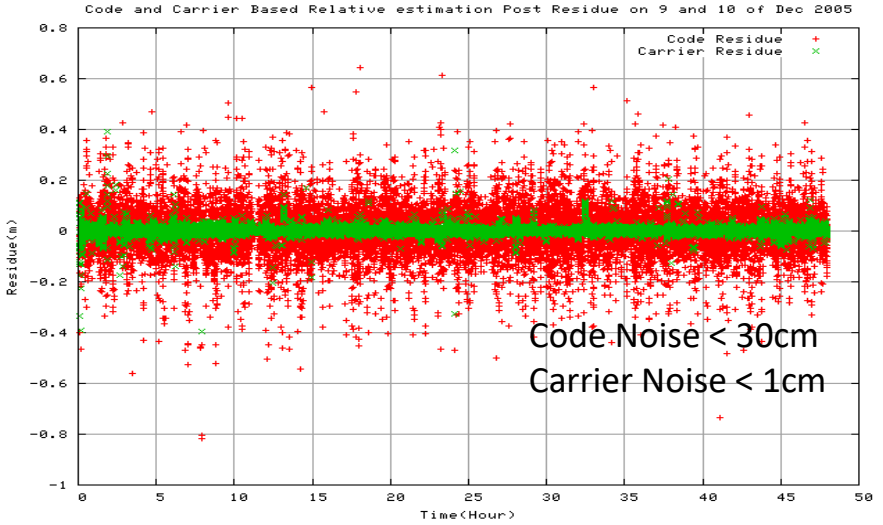
Input

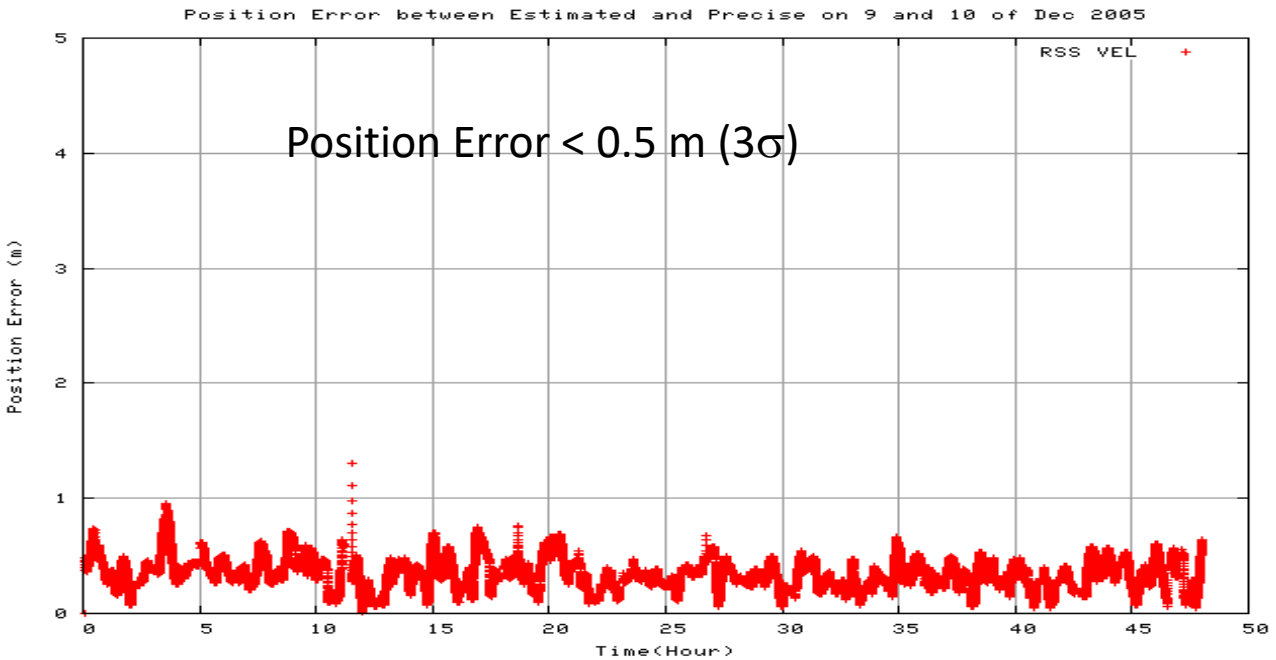
- GRACE A&B satellite carrier phase measurements
- GNSS satellites orbit and clock from Brdc file
- Absolute estimated state of Target (from ODP software)

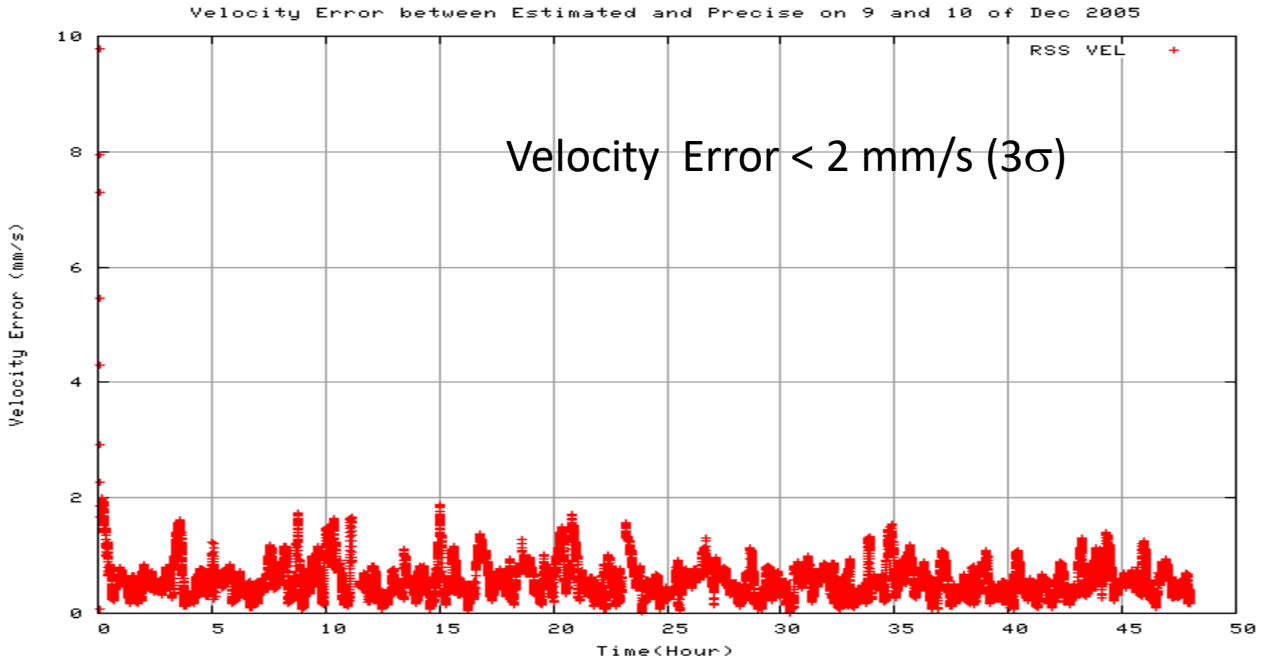
Output

- Estimated relative Orbit compared with the precise relative orbit





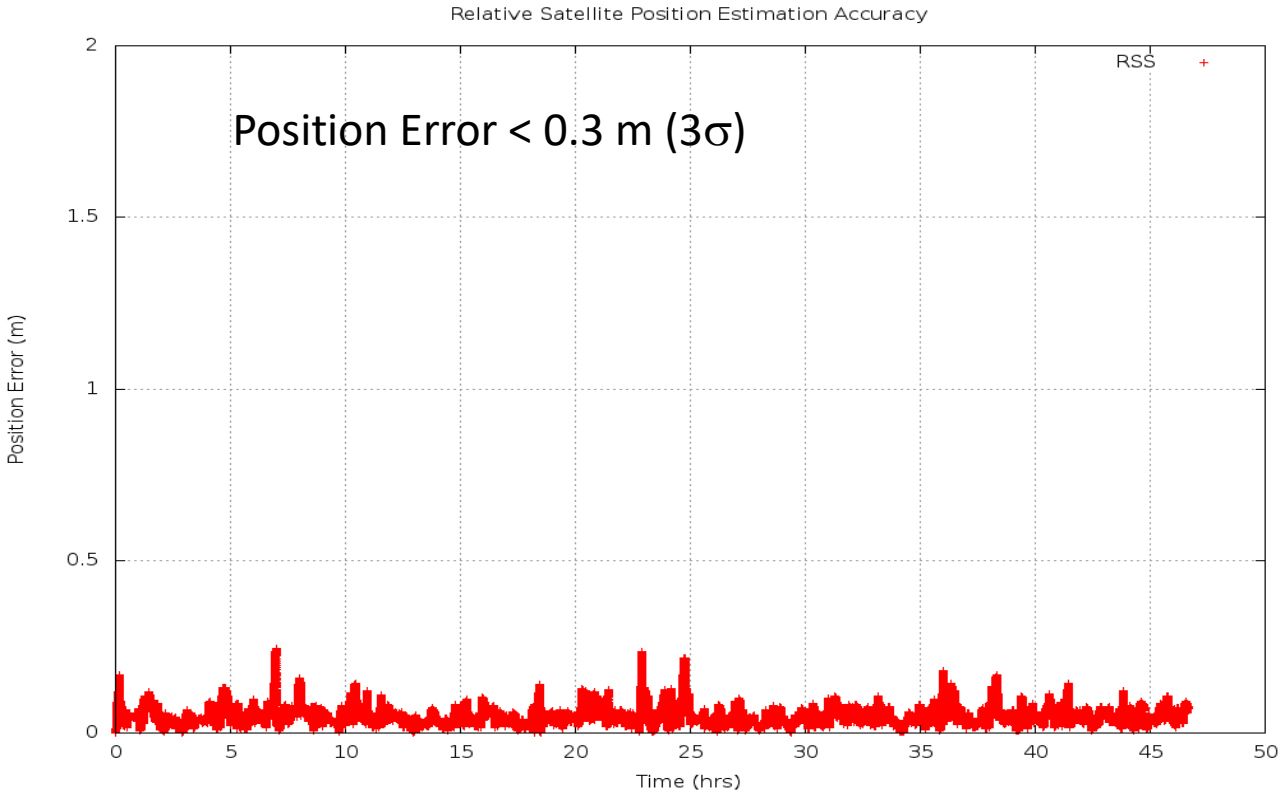


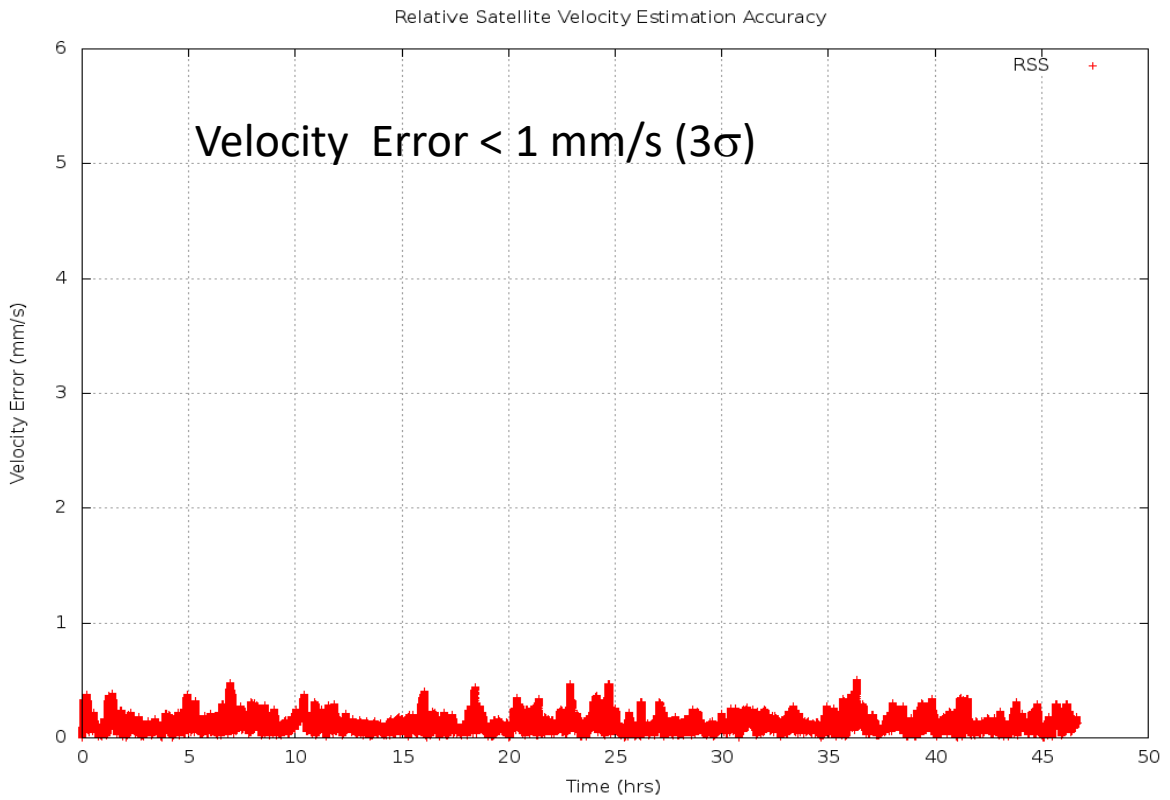


Simulation Setup & Results

RODP Simulation Setup

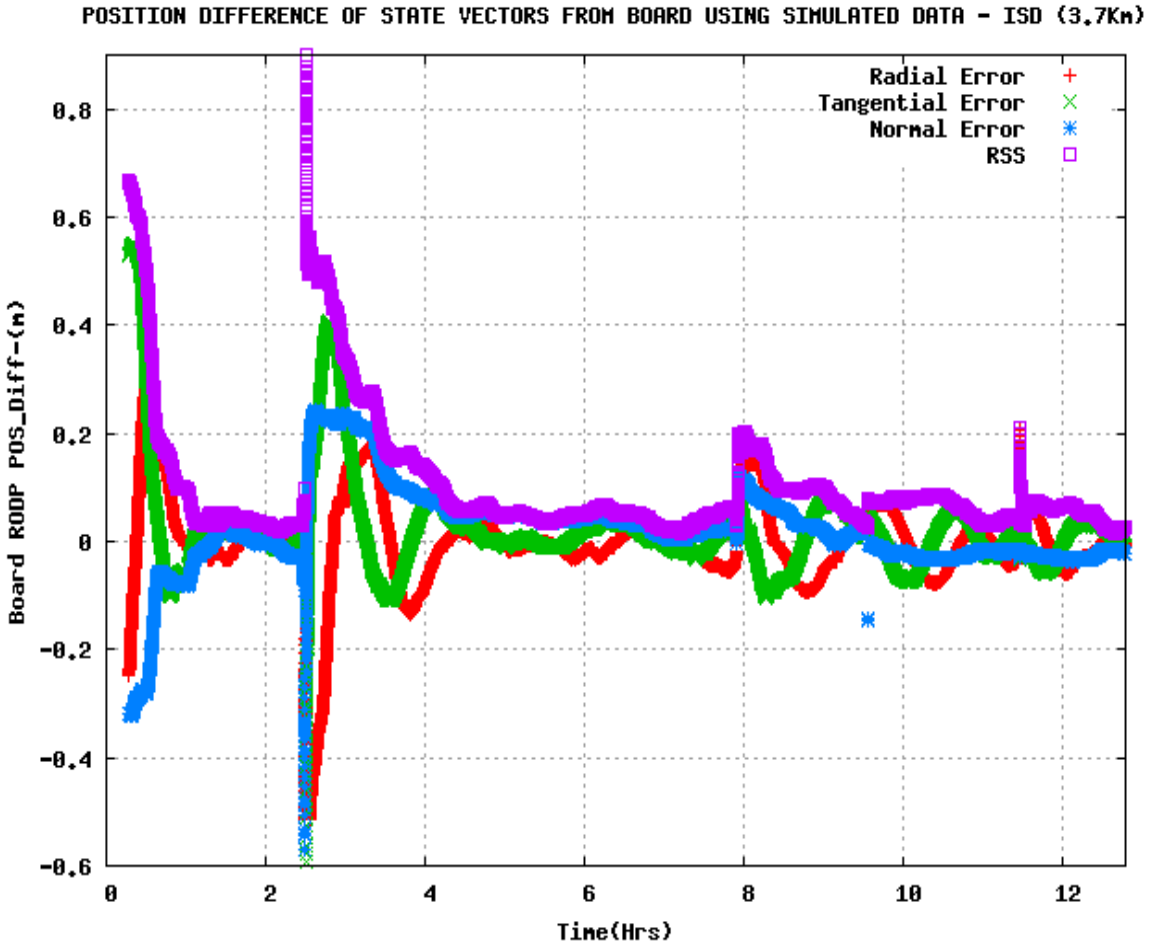
- **SPADEX** satellites simulated mission profile (Relative position – 1.5 to 1.7 Km (ISD) and Relative velocity – 1.5 to 1.9 m/s)
- GNSS orbit and clock taken from the Broadcast file (Brdc)
- GNSS measurements data simulation (of both target and chaser satellites using the s/w simulator) – period 2days

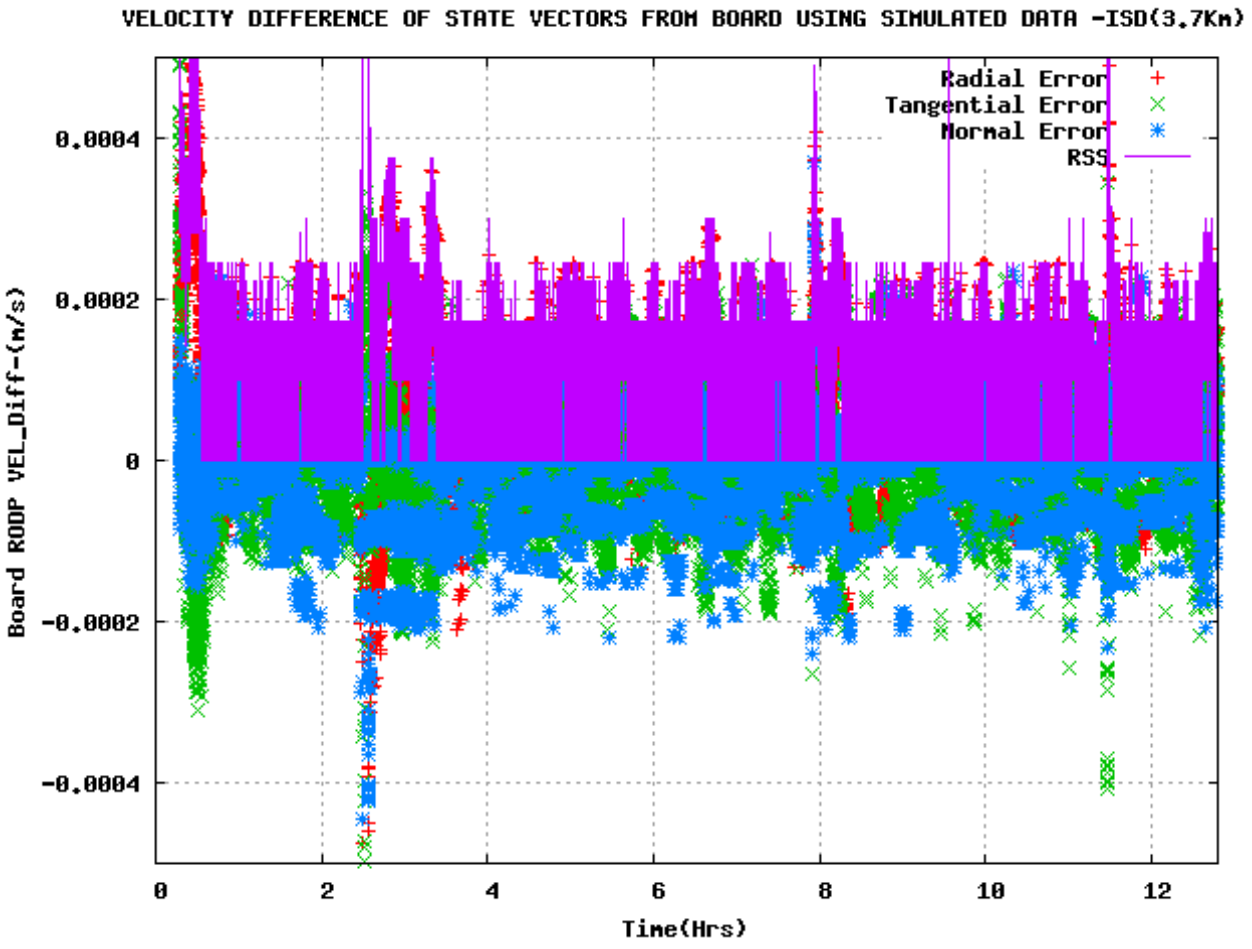




RODP Performance

Simulation setup with two Rx and ISL link (near real time) – data exchange established and R-T-N error results are shown below compared with precise for ISD – 3.7km





Summary

- Accuracy of the algorithm is based on the carrier phase measurements accuracy and common number of visible GNSS satellites with same time stamp epoch between 2 satellites
- Better accuracy than standalone Orbit Determination & Propagation (ODP) solution difference
- For various simulated and real data - RODP accuracy has been shown
- Outages can be handled with an accuracy of as relative propagation is part of RODP
- ISL Interfaces – delays can be handled
- Manoeuvres seamlessly handled using Delta-V information
- Simulation setup with two Rx and ISL link (near real time) – data exchange established and results shown

THANK YOU