Multi-GNSS: experience and the benefits from India in GPS-GLONASS hybrid operation Mode

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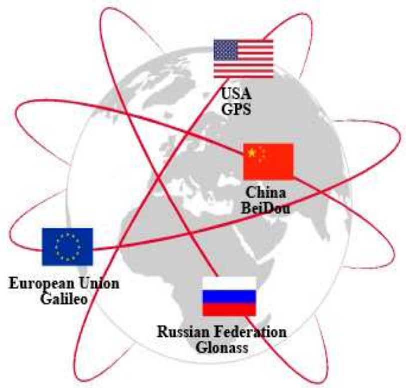

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Kathmandu, Nepal
12th December, 2016

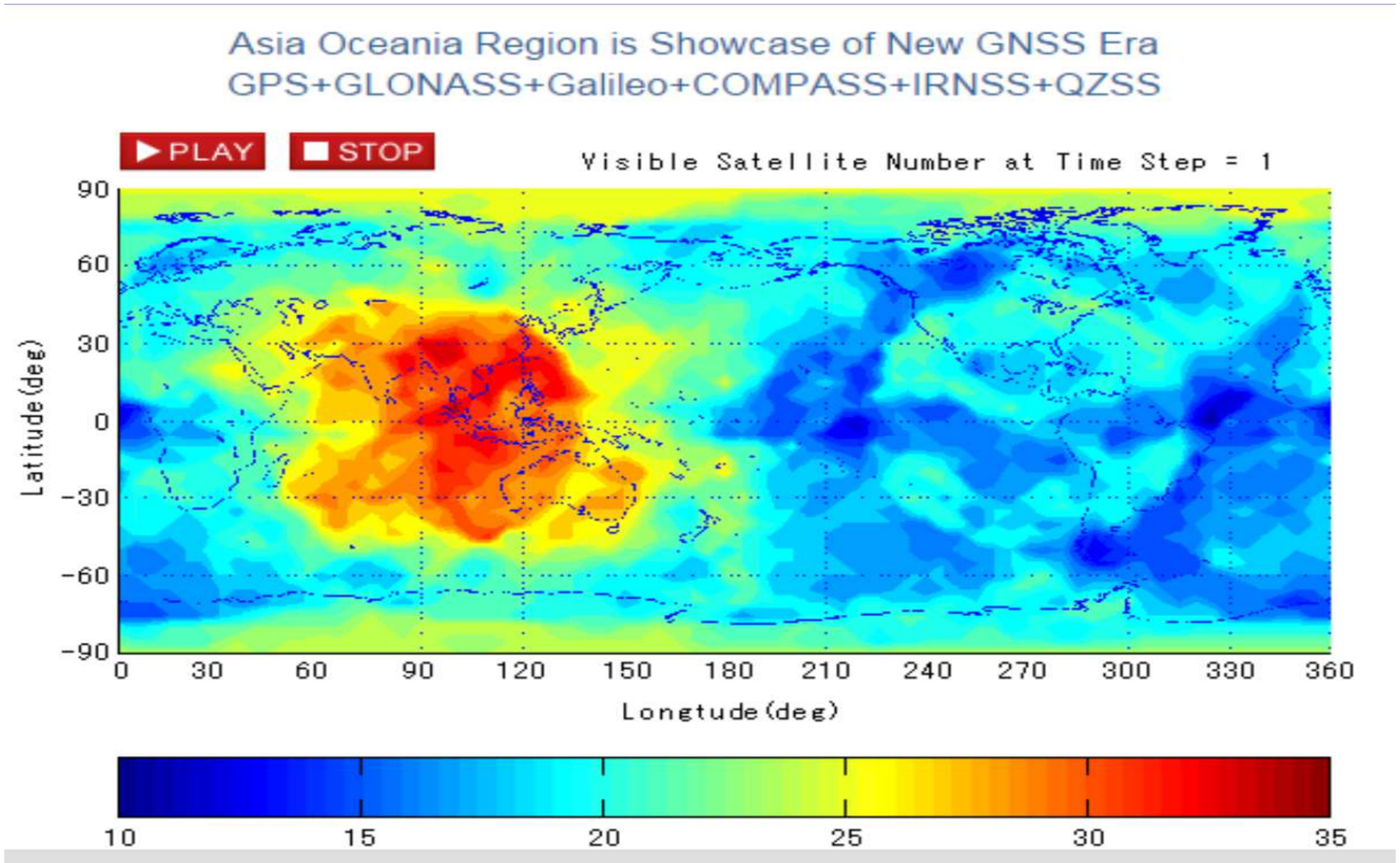
Menu

- Different GNSS systems by different countries
- Why India is suitable to study Multi-GNSS
- Data monitoring Plan and set-up
- Experience on GPS, GLONASS and GPS+GLONASS availability: few results
- Effect of presence of GLONASS on Accuracy: few results
- Advantages and challenges of Multi-GNSS

Current GNSS constellations at a glance (30/11/16)

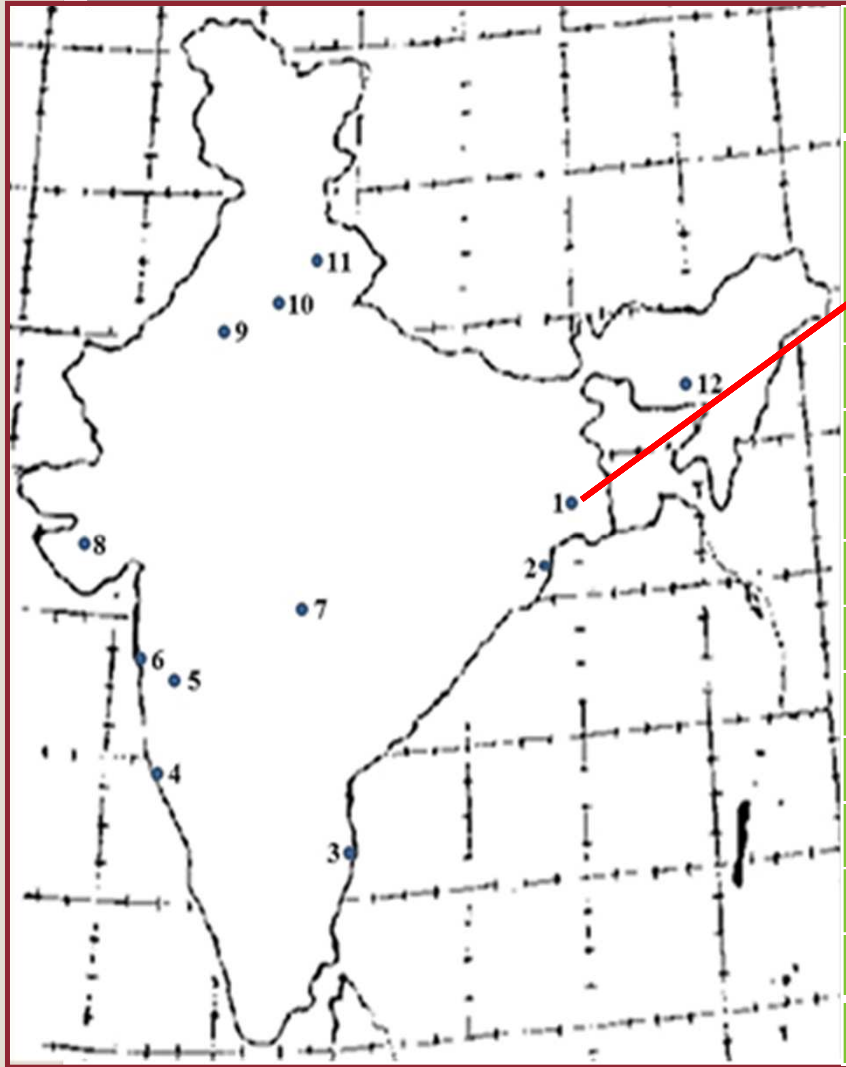
SYSTEM	OWNER	No. of active satellites (Total No. of satellites in constellation)	Present STATUS
GPS (Global Positioning System)	USA	30 (31)	Operational
GLONASS (GLObal Navigation Satellite System)	Russia	23 (27)	Operational
GALILEO	European Union	09 (18)	Under Development
COMPASS	China	19 (27)	Under Development
QZSS	Japan	01 (01)	Under Development
IRNSS	India	07 (07)	Under Test

Presence of multiple systems: SE Asian region



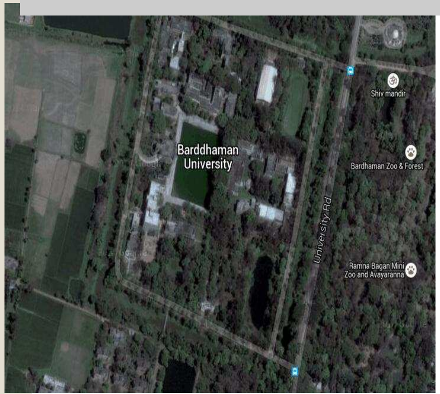
- Number of navigational satellites above India will increase significantly in the next decade.
- Typical geographical location of India helps the users to take the advantages of multi-GNSS for better coverage, system independence, redundancy and more signals in space.
- GLONASS is the only active alternative to GPS, study is initiated using stand-alone GLONASS and an active alternative to GPS as a contributor to GPS+GLONASS hybrid operations.

GPS-GLONASS data monitoring plan

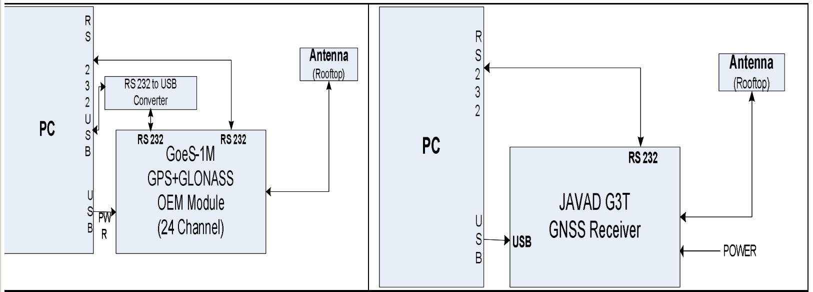


Location No	Location	Comment
1	Burdwan	Permanent station (GoeS-1M, G3T)
2	Balasore	Data recorded for 2-4 days at each data monitoring point during August, 2012 – November, 2012. (GoeS-1M)
3	Chennai	
4	Goa	
5	Pune	
6	Panvel	
7	Nagpur	
8	Rajkot	
9	Pilani	
10	Noida	
11	Dehradun	
12	Shillong	

Data monitoring set-up

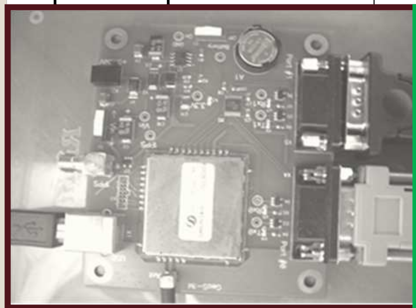


Monitoring Site	Appox. Location
The University of Burdwan, INDIA	23^0 15.27′ N 87^0 50.81′ E 49.44 Meters



Experimental setup for GoeS-1M receiver

Experimental setup for JAVAD G3T receiver



Receiver Designator	Brief Hardware Description	Data Collection Software	Collected data format, Data Rate
Rx #1	GoeS-1M OEM Board, Active antenna with 10…35dB exceeding gain, Single Frequency	Developed in House	National Marine Electronics Association (NMEA) 0183, 1 Hz
Rx #2	Javad DELTA G3T with GrAnt G3T Antenna, Multi-Frequency	Javad NetView®	

NMEA DATA in RAW form

```
$GNGGA,094603.00,2315.2728,N,08750.8075,E,1,15,0.8,00047.9,M,-056.9,M,,*61
$GNGSA,A,3,13,11,07,17,01,28,26,09,08,,,,1.4,0.8,1.2*2F
$GNGSA,A,3,80,78,82,83,79,81,,,,,,,1.4,0.8,1.2*23
$GPGSV,3,1,11,01,47,082,46,07,64,134,43,08,76,001,46,09,51,324,46*75
$GPGSV,3,2,11,11,37,054,41,13,09,176,32,17,46,251,46,19,02,043,27*7A
$GPGSV,3,3,11,20,04,132,,26,22,295,41,28,43,335,44*48
$GLGSV,2,1,06,78,25,127,19,79,66,054,41,80,31,339,41,81,38,020,45*69
$GLGSV,2,2,06,82,73,278,42,83,17,220,36*6E
$GNRMC,094603.00,A,2315.2728,N,08750.8075,E,000.01320,145.5,170613,,,A*45
$GNVTG,145.5,T,,,0000.0,N,0000.0,K,A*5B
$GNZDA,094603.00,17,06,2013,+03,00*58
```

DATA in SORTED form (using our utility)

```
17 06 2013 15 16 02.00 23 15.2728 087 50.8075 1 -9 3 13 11 07 17 01 28 26 09 08 80 82 83 79 81 1.5 0.8 1.2 0.007 ……
17 06 2013 15 16 03.00 23 15.2728 087 50.8075 1 -9 3 13 11 07 17 01 28 26 09 08 80 82 83 79 81 1.5 0.8 1.2 0.007 …….
17 06 2013 15 16 04.00 23 15.2728 087 50.8075 1 -9 3 13 11 07 17 01 28 26 09 08 80 82 83 79 81 1.5 0.8 1.2 0.007 …….
17 06 2013 15 16 05.00 23 15.2728 087 50.8075 1 -9 3 13 11 07 17 01 28 26 09 08 80 82 83 79 81 1.5 0.8 1.2 0.007 …….
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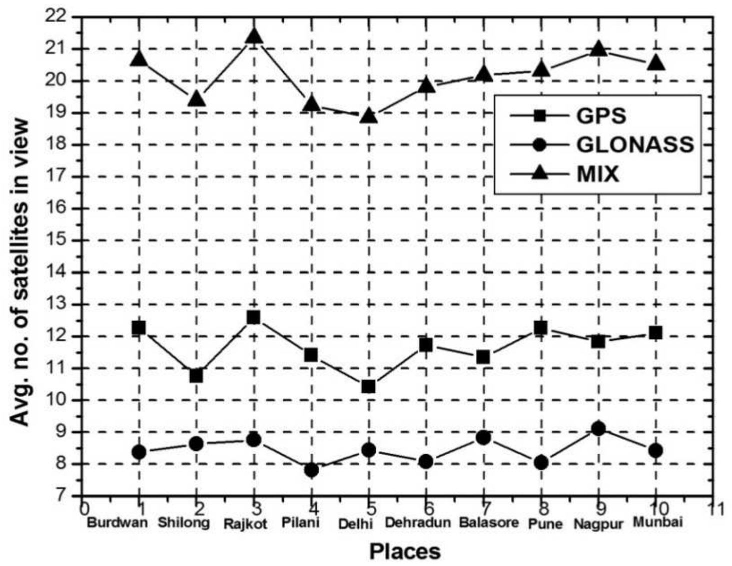
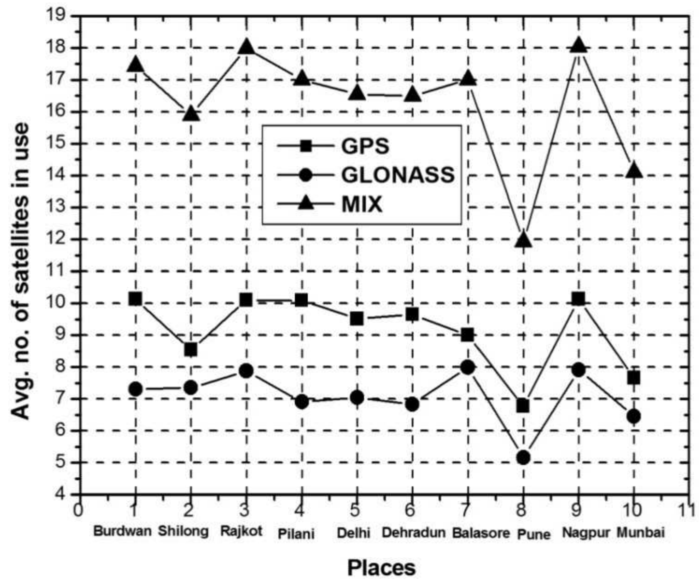
NMEA: comes out from all receivers, suitable for cost effective use of GNSS

GPS, GLONASS and GPS+GLONASS availability

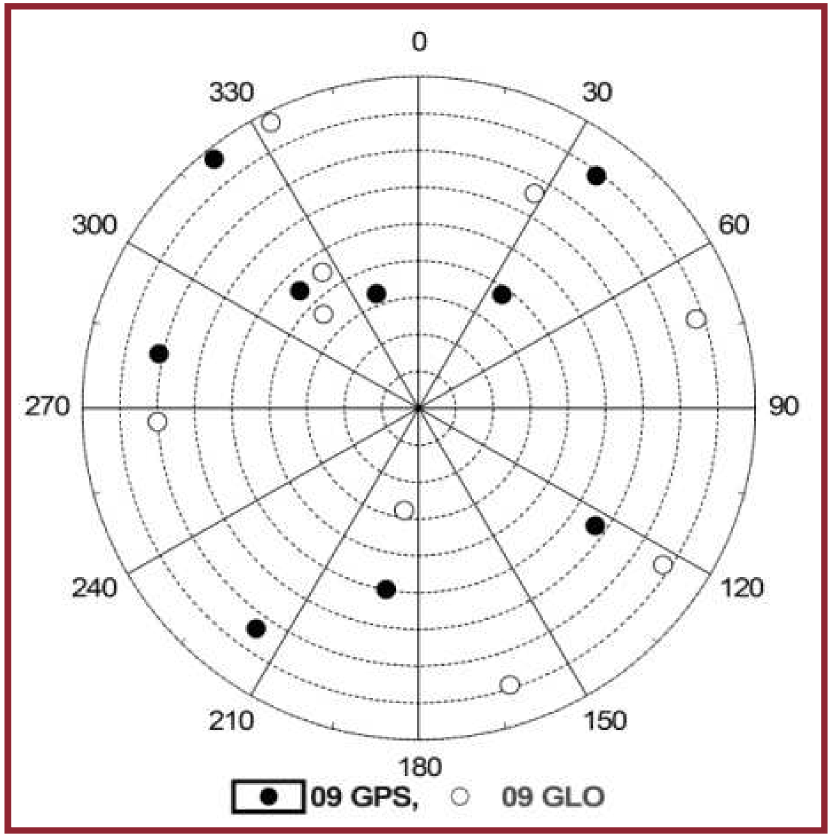


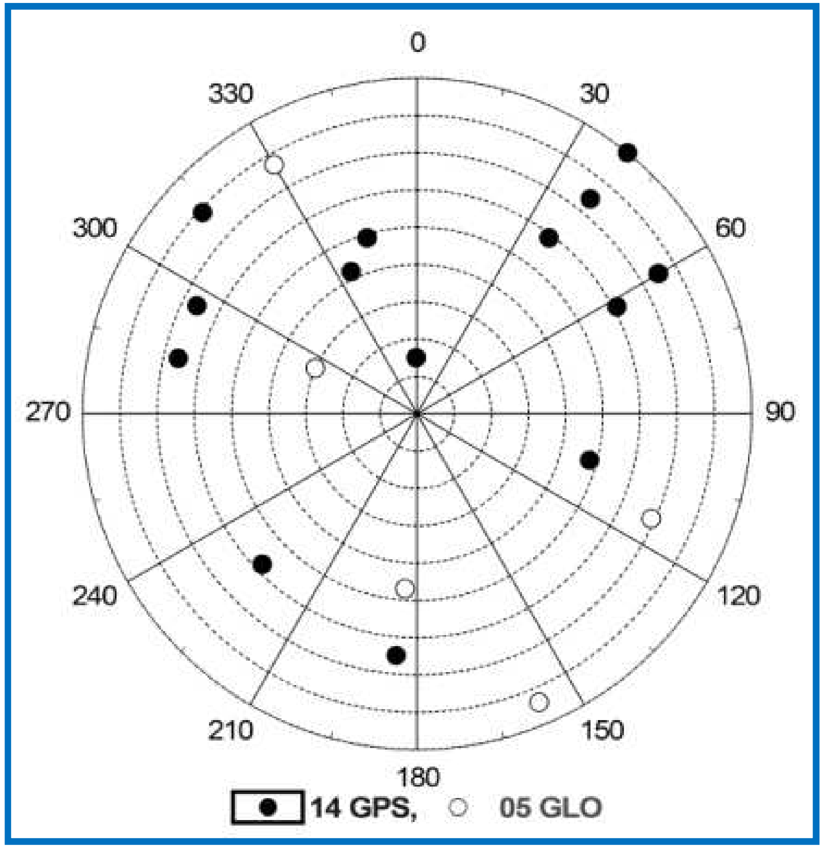


- ➢Visible and Usable GLONASS are below those of GPS.

- ➢Number of usable satellites varies between 15 to 21 out of 18 to 24 visible satellites in GPS-GLONASS hybrid mode.

GPS, GLONASS satellite geometry

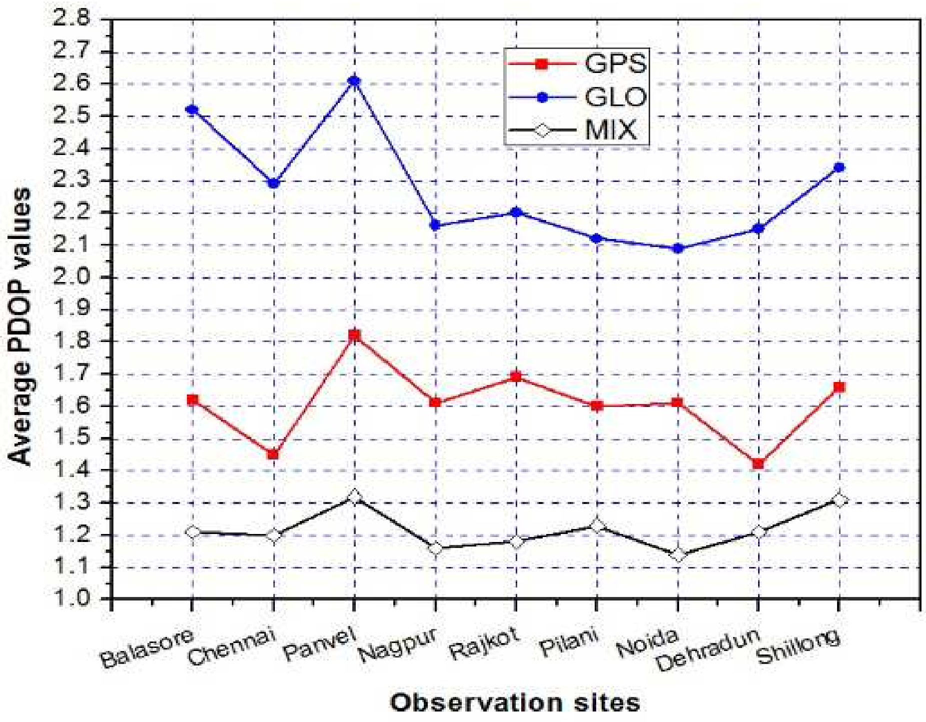




GPS and GLONASS satellite distribution for Burdwan (28/11/2016; 13:46:00 IST)

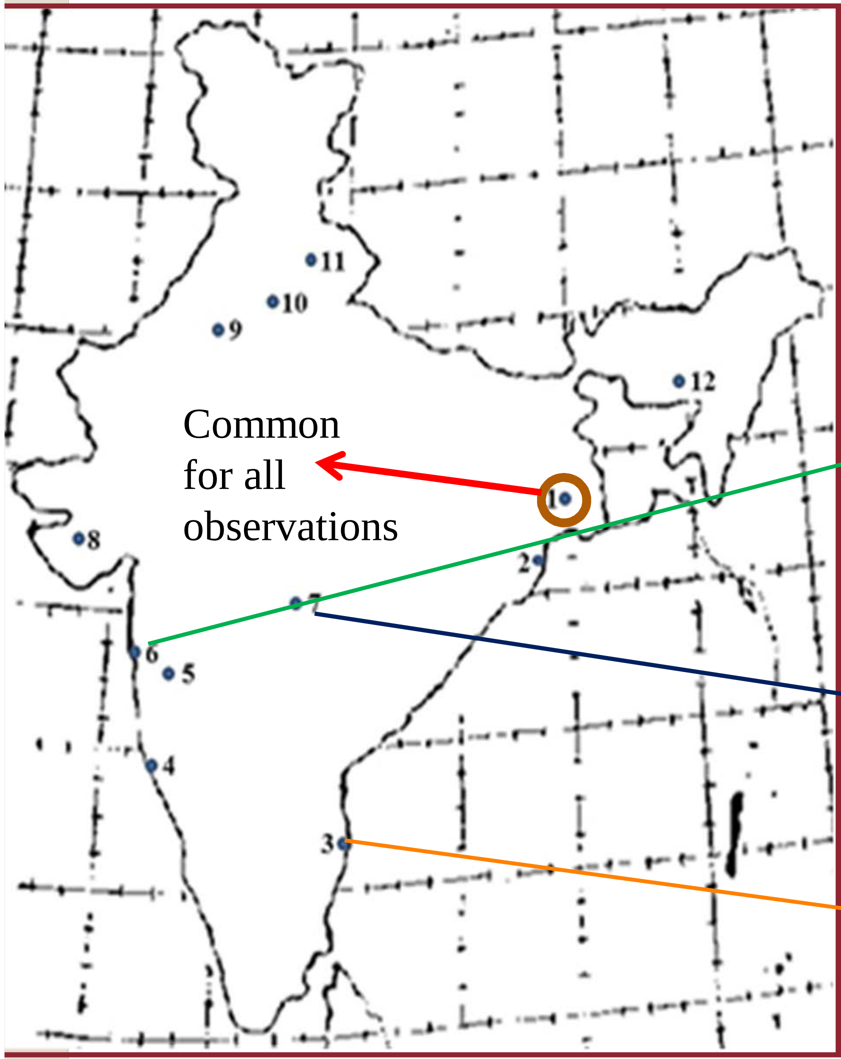
GPS and GLONASS satellite distribution for Burdwan (28/11/2016; 20:09:30 IST)

GLONASS contribution in Multi-GNSS: Effects on satellite geometry



Average PDOP variation for different GNSS modes, Various places, GeoS-1M

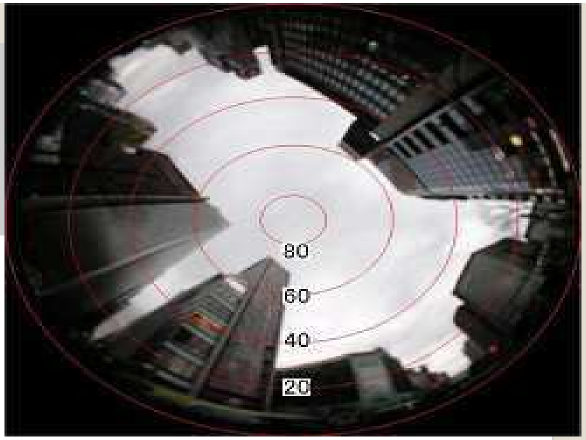
Common GLONASS usability over India



Date	Observation from Burdwan and	GLONASS Usable [Burdwan] [Place 2] Common PRN no.[SV no #] **(Total)**
29.08.12	Panvel	[8][7] 744, 742, 734, 721, 715, 716, 754 **(7)**
29.08.12		[9][7] 744, 742, 721, 714, 754, 720 **(6)**
29.08.12		[7][6] 747, 744, 742, 714, 754, 735 **(6)**
31.08.12		[9][8] 742, 734, 733, 716, 738, 720, 719, 755 **(8)**
31.08.12		[6][6] 737 , 721, 715, 714, 732, 735 **(6)**
04.09.12	Nagpur	[9][9] 730, 747, 744, 723, 737, 721, 714, 754, 735 **(9)**
05.09.12		[8][9] 730, 747, 744, 737, 721, 714, 754 **(7)**
07.11.12	Chennai	[7][7] 747, 744, 742, 721, 715, 716 **(6)**
08.11.12		[6][8] 736, 717, 738 , 720, 719, 755 **(6)**
08.11.12		[8][8] 730, 745, 743, 737, 721, 755, 731, 732 **(8)**

➢Same group of satellites is usable from different places for most of the time- May be helpful for common view mission planning.

GLONASS in low visibility condition



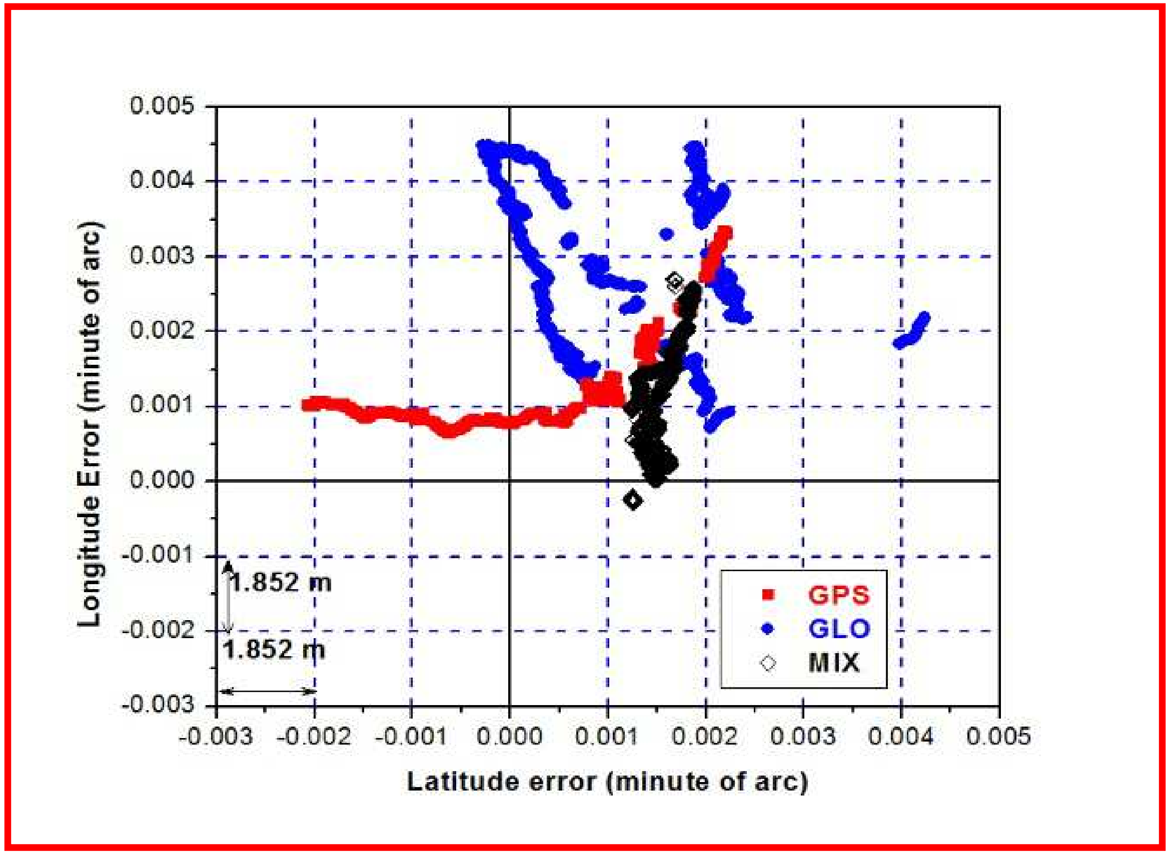
Data recorded with intentional degraded elevation mask angle

Elevation Mask Angle (deg)	Location	GPS satellite nos in use (Available GPS sats)	GLONASS sat. Nos in use (Available GLONASS sats)
30	Chennai	5 (12)	4 (9)
	Balasore	5 (13)	4 (6)
	Pilani	5 (10)	4 (9)
	Burdwan	7 (12)	3 (9)
45	Chennai	3 (13)	2 (10)
	Balasore	2 (12)	4 (9)
	Shillong	4 (12)	2 (9)
	Dehradun	3 (12)	3 (9)
	Burdwan	4 (14)	2 (9)

- In limited satellite visibility conditions (urban canyons or Deep foliage) simultaneous 04 satellites may be available using GPS and GLONASS together only.

GPS-GLONASS Combined operation: Instantaneous Solution in different modes

- ➢Errors of individual latitude and longitude values for each observation are calculated and are plotted.
- ➢The dark lines in the graph indicated the reference coordinates.



1 hour data @1 Hz each for GPS, GLONASS, GPS+GLONASS
08/04/14, GoeS-1M

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➢The figure shows lowest variations in MIX mode while GLONASS results in the highest variations.

Solution Accuracy background

- **Collected data are categorized for each month**
- **Reference location is calculated averaging large number of GPS solution**
- **Errors 2-d (2 dimensional) and 3-d (3 dimensional) are calculated using :**

Latitude error ΔLa (in meters) = $(L_i - L_0)$ x 1852 (1)

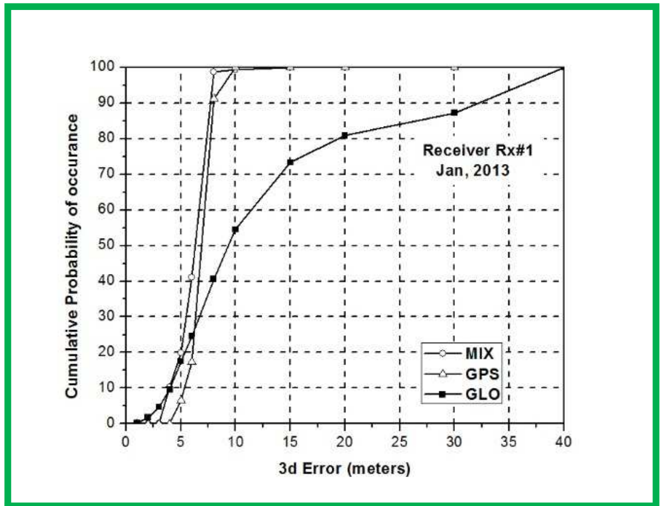
Longitude error ΔLo (in meters)= $(LO_i - LO_0)$ x 1852 x cos (L_0) (2)

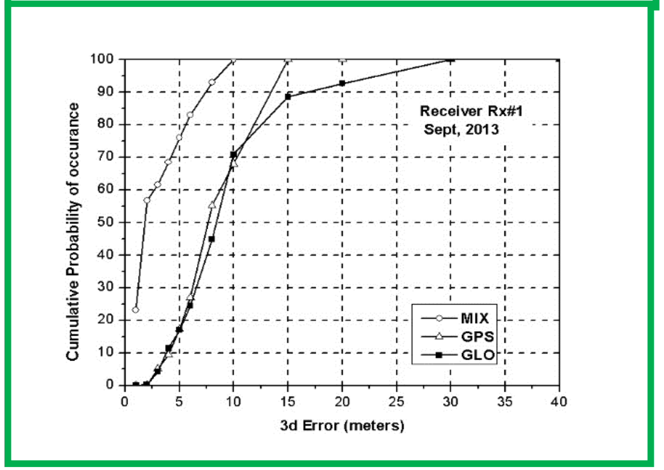
$$Error_{2d} = \sqrt{\Delta Lo^2 + \Delta La^2} \qquad (3)$$

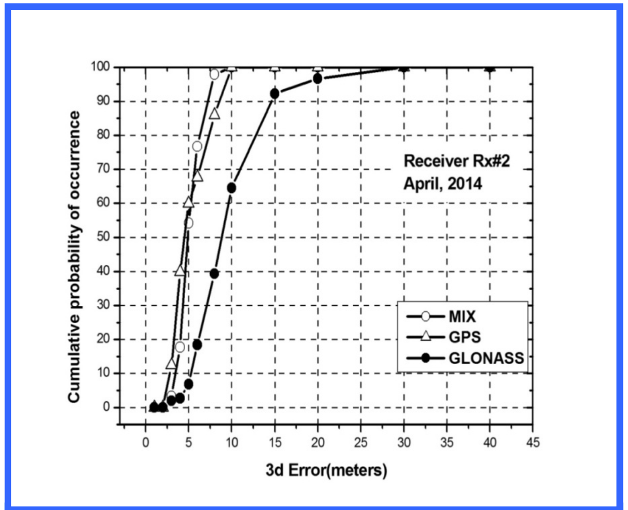
$$Error_{3d} = \sqrt{\Delta h^2 + \Delta Lo^2 + \Delta La^2} \qquad (4)$$

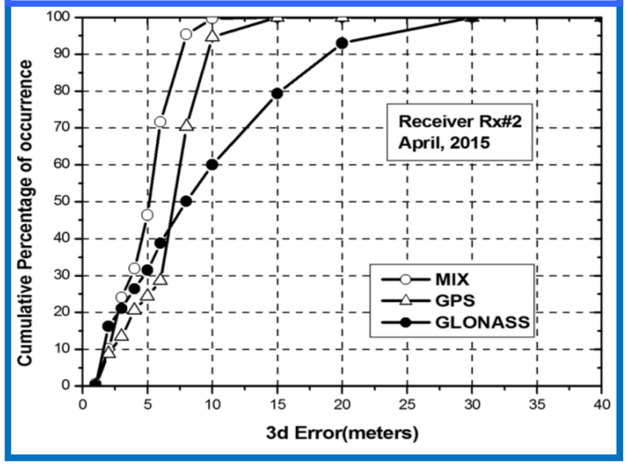
where, **L_0, and LO_0 are reference Latitude and Longitude of antenna**.
L_i and LO_i are instantaneous position solutions
***Δh is* Instantaneous height error in meters**

GLONASS contribution in hybrid operation





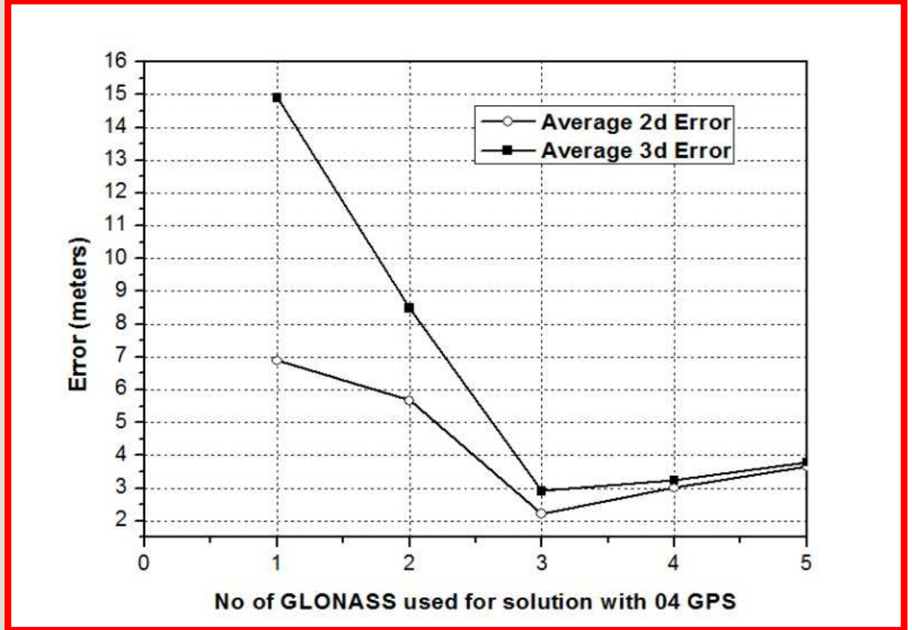


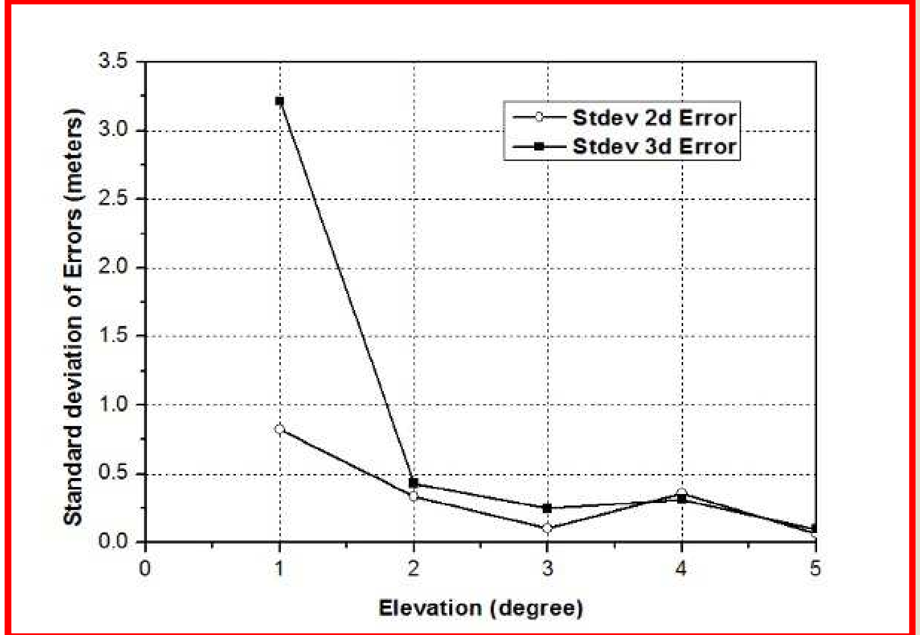


3d errors (Receiver GeoS-1M) **3d errors (Receiver Javad DELTA G3T)**

- GLONASS only mode shows worse solution accuracy than GPS.
- GLONASS strongly helps MIX operation providing best accuracy.

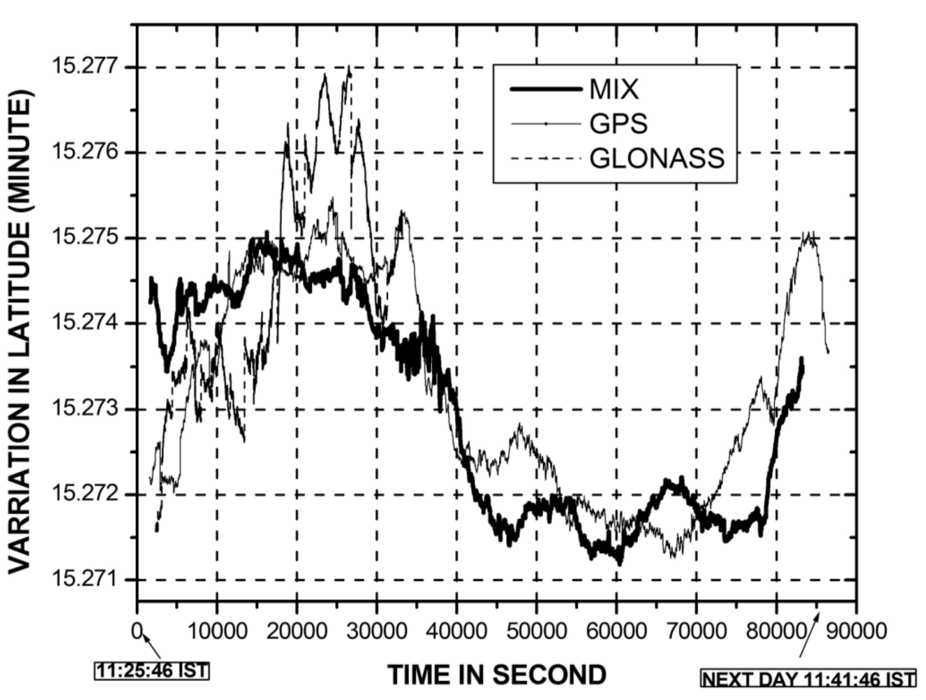
GLONASS contribution with 04 GPS (27/05/2014: Javad DELTA G3T)

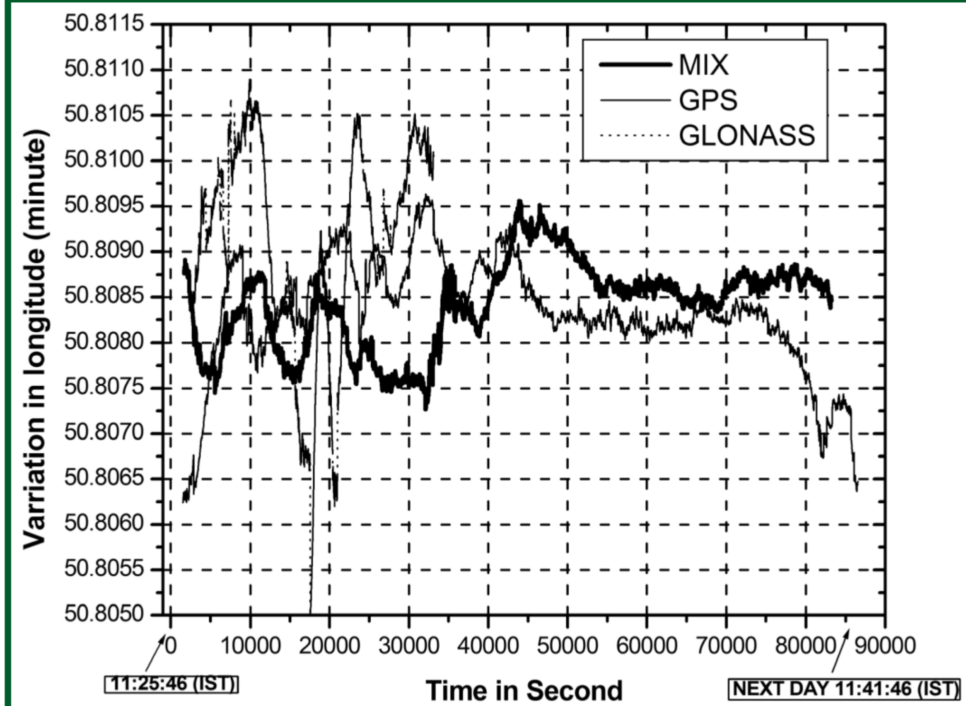




- Number of GLONASS satellites are increased one by one along with 04 GPS satellites with modest geometry for solution.
- 10-15 minutes data @ 1Hz are collected for each case.
- Increasing GLONASS shows increasing solution accuracy.

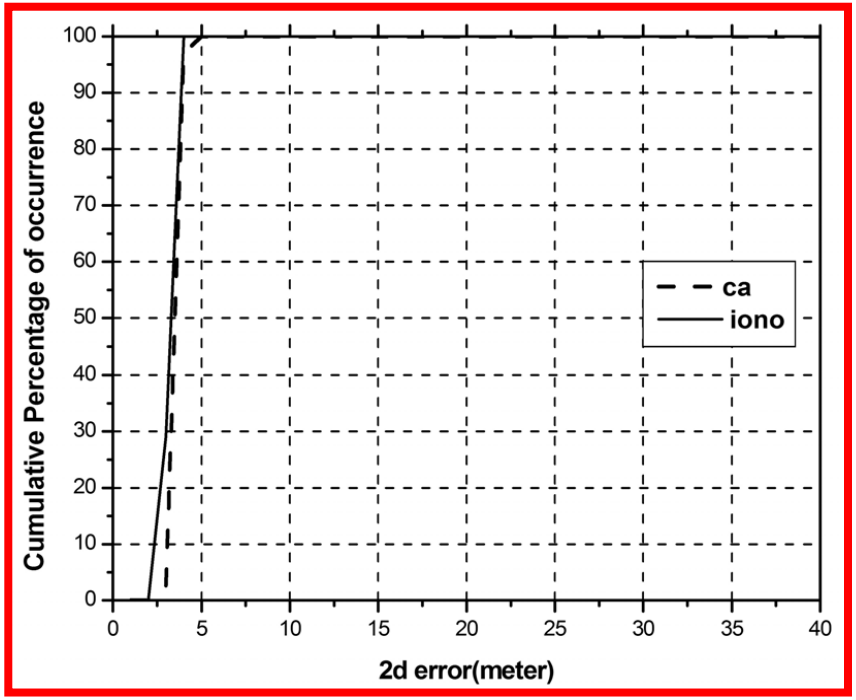
Co-ordinate variation over the day

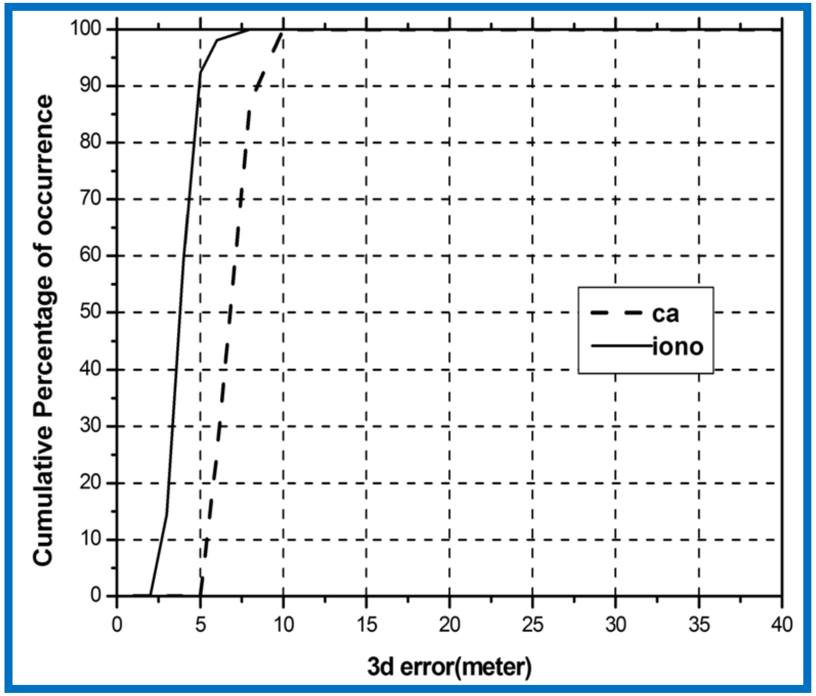




- Latitude variations are high than longitude variations.
- Variation in Latitude and Longitude are steady throughout a day in MIXED mode; while in GPS and GLONASS stand-alone mode of operation fluctuations are high.

Single and dual frequency operation comparison (Javad DELTA G3T)





Cumulative Percentage of occurrence of 2-d Error (For 30 min duration, MIXED mode)	Cumulative Percentage of occurrence of 3-d Error (For 30 min duration, MIXED mode)

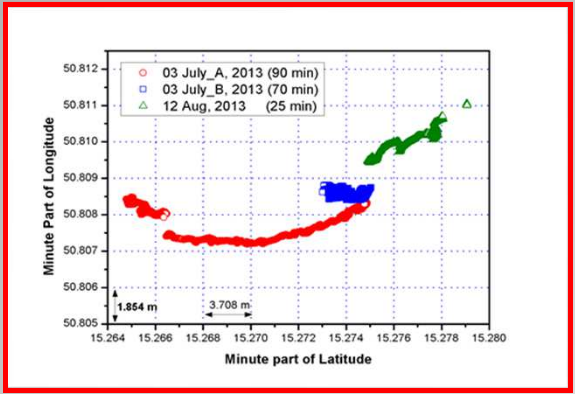
Minimum Achievable solution Accuracy

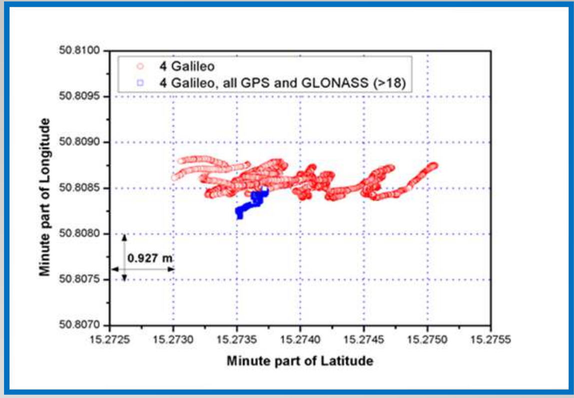
Error values lie below for 100% of cases in MIXED mode (in meter)		
Receivers used	Geos-1M	Javad DELTA G3T
2-d	15	10
3-d	20	10

Low cost low to medium level accuracy can be achieved using NMEA data in GPS-GLONASS hybrid mode without any post processing.

GALILEO- stand alone and integrated solutions

- Study initiated with GALILEO to enrich the potentiality of multi-GNSS
- 4 GALILEO was observed and used for position solutions from India in 3rd July, 2013





- **G=Galileo, P=GPS, L=GLONASS satellites; 1/2/3/4 = No of satellites used for a constellation, A=all satellites in a constellation; σ denotes standard deviation of observation.**

Constell-ation* used	No of Samples	Variation of (mt)						Mean PDOP	Remarks GPS/GLO sats)
		Latitude		Longitude		Altitude			
		σ	Max	σ	Max	σ	Max		
1G AP AL	3524	0.21	1.04	1.20	4.20	1.45	5.06	1.33	P=11; L=6
1G AP AL	2586	0.50	2.04	0.80	2.81	0.57	2.67	1.27	P=9;L=6
2G AP AL	4082	0.40	2.43	0.39	1.85	2.35	9.53	1.05	P=11;L=7
3G AP AL	1979	0.46	2.99	0.90	2.54	0.67	3.18	1.08	P=10; L=7
4G AP AL	739	0.09	0.41	0.11	0.58	0.26	0.82	1.06	P+L>18

GALILEO+GPS+GLONASS solutions

- **Increase in active GALILEO values along with GPS-GLONASS reduced the error values and the PDOP values as well**

Benefits of Multi-GNSS

- MIXED mode provides advantages for redundancy, system independence and more signals in space to use.

- Low cost NMEA data can provide moderate solution accuracy in MIXED mode without any post-processing.

- Position solution affected by atmospheric variations possibly be mitigated using multi-mode.

- MIXED mode proved its reliability despite of spatial, temporal and electronic variations.

Challenges

- For efficient utilization of multi-GNSS, compatibility and interoperability between individual GNSS components are big issues while they are used in tandem.

- A more robust and efficient algorithm appropriate for Indian subcontinent would definitely improve the benefits of GPS-GLONASS hybrid operation.

- GLONASS when introduced one by one (<04) strongly helps improving solution when incorporated along with 04 GPS.

THANK YOU