Importance of GNSS CORS in the Perspectives of Sagarmatha Height Measurement

Workshop on Sagarmatha (Mt. Everest) Height Measurement Project (SHMP)

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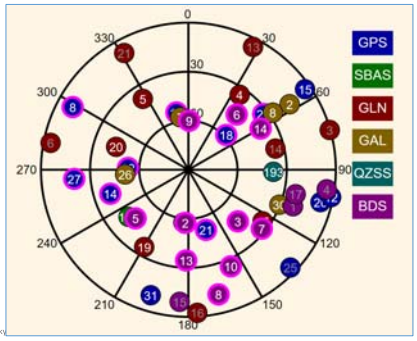
What is GNSS?

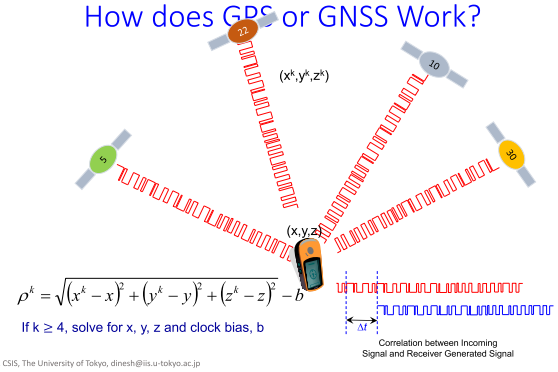
Global Navigation Satellite System (GNSS) is the standard generic term for all navigation satellites systems like GPS, GLONASS, GALILEO, BeiDou, QZSS & IRNSS

- Global Constellation
  - GPS USA
  - GLONASS, Russia
  - Galileo, Europe
  - BeiDou (COMPASS), China
- Regional Constellation
  - QZSS (MICHIBIKI), Japan
  - IRNSS (NAVIC), India
- Satellite Based Augmentation System (SBAS)
  - WAAS, USA
  - MSAS, Japan
  - EGNOS, Europe
  - GAGAN, India
  - SDCM, Russia

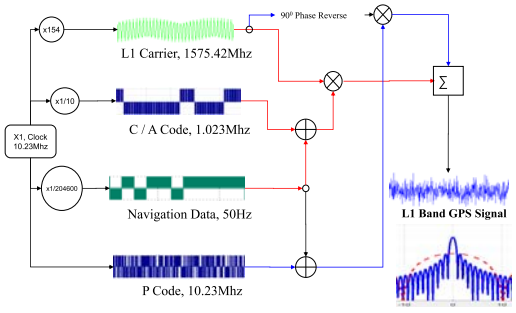
GNSS Visible Satellites at Nagarkot Station, 8th Sep 2017



How does GPS or GNSS Work?

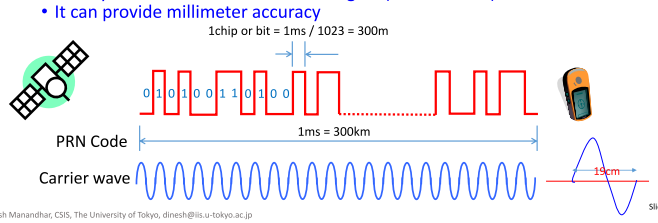


GPS Signal Structure



Code Phase and Carrier phase

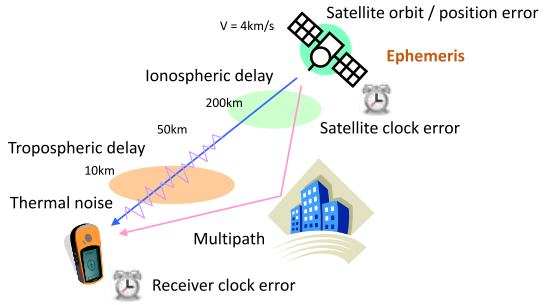
- PRN Code repeats every 1ms
  - It corresponds 300 km in distance at the speed of light
  - Code-phase (Pseudorange) accuracy is about 1m
- Carrier-phase repeats every cycle
  - One cycle is about 19cm for GPS L1 signal (1575.42MHz)
  - It can provide millimeter accuracy



QZSS Satellites & Signal Types

Signal Name	QZS-1 Block IQ (QZO) 1	QZS-2 to QZS-4 Block IIQ (QZO) 2	Block IIG (GEO) 1	Transmission service	Center Frequency MHz
L1C/A	◎	◎	◎	Satellite positioning service	1575.42
L1C	◎	◎	◎	Satellite positioning service	
L1SAIF	◎			Sub-meter Level Augmentation Service (SLAS) / Disaster and Crisis Management	
L1S		◎	◎		
L1Sb	-	-	◎	SBAS Transmission Service from around 2020	
L2C	◎	◎	◎	Satellite positioning service	1227.60
L5	◎	◎	◎	Satellite positioning service	1176.45
L5S	-	◎	◎	Positioning Technology Verification Service	
LEX	◎			MADOCA	1278.75
L6		◎	◎	Centimeter Level Augmentation Service (CLAS)	
S-band	-	-	◎	QZSS Safety Service / SAR (Search-And-Rescue)	2GHz

Error sources



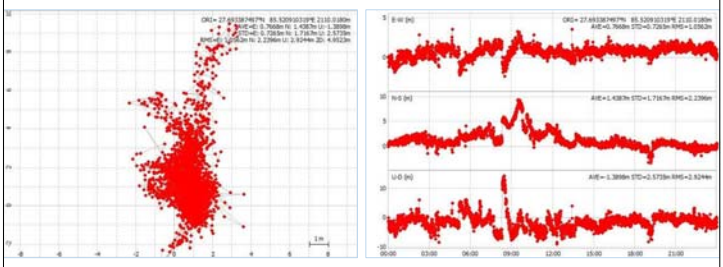
Errors in GPS Observation (L1C/A Signal)

Error Sources	Approx. One-Sigma Error , m: Single Observation	Approx. One-Sigma Error , m: Differential Correction	Comments
Satellite Orbit	2.1	0.0	Common errors are removed
Satellite Clock	2.1	0.0	
Ionosphere Error	4.0	0.4	Common errors are reduced
Troposphere Error	0.7	0.2	
Multipath	1.4	1.4	
Receiver Circuits	0.5	0.5	

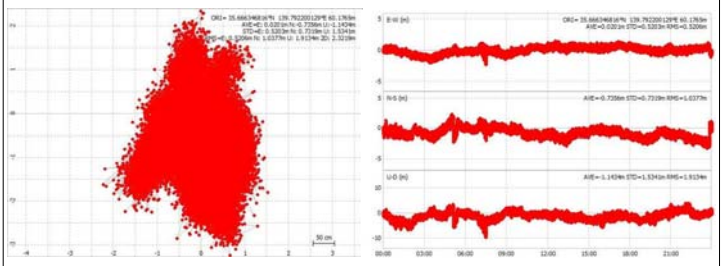
If we can remove common errors, position accuracy can be improved

Common errors are: <u>Satellite Orbit Errors, Clock Errors and Atmospheric Errors (within few km)</u>

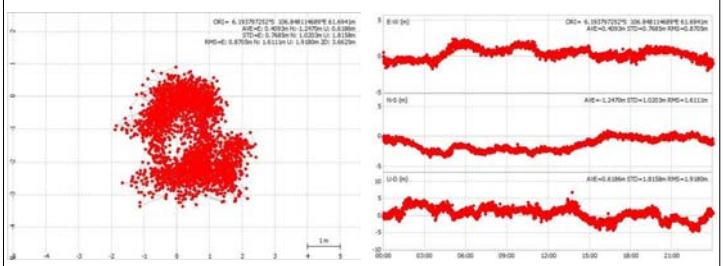
Single Point Position, Nagarkot Station



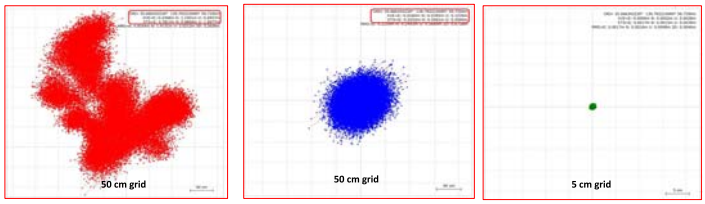
Single Point Position, Tokyo Station



Single Point Position, Jakarta Station



How Precise is GPS Position?
How to get Millimeter Level Accuracy?

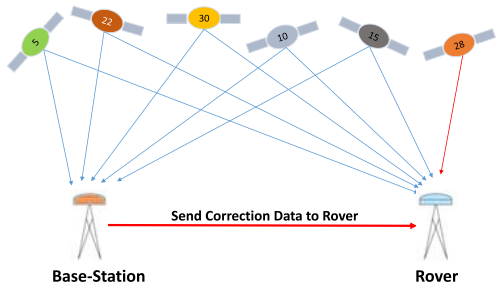


SPP (Single Point Position) | DGPS (Differential GPS) | RTK (Real Time Kinematic)

Survey Methods

- Single Point Positioning (SPP)
- Differential Observation
  - A Reference or Base Station is Required
  - Code-based Observation : DGPS Survey
  - Carrier-based Observation : RTK Survey
- PPP (Precise Point Positioning)
  - MADOCA : PPP
  - CLAS : PPP-AR

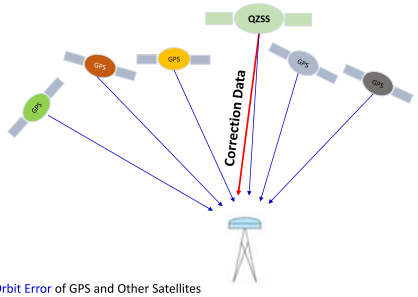
Principle of Differential Correction
Remove Common Errors



Base-Station
Antenna is installed at a known-position

Rover

Principle of QZSS MADOCA Service
Provides Centimeter Level Accuracy



Correction Data:
Satellite Orbit Error of GPS and Other Satellites
Satellite Clock Error of GPS and Other Satellites

Rover

What is CORS?

- CORS: Continuous Observation Reference Station
  - Also, called GNSS Permanent Base-Stations
  - Observes GNSS Signals Continuously
- Many CORS stations provide data for Global use
  - IGS
  - USGS
  - JAXA, MGA Stations
  - The University of Tokyo Stations in Asia and Africa
  - Many others.....

Why do we need CORS?

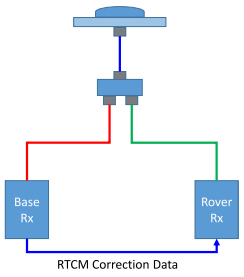
- To provide millimeter level accuracy for GNSS survey by
  - Removing all common errors
    - Satellite Orbit Error, Satellite Clock Error
  - Minimize Atmospheric Errors
    - Ionospheric Errors, Tropospheric Errors
  - Analyze the receiver's errors
    - Clock Error, Antenna Phase Center Variation, Impact of Temperature on Receiver Clock
- Serve as Ground Control Points
  - Provide RTK Services
- Tectonic Movement Analysis
  - Nepal is in Earthquake Prone Zone

GNSS Receiver's Performance Analysis

- Necessary to analyze the performance of the GNSS Receiver including GNSS Antenna
  - To identify the impact of receiver noise on position computation
  - Antenna Phase Center Variation shall be known or calibrated
- Standard procedures for survey, analysis and calibration shall be decided

Zero Base-Length Test

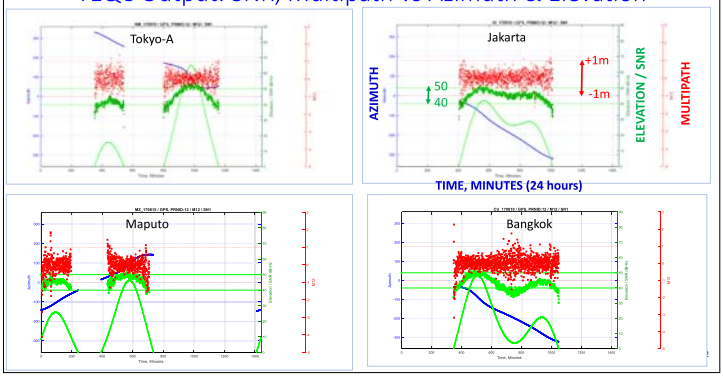
- Satellite Related Errors
  - Orbit and Clock
- Atmospheric Errors
  - Ionosphere and Troposphere
- Multipath Effects
- Antenna Effects
- Receiver Clock Errors Remain



Receiver Signal Quality Monitoring

How Good is your GNSS Receiver and Antenna?

TEQC Output: SNR, Multipath vs Azimuth & Elevation



TEQC Output for Mean SNR Values

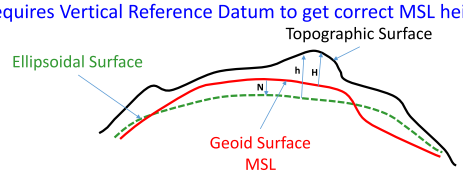
	GPS Signal				GALILEO Signal
ID	SN1	SN2	SN5	SN7	SN8
Jakarta	43.62	34.39	45.24	44.17	47.56
Bangkok	43.79	35.04	45.34	43.54	47.43
Manila	44.20	34.81	46.37	45.47	51.32
Tokyo-A	43.57	34.36	~~NA~~	~~NA~~	~~NA~~
Tokyo-B	44.75	36.25	46.53	44.63	48.34
Maputo	45.34	36.84	47.19	45.31	49.03

TEQC Output for Mean MP Values

	GPS Signal				GALILEO Signal			
ID	mp 12	mp 21	mp 15	mp 51	mp 17	mp 71	mp 18	mp 81
Jakarta	0.37	0.45	0.33	0.33	0.84	0.89	0.86	0.83
Bangkok	0.30	0.33	0.28	0.29	0.89	0.95	0.90	0.88
Manila	0.52	0.61	0.37	0.57	0.69	0.85	0.71	0.66
Tokyo-A	0.32	0.47	NA	NA	NA	NA	NA	NA
Tokyo-B	0.39	0.43	0.25	0.33	0.79	0.86	0.80	0.80
Maputo	0.49	0.44	0.32	0.36	0.49	0.57	0.50	0.42

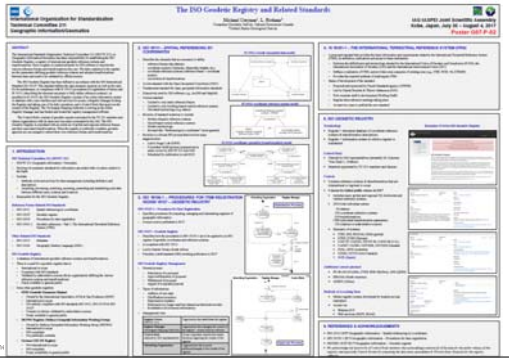
Coordinate System, Geiod Model, Reference Frame etc

- GPS provides coordinates based on WGS-84
  - Thus, the height from GPS is Ellipsoidal height, not MSL height
  - It requires Vertical Reference Datum to get correct MSL height

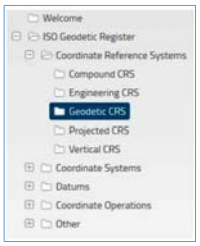


Topographic Height (H) = Ellipsoidal Height (h) - Geoid Height (N)

ISO Geodetic Registry and Related Standards



ISO Geodetic Registry



Item class group	Contained item classes
Coordinate Reference Systems	• Engineering CRS • Geodetic CRS • Projected CRS
Coordinate Systems	• Cartesian Coordinate System • Ellipsoidal Coordinate System • Spherical Coordinate System • Vertical Coordinate System
Datums	• Engineering Datum • Geodetic Datum • Vertical Datum
Coordinate Operations	• Concatenated Operation • Conversion • Transformation
Other	• Coordinate System Axis • Ellipsoid • Operation Method • Operation Parameter • Prime Meridian • Unit of Measurement

Recommendations

- Establish Permanent GNSS Stations (CORS)
  - Near Base-camp
  - Other Reference Control Points
- GNSS Survey on all Level Points
- Selection of GNSS Receiver
  - Considering Harsh Environment and Extremely Difficult Terrain
  - Built-in Battery pack, Ethernet/NTRIP server, BT link, One button operation
  - Abrupt change in temperature
  - In the case of GLONASS, ICB (Inter-channel bias) calibration capability
- Selection of Antenna
  - It shall have measured phase center and phase center variation data
  - Multipath rejection capability
- Human Resource Development
  - Training, Education and Workshops etc for Survey Department and other related organization

Reference Documents

UN-Nepal Workshop on GNSS

- Organized by Survey Dept. of Nepal and UNOOSA/ICG
- About 150 participant from 32 different countries
- Full Five days workshop including ICG's IDM WG Meetings

Seminar at NIMT, Thailand

3nd Seminar in AUG – 2017, About 100 Participants

Demonstration of GPS Spoofing

NIMT: National Institute of Metrology