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DETERMINATION OF OPTIMAL SITE LOCATION FOR CONTINUOUSLY OPERATED REFERENCE STATION (CORS) AND IT'S VALIDATION WITH CORS STATION QUALITY INDEX (CSQI)

Mr Deepak KUMAR[1] & Mr Neeraj GURJAR[2], India

[1&2] Survey of India, India [deepak.soi@gov.in, neeraj.gurjar.soi@gov.in]

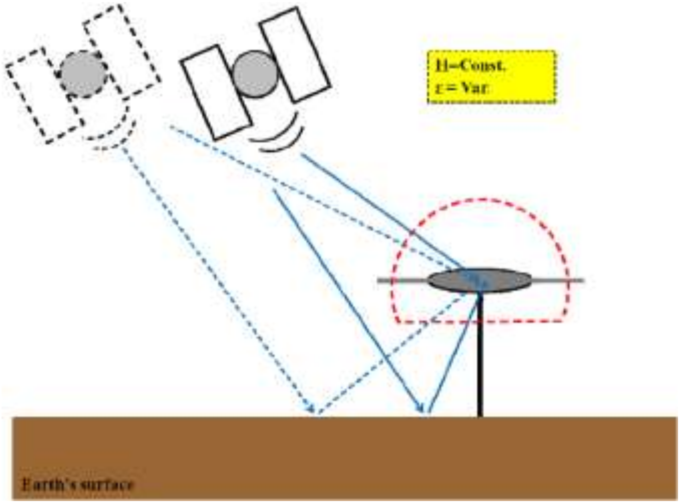
http://www.surveyofindia.gov.in/

Objective of the study

- The optimal positioning on ground of a GNSS station in a CORS network is crucial for network quality and optimal correction dissemination to rover in field.
- A CORS Station Quality Index (CSQI) is proposed as an explicit indicator of the quality of location for CORS on ground.
- By the proposed approach, relative weightage to each CORS station could be assigned for network solution.
- Using CSQI high-quality GNSS station could be assigned more weightage that will improve the performance of Network Real Time Kinematics (NRTK).

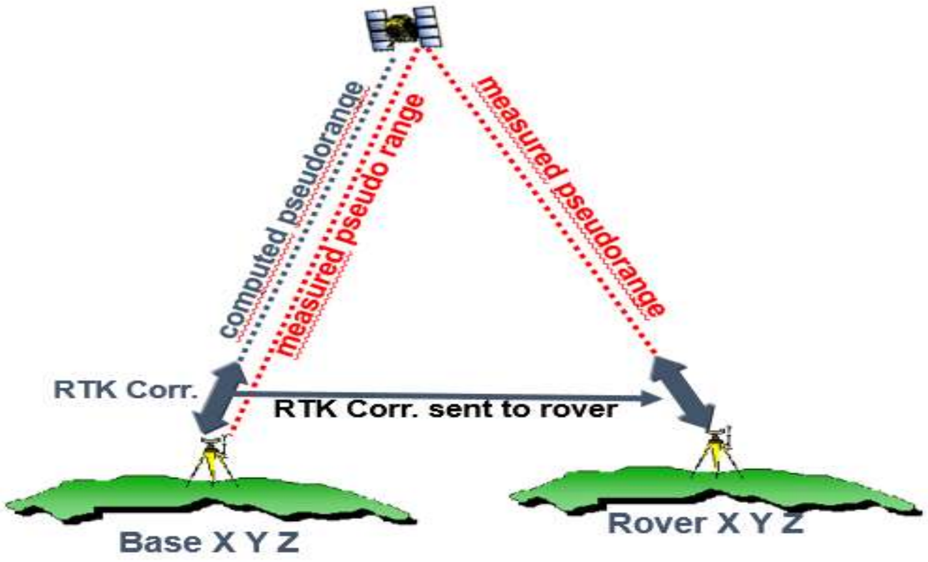
Poor GNSS Data Quality

- GNSS signals loss and attenuation are induced by surrounding structures, multipath sources and vegetation etc. in the real world.
- Raw GPS measurements from these stations are corrupted and consequently may produce erroneous estimates of instantaneous position.
- Hence, these sub-optimal sites have to be provided less weightage in network solution. Which will prevent the transmission of error to the complete network.



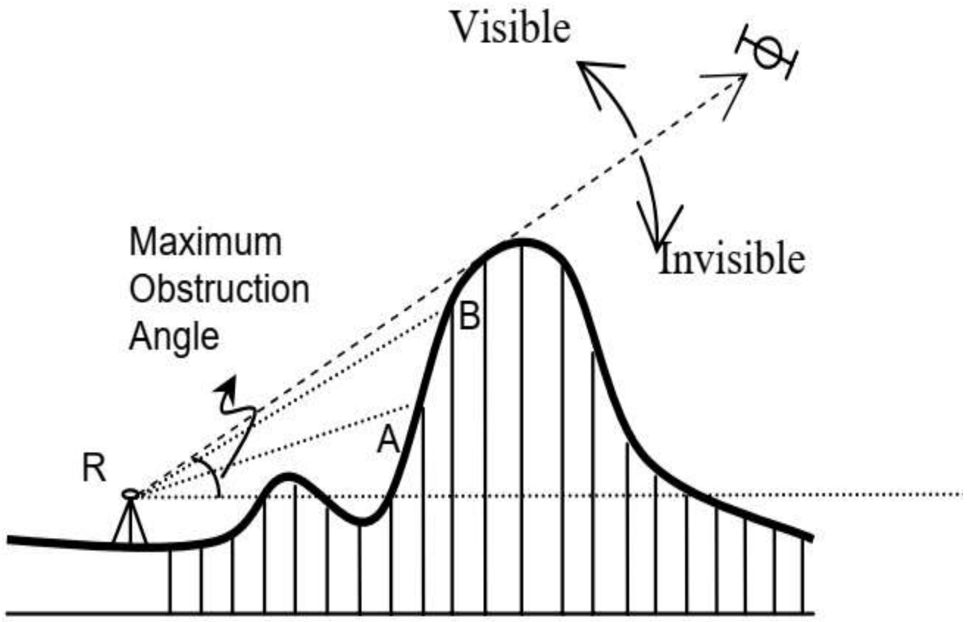
Satellite Visibility Determination

- Satellite visibility at a CORS site is an important criteria for ideal site selection.
- Mutual satellite visibility to Base and Rover is one of the positional accuracy governing factor.
- Actual satellite visibility is highly affected by the terrain variation. In this study Digital Elevation Model (DEM) is used and radial profile of a probable CORS site is analyzed for maximum obstruction angle.

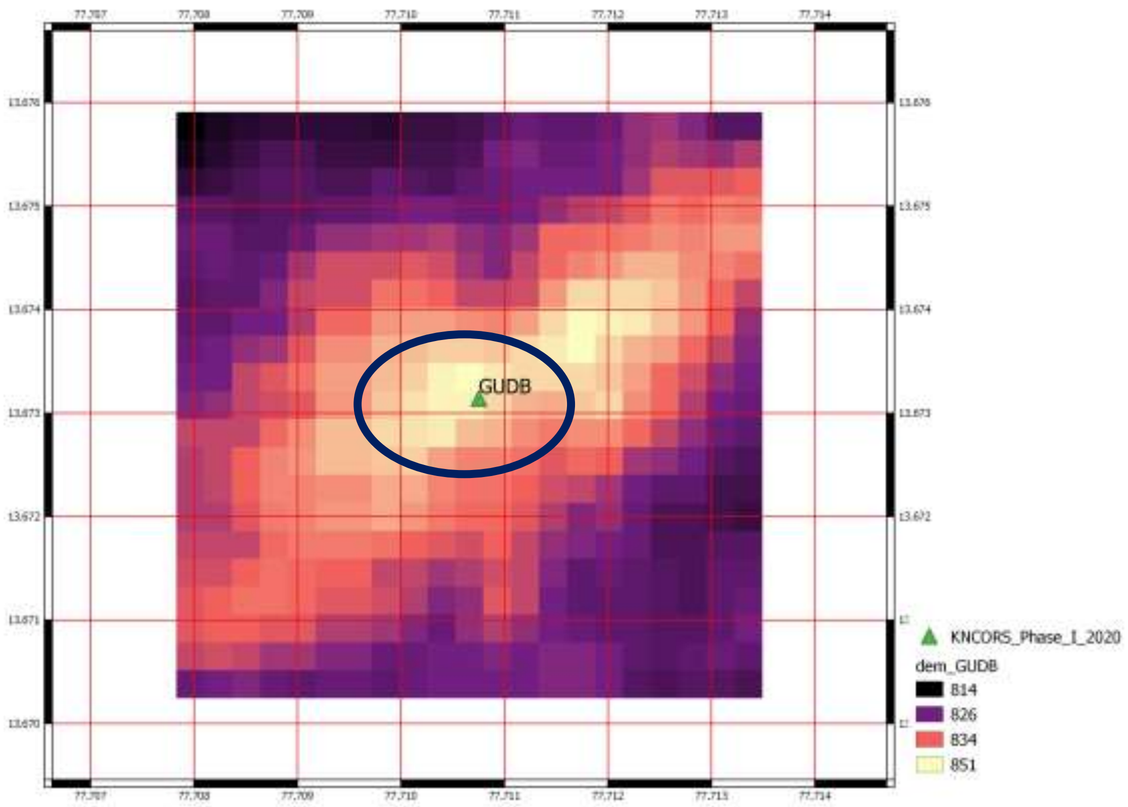


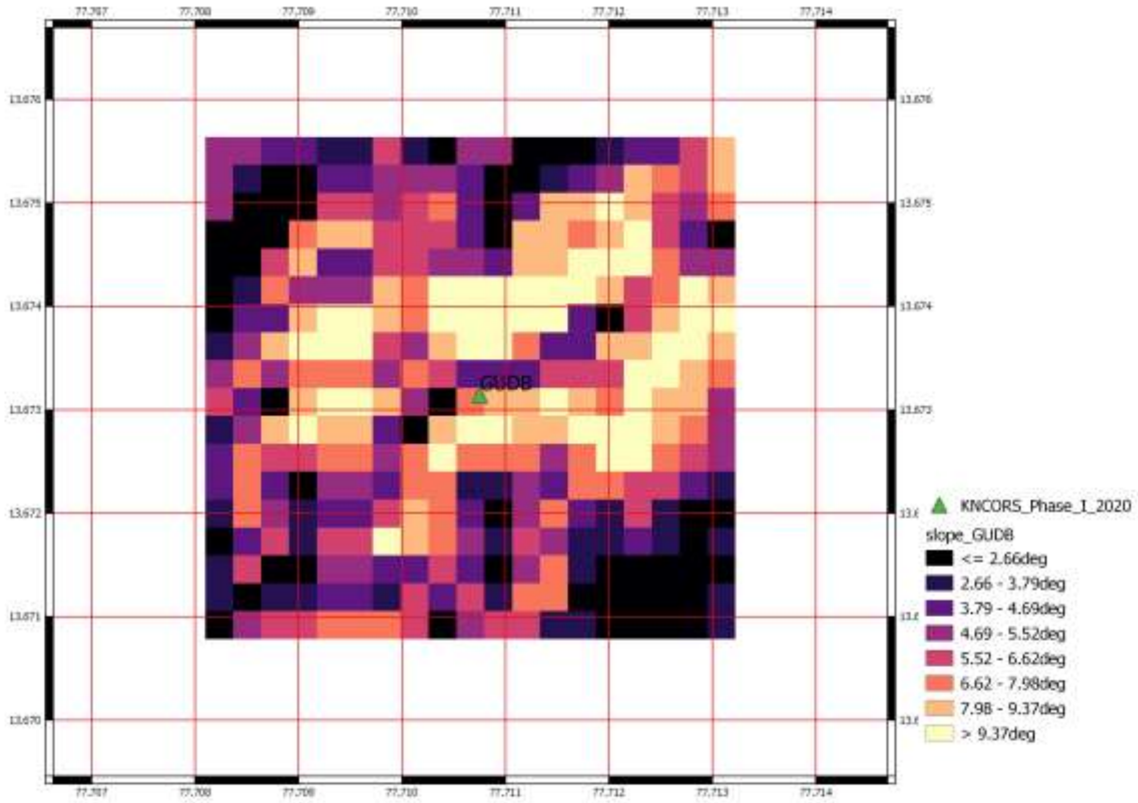
Validation Exercise using DEM

- It’s better to place the CORS at relatively higher ground that will result into smaller slope.
- At the planning stage open-source available DEM dataset could be used.



Validation Exercise using DEM contd.





* The above depicted representation of CORS GUDB is based on the NASA SRTM Digital Elevation 30 m

GNSS Data Quality Measurement Algorithm

The selected approach of GNSS data quality determination in this study is Pre-processing of GNSS data with the TEQC algorithm output (Estey & Meertens, 1999). Some of these outputs were considered in further evaluation:

I. The percentage of observations (% obs) analysis: It's the percentage observed/ recorded of total possible GNSS data, apart from availability and integrity of data this number also points about the stability of receiver signals.

II. Cycle Slips: A cycle slip is a discontinuity in a receiver's phase lock on a satellite's signal. An ideal CORS station should have minimum cycle slips.

GNSS Data Quality Measurement Algorithm contd.

III. Multipath, mp_{12} & mp_{21}: Multipath effect is caused due to reflected satellite signals, which will result into satellite lock loss in extreme cases. Multipath analysis is a good indicator of environmental quality around the station as well as GNSS observation data quality (Xiao, et al., 2020).

$$mp_{12} = P_1 - \left[1 + \frac{2}{\alpha - 1}\right]\varphi_1 + \left[\frac{2}{\alpha - 1}\right]\varphi_2$$

$$mp_{21} = P_2 - \left[\frac{2\alpha}{\alpha - 1}\right]\varphi_1 + \left[\frac{2\alpha}{\alpha - 1} - 1\right]\varphi_2$$

IV. TEQC algorithm was used for quantifying the above three mentioned quality parameters. The TEQC (Translate, Edit, Quality Check, Coordinate) software is freely available tool used to check data quality of GNSS data in the RINEX format.

Hypothesis

We adopted some parts of TEQC algorithms to develop a comprehensive quality indicator for CORS site location.

1. The percentage of observations (% obs),
2. The RMS of multipath on L1 and L2 code measurements (i.e. mp12, mp21), and
3. The number of IOD cycle slips (at elevation >10^0)

CSQI derivation and its validation :

Two expressions for relative weight determination were derived namely for values for which lesser numerical value is preferable and another for which higher numerical value is preferable.

Hypothesis contd.

Expression of weight calculation for parameter *i* where lesser value is better e.g. No of IOD or MP cycle slips, RMS mp12, RMS mp21, RMS Northing, RMS Easting and RMS Height etc.

$$Wt\_ik = 1 - \frac{1}{\left[\left(1 + \frac{[Obs_{ik} - min(Obs_i)] \times N}{[\max(Obs_i) - \min(Obs_i)]}\right)\right]}$$

Expression of weight calculation for parameter j where higher value is better e.g. % of observation.

$$Wt\_jk = 1 - \frac{1}{\left[\left(1 + \frac{[max(Obs_j) - Obs_{jk}] \times N}{\max(Obs_j) - \min(Obs_j)}\right)\right]}$$

Where,

$Wt_{ik} = weight\ of\ k^{th}\ observation\ of\ parameter\ i$

$Obs_{ik} = k^{th}\ observation\ of\ parameter\ i$

$min(Obs_i) = minimum\ of\ all\ observation\ for\ parameter\ i$

$\max(Obs_i) = maximum\ of\ all\ observation\ for\ parameter\ i$

$N = Total\ number\ of\ observation$

$Wt\_jk = weight\ of\ k^{th}\ observation\ of\ parameter\ j$

$Obs_{jk} = k^{th}\ observation\ of\ parameter\ j$

$min(Obs_j) = minimum\ of\ all\ observation\ for\ parameter\ j$

$\max(Obs_j) = maximum\ of\ all\ observation\ for\ parameter\ j$

Hypothesis contd.

Expression for CSQI determined using the earlier mentioned GNSS data quality indicators (1,2,3 & 4) is:

$$CSQI = 1 - \frac{1}{\left[\left(1 + \frac{Wt_1}{Min\,Wt_1}\right) \times \left(1 + \frac{Wt_2}{Min\,Wt_2}\right) \times \left(1 + \frac{Wt_3}{Min\,Wt_3}\right) \times \left(1 + \frac{Wt_4}{Min\,Wt_4}\right)\right]}$$

The above derived CSQI is validated against the Weighted Standard Error Wt_SE derived for the respective CORS stations using the positional errors determined after network solution, using Bernese 5.2 via minimum constrained network solution strategy.

$$Wt\_SE = 1 - \frac{1}{\left[\left(1+\frac{Wt\_A}{Min\,Wt\_A}\right)\times\left(1+\frac{Wt\_B}{Min\,Wt\_B}\right)\times\left(1+\frac{Wt\_C}{Min\,Wt\_C}\right)\right]}$$

Where, A,B & C are RMS Northing, RMS Easting and RMS Height respectively.

Numerical Validation

Observation Set 1: Comparative for observed data (>10 deg) elevation of all the stations (of set 1) on (JD 197)

Station Code	% of Obser-vation (Col 1)	No of IOD or MP cycle slips (at elevation >10^0) (Col 2)	RMS mp12 (in m) (Col 3)	RMS mp21 (in m) (Col 4)	Signal to noise ratio for L1 (Col 5) S1	Signal to noise ratio for L2 (Col 6) S2	Observation /Slip (o/slps) (Col 7)	Wt_1 Weight of CORS site based on Col 1	Wt_2 Weight of CORS site based on Col 2	Wt_3 Weight of CORS site based on Col 3	Wt_4 Weight of CORS site based on Col 4	CSQI
BANG	90	106	0.327447	0.379752	47.04	46.49	224	0.16667	0.41071	0.98390	1.00000	0.99701
GUDB	97	123	0.458411	0.461198	46.38	45.84	207	0.47368	0.31507	0.28125	0.27688	0.98741
KANK	95	109	0.490078	0.432254	46.75	46.12	231	0.31034	0.38983	0.23984	0.37264	0.98674
KOLA	99	73	0.326603	0.417407	46.61	45.86	359	1.00000	1.00000	1.00000	0.45301	0.99922
MADH	93	188	0.584493	0.535679	46.53	46.03	130	0.23077	0.16667	0.16667	0.16667	0.94758

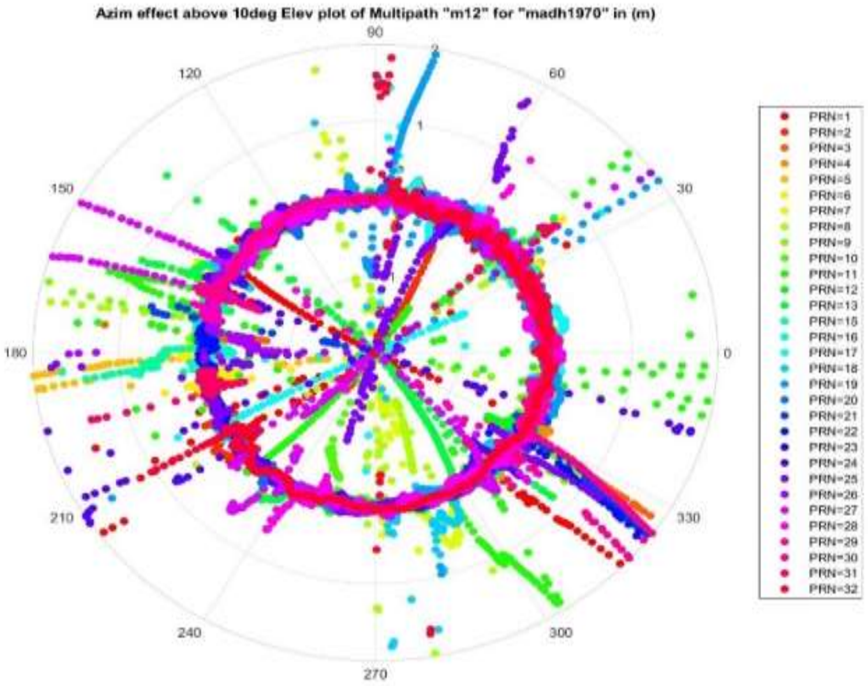
Numerical Validation contd.

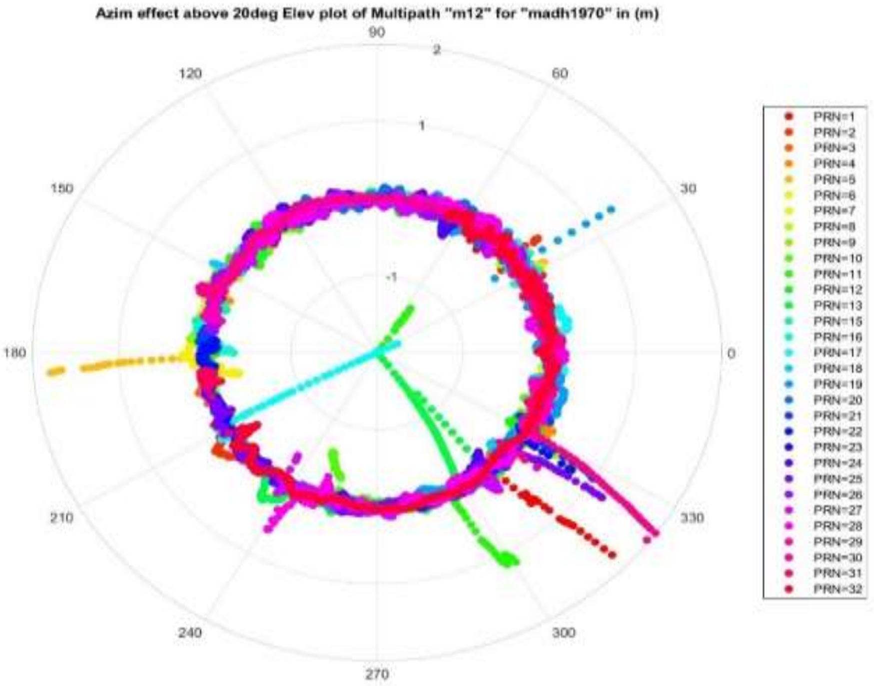
Observation Set 1: Standard error derived from network solution (of set 1) at each CORS location

Station	RMS (Northing) (in m) (Col 1)	RMS (Easting) (in m) (Col 2)	RMS (Height) (in m) (Col 3)	Wt_1 Weight of CORS site based on Col 1	Wt_2 Weight of CORS site based on Col 2	Wt_3 Weight of CORS site based on Col 3	Relative weight in CORS network based on spherical error SE
BANG	0.00041	0.00039	0.00127	0.0909	0.1667	0.1558	0.8750
GUDB	0.00039	0.00037	0.00117	1.0000	0.3750	0.4444	0.9933
KANK	0.0004	0.00038	0.00125	0.1667	0.2308	0.1791	0.9311
KOLA	0.00039	0.00036	0.00114	1.0000	1.0000	1.0000	0.9984
MADH	0.00039	0.00039	0.00126	1.0000	0.1667	0.1667	0.9799

Numerical Validation contd.

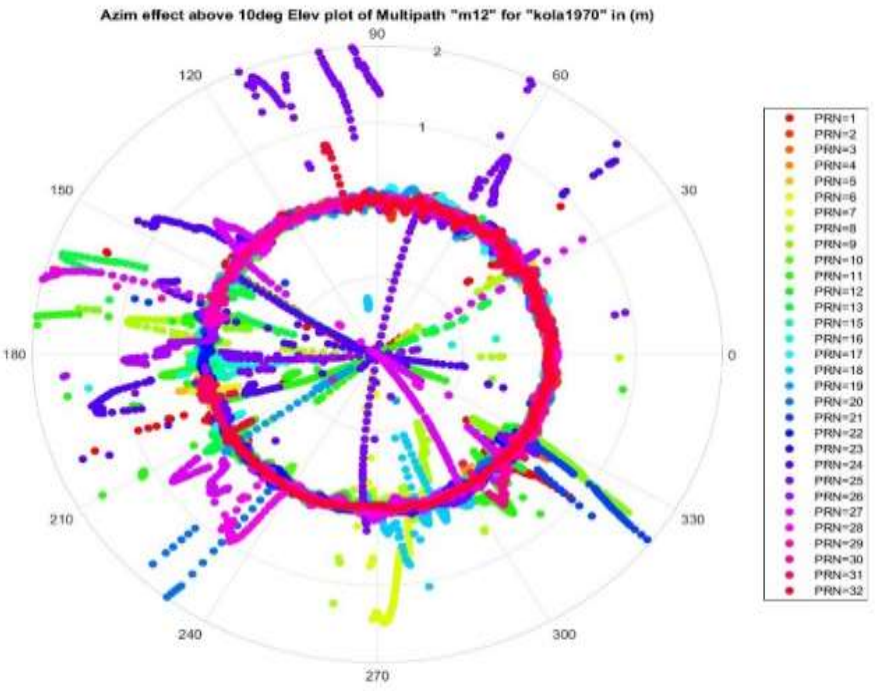
Plot of Azimuth vs. Multipath (m12) for Julian Day 197 at site MADH for all the GPS SVs above 10 and 20 degree elevation respectively.

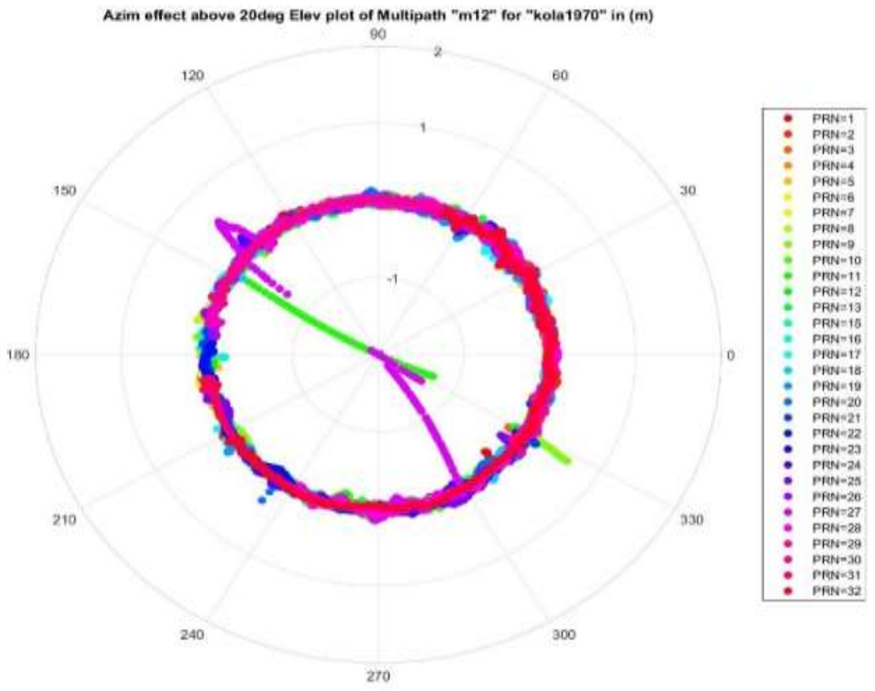




Numerical Validation contd.

Plot of Azimuth vs. Multipath (m12) for Julian Day 197 at site KOLA for all the GPS SVs above 10 and 20 degree elevation respectively.





Numerical Validation contd.

Observation Set 2: Comparative for observed data (>10 deg) elevation of all the stations (of set 2) on (JD 245)

Station Code	% of Obser-vation (Col 1)	No of IOD or MP cycle slips (at elevation >10^0) (Col 2)	RMS mp12 (in m) (Col 3)	RMS mp21 (in m) (Col 4)	Signal to noise ratio for L1 (Col 5) S1	Signal to noise ratio for L2 (Col 6) S2	Observation /Slip (o/slps) (Col 7)	Wt_1 Weight of CORS site based on Col 1	Wt_2 Weight of CORS site based on Col 2	Wt_3 Weight of CORS site based on Col 3	Wt_4 Weight of CORS site based on Col 4	CSQI
DHAN	98	85	0.423	0.438	46.79	46.27	288	0.37500	0.45423	0.33862	0.30091	0.99029
MULC	95	90	0.348	0.365	46.95	46.42	265	0.19355	0.41748	1.00000	0.67577	0.99627
MULS	100	54	0.365	0.346	46.93	46.35	460	1.00000	1.00000	0.69314	1.00000	0.99943
RAJU	94	183	0.54	0.544	46.7	46.24	129	0.16667	0.16667	0.16667	0.16667	0.93750
WADS	98	99	0.45	0.471	46.81	46.22	247	0.37500	0.36441	0.27350	0.24058	0.98504

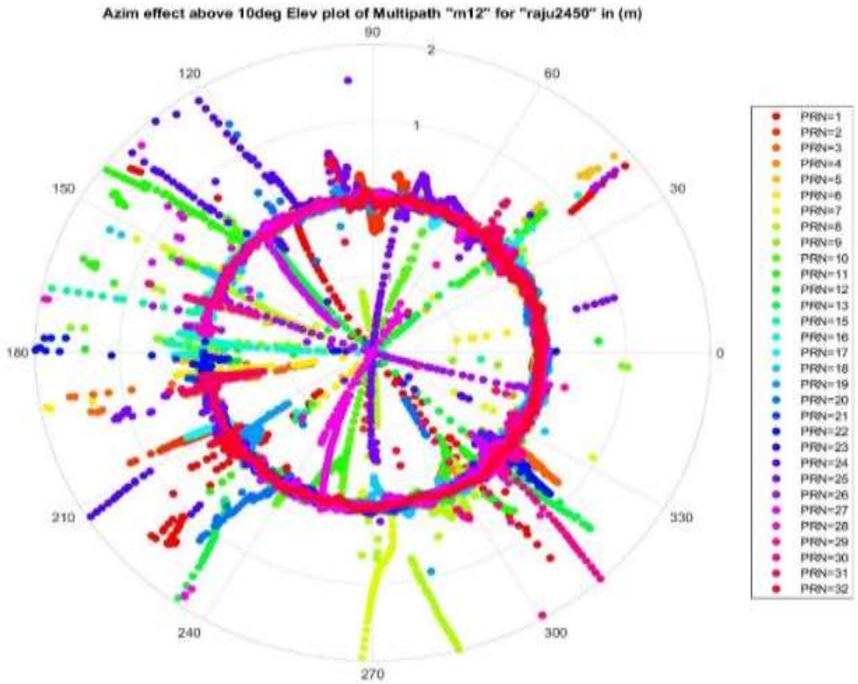
Numerical Validation contd.

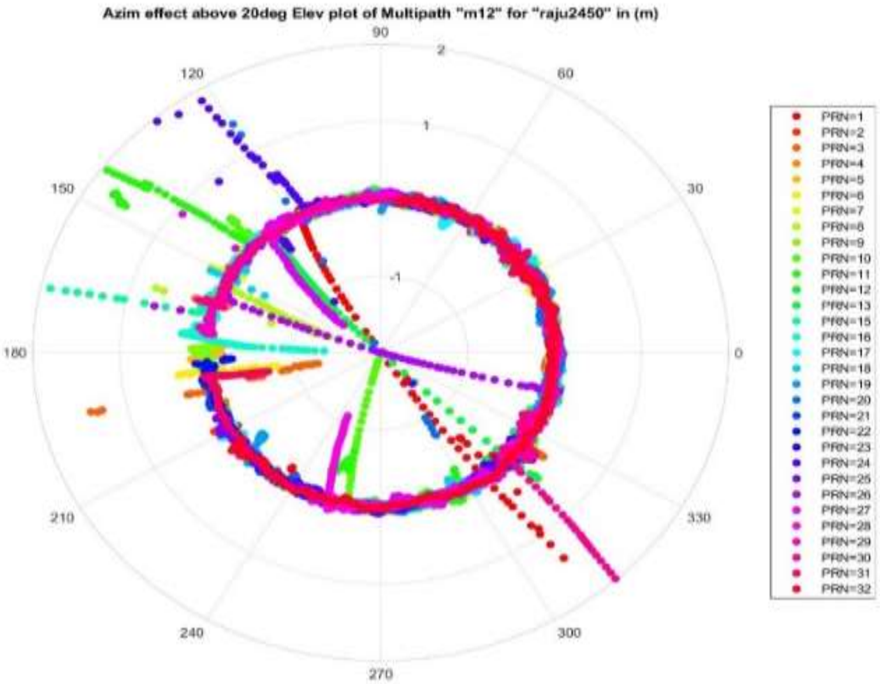
Observation Set 2: Standard error derived from network solution (of set 2) at each CORS location

Station	RMS (Northing) (in m) (Col 1)	RMS (Easting) (in m) (Col 2)	RMS (Height) (in m) (Col 3)	Wt_1 Weight of CORS site based on Col 1	Wt_2 Weight of CORS site based on Col 2	Wt_3 Weight of CORS site based on Col 3	Relative weight in CORS network based on spherical error SE
DHAN	0.00032	0.00036	0.00111	1.0000	0.1250	0.2222	0.9800
MULC	0.00033	0.00036	0.00112	0.1250	0.1250	0.1860	0.8995
MULS	0.00032	0.00035	0.00107	1.0000	1.0000	1.0000	0.9986
RAJU	0.00033	0.00036	0.00115	0.1250	0.1250	0.1250	0.8750
WADS	0.00032	0.00035	0.00108	1.0000	1.0000	0.5333	0.9977

Numerical Validation contd.

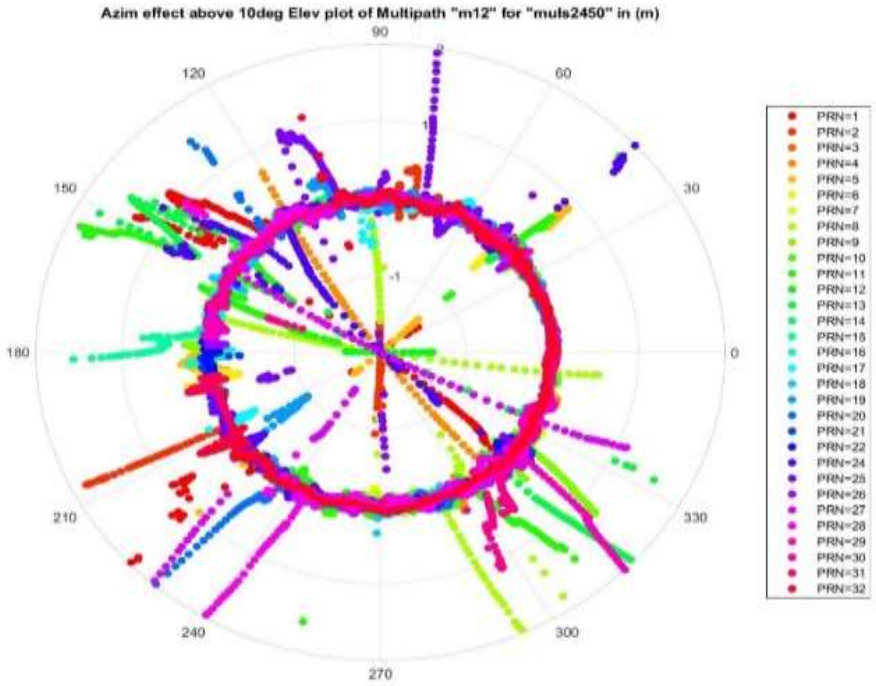
Plot of Azimuth vs. Multipath (m12) for Julian Day 245 at site RAJU for all the GPS SVs above 10 and 20 degree elevation respectively.

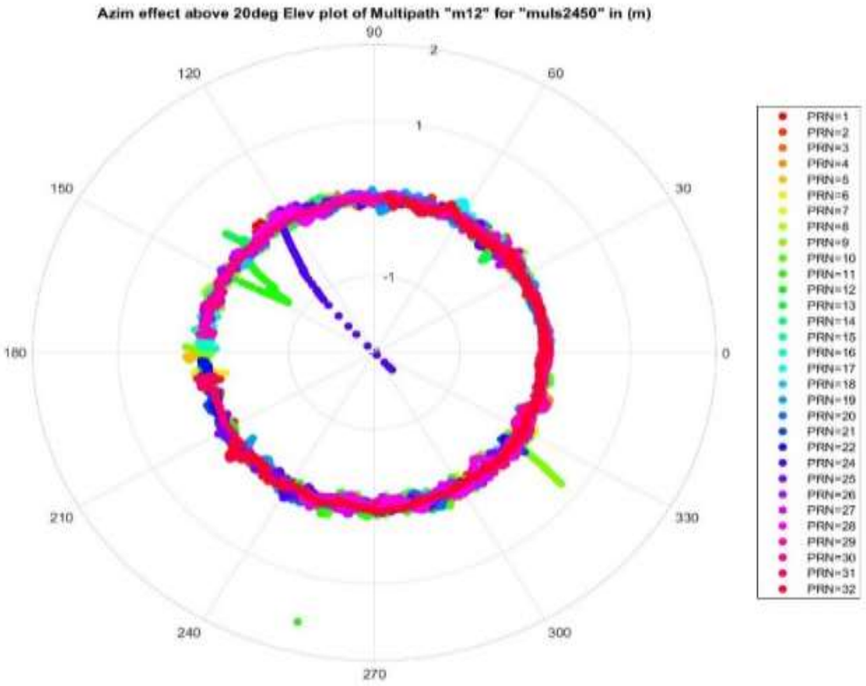




Numerical Validation contd.

Plot of Azimuth vs. Multipath (m12) for Julian Day 245 at site MULS for all the GPS SVs above 10 and 20 degree elevation respectively.





Numerical Validation for Set 1 & 2 combined

Station Code	% of Obser-vation (Col 1)	No of IOD or MP cycle slips (at elevation >10^0) (Col 2)	RMS mp12 (in m) (Col 3)	RMS mp21 (in m) (Col 4)	Signal to noise ratio for L1 (Col 5) S1	Signal to noise ratio for L2 (Col 6) S2	Observation /Slip (o/slps) (Col 7)	Wt_1 Weight of CORS site based on Col 1	Wt_2 Weight of CORS site based on Col 2	Wt_3 Weight of CORS site based on Col 3	Wt_4 Weight of CORS site based on Col 4	CSQI
BANG	90	106	0.327447	0.379752	47.04	46.49	224	0.09091	0.20489	0.96831	0.36973	0.99740
GUDB	97	123	0.458411	0.461198	46.38	45.84	207	0.25000	0.16262	0.16364	0.14667	0.98693
KANK	95	109	0.490078	0.432254	46.75	46.12	231	0.16667	0.19591	0.13626	0.18670	0.98534
KOLA	99	73	0.326603	0.417407	46.61	45.86	359	0.50000	0.41358	1.00000	0.21709	0.99932
MADH	93	188	0.584493	0.535679	46.53	46.03	130	0.12500	0.09091	0.09091	0.09452	0.94839
DHAN	98	85	0.423	0.438	46.79	46.27	288	0.33333	0.30180	0.21106	0.17710	0.99493
MULC	95	90	0.348	0.365	46.95	46.42	265	0.16667	0.27126	0.54654	0.51031	0.99809
MULS	100	54	0.365	0.346	46.93	46.35	460	1.00000	1.00000	0.40179	1.00000	0.99989
RAJU	94	183	0.54	0.544	46.7	46.24	129	0.14286	0.09410	0.10782	0.09091	0.95629
WADS	98	99	0.45	0.471	46.81	46.22	247	0.33333	0.22945	0.17286	0.13674	0.99163

Numerical Validation for Set 1 & 2 combined contd.

Station	RMS (Northing) (in m) (Col 1)	RMS (Easting) (in m) (Col 2)	RMS (Height) (in m) (Col 3)	Wt_A Weight of CORS site based on Col 1	Wt_B Weight of CORS site based on Col 2	Wt_C Weight of CORS site based on Col 3	Relative weight in CORS network based on spherical error SE
BANG	0.00041	0.00039	0.00127	0.0816	0.0909	0.0868	0.8750
GUDB	0.00039	0.00037	0.00117	0.1026	0.1667	0.1597	0.9449
KANK	0.00040	0.00038	0.00125	0.0909	0.1176	0.0955	0.9018
KOLA	0.00039	0.00036	0.00114	0.1026	0.2857	0.2135	0.9691
MADH	0.00039	0.00039	0.00126	0.1026	0.0909	0.0909	0.8918
DHAN	0.00032	0.00036	0.00111	1.0000	0.2857	0.3220	0.9961
MULC	0.00033	0.00036	0.00112	0.4444	0.2857	0.2754	0.9910
MULS	0.00032	0.00035	0.00107	1.0000	1.0000	1.0000	0.9995
RAJU	0.00033	0.00036	0.00115	0.4444	0.2857	0.1919	0.9883
WADS	0.00032	0.00035	0.00108	1.0000	1.0000	0.6552	0.9993

Results and Discussion

- The CORS Station Quality Index, CSQI derived in this paper is an indicator of CORS relative strength in the network under study.
- It's evident from the numerical validations that the CSQI and the corresponding relative standard error for the respective CORS stations are in agreement.
- The positional accuracy derived from the CORS network is dependent upon the individual CORS site and the CSQI discussed in this paper is a quantitative measure of this.
- CSQI values can be used as primary tool when deciding upon an optimal CORS site location. Which will result into an overall better CORS network.
- CSQI could further be used as a tool for defining the priority of individual CORS among a large network for devising a weighting or control strategy.

Thank You!