Ground Subsystem Error Contribution of a Multi-Constellation GBAS Based on a CORS Network in the Vicinity of Airport Areas

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Guideline

I. Overview

II. Methodology

III. Experimental Setup

IV. Results

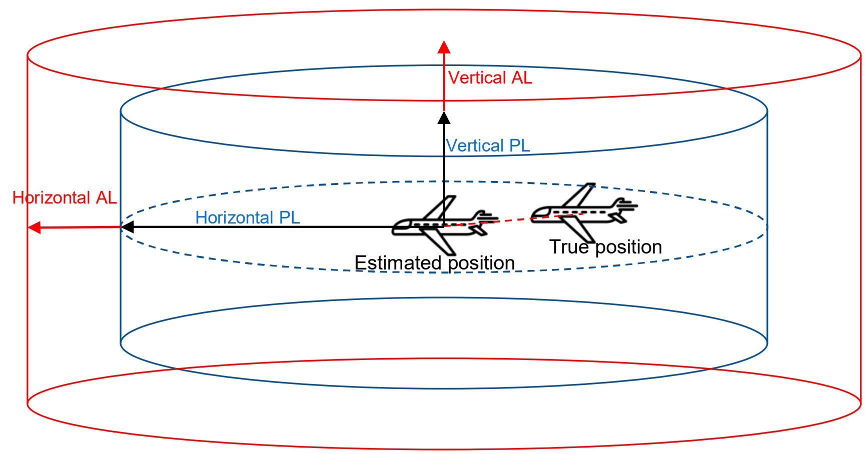
V. Conclusions

I. Overview

i. Ground Based Augmentation System - Protection Levels

- In GBAS, **Protection level** is the maximum error allowed before a navigation system becomes unsafe.

- Protection levels are influenced by various **error sources** represented by the error model σ as:



$$\sigma^2 = \boxed{\sigma^2_{pr\_gnd}} + \sigma^2_{pr\_air} + \sigma^2_{tropo} + \sigma^2_{iono}$$

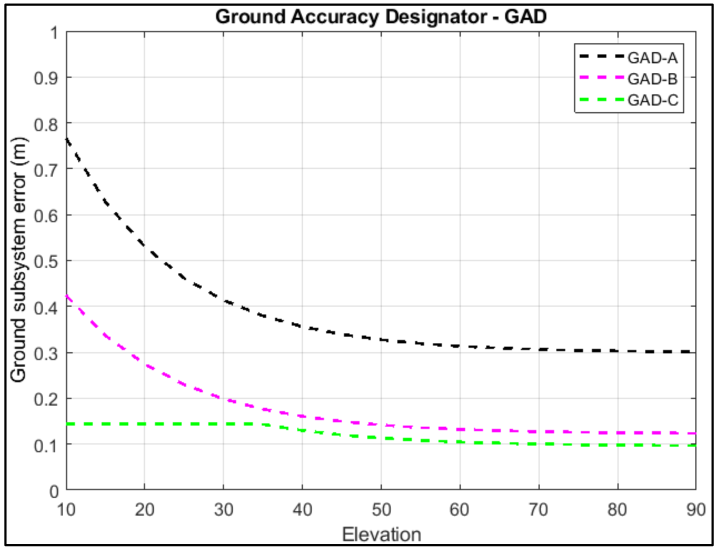
Ground subsystem error | Airborne error | Tropospheric error | Ionospheric error

Ref. RTCA SC-159. (2017). Minimum Operation Performance Standards for GPS Local Area Augmentation System Airborne Equipment. RTCA DO-253D

I. Overview

ii. Protection Levels – Ground subsystem error contribution

- The ground subsystem error σ_{pr_gnd} is the standard deviation of the **pseudorange error** as observed from GBAS Network receivers
- The σ_{pr_gnd} is then evaluated according to the **ground accuracy designator (GAD)** model
- The GAD model uses the **elevation** as a reference and was initially developed for **GPS**

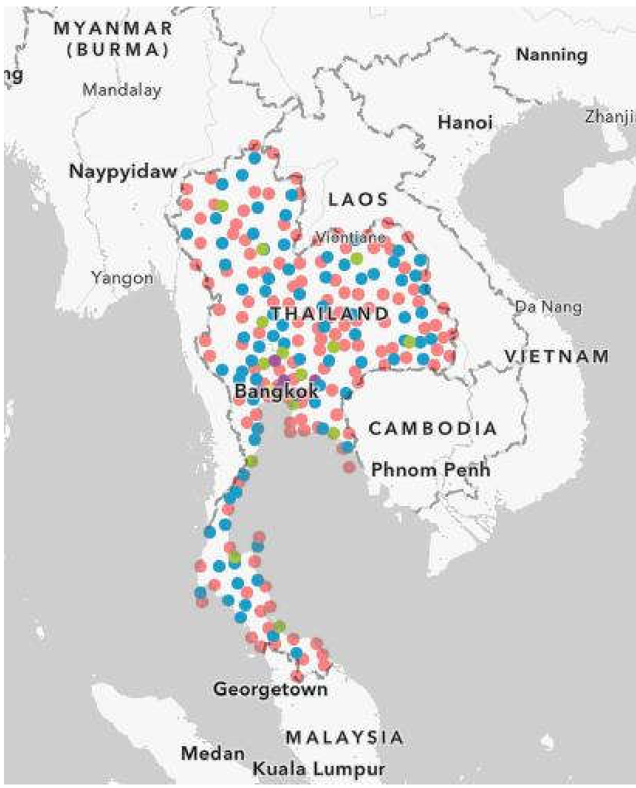


Can we include the **azimuthal** distribution of the ground subsystem error for different constellations?

Ref. RTCA SC-159. (2017). Minimum Operation Performance Standards for GPS Local Area Augmentation System Airborne Equipment. RTCA DO-253D

I. Overview

iii. National CORS Data Center of Thailand (NCDC)



- Diverse types of receivers
- **250** stations across the kingdom
- Multi-stakeholders
- Real time and post processing

Source: https://ncdc.in.th/

I. Overview

iv. Literature review

	CORS with GPS	CORS with BDS	CORS with GPS&BDS	Dedicated Network GPS	Dedicated Network BDS
Ionospheric modeling	Y [1]	Y [2]	Y [3]	Y [6],[7]	Y [5]
1D Ground subsystem error	N	N	N	Y [6],[7]	Y [4]
2D Ground subsystem error	N	N	N	Y [7]	N

1.Lee 2006, Yoshihara 2010

2. Zhang 2020

3.Natras 2023

4.Zhu 2020

5.Wang 2020

6.Silva 2022

7.Budtho 2020, 2023

I. Overview

Question

Can we use a **CORS** Network for a Multi-Constellation **GBAS implementation** in terms of **ground subsystem error** contribution?

Objective

Assess the **feasibility of a GBAS implementation** using a **CORS** Network with **GPS and BDS** signals in terms of ground subsystem error contribution.

II. Methodology

NCDC data

- Geometric Range
- Elevation
- Sat clock errors
- Azimuth

For GPS and BDS

Signal Smoothing

Hatch Filter (100s)

- *MQM*
- *PRC*
- *PRC_csa*
- *PRC_TX*
- *B-Values*

Corrections

σ_B

Calcul.

σ_{pr_gnd}

- *GPS***
- *BDS***

***1D and 2D*

GAD evaluation

II. Methodology

a. 1D Ground subsystem error contribution

$$\sigma_B^2(E) = \frac{1}{N(E)} \sum_{k=1}^{N(E)} (B_k(E) - \overline{B(E)})^2,$$

$$\sigma_{pr\_gnd}(E) = \sqrt{\sigma_B^2(E) * (N(E) - 1)}.$$

$B(E)$: B-values in the elevation range *E*

$N(E)$: is the number of B-values in the elevation range *E*

$\sigma_B(E)$: standard deviation of the B-Values

$\sigma_{pr\_gnd}(E)$: Ground Subsystem error in the elevation range

b. 2D Ground subsystem error contribution

$$\sigma_{pr\_gnd}(E, A) = \sqrt{\sigma_B^2(E, A) * (N(E, A) - 1)}.$$

$N(E, A)$: is the number of B-values in the elevation range *E* and azimuth *A*

$\sigma_B(E, A)$: standard deviation of the B-Values in elevation range *E* and azimuth *A*

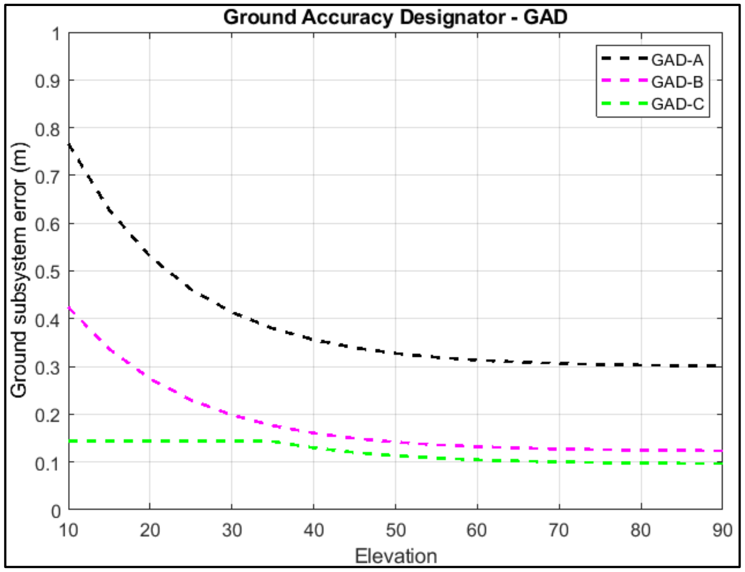
$\sigma_{pr\_gnd}(E,A)$: Ground Subsystem error in the elevation range *E* and azimuth *A*

II. Methodology

c. Ground Accuracy Designator (GAD) model

$$\sigma_{pr\_gnd} \leq \sqrt{\frac{(a_0 + a_1 e^{\theta_i/\theta_0})^2}{M} + (a_2)^2}$$

Ground Accuracy Designator (GAD)	θ_i degrees	a_0 meters	a_1 meters	θ_0 degrees	a_2 meters
A	>5	0.5	1.65	14.3	0.08
B	>5	0.16	1.07	15.5	0.08
C	>35	0.15	0.84	15.5	0.04
	≤35	0.24	0	--	0.04



The GAD model **evaluates** the resulting σ_{pr_gnd}

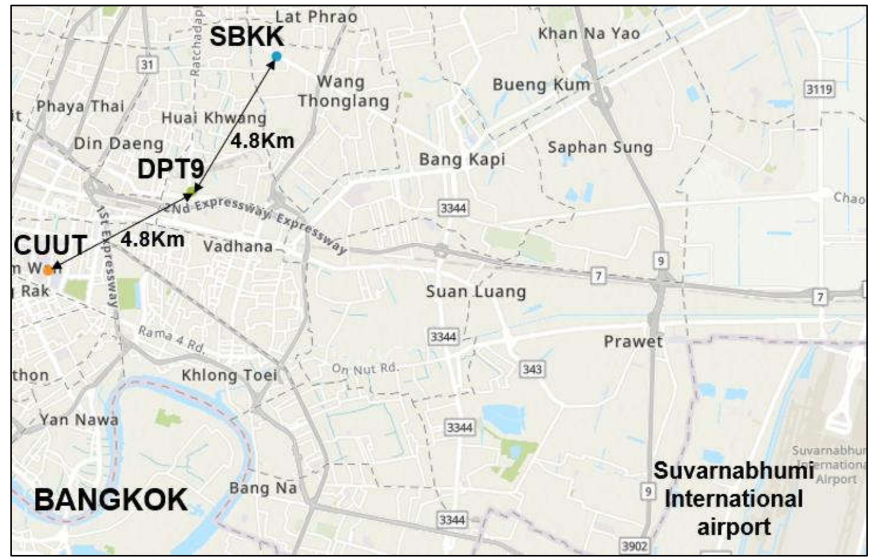
III. Experimental Setup

a. NCDC selected receivers:
   - **SBKK** receiver Leica GR50, choke ring Antenna Leiar20.
   - **DPT9** receiver Leica GR50, choke ring Antenna Leiar10.
   - **CUUT** receiver Trimble NETR9, choke ring Antenna Zephyr.

b. Dates: From January 15th to January 20th 2023.

c. Signals:
   - L1 C/A GPS (1575.42MHz)
   - B1I BDS (1561.098MHz)

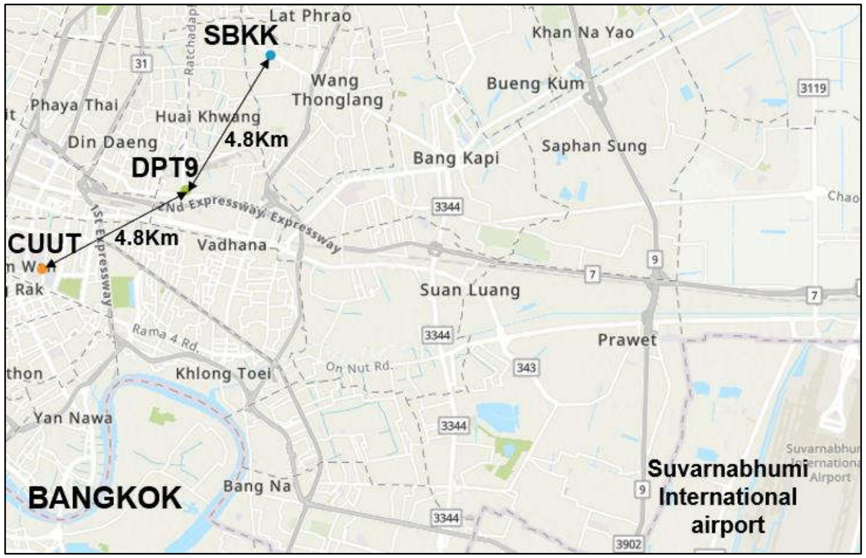
d. Number of available satellites:
   - GPS: 31
   - BDS: 13



III. Experimental Setup

c. Signals

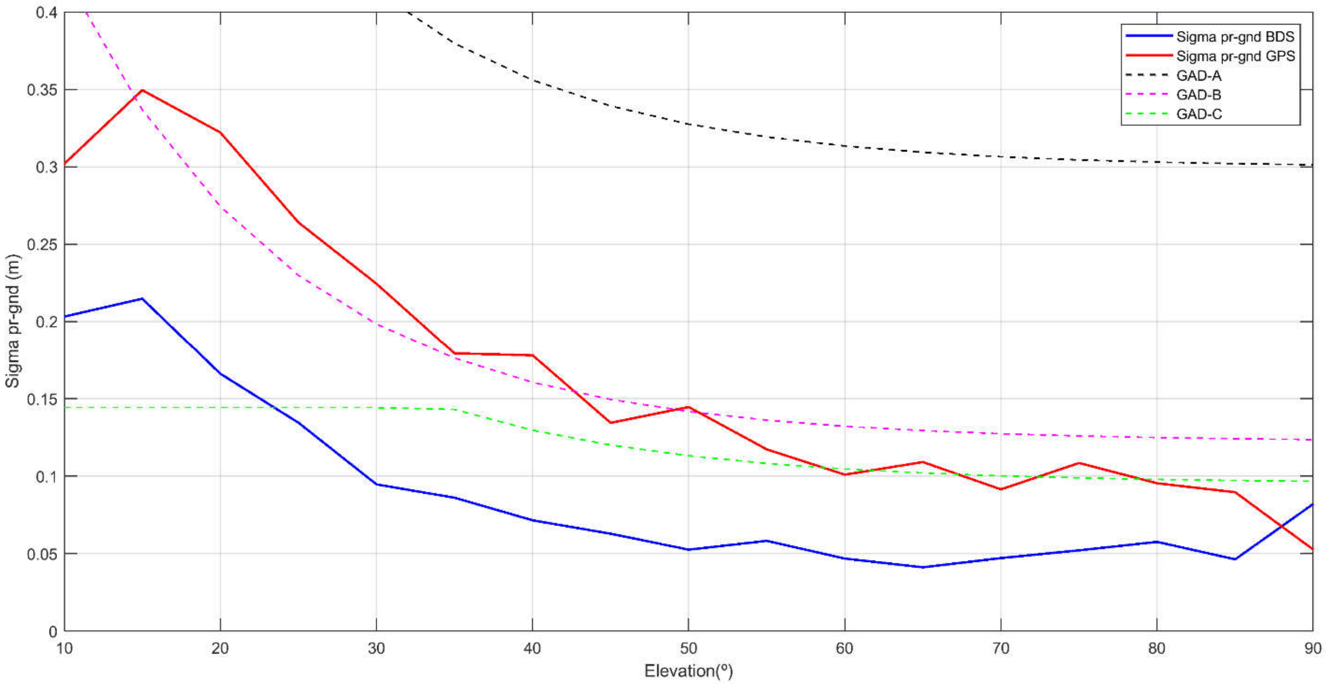
	L1 C/A GPS	B1I BDS
Frequency	1575.42Mhz	1561.098Mhz
modulation	BPSK	BPSK
Encoding type	DS-CDMA	DS-CDMA
Code scheme	**GOLD**	**LFSR**
Chipping rate	**1.023MHz**	**2.046MHz**



BPSK: Binary Phase-Shift Key
DS-CDMA: Direct Sequence Code Division Multiple Access
LFSR: Linear Feedback Shift Register

IV. Results

a. 1D ground subsystem error contribution using **BDS B1I**, **GPS L1 C/A**



GPS B-values: 359338

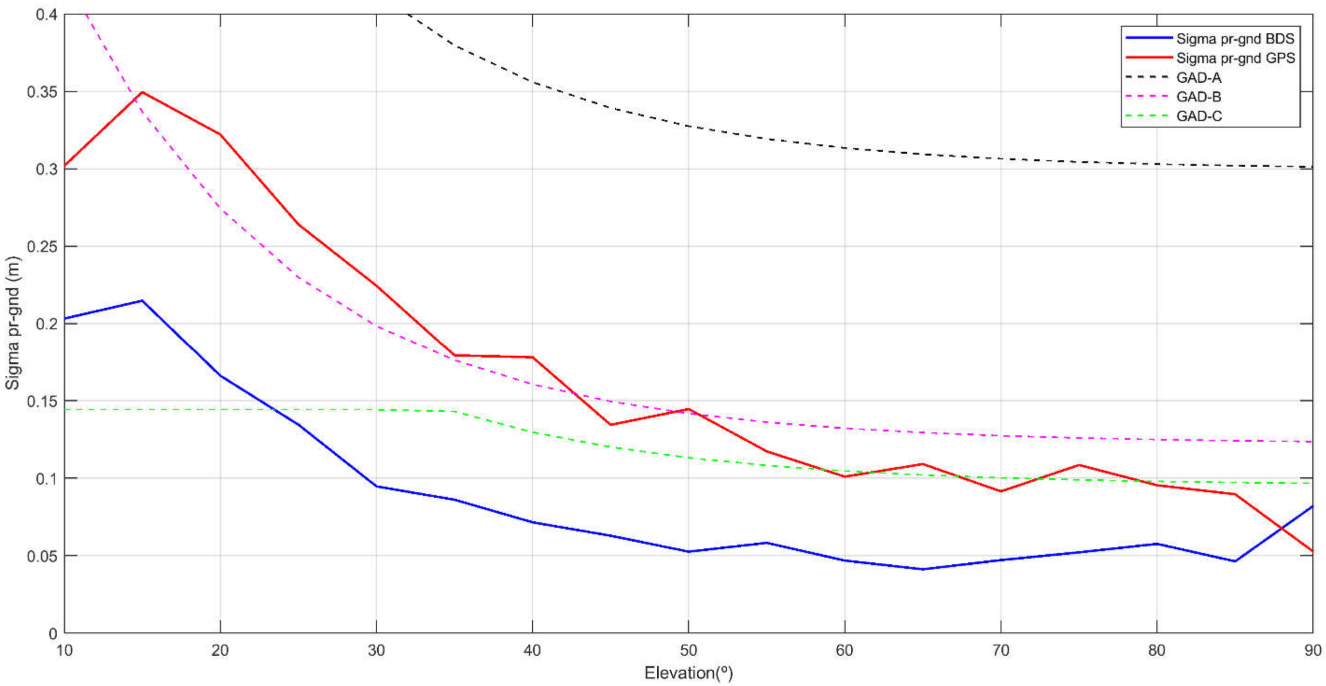
BDS B-values: 194861

Both **GPS L1 C/A** and **BDS B1I** satisfy the requirements of the GAD-A.

BDS B1I satisfies the requirements of GAD-B.

IV. Results

a. 1D ground subsystem error contribution using **BDS B1I**, **GPS L1 C/A**

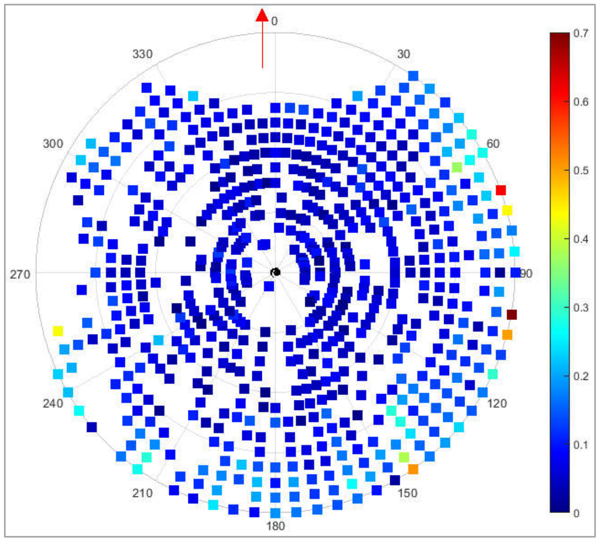


Elevation	σ_{pr_gnd} L1 C/A GPS	σ_{pr_gnd} B1I BDS	% decrement
10°	0.303	0.205	32.3%
50°	0.14	0.05	64.2%
80°	0.09	0.06	33.3%

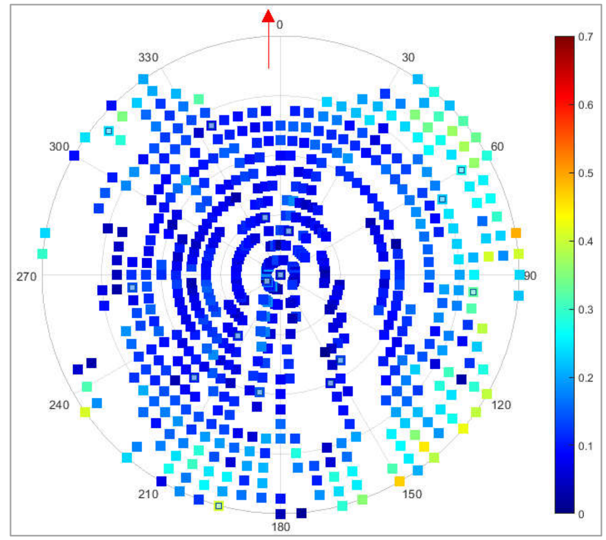
IV. Results

b. 2D ground subsystem error contribution using **BDS B1I**, **GPS L1 C/A**

BDS B-values:
194861



GPS B-values:
359338



We cannot observe GPS or BDS satellites in the north below 30º due to our geographical location.

for both GPS and BDS between **70º to 150º of azimuth** and **below 30º of elevation** show the higher levels of ground subsystem error

V. Conclusions

- The dispersed location of the NCDC receivers, their types, antennas and environmental conditions introduced different levels of error contribution, still satisfying the ICAO requirements for GBAS CAT-I.
- The 2D Ground subsystem error can identify azimuthal areas where the multipath levels might be higher. Further studies should address the effect in mitigating them.
- **B1I** signal returned a better response, mainly attributable to the coding signal schemes, chipping rates, also to the correlation spacing in the receivers which influenced the multipath mitigation due to the shorter chip length of the delayed multipath signals.
- As CORS Networks continue growing, under suitable conditions that satisfy ICAO requirements, **GBAS implementation using a CORS Network would be possible**.

Acknowledgments

ASEAN IVO (http://www.nict.go.jp/en/asean_ivo/index.html) project
Research and development for precise positioning with Artifcial Intelligence (AI) during ionospheric disturbances in low-latitude region in ASEAN

About us

http://iono-gnss.kmitl.ac.th/

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Thank you!

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