SPATIAL VARIABILITY OF THE HORIZONTAL ERROR OF RAPID STATIC GPS SURVEYING.

THE CASE IN THE ROAD INVENTORIES IN SOUTH-WESTERN OF COLOMBIA.

Nixon Alexander Correa Muñoz

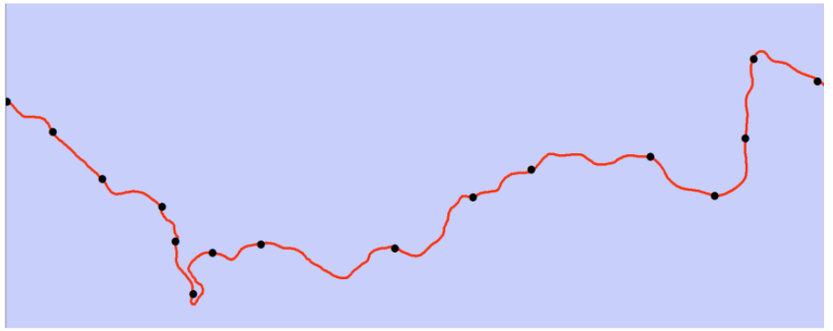
Carol Andrea Murillo Feo

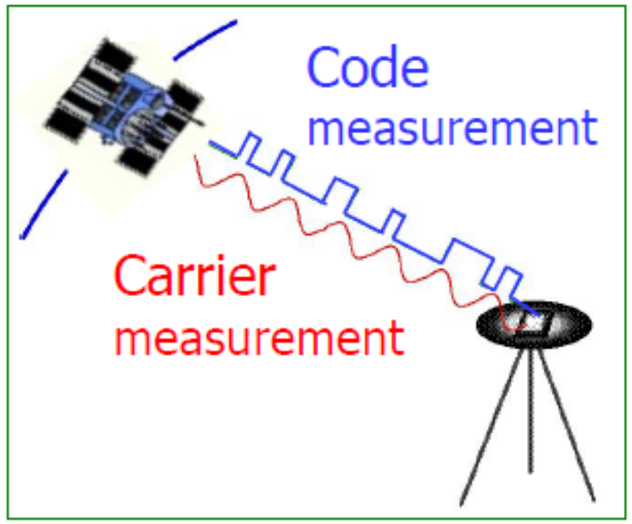
INTRODUCTION

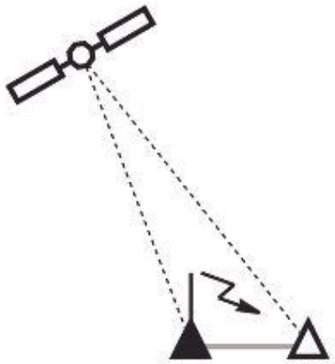
The Global Positioning System

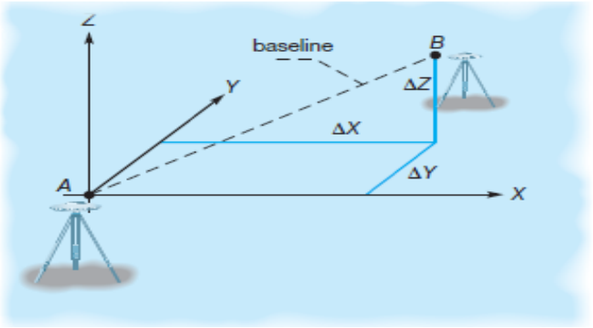
CRS: WGS84
Single-frequency L1-GPS receiver
MAGNA-ECO CORS

Static and dynamic mode









DifferentialGPS

$$X_B = X_A + \Delta X$$
$$Y_B = Y_A + \Delta Y$$
$$Z_B = Z_A + \Delta Z$$

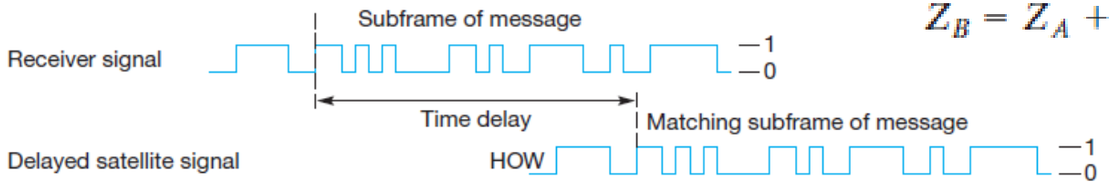
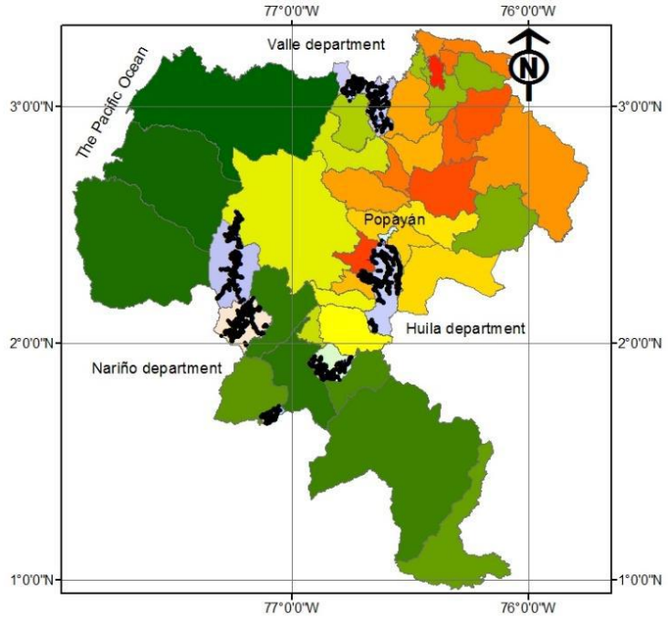


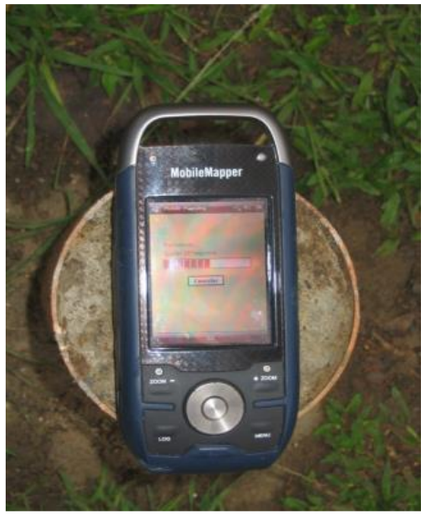
Image credit: Ghilani &Wolf (2012)



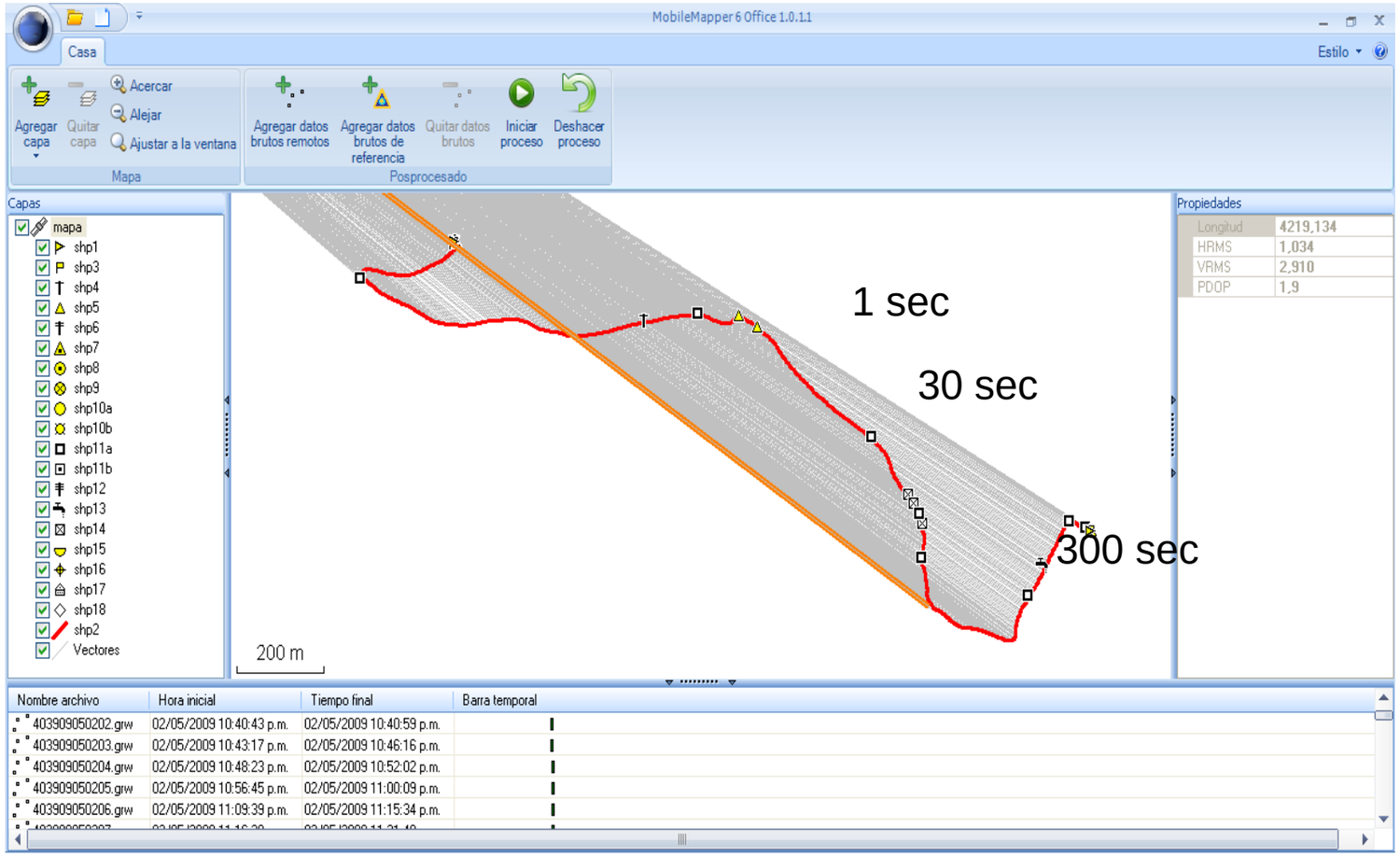
BACKGROUND

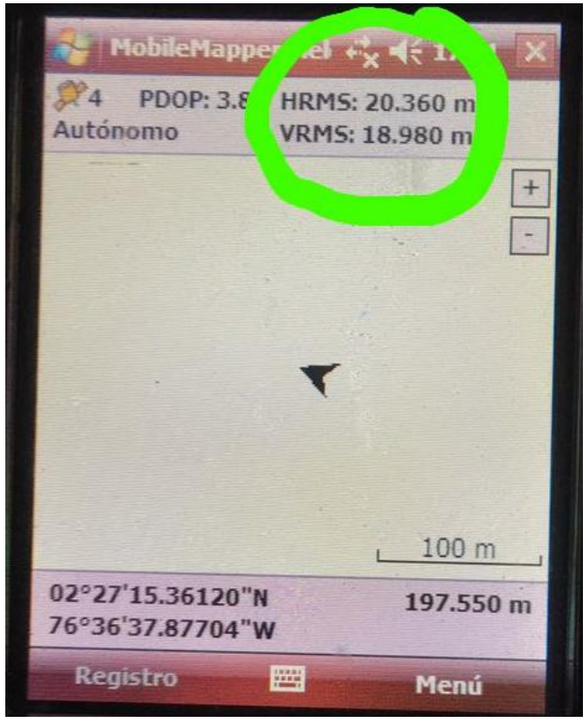
Road plans at the tertiary road network of Cauca state (2014).

Cartographic grade-GPS surveying in 2015.



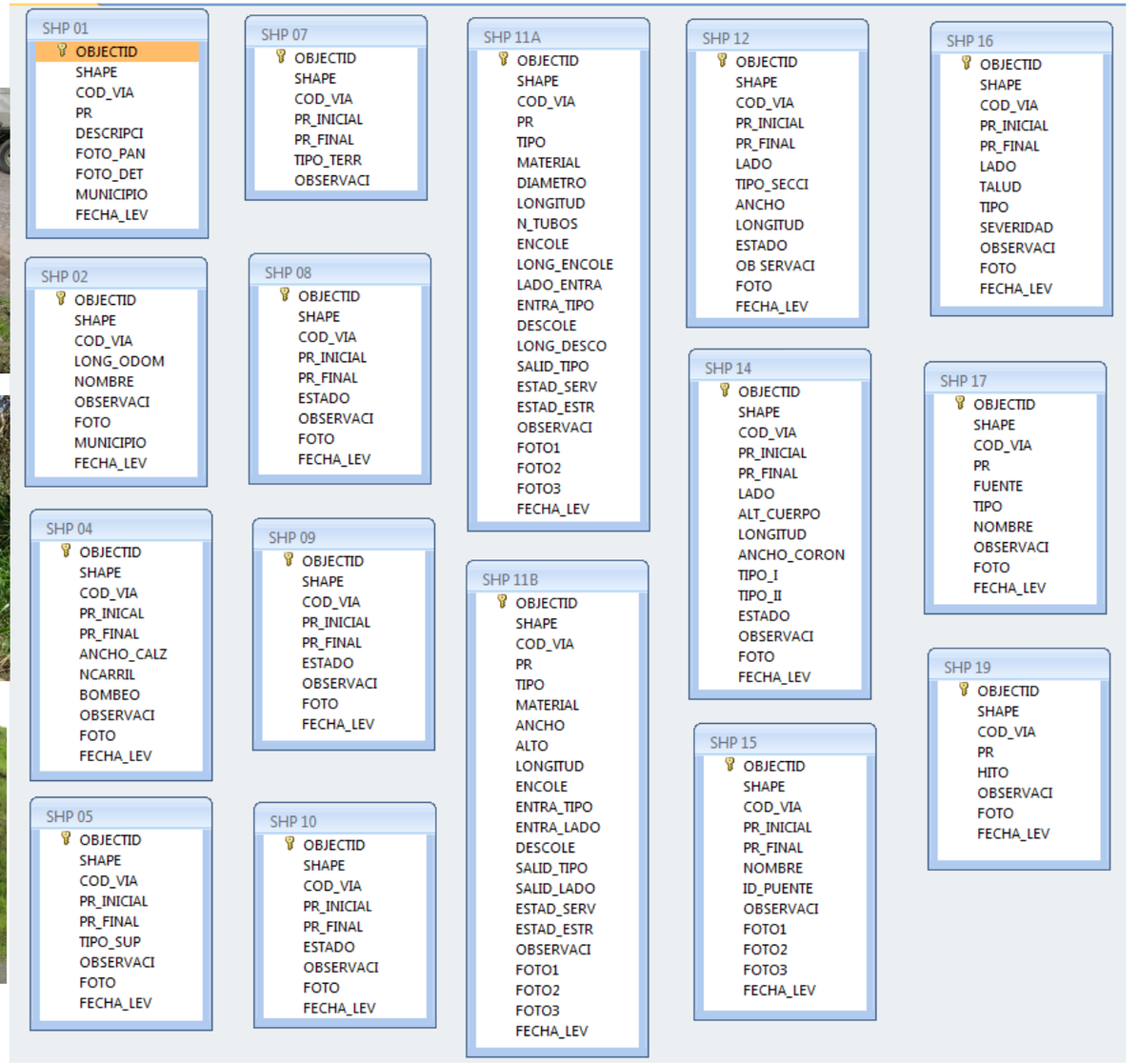
Mobile Mapper 6





BACKGROUND

Type	Code	Description of the attribute
Point	Shp01	Start and end of the road
Line	Shp02	Road axis
Line	Shp04	Roadway and lane widths
Line	Shp05	Type of surface
Line	Shp07	Type of terrain
Line	Shp08	Asphalt damage
Line	Shp09	Rigid pavement damage
Line	Shp10	Damage to the foundation (gravel Surface)
Point	Shp11A	Sewers
Point	Shp11A	Box Culvert
Line	Shp12	Coated ditches (cunetas)
Line	Shp13	Filters and drains
Line	Shp14	Retaining walls
Line	Shp15	Bridges and pontoons
Line	Shp16	Critical sites
Point	Shp17	Location of quarries and sources of material
Point	Shp19	Milestones



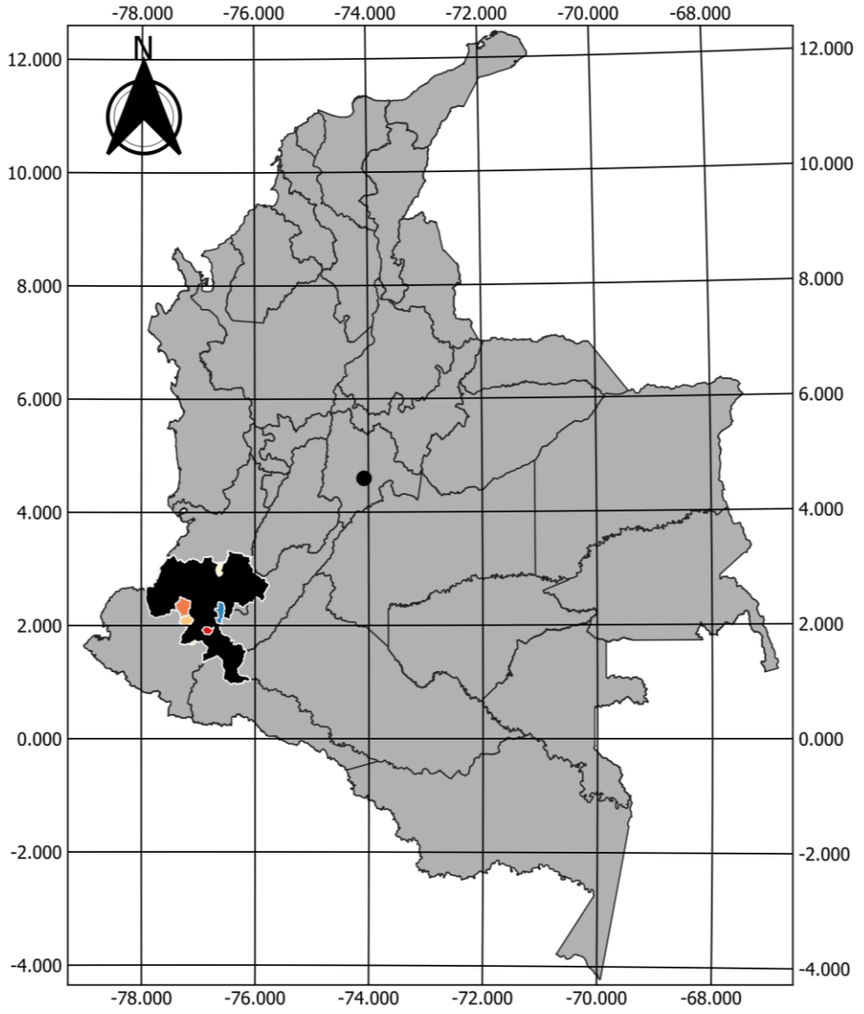
BACKGROUND

Consulting contract 1506 of 2014. HLDD S.A.S engineers.

Scope: Design, formulation and implementation of the pilot project of the **road plans** in the municipalities **Almaguer**, **Argelia**, **Balboa**, **Buenos Aires**, **Florencia** and **Sotara** for the tertiary network and its articulation to the road plan of the department, Cauca, Occidente.

Specifications:
In numeral 5 of the Terms of Reference “Methodology for the preparation of the inventory”, section 5.1. **Location of the road** (**SHP01 – SHP02**), the following is specified: “Once this (**start point** and **end point**) is determined, the location is materialised and recorded by positioning with the GPS equipment for at least ten (10) minutes and guaranteeing an **error of less than 5 m**.”

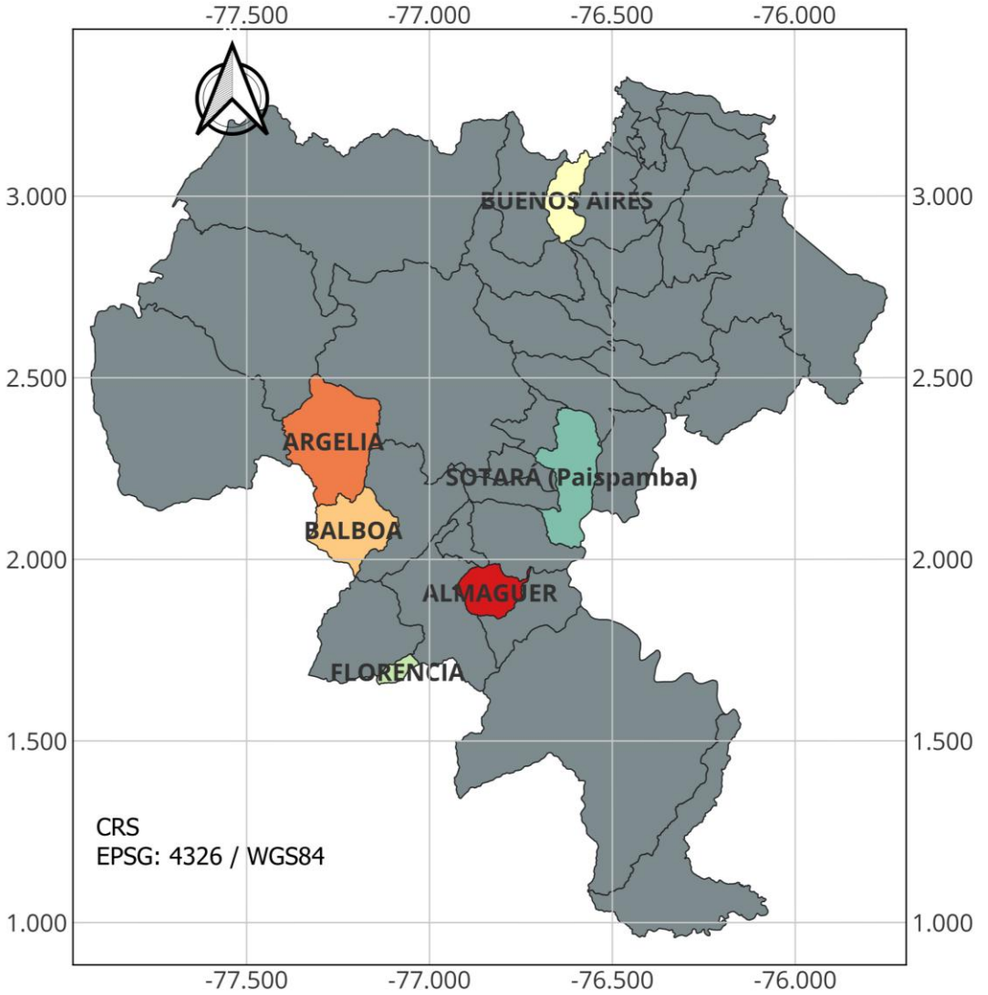
BACKGROUND



National and regional location

Municipal road plans
- ALMAGUER
- ARGELIA
- BALBOA
- BUENOS AIRES
- FLORENCIA
- SOTARÁ
- Bogotá
- Cauca state
- Colombia's states

CRS: WGS 84



METHODOLOGY

Fieldwork (road inventory)

SHP 1: Landmarks (OT= 5 min)
SHP2: Road axis (OT = 1 sec)
Other shapes: (OT= 0.5 min)

Georeferencing ↔ Road attributes

Raw data ↔ RINEX files [MAGNA-ECO CORSs]

Post-processing

GDB
- Static mode
- Fast static mode
- Dynamic mode

↔

- Distance to the base
- HRMS
- VRMS
- DOP

Officework (data analysis)

DB exploratory analysis

DB Principal Components Analysis

Internal validation

External validation

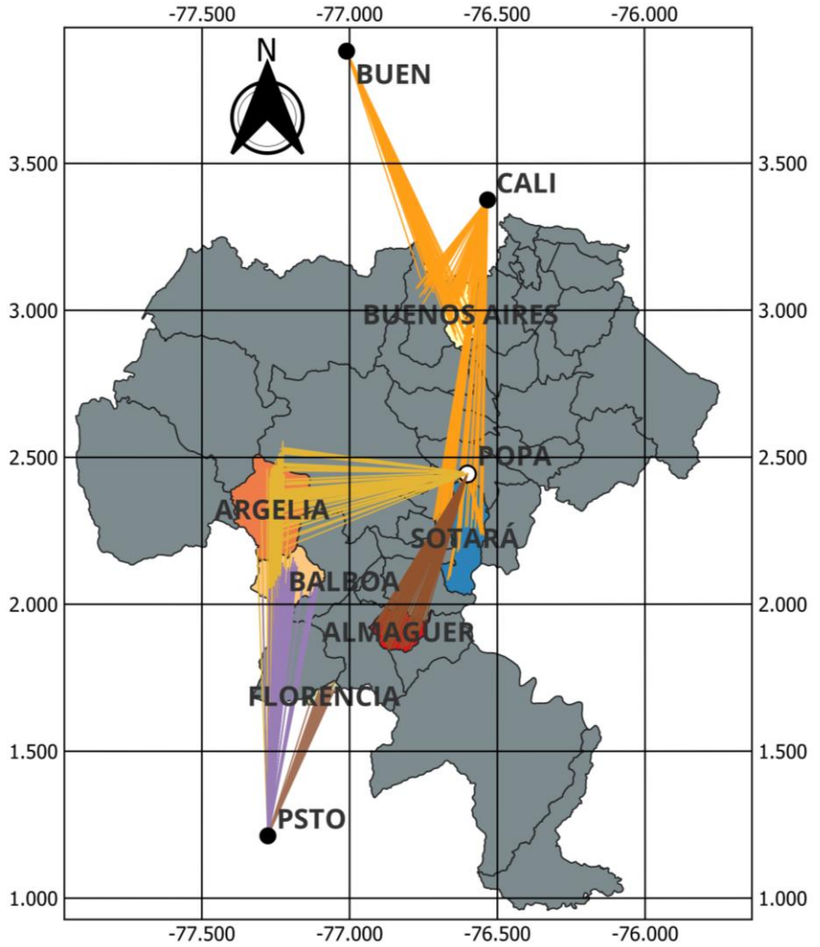
Geostatistical analysis

Accuracy standard comparison

Error's analysis

HRMS, static mode

RESULTS



Vectors of differential correction

- Balboa vectors
- Buenos Aires vectors
- Argelia vectors
- Almaguer vectors
- Florencia vectors
- Sotará vectors

Municipal road plans

- ALMAGUER
- ARGELIA
- BALBOA
- BUENOS AIRES
- FLORENCIA
- SOTARÄ
- Other Cauca's municipalities

CRS: WGS 84

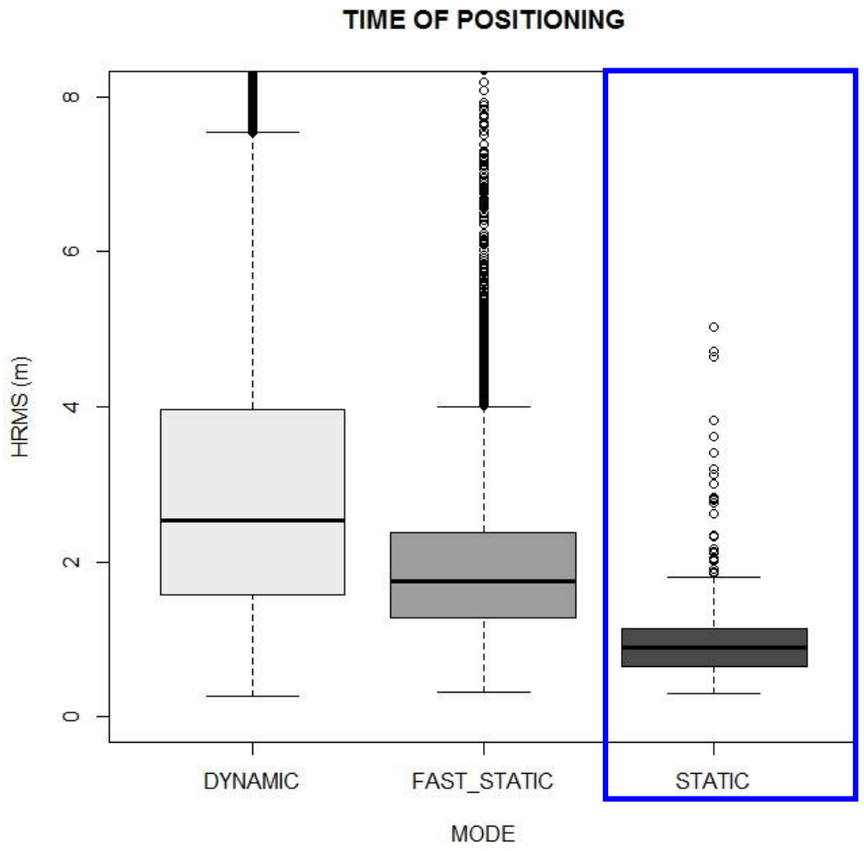
Baseline's vectors

Distance to the base station (km)

Municipality	CORS	Minimum	Maximum
Almaguer	POPA	58	72
Argelia	POPA/PSTO	66	149
Balboa	PSTO	87	109
Buenos Aires	BUEN/CALI	33	118
Florencia	PSTO	53	63
Sotará	CALI	4	134

The maximum recommended length is 15 km (L1 Band).

RESULTS

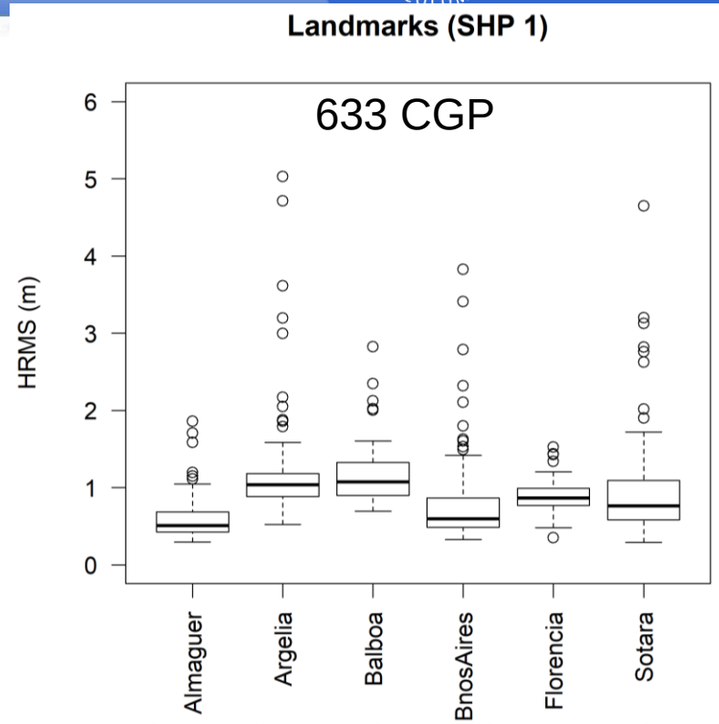


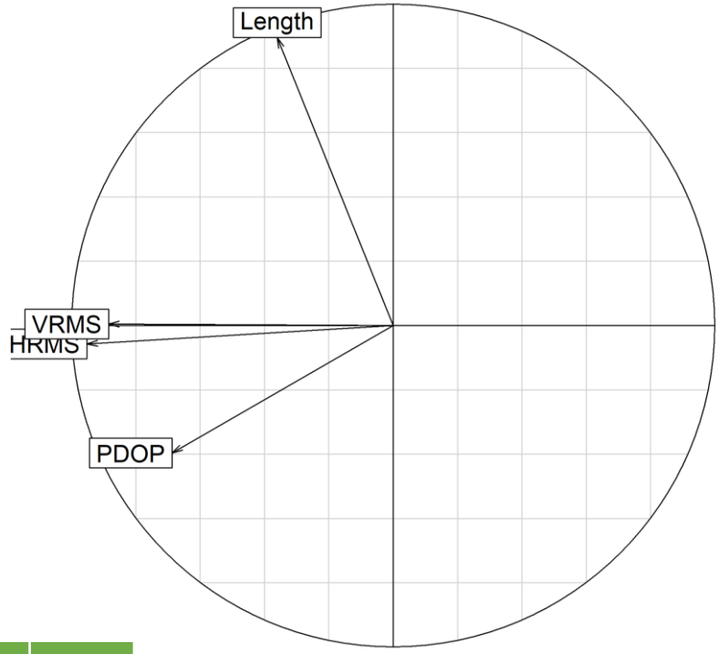
1 second | 30 seconds | 300 seconds

Occupation time for GPS surveying

Horizontal error GPS (m)

Percentile	Dynamic	Fast static	Static
P25	1,569	1,274	0,654
P50	2,540	1,742	0,897
P75	3,960	2,368	1,132
P95	6,746	4,050	1,886





Static mode

Normalized Median Absolute Deviation

$$NMAD = 1{,}4826 x Median_j(|e_j - m_e|)$$

Municipality	RMSE	NMAD	ECP_{95}
Almaguer	0,705	0,173	0,34
Argelia	1,538	0,224	0,44
Balboa	1,254	0,277	0,54
Buenos Aires	0,954	0,219	0,43
Florencia	0,927	0,156	0,31
Sotará	1,190	0,323	0,63

< 0,7 m

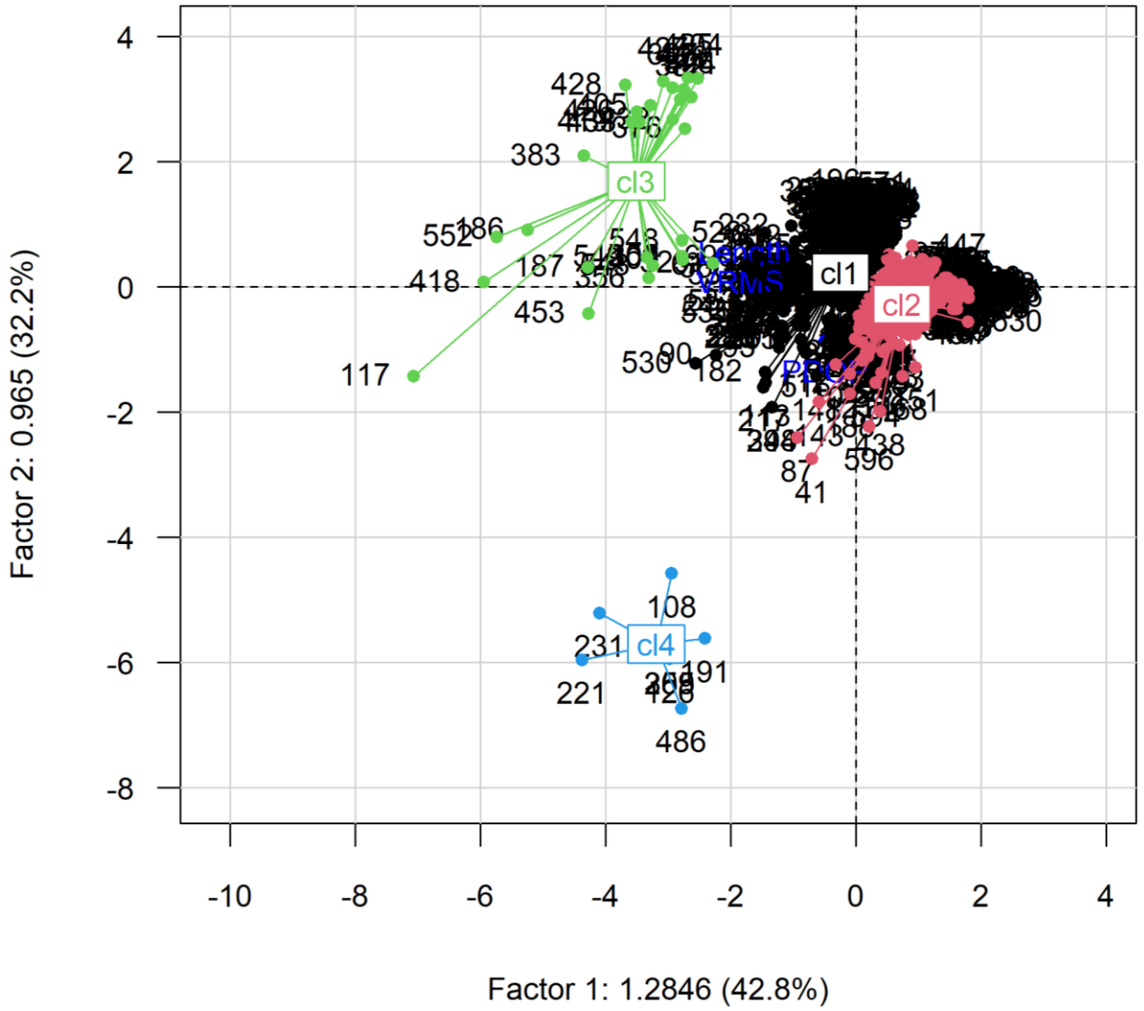
Mun	Al	Ar	Ba	BnAir	Flor	Sot
n	59	176	110	124	57	107
Min	0,3	0,5	0,7	0,3	0,4	0,3
Mean	0,6	1,2	1,2	0,8	0,9	1,0
Median	**0.5**	**1.0**	**1.1**	**0.6**	**0.9**	**0.8**
P95	**1,2**	**1,9**	**2,1**	**1,6**	**1,4**	**2,5**
Max	1,9	11,7	2,8	3,8	1,5	4,7

Variables of DiffGPS	Relationship
HRMS & VRMS (r=0,85)	Strong
HRMS & DOP (r=0,57)	Moderate
HRMS & Bline (r=0,25)	Weak

1,4<VRMS/HRSM < 2,1

	RMSE (m) ASPRS(1990)
ESCALA	0.25mm
1: 50	0,013
1: 100	0,025
1: 200	0,050
1: 250	0,063
1: 500	0,125
1: 1.000	0,250
1: 2.000	0,5
1: 5.000	1,3
1: 10.000	2,5

Ward classification



Function: HRMS ~ (Length, VRMS, PDOP)

Test.Value

Cluster	HRMS(avg)	n	function	Length	VRMS	PDOP
Class 1	1,074	312	4,27	8,27	2,73	-
Class 2	0,733	282	-10,19	-15,00	-9,55	-2,97
Class 3	2,276	30	13,30	15,46	15,56	-
Class 4	-	8				19,62
	Σ =	632				

HRMS (global mean) = 0,98

RESULTS

Precision and accuracy of measurement

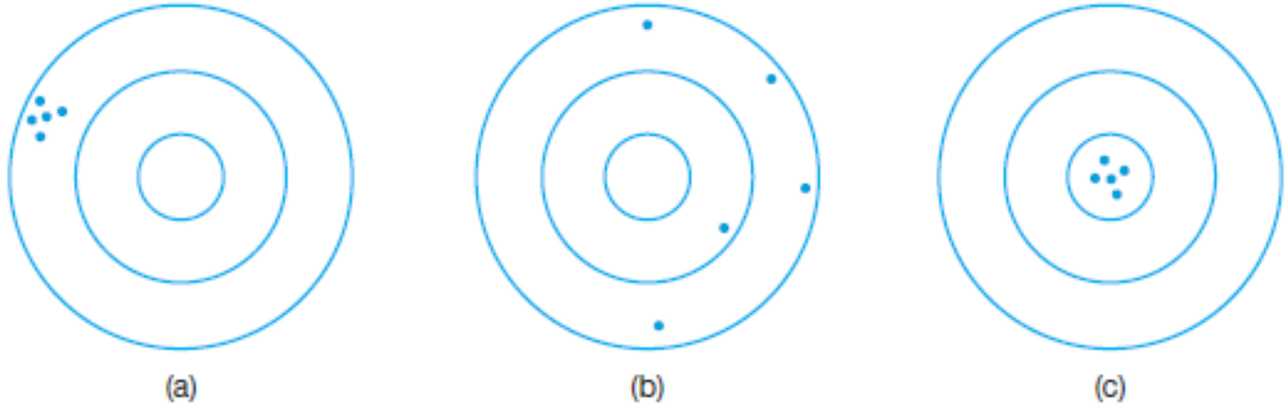
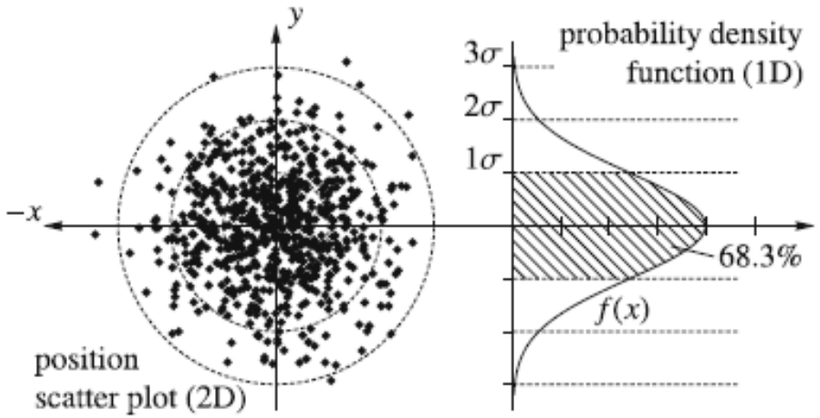


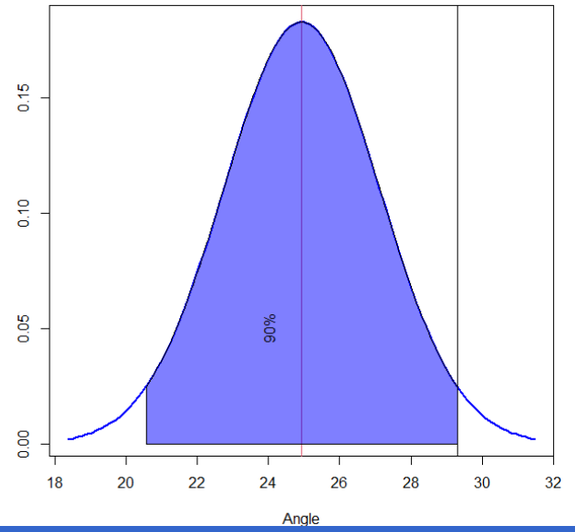
Image credit: Ghilani & Wolf (2012) p. 48

$$RMS = \sqrt{\frac{\sum_1^n e_i^2}{n}}$$

$$HRMSE = \sqrt{\frac{\sum[(X,Y)_i - (X,Y)_{ref}]^2}{n}}$$

Confidence level





Error = $x - \bar{x}$

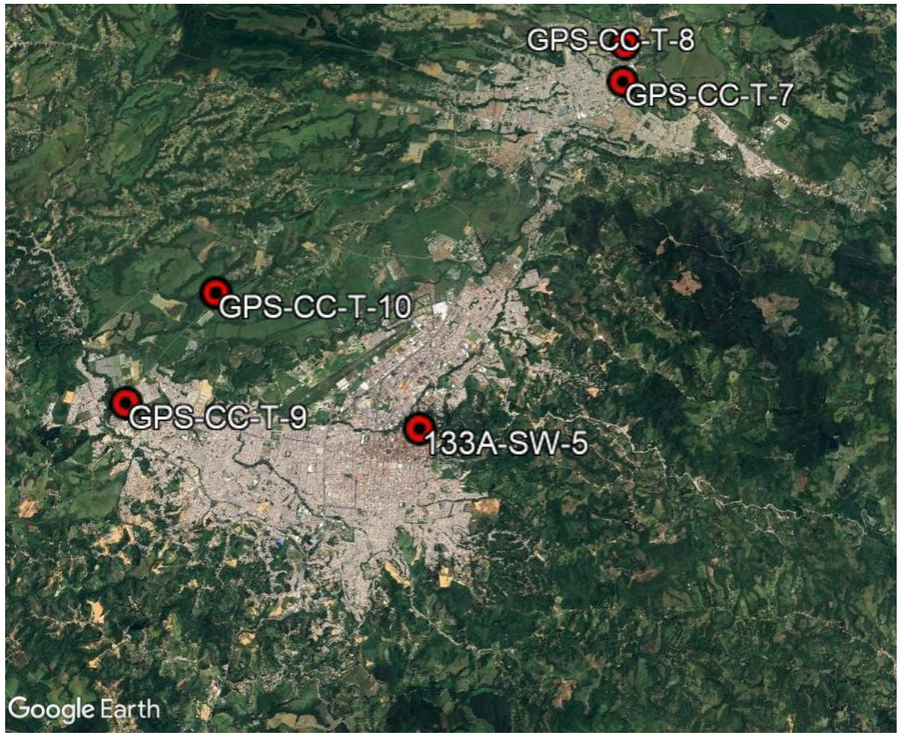
Residual = $M - \bar{M}$ $\quad \bar{M} = \frac{\Sigma M}{n}$

$E_{50} = \pm 0.675 * \sigma$

$E_{90} = \pm 1.645 * \sigma$ $\quad \sigma = \pm\sqrt{\frac{\sum v^2}{n-1}}$

$E_{95} = \pm 1.96 * \sigma$

Geodetic network of Popayán



Comparison of the coordinates from epoch (ITRF 1995.4)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{ITRF1995,4} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{March\ 24th,2015} - \begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} \times \delta T$$

FIELD CHECK TEST

EQUIPMENT: MOBILE MAPPER 6 (ANTIGUO)

Survey date 14/03/2015 — Software: MM1.0

ID	1 minute Puntos_Geo	INTERNA (m) Bogotá	INTERNA (m) Cali	EXTERNA (m) Bogotá	EXTERNA (m) Cali
0	GPS-CC-T-7	1.851	1.197	1.323	1.522
1	GPS-CC-T-8	1.855	1.080	2.491	2.844
2	GPS-CC-T-10	1.438	0.810	4.921	3.420
3	GPS-CC-T-9	1.766	1.050	4.865	3.631
4	133A-SW-5	2.452	1.916	0.900	0.222
	RMSE	1.901	1.267	3.366	2.658

Survey date 24/03/2015 — Software: MM1.0

5 minutes Puntos_Geo	INTERNA (m) Bogotá	INTERNA (m) Cali	EXTERNA (m) Bogotá	EXTERNA (m) Cali
GPS-CC-T-7	1.248	0.601	1.060	1.461
GPS-CC-T-8	1.664	0.945	2.191	2.498
GPS-CC-T-10	1.850	1.194	2.325	2.556
GPS-CC-T-9	2.082	1.029	1.882	1.289
133A-SW-5	3.264	2.025	3.097	3.457
RMSE	2.132	1.252	2.212	2.388

Software: MM4.6

ID	1 minute Puntos_Geo	INTERNA (m) Bogotá	INTERNA (m) Cali	EXTERNA (m) Bogotá	EXTERNA (m) Cali
0	GPS-CC-T-7	2.237	1.625	1.284	1.509
1	GPS-CC-T-8	2.212	1.475	2.679	3.136
2	GPS-CC-T-10	2.191	1.411	4.862	3.844
3	GPS-CC-T-9	2.589	1.779	4.322	3.185
4	133A-SW-5	2.874	2.381	1.797	1.002
	RMSE	2.436	1.769	3.298	2.758

Software: MM4.6

5 minutes Puntos_Geo	INTERNA (m) Bogotá	INTERNA (m) Cali	EXTERNA (m) Bogotá	EXTERNA (m) Cali
GPS-CC-T-7	1.664	0.824	4.397	1.432
GPS-CC-T-8	1.916	1.164	3.255	2.462
GPS-CC-T-10	2.509	1.419	6.472	2.876
GPS-CC-T-9	2.234	1.292	4.090	1.272
133A-SW-5	2.929	1.741	8.723	3.677
RMSE	2.294	1.323	5.738	2.511

MOBILE MAPPER 4.6 (NUEVO)

Survey date 24/03/2015 — Software: MM1.0

5 minutes Puntos_Geo	INTERNA (m) Bogotá	INTERNA (m) Cali	EXTERNA (m) Bogotá	EXTERNA (m) Cali
GPS-CC-T-7	1.188	0.552	1.083	1.731
GPS-CC-T-8	1.617	0.810	1.358	1.634
GPS-CC-T-10	1.733	0.734	1.495	1.728
GPS-CC-T-9	1.273	0.708	2.446	1.717
133A-SW-5	2.805	1.298	1.395	1.456
RMSE	1.818	0.859	1.624	1.657

Software: MM4.6

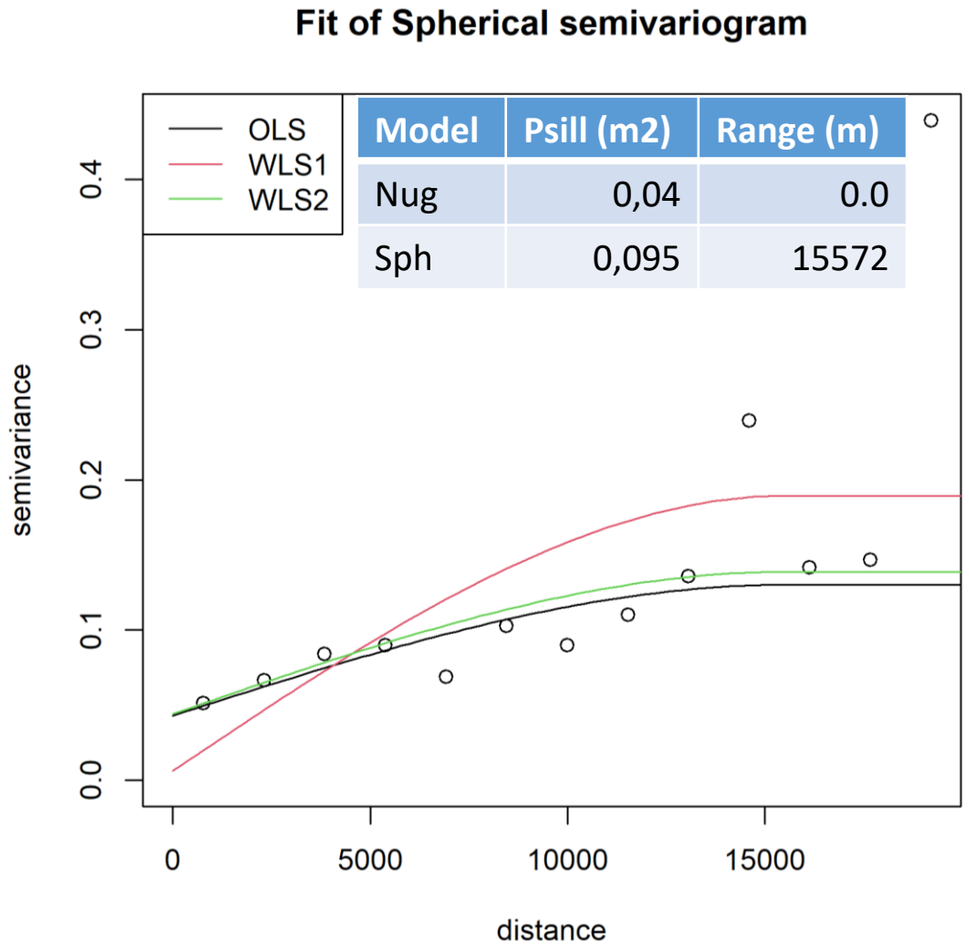
5 minutes Puntos_Geo	INTERNA (m) Bogotá	INTERNA (m) Cali	EXTERNA (m) Bogotá	EXTERNA (m) Cali
GPS-CC-T-7	2.874	2.381	1.797	1.002
GPS-CC-T-8	2.237	1.625	1.284	1.509
GPS-CC-T-10	2.212	1.475	2.679	3.136
GPS-CC-T-9	2.589	1.779	4.322	3.185
133A-SW-5	2.191	1.411	4.862	3.844
RMSE	2.436	1.769	3.298	2.758

Summary of validity	PRECISIÓN				EXACTITUD			
	BOGA		CALI		BOGA		CALI	
E \ S	MM1	MM46	MM1	MM46	MM1	MM46	MM1	MM46
MM6	2.017	2.365	1.260	1.546	2.789	4.518	2.523	2.634
MM4.6	1.818	2.436	0.859	1.769	1.624	3.298	1.657	2.758
RMSE(m)	2.159		1.358		3.057		2.393	

Accuracy/Precision (2,393/1,358) =1,762
Confidence level of 92.2%

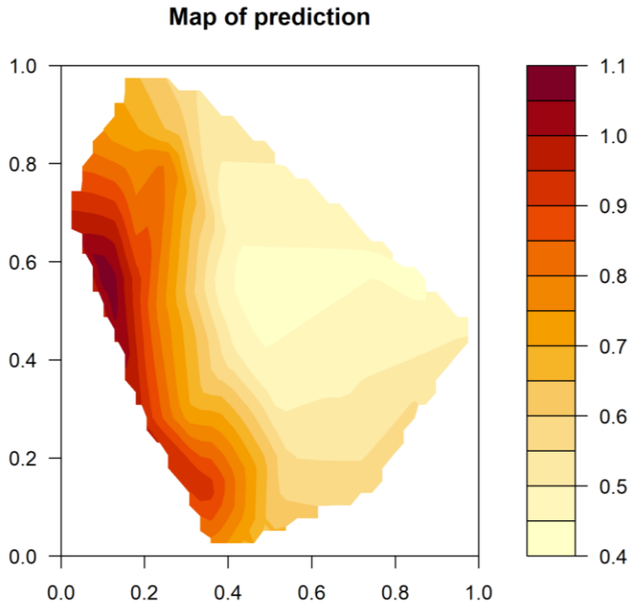
IGAC MS Magna Sirgas 5.0

Almaguer municipality

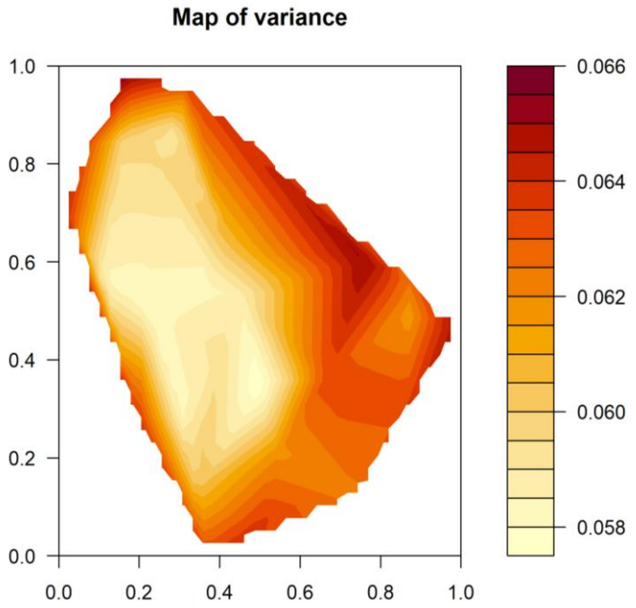


minimised sum of squares = 0.0855

HRMS(pred) range {0.426,1.107}



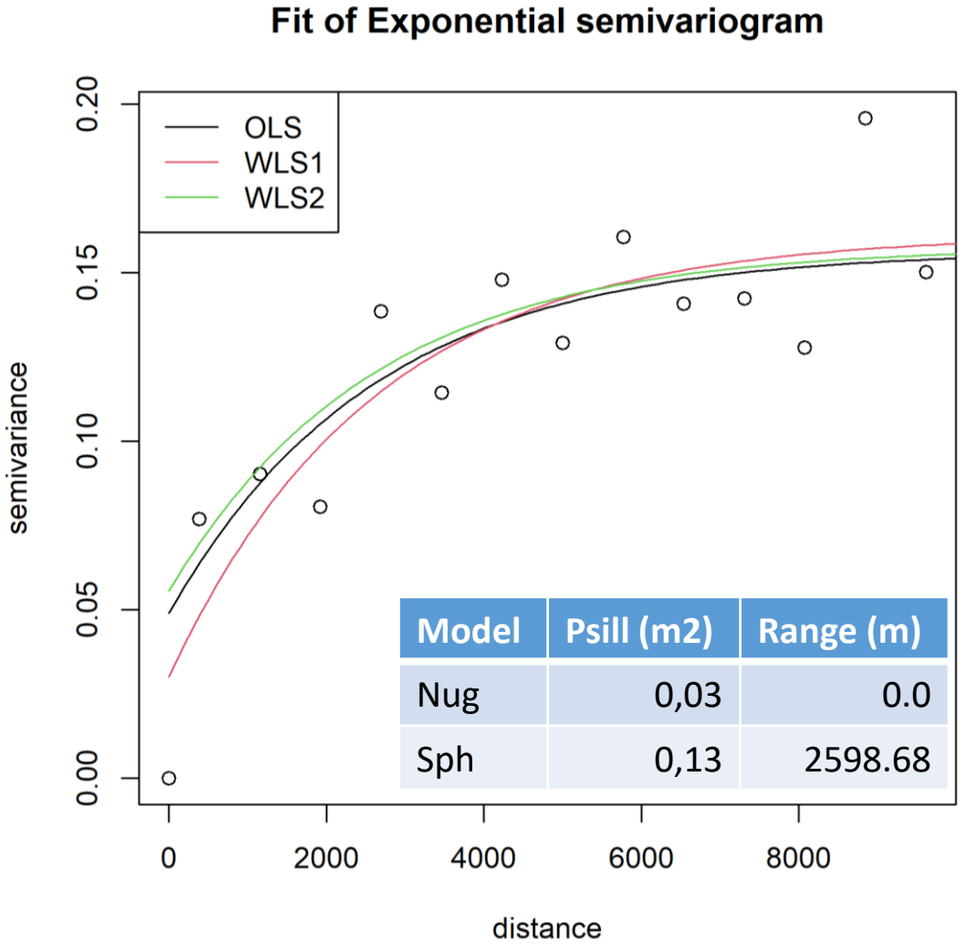
HRMS(varp) range {0.239,0.257}



Cross-validation

Model	RMSSPE	MSPE	RMSPE	ASE	MPE
KO.Sph.cv	0,330	0,003	0,087	0,266	0,002

Argelia municipality

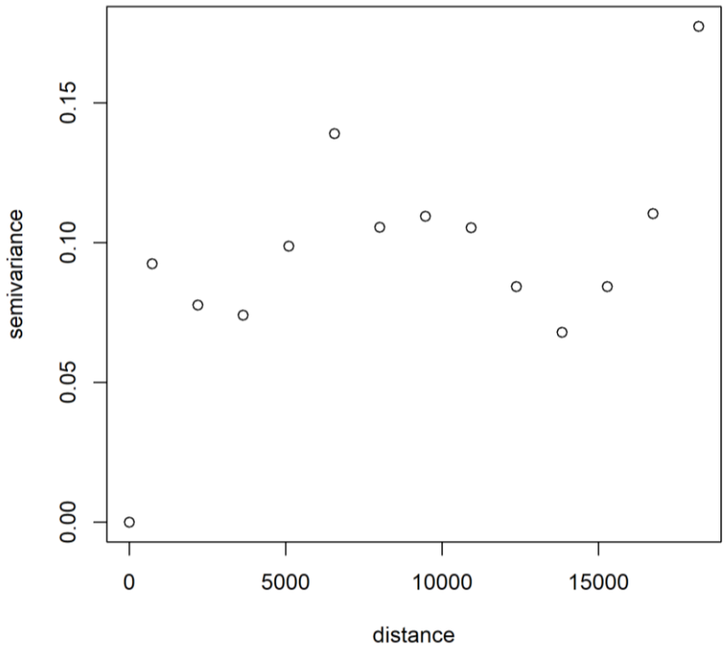


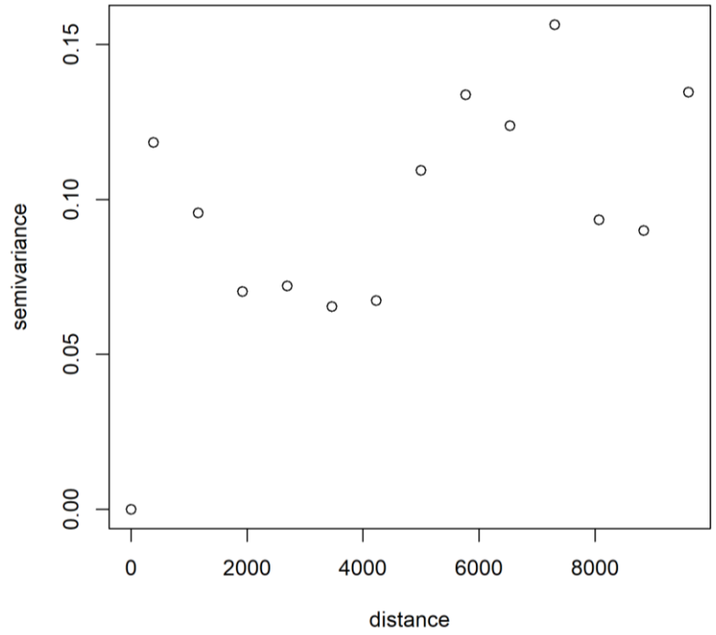
Model	Psill (m2)	Range (m)
Nug	0,03	0.0
Sph	0,13	2598.68

minimised sum of squares = 0.006

Covariance matrix singularity

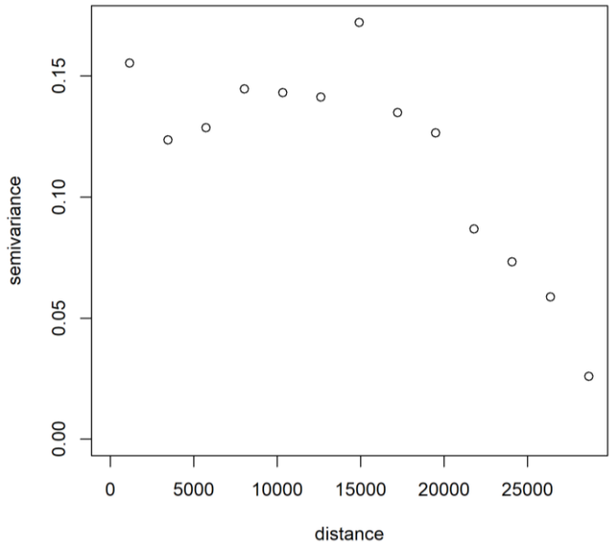
Balboa municipality

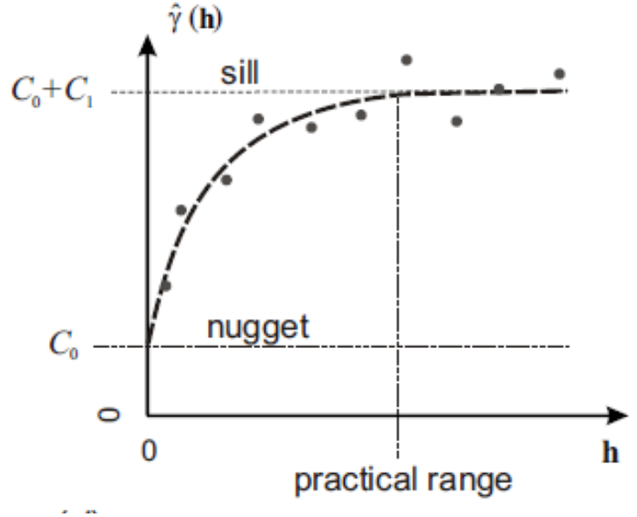




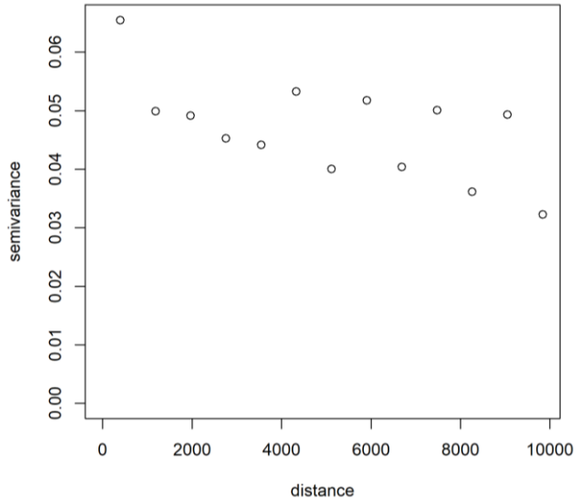
No structure of spatial dependency

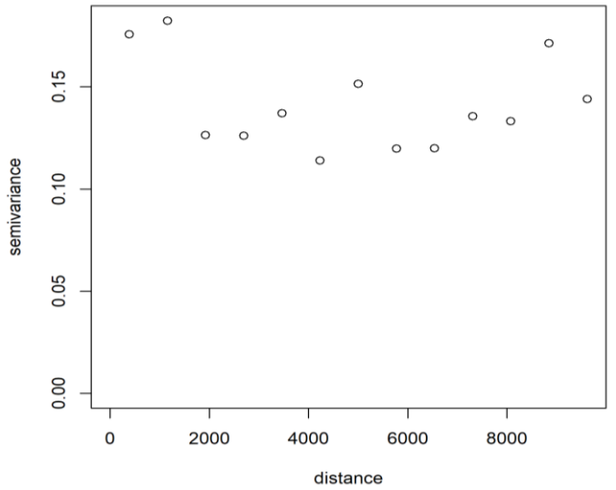
Buenos Aires municipality



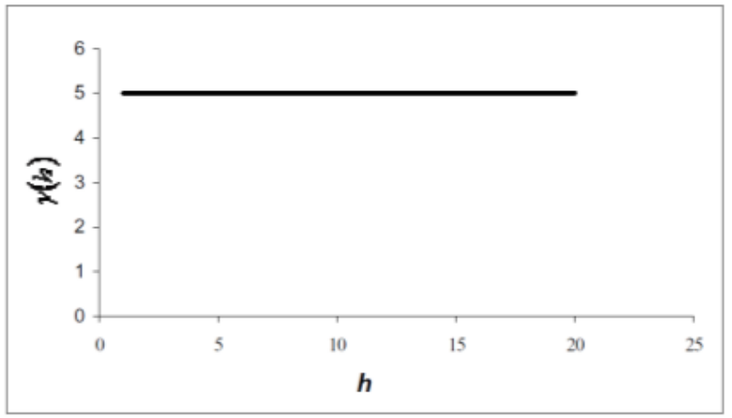


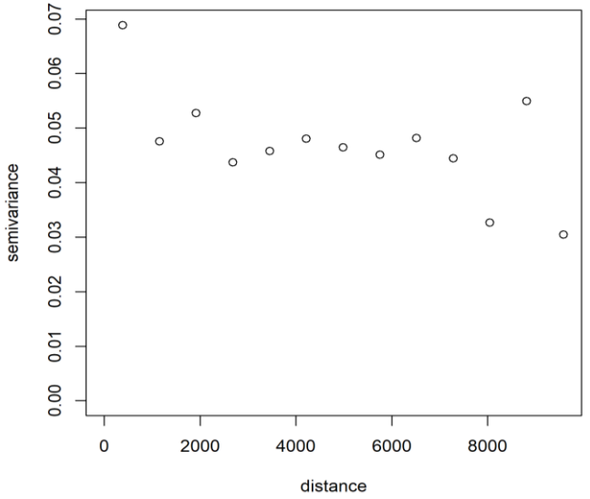
Florencia municipality



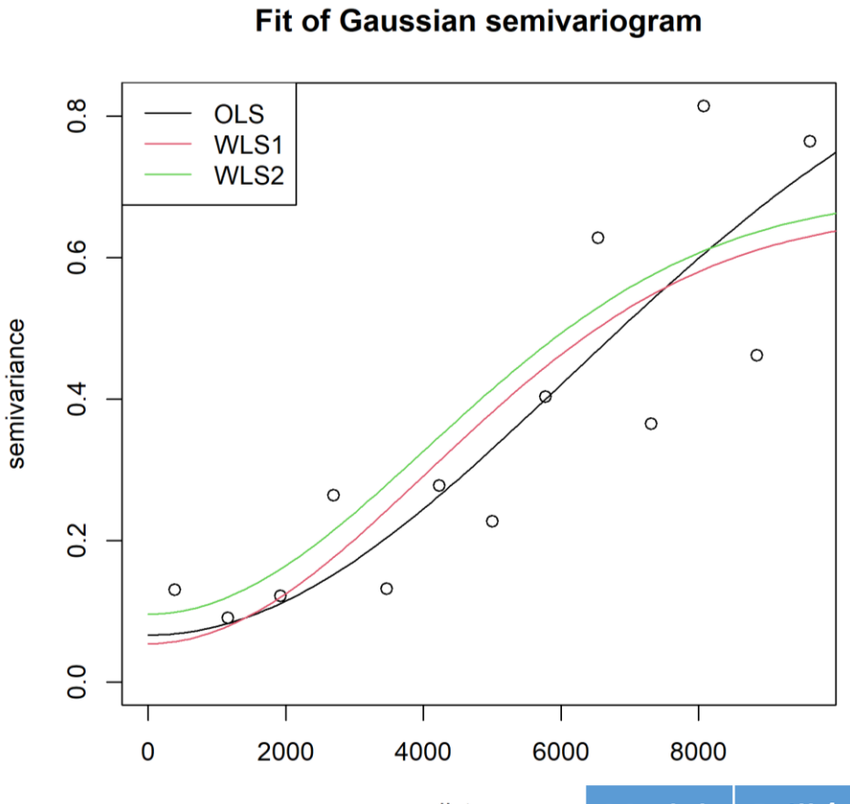


No structure of spatial dependency

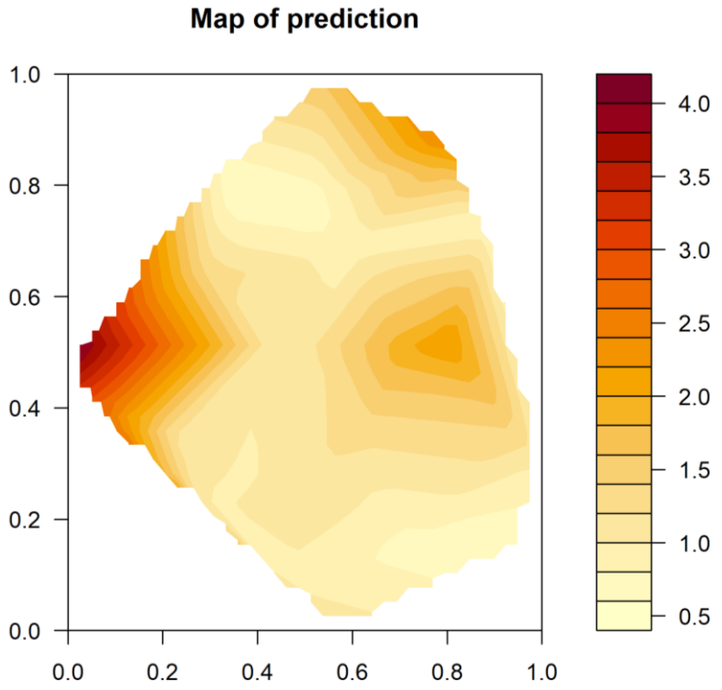




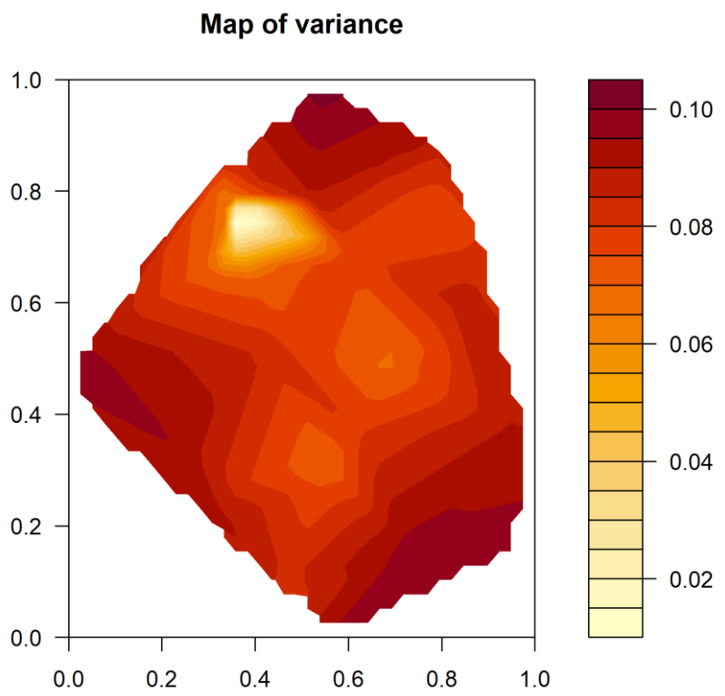
Sotará municipality



HRMS(pred) range {0.58, 4.23}



HRMS(varp) range {0, 0.32}



Model	Psill (m2)	Range (m)
Nug	0,055	0.0
Gau	0,612	5716.8

minimised sum of squares = 0.195

Cross-validation

Model	RMSSPE	MSPE	RMSPE	ASE	MPE
KO.Gau.cv	0,521	0,0039	0,234	0,352	0,0025

Conclusions

- ✓ The precision metrics gave less than tolerance (5 m).
- ✓ Horizontal error in external validation is more critical than internal validation.
- ✓ Exist a moderate direct linear relationship between Horizontal error and Dilution of Precision.
- ✓ The proximity to the base station did not imply high accuracy.
- ✓ The Kriging Ordinary method has the potential to predict horizontal error GPS (in the L1 band), when the empirical semivariogram show spatial dependency.
- ✓ According to ASPRS 1990, the scale obtained by cartographic-grade GPS was beteween 1:5000 and 1:20000. It is appropriate for road inventory mapping.

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Cauca Department
Infrastructure Secretariat

Nixon Alexander Correa Muñoz
nico@unicauca.edu.co
Carol Andrea Murillo Feo
camurillof@unal.edu.co