Impact of Galileo on geodetic positioning applications

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The impact of Galileo, the proposed European satellite navigation system, on geodetic positioning and zenith delay estimation is discussed.

Galileo and the modernized GPS system will provide more and better signals on both existing and new frequencies, resulting in improved observations.

	carrier	code	comp.	chip-rate	data	remarks
L1	1575.42 MHZ	**P(Y)**	**I(cos)**	**10.23 Mcps**	yes	
		CA	**Q(sin)**	**1.023 Mcps**	yes	
		M	Binary Offset Carrier			2004 onwards
L2	1227.60 MHz	**P(Y)**	**I(cos)**	**10.23 Mcps**	no	
		CS	Q(sin)	1.023 Mcps	TDMA	2004 onwards retrofit IIR
		M	Binary Offset Carrier			
L5	1176.45 MHz	P-like	I(sin)	10.23 Mcps	yes	2006 onwards Block IIF
		P-like	Q(sin)	10.23 Mcps	pilot	

Contemporary (bold) and modernized GPS signals. GPS: 24 nominal satellites, circular orbits 20,200 km, orbital period 11^h58^m, inclination 55^0, 6 planes.

	carrier	code	comp	chip-rate	data	service
E2-L1-E1	1575.42 MHZ	BOC[2,2] or[1,1]	I(cos)	2.026 Mcps	200sps	**OS**/SAS
			Q(sin)	2.026 Mcps	pilot	
		BOC[14,2]	*E2 and E1 subcarriers*			*PRS*
E5a = L5	1176.45 MHz	BPSK (P-like)	I(sin)	10.23 Mcps	50sps	**OS**/SAS
			Q(sin)	10.23 Mcps	pilot	
E5b	1207.14 MHz	BPSK (P-like)	I(sin)	10.23 Mcps	*500sps*	**OS**/SAS/ *CS*
			Q(sin)	10.23 Mcps	pilot	
E6	*1278.75 MHz*	*BPSK (CA-like)*	*I(sin)*	*5.115 Mcps*	*1000sps*	*CS*
			Q(sin)	*5.115 Mcps*	*pilot*	
		BOC[10,5]		*5.115 Mcps*	*1000sps*	*PRS*

Planned Galileo signals and services (subject to change). Galileo: 27 nominal + 3 spare satellites, circular orbits 23,616 km, orbital period 14^h24^m, inclination 56^0, 3 orbital planes (OS: Open Service).

The new signals on L5 result in a 24% improvement in precision of the ionosphere free linear combination (IF) if used instead of L2, or 30% if all three frequencies are used, under the assumption that the carrier phase observations have the same accuracy as GPS today.

The geometry free linear combination (I1) is improved likewise.

Two frequency GPS L1&L2

$\phi_{if} = 2.5457\ \phi_{L1} - 1.5457\ \phi_{L2}$ $\sigma_{if} = \mathbf{2.98}\ \sigma_0$

$\phi_{I1} = -1.5457\ \phi_{L1} + 1.5457\ \phi_{L2}$ $\sigma_{I1} = 2.19\ \sigma_0$

Two frequency GPS L1&L5

$\phi_{if} = 2.2606\ \phi_{L1} - 1.2606\ \phi_{L5}$ $\sigma_{if} = \mathbf{2.59}\ \sigma_0$

$\phi_{I1} = -1.2606\ \phi_{L1} + 1.2606\ \phi_{L5}$ $\sigma_{I1} = 1.78\ \sigma_0$

Three frequency GPS L1,L2&L5

$\phi_{if} = 2.3269\ \phi_{L1} - 0.3596\ \phi_{L2} - 0.9673\ \phi_{L5}$ $\sigma_{if} = \mathbf{2.55}\ \sigma_0$

$\phi_{i1} = -1.3470\ \phi_{L1} + 0.4682\ \phi_{L2} + 0.8788\ \phi_{L5}$ $\sigma_{i1} = 1.68\ \sigma_0$

Two frequency GALILEO E2-L1-E1 & E5b

$\phi_{if} = 2.3932\ \phi_{L1} - 1.3932\ \phi_{E5b}$ $\sigma_{if} = \mathbf{2.77}\ \sigma_0$

$\phi_{i1} = -1.3932\ \phi_{L1} + 1.3932\ \phi_{E5b}$ $\sigma_{I1} = 1.97\ \sigma_0$

Two frequency GALILEO E2-L1-E1 & E5a

$\phi_{if} = 2.2606\ \phi_{L1} - 1.2606\ \phi_{E5a}$ $\sigma_{if} = \mathbf{2.59}\ \sigma_0$

$\phi_{i1} = -1.2606\ \phi_{L1} + 1.2606\ \phi_{E5a}$ $\sigma_{I1} = 1.78\ \sigma_0$

Three frequency GALILEO E2-L1-E1, E5b & E5a

$\phi_{if} = 2.3088\ \phi_{L1} - 0.5063\ \phi_{E5b} - 0.8024\ \phi_{E5a}$ $\sigma_{if} = \mathbf{2.50}\ \sigma_0$

$\phi_{i1} = -1.3138\ \phi_{L1} + 0.5584\ \phi_{E5b} + 0.7553\ \phi_{E5a}$ $\sigma_{i1} = 1.62\ \sigma_0$

The main improvement comes from having additional satellites, as is illustrated by the following conservative simulation experiments.

24 h data-set for:
- The Netherlands (52.22º N, 4.42 º E)
- 24 GPS and 30 Galileo satellites
- 10º elevation cut-off angle

Ionosphere free single diff. observation
- phase (σ=√2*9 mm) & code (σ=√2*0.9 m)

Precise orbits (orbit errors neglected)

Estimated parameters:
- independent receiver clock errors for GPS and Galileo (1-2 per epoch)
- zenith delay (one per epoch)
- station position (static or kinematic)
- phase ambiguities (float and fixed)

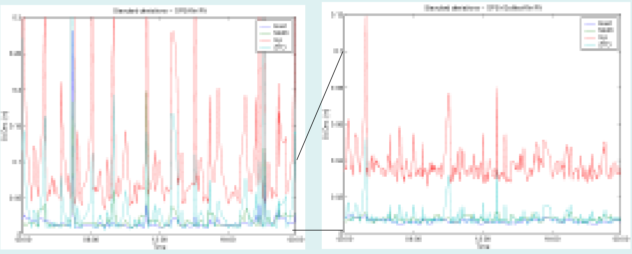
Satellite clock errors are taken care of by the single difference.

NEU [mm]		GPS/float E	GPS/float N	GPS/float U	GPS/fixed E	GPS/fixed N	GPS/fixed U	G&G/float E	G&G/float N	G&G/float U	G&G/fixed E	G&G/fixed N	G&G/fixed U
Static		1.4	0.7	2.9	0.4	0.5	2.6	0.8	0.4	1.7	0.3	0.3	1.5
Kinematic w/o ZTD	median	10.8	11.7	24.3	8.7	11.0	22.9	6.1	7.3	14.5	5.7	7.1	14.1
	mean	11.0	13.9	25.0	9.3	13.0	23.9	6.3	7.5	14.7	5.8	7.2	14.4
	min	7.7	8.8	15.1	6.7	8.1	14.1	4.8	5.5	10.6	4.3	5.6	10.3
	max	24.8	29.3	55.9	23.5	28.9	55.2	9.3	10.5	20.8	8.5	10.3	20.6
Kinematic w/ ZTD	median	13.0	14.9	73.1	10.5	13.4	70.6	6.6	7.7	35.7	6.0	7.4	35.0
	mean	15.4	19.2	126.8	12.7	17.4	122.1	6.7	7.9	37.8	6.2	7.6	37.2
	min	8.5	9.4	34.1	6.7	8.2	32.5	4.8	5.9	25.7	4.3	5.6	25.3
	max	282.1	198.0	8830	278.1	194.2	8712	10.4	12.0	119.4	9.4	11.7	117.9

ZTD [mm]	Kinematic/float GPS	Kinematic/float G&G	Kinematic/fixed GPS	Kinematic/fixed G&G	Static/float GPS	Static/float G&G	Static/fixed GPS	Static/fixed G&G
median	19.1	7.9	18.3	7.8	4.5	2.9	4.5	2.8
mean	43.3	9.2	41.7	9.0	5.5	3.1	5.3	3.1
Min-max	5.6-3943	4.9-52.2	5.3-3891	4.8-51.6	2.3-18.3	1.8-9.0	2.3-18.2	1.8-9.0

Results: Standard deviation of estimated parameters in [mm].

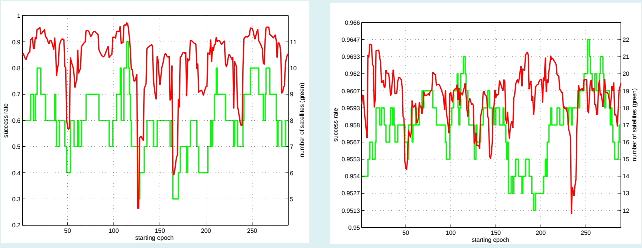
Ambiguity fixing was assumed to be 100% successful; success rates were not evaluated



Example of a simulation: Standard deviation of East, North, Height and ZTD for GPS (left) and GPS & GALILEO (right) for a kinematic receiver with float ambiguities.

St.Dev.Ratio	Float Ambiguities E	Float Ambiguities N	Float Ambiguities U	Float Ambiguities ZTD	Fixed Ambiguities E	Fixed Ambiguities N	Fixed Ambiguities U	Fixed Ambiguities ZTD	Theoretical benchmark
Static w/ ZTD	0.61	0.65	0.59	0.64	0.64	0.61	0.58	0.63	0.62
Kinematic w/o ZTD	0.56	0.62	0.60	-	0.65	0.64	0.62	-	0.51
Kinematic w/ ZTD	0.50	0.52	0.49	0.41	0.57	0.55	0.50	0.42	0.43

Ratio of standard deviations GPS & Galileo versus GPS only for different scenarios, showing the improvement in precision due to extra satellites.



Probability of successful single epoch ambiguity resolution (red line) for GPS (left) and GPS & Galileo (right) for a 24 hour period in the Netherlands, using all publicly available frequencies. The green line is the number of available satellites. The probability is increased by combining GPS with Galileo and using all available frequencies.

The improved redundancy of a dual GNSS system will make it possible to introduce additional parameters to reduce (systematic) errors and improve the accuracy even further. The improved accuracy will also make new applications possible, especially for moving receivers.

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