Inter-system biases estimation in multi-GNSS relative positioning with GPS and Galileo

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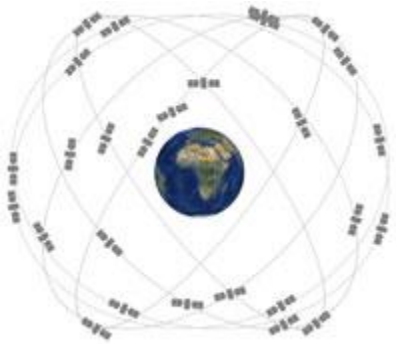
Multi-GNSS

- Many systems : GPS, GLONASS, Galileo, BeiDou, QZSS, IRNSS

Improved reliability – availability - precision

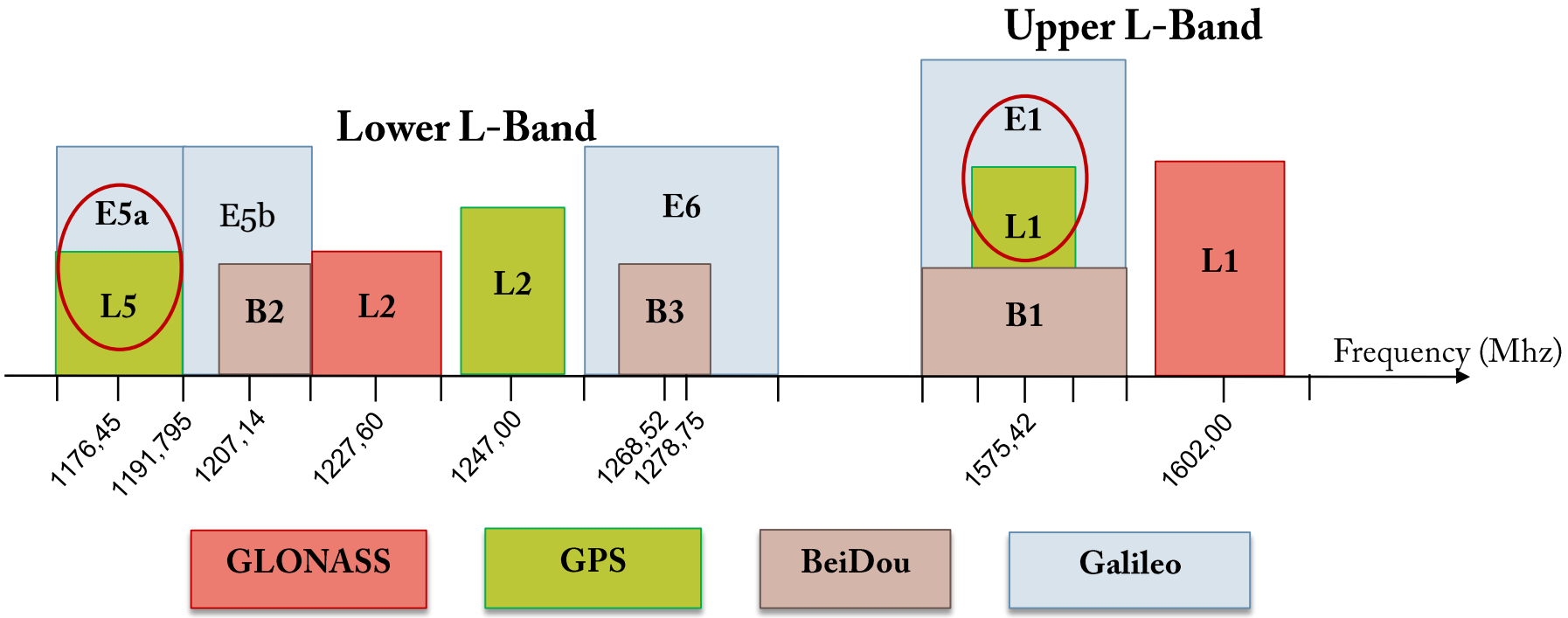


Independent but compatible…

Possibility for Multi-GNSS RTK !

Multi-GNSS

- Overlapping frequencies :
  - L1 (GPS) – E1 (Galileo) – B1 (BeiDou) – L1 (QZSS)
  - L5 (GPS) – E5a (Galileo) – L5 (QZSS) – L5 (IRNSS)
  - L2 (GPS) – L2 (QZSS)
  - E5b (Galileo) – B2 (BeiDou)



Inter-system Biases (ISBs)

- One-way code observable model

$$\text{GPS}: P_{1,k}^{G} = D_1^{G} + T_1^{G} + I_{1,k}^{G} + M_{1,k,m}^{G} + c.\left(\delta t_1^{(G)} - \delta t^{G}\right) + d_1 - d^{G} + \epsilon_{1,k,m}^{G}$$

$$\text{Galileo}: P_{1,k}^{E} = D_1^{E} + T_1^{E} + I_{1,k}^{E} + M_{1,k,m}^{E} + c.\left(\delta t_1^{(E)} - \delta t^{E}\right) + d_1 - d^{E} + \epsilon_{1,k,m}^{E}$$

$$+ c.(\delta t_1^{(E)} - \delta_{GGTO} - \delta t^{E})$$

Galileo to GPS Time Offset = Different Time Systems

$P_{1,k}^{*}$: Pseudo-range	δt_1: Receiver clock errors
D_1^{*}: Geometric distance	δt^{*}: Satellite clock errors
T_1^{*}: Tropospheric delay	d_1: Receiver hardware delay
$I_{1,k}^{*}$: Ionospheric delay	d^{*}: Satellite hardware delay
$M_{1,k,m}^{*}$: Multipath	$\epsilon_{1,k,m}^{*}$: Code noise

Inter-system Biases (ISBs)

- In a ZERO baseline case :
  - Single Difference

$$P_{12,k}^{G} = D_{12}^{G} + \delta t_{12}^{(G)} - d_{12}^{(G)} + \epsilon_{12,k,m}^{G}$$

$$P_{12,k}^{E} = D_{12}^{E} + \delta t_{12}^{(E)} - d_{12}^{(E)} + \epsilon_{12,k,m}^{E}$$

The GGTO term disappears

  - Double Difference

$$P_{12,k}^{GG} = D_{12}^{GG} + \epsilon_{12,k,m}^{GG}$$

$$P_{12,k}^{GE} = D_{12}^{GE} - d_{12}^{(GE)} + \epsilon_{12,k,m}^{GE}$$

Single reference satellite for all observations

4 unknowns :

X,
Y,
Z,
Differential hardware delay between GPS and Galileo (ISB)

Equipment

- Receivers :
  - 2 x Septentrio PolaRx4 (Sept 1 & Sept 2)
  - 2 x Trimble NetR9 (TRM 1 & TRM 2)
  - 1 x Septentrio PolaRxS (Sept 3)
- Antennae :
  - 2 x TRIMBLE TRM 59800 SCIS (choke ring antenna) (ULG0 & ULG1)
- Splitter :
  - 1 x 2-way splitter
  - 1 x 4-way splitter

Fixed precise coordinates

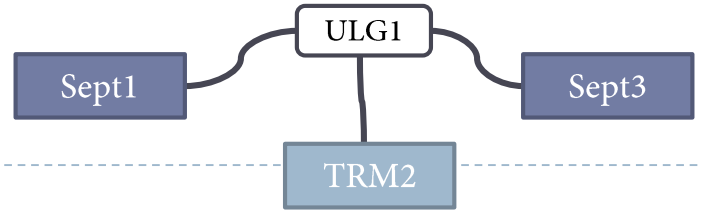
Configurations

- End of 2014 – DOY 179 of 2015

- DOYs180-292 of 2015

- DOYs 293-365 of 2015 – DOYs 1-12 of 2016

- DOYs 13 –now of 2016



Results

Zero baselines results – Identical Receivers with identical firmware

		GPS L1/Galileo E1				GPS L5/Galileo E5a			
		Mean ISB (m)		Std ISB (m)		Mean ISB (m)		Std ISB (m)	
		Epochs	10-min	Epochs	10-min	Epochs	10-min	Epochs	10-min
Sept2 – Sept1	14'	NO DATA							
	15'	0,004	0,003	0,003	0,003	0,005	0,008	0,004	0,008
	16'	0,002	0,002	0,000	0,001	0,002	0,008	0,003	0,008
Sept2 – Sept3	14'	NO DATA							
	15'	0,001	0,001	0,004	0,005	0,050	0,047	0,006	0,005
	16'	0,000	0,002	0,009	0,007	0,040	0,021	0,010	0,049

Not considered in the computation : Galileo satellites E18 - E14 - E20

Results

Zero baselines results – Identical Receivers with identical firmware

		GPS L1/Galileo E1				GPS L5/Galileo E5a			
		Mean ISB (m)		Std ISB (m)		Mean ISB (m)		Std ISB (m)	
		Epochs	10-min	Epochs	10-min	Epochs	10-min	Epochs	10-min
Sept1 – Sept3	14'	0,023	0,027	0,018	0,017	0,078	0,058	0,036	0,029
	15'	0,004	0,002	0,003	0,005	0,044	0,042	0,007	0,012
	16'	0,003	0,003	0,016	0,017	0,034	0,037	0,008	0,016
TRM1 – TRM2	14'	0,120	0,120	0,011	0,012	0,003	0,004	0,019	0,076
	15'	0,150	0,150	0,004	0,004	0,0017	0,013	0,020	0,036
	16'	0,140	0,140	0,004	0,004	0,008	0,01	0,021	0,030

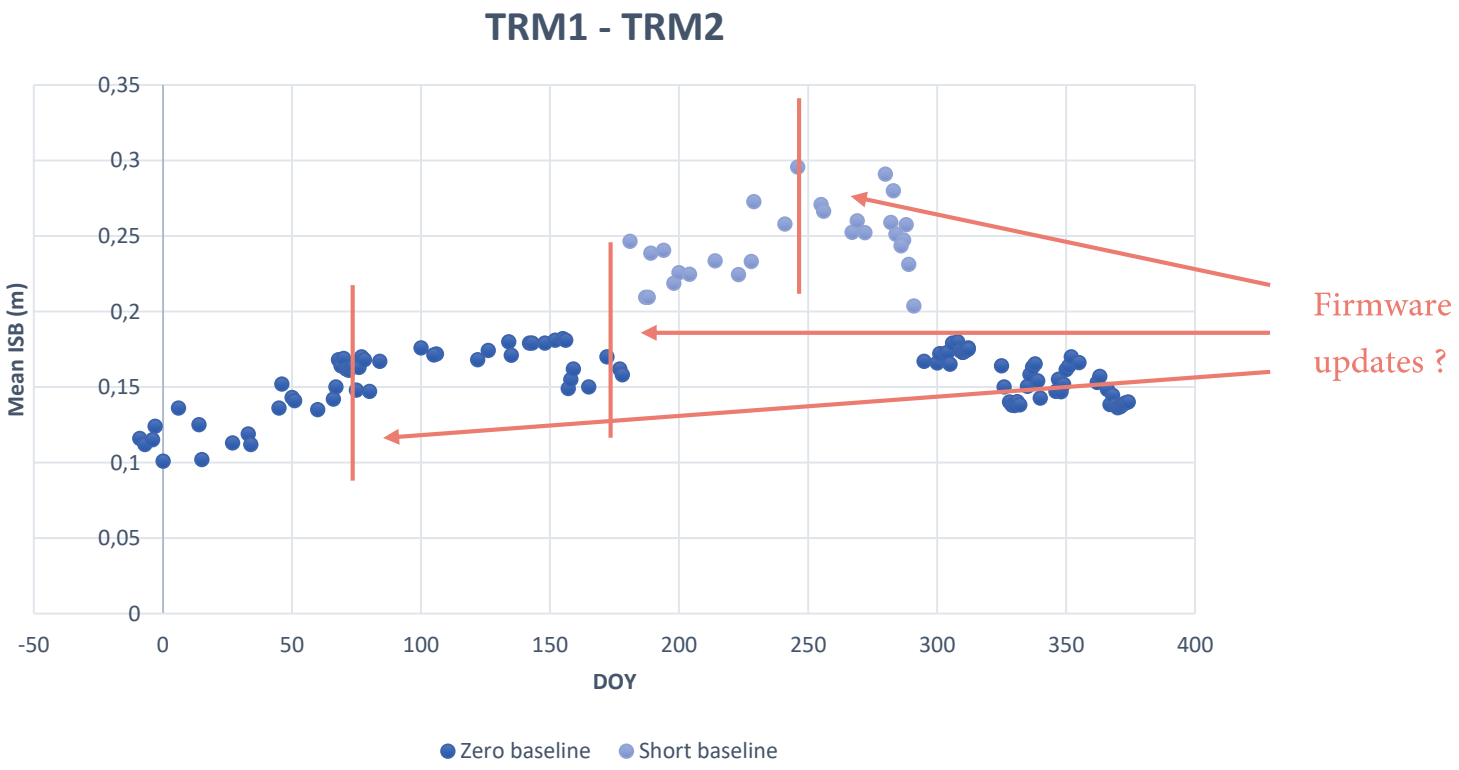
Same receivers show ISBs different from 0?

Not considered in the computation : Galileo satellites E18 - E14 - E20

Results

Zero baselines results – Identical Receivers with identical firmware

Analysis over the year 2015



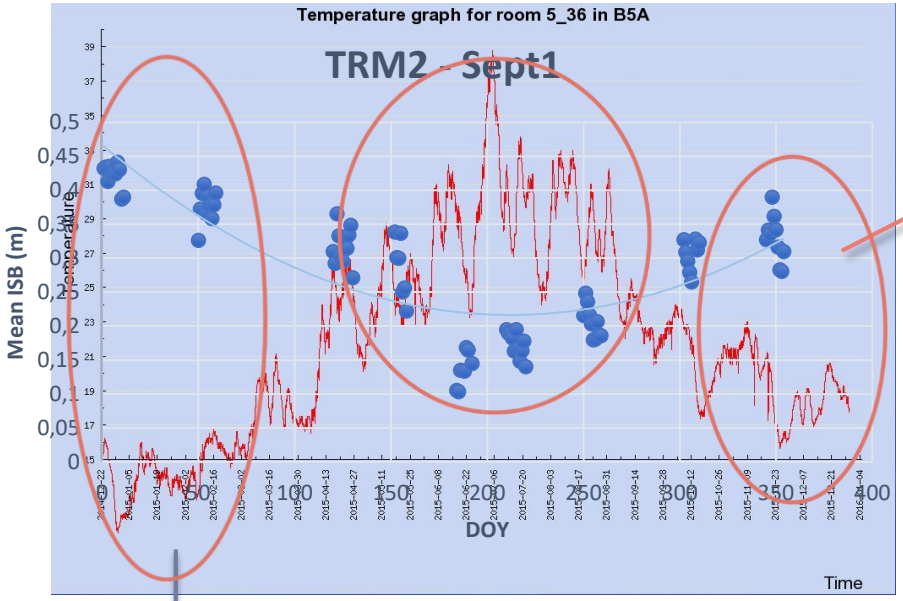
Results

Zero baselines results – Identical Receivers with identical firmware

Analysis over the year 2015

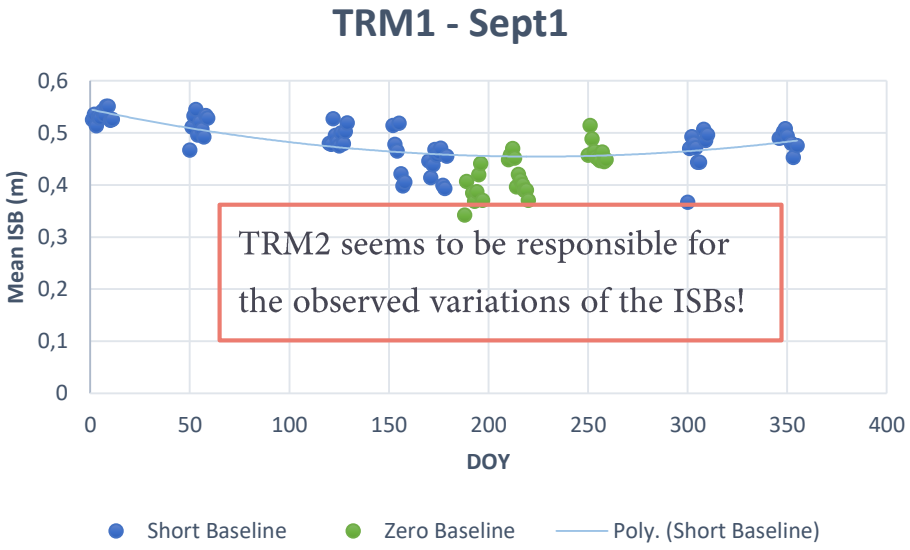
New satellites influence?

Results



Influence of the temperature?

Temperature registered inside the receiver's room



Results

Zero baselines results – Different Receivers

ZB TRM1-TRM2 = 0,26

		GPS L1/Galileo E1				GPS L5/Galileo E5a			
		Mean ISB (m)		Std ISB (m)		Mean ISB (m)		Std ISB (m)	
		Epochs	10-min	Epochs	10-min	Epochs	10-min	Epochs	10-min
TRM1 – Sept2	16a'	0,478	0,479	0,015	0,017	4,359	4,404	0,125	0,080
	16b'	0,432	0,443	0,016	0,052	4,360	4,361	0,098	0,069
TRM2 – Sept1	16a'	0,288	0,287	0,022	0,021	4,427	4,407	0,176	0,082
	16b'	0,182	0,187	0,026	0,024	4,359	4,399	0,064	0,041

ZB TRM1-TRM2 = 0,19

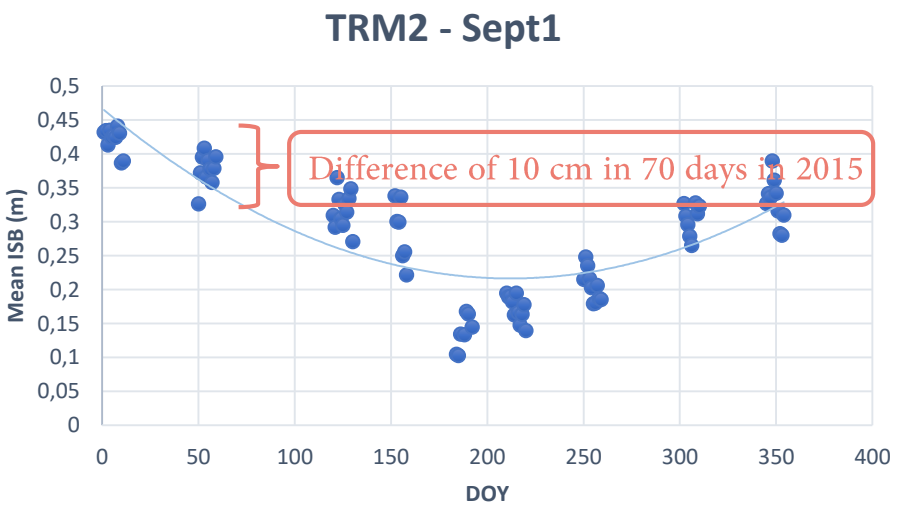
Not considered in the computation : Galileo satellites E18 - E14 - E20

Results

Zero baselines results – Different Receivers

GPS

		Mean ISB (m)	
		Epochs	10-m
TRM1 – Sept2	16a’	0,478	0,479
	16b’	0,432	0,443
TRM2 – Sept1	16a’	0,288	0,287
	16b’	0,182	0,187



Difference of 10 cm in 70 days

Not considered in the computation : Galileo satellites E18 - E14 - E20

Results

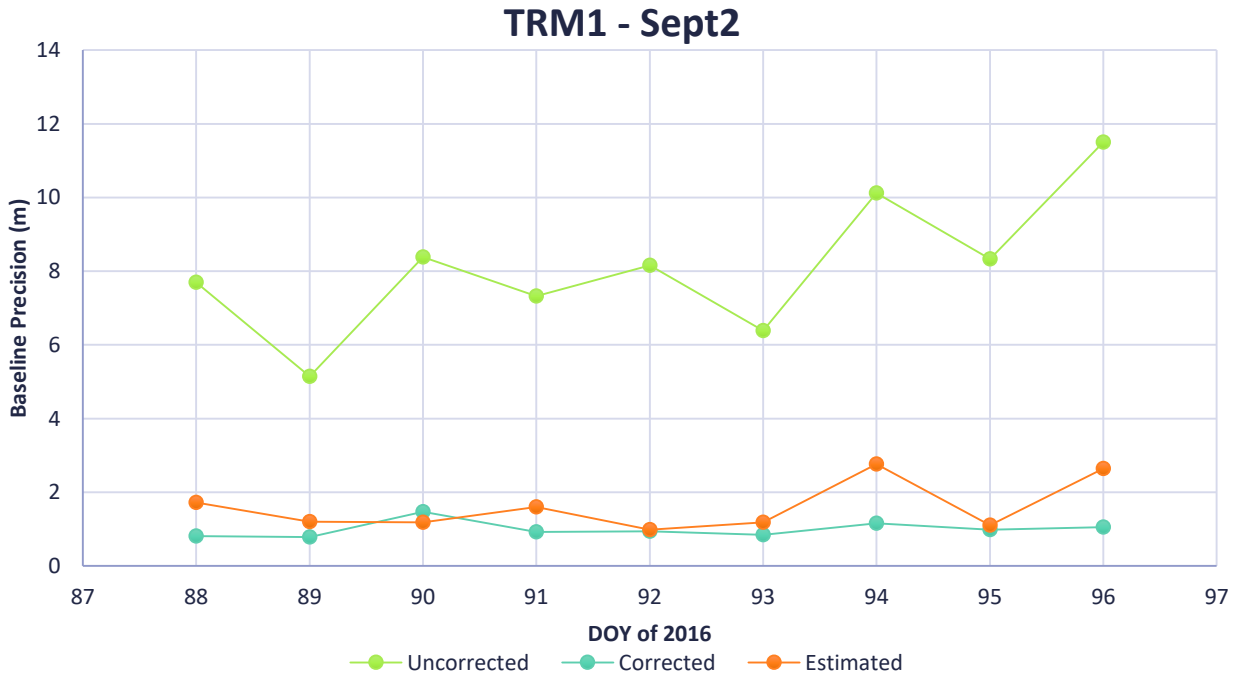
Zero baselines results – Different Receivers

		GPS L1/Galileo E1				GPS L5/Galileo E5a			
		Mean ISB (m)		Std ISB (m)		Mean ISB (m)		Std ISB (m)	
		Epochs	10-min	Epochs	10-min	Epochs	10-min	Epochs	10-min
TRM1 – Sept1	14’	0,488	0,491	0,009	0,013	4,372	4,393	0,009	0,110
	15’	0,385	0,387	0,031	0,037	4,238	4,359	0,099	0,145
TRM2 – Sept3	14’	0,248	0,261	0,052	0,062	4,586	4,563	0,382	0,421
	15’	0,145	0,120	0,022	0,102	4,104	4,451	0,295	0,161
	16a’	0,278	0,292	0,062	0,038	4,321	4,238	0,276	0,250
	16b’	0,163	0,168	0,011	0,024	4,431	4,361	0,050	0,125

Not considered in the computation : Galileo satellites E18 - E14 - E20

Positioning with ISBs

Precision of the computed positions with Galileo E5a/ GPS L5 in zero baseline



Conclusions

- ISBs results in zero baseline
  - Identical receivers :
    - Septentrio receivers : zero value
    - Trimble receivers : non zero value + variation in time
      - Investigation of the variation : Influence of firmware updates, new Galileo's satellites and temperature
  - Different receivers :
    - Variation in time
    - Triangle loop

- Positioning
  - Removing mean ISBs form previous days improve positioning results

Prospects

- Compute phase ISBs
- Further investigate GPSL5/GalileoE5a ISB behaviour
- Extend this research to other frequencies/GNSS
- Tests of the new Septentrio PolaRx5
- Study the longer baseline's ionospheric issues

Thank you for your attention

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