Benefits of additional signals in multi-GNSS PPP measurement processing

Sunil Bisnath
GNSS Laboratory, York University, Toronto, Canada

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INTRODUCTION

- GNSS is a timing system
- GNSS Lab at York University primarily focusses on "PN" of "PNT"
- PPP overview and advancements
- Constellation and signal "evolution"
- Effects of adding constellations and frequencies
- Additional relevant developments
- Conclusions / final thoughts

PRECISE POINT POSITIONING OVERVIEW

Historical context:
Developed to reduce processing load from relative positioning mode for static geodynamics networks

Concept:

Apply *state-space* corrections to *direct* measurements

Fundamental equations:

$$P^s_{r,i} = \rho^s_r + c(dt_r - dt^s) + \gamma_i I^s_1 + M^s_r.T_r + (b_{r,i} - b^s_i) + \epsilon_{P_i}$$
$$\Phi^s_{r,i} = \rho^s_r + c(dt_r - dt^s) - \gamma_i I^s_1 + M^s_r.T_r + \lambda_i(N^s_i + B_{r,i} - B^s_i) + \epsilon_{\Phi_i}$$

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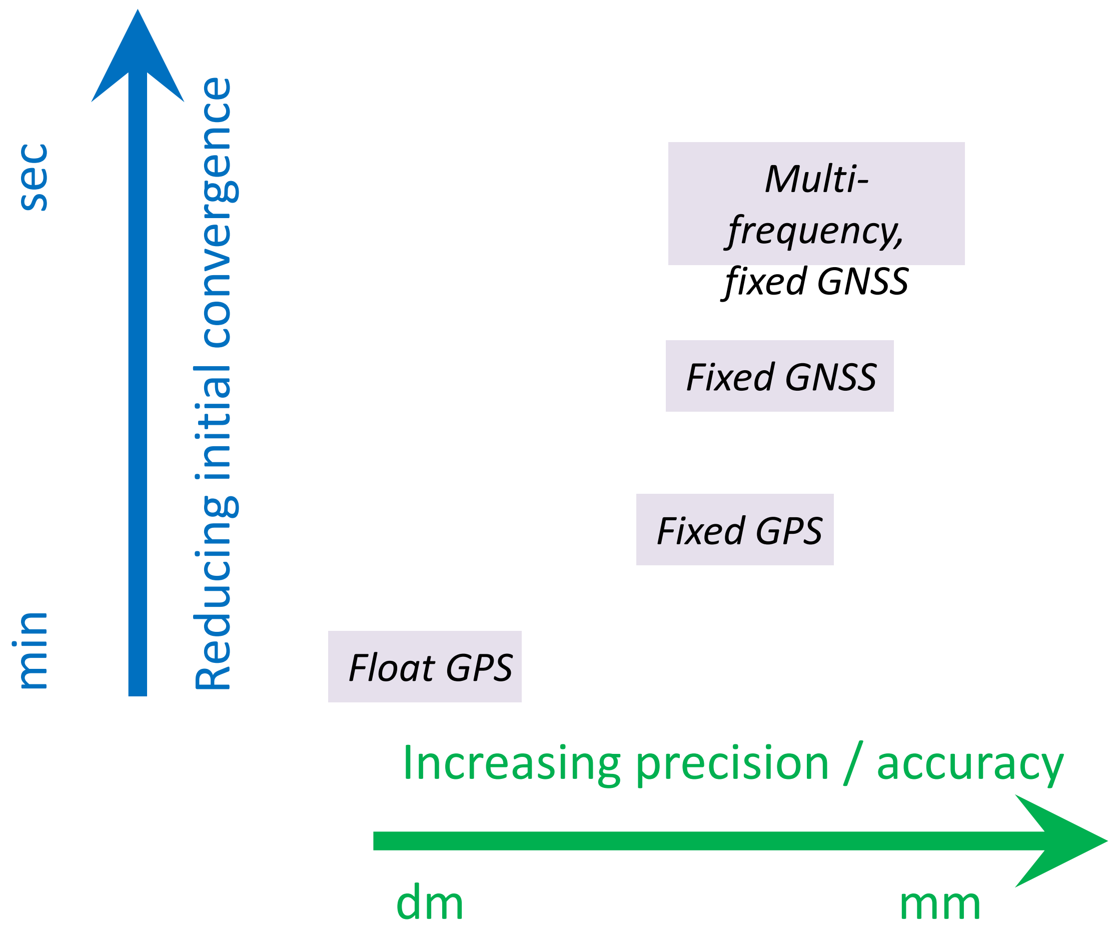
ADVANCEMENTS IN PPP ALGORITHMS AND USAGE

- Dual-frequency GPS float → "conventional PPP"
  - Scientific applications
  - Select commercial applications in remote areas
- Dual-frequency GPS fixed; ionospheric constraining
  - Reduced initial convergence and re-convergence; increased accuracy
  - Wider scientific and commercial adoption
- Dual-frequency GNSS fixed
- Multi-frequency GNSS fixed; ionospheric constraining
  - Rapidly expanding commercial use

PRIMARY DRIVER FOR INCREASING PPP PERFORMANCE – *MEASUREMENT STRENGTH*



Also function of:

- Iono constraining
- Quality of h/w
- Quality of corrections
- Processing s/w
- Static/kinematic

CURRENT NUMBER OF ACTIVE SATELLITES

Constellation	MEO	GEO / IGSO
GPS	31	-
GLONASS	24	-
Galileo	22	-
BDS-2 (15) / BDS-3 (29)	27	7 / 10
QZSS	-	4
NAVIC	-	3 / 4
Totals	**104**	**28**

→ ***132***

100+ satellite
global constellation

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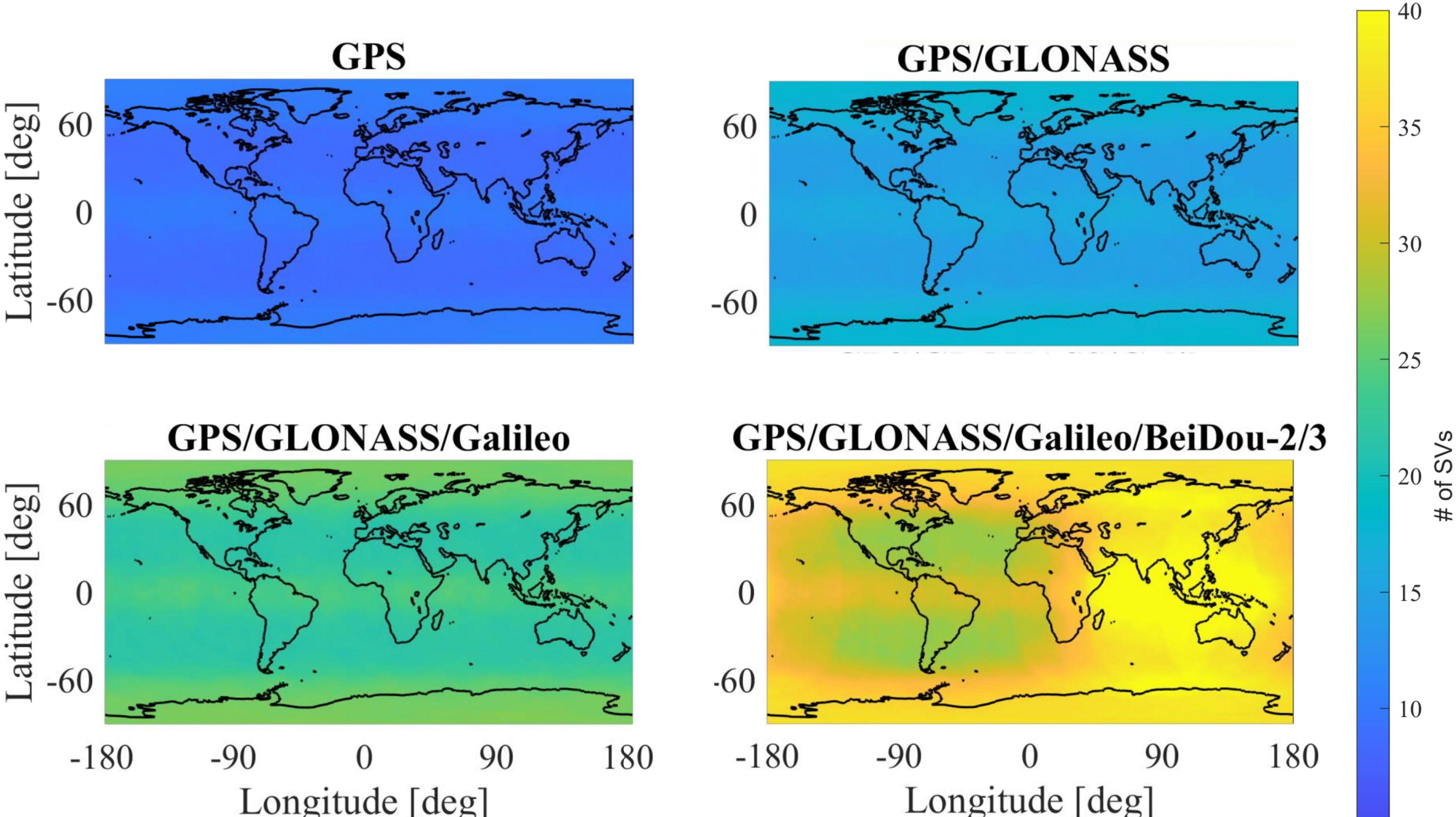
IMPACT OF MULTI-GNSS ON TERRESTRIAL USERS:

SATELLITE AVAILABILITY



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Observed satellites, daily average, 10° cutoff

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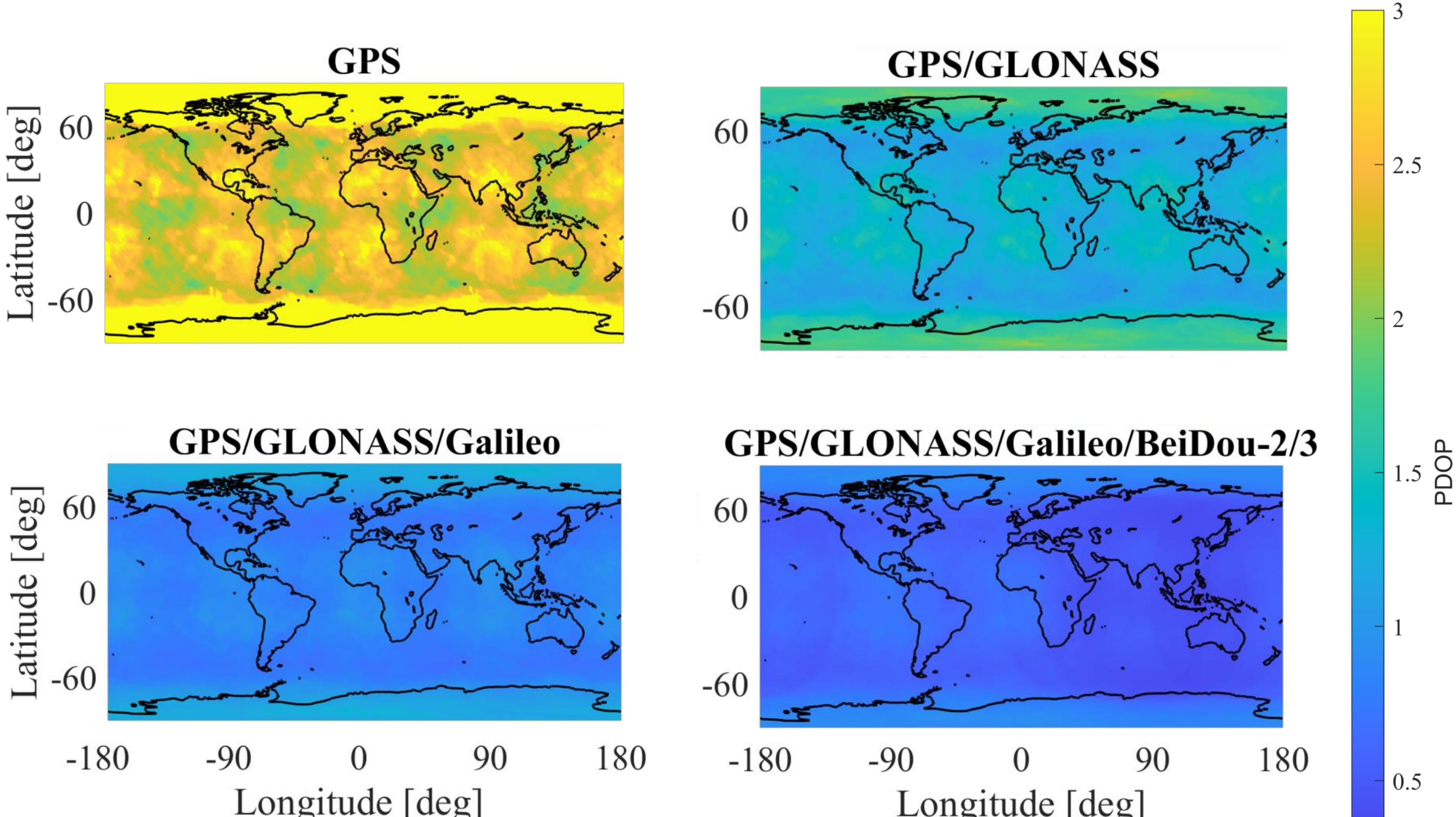
IMPACT OF MULTI-GNSS ON TERRESTRIAL USERS: *MEASUREMENT GEOMETRY – **POSITIONING***



PDOP, daily average, 10° cutoff

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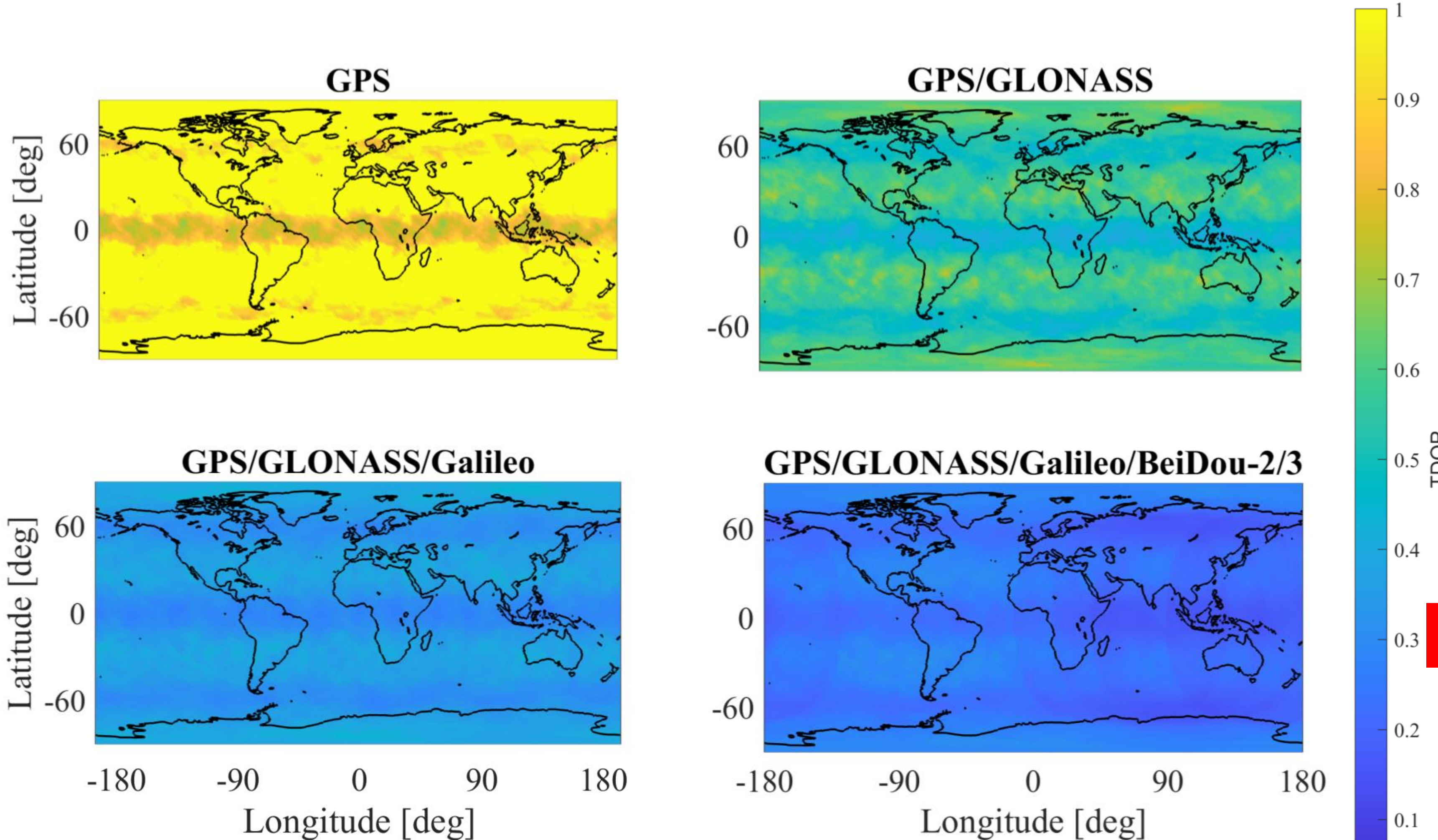
IMPACT OF MULTI-GNSS ON TERRESTRIAL USERS:

*MEASUREMENT GEOMETRY – **TIMING***



~ ns

TDOP, daily average, 10° cutoff

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AVAILABLE MULTI-GNSS SIGNALS / MODULATIONS: *ORIGINAL SINGLE-FREQUENCY*

Constellation	Link	Frequency (MHz)	Bandwidth (±MHz)	Wavelength (cm)	Modulations *FDMA
GLONASS*	G1	1602.00	0.5, 5.0	18.7	C/A, P
GPS	L1	1575.42	1.023, 10.23, 2, 15	19.0	C/A, P(Y), L1C, M

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AVAILABLE MULTI-GNSS SIGNALS / MODULATIONS:
ORIGINAL GPS AND GLONASS

Constellation	Link	Frequency (MHz)	Bandwidth (±MHz)	Wavelength (cm)	Modulations *FDMA
GLONASS*	G1	1602.00	0.5, 5.0	18.7	C/A, P
GPS	L1	1575.42	1.023, 10.23, 2, 15	19.0	C/A, P(Y), L1C, M
GLONASS*	G2	1246.00	0.5, 5.0	24.1	C/A, P
GPS	L2	1227.6	10.23, 1.023, 15	24.4	P, L2C, M

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AVAILABLE MULTI-GNSS SIGNALS / MODULATIONS: *CURRENT*

Constellation	Link	Frequency (MHz)	Bandwidth (±MHz)	Wavelength (cm)	Modulations *FDMA
GLONASS*	G1	1602.00	0.5, 5.0	18.7	C/A, P
GPS	L1	1575.42	1.023, 10.23, 2, 15	19.0	C/A, P(Y), L1C, M
Galileo	E1	1575.42	12.276	19.0	E1A, E1B, E1C
BeiDou	B1C	1575.42	16.368	19.0	B1C
BeiDou	B1I	1561.098	2.046	19.2	B1
Galileo	E6	1278.75	20.46	23.4	E6A, E6,B, E6C
BeiDou	B3	1268.52	10.23	23.6	B3, B3-A
GLONASS*	G2	1246.00	0.5, 5.0	24.1	C/A, P
GPS	L2	1227.6	10.23, 1.023, 15	24.4	P, L2C, M
Galileo	E5b	1207.14	10.23	24.8	E5b-I, E5b-Q
BeiDou	B2b	1207.14	10	24.8	B2b-P, B2b-D
Galileo	E5	1191.795	25.575	25.2	AltBOC
GPS	L5	1176.45	10.23	25.5	L5I, L5Q
Galileo	E5a	1176.45	10.23	25.5	E5a-I, E5a-Q
BeiDou	B2a	1176.45	10.23	25.5	B2a-P, B2a-D

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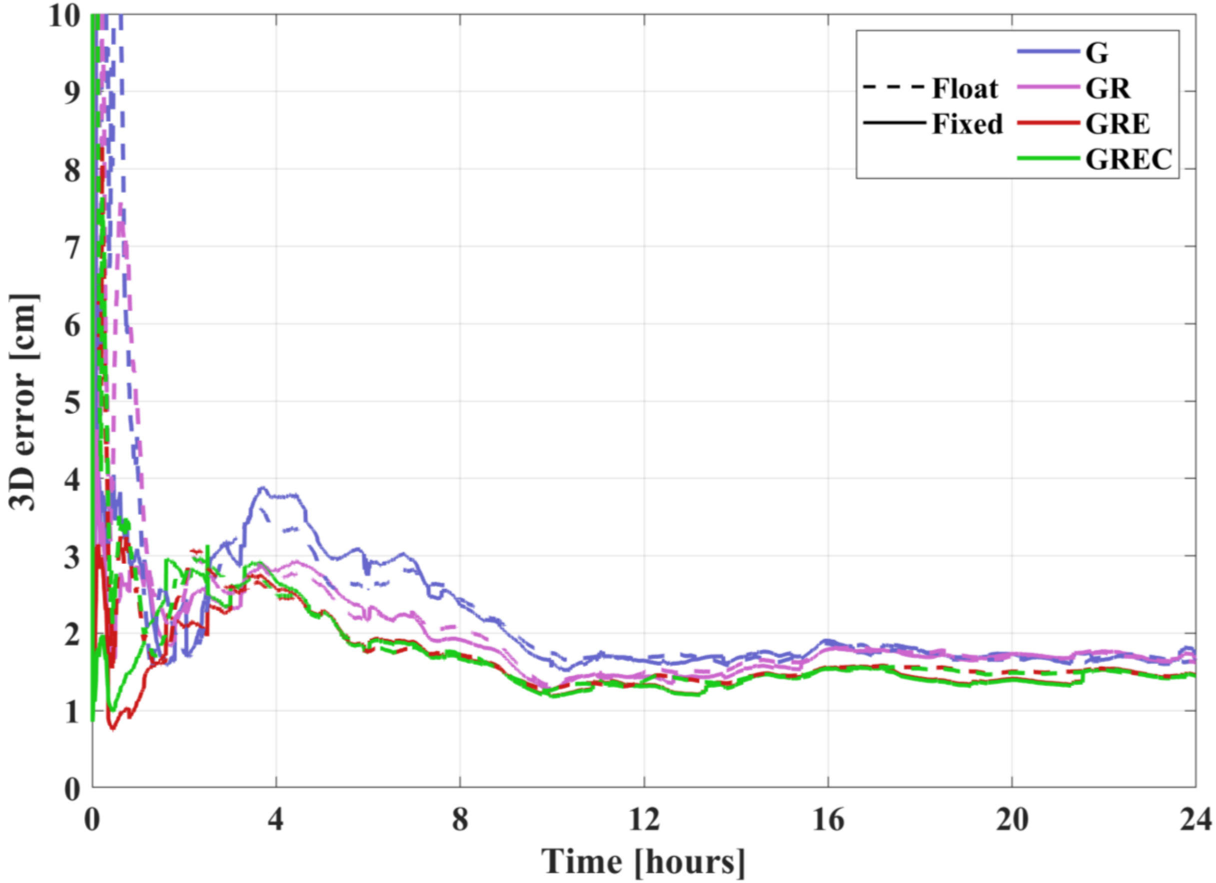
EFFECTS OF ADDING CONSTELLATIONS

Static station UNB3, Canada on DOY 72, 2021. Rapid products. Dual-frequency



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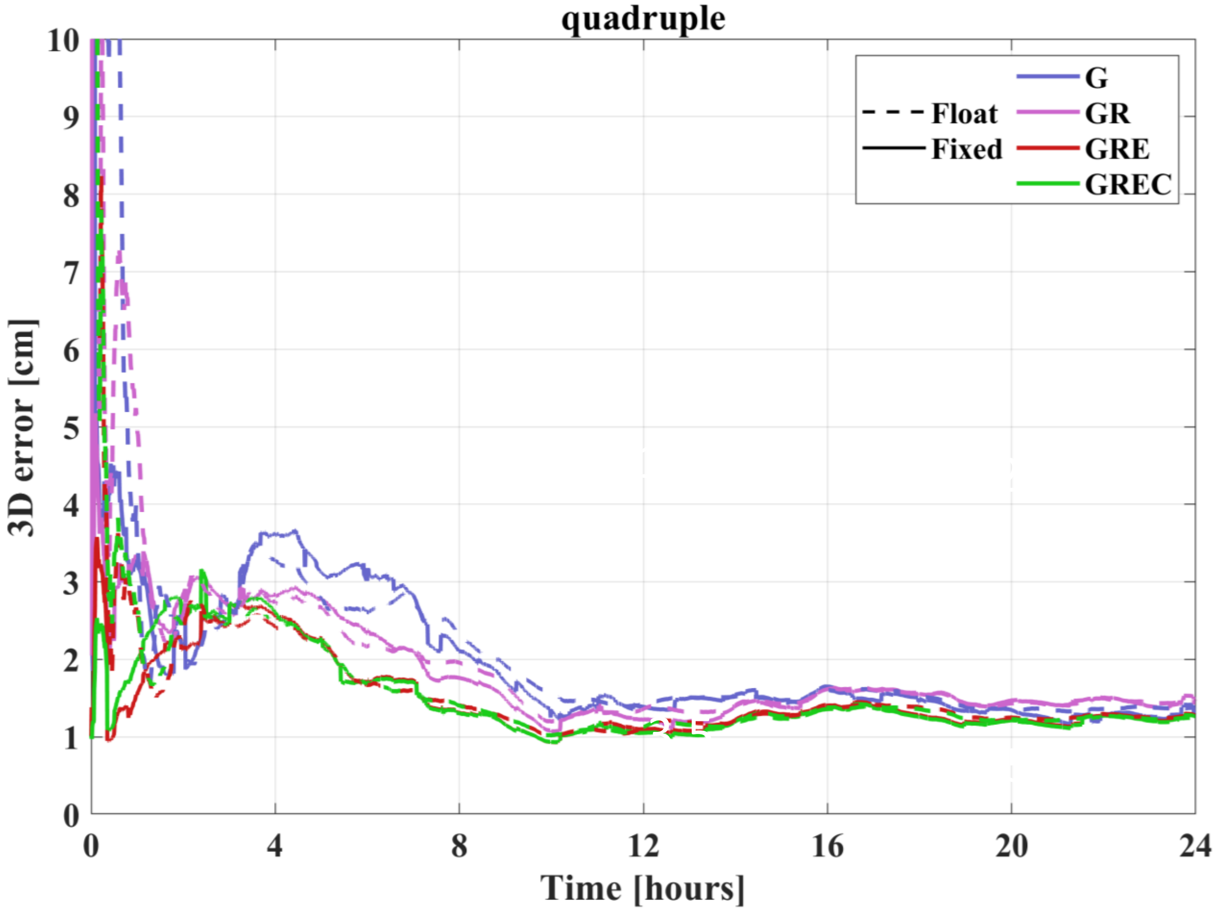
EFFECTS OF ADDING FREQUENCIES

Static station UNB3, Canada on DOY 72, 2021. Rapid products.



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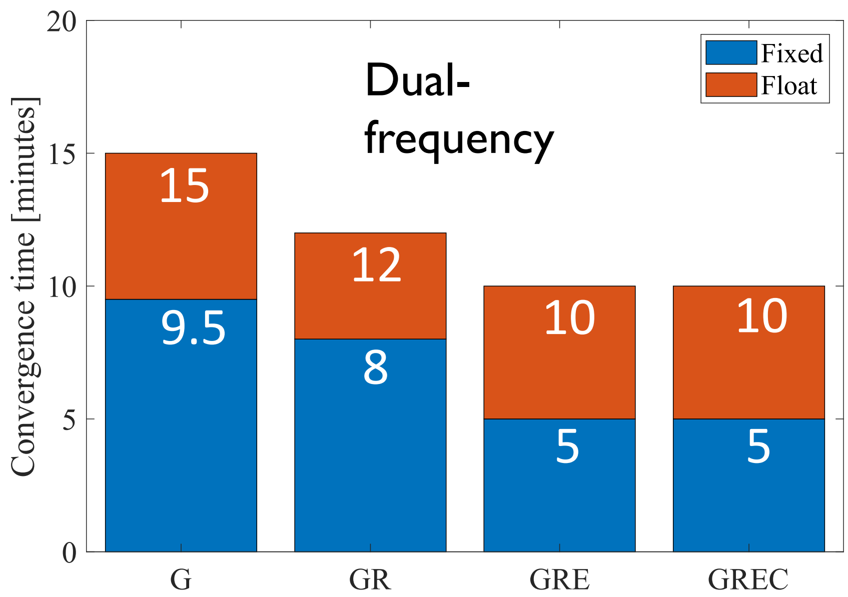
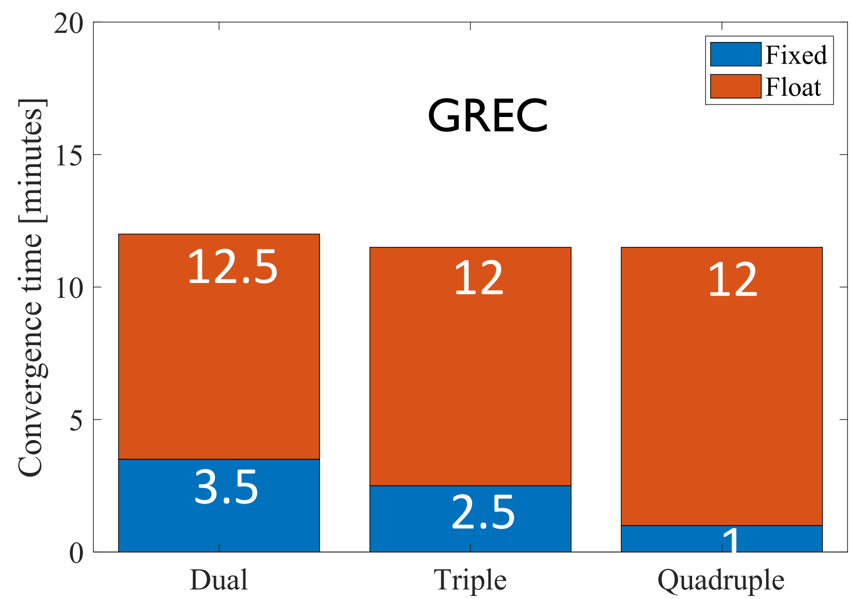
INITIAL CONVERGENCE IMPROVEMENT WITH ADDITIONAL CONSTELLATIONS AND FREQUENCIES

Average processing *95 percentile* results from one week of global, stationary geodetic data, processed in *kinematic mode*

Convergence time: time to *10 cm horizontal error*



(BDS-3 not included)



(slightly different dataset; BDS-3 included)

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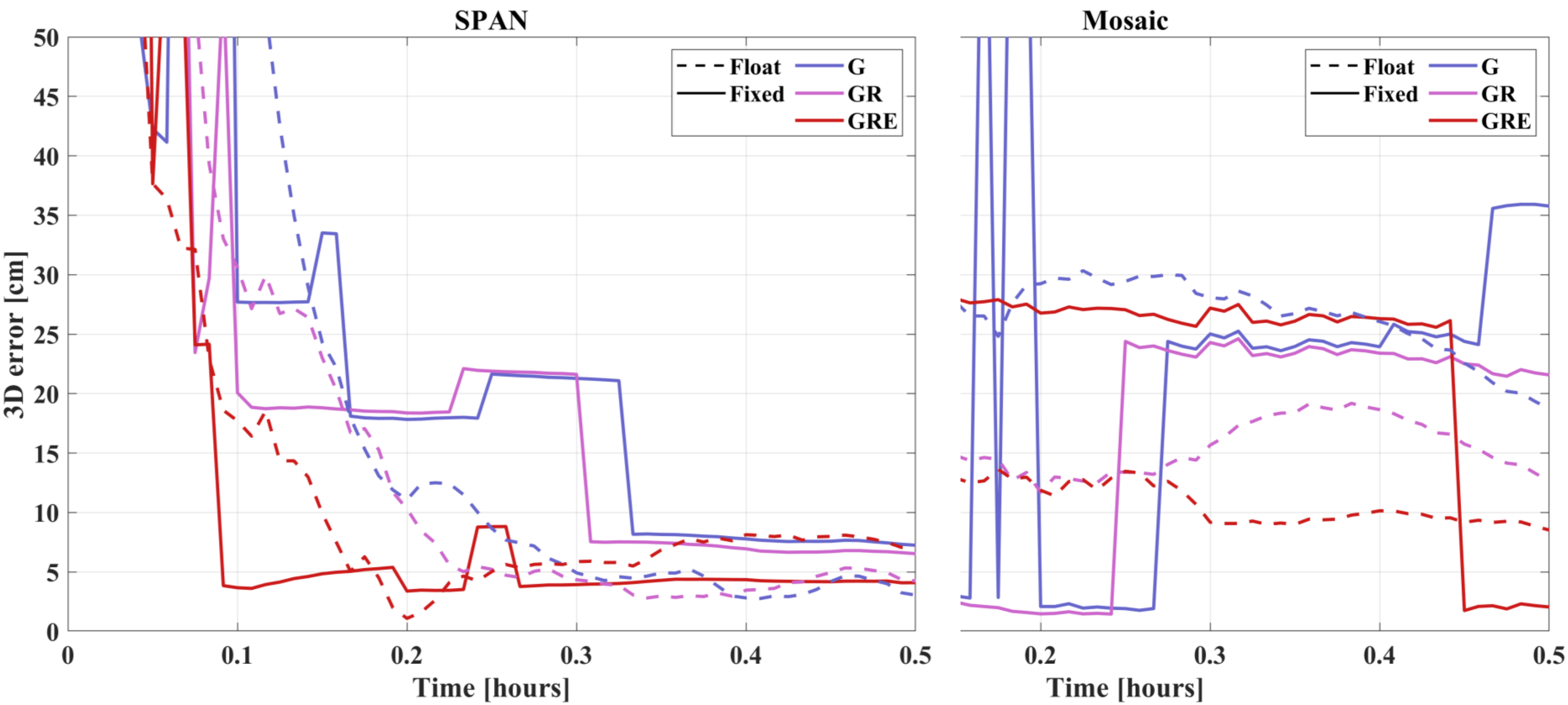
STATIC GEODETIC COMPARED TO MASS-MARKET HARDWARE

Dual-frequency geodetic (OEM7/SPAN) and mass-market (Mosaic/Tallysman) static in Toronto on DOY 151, 2021



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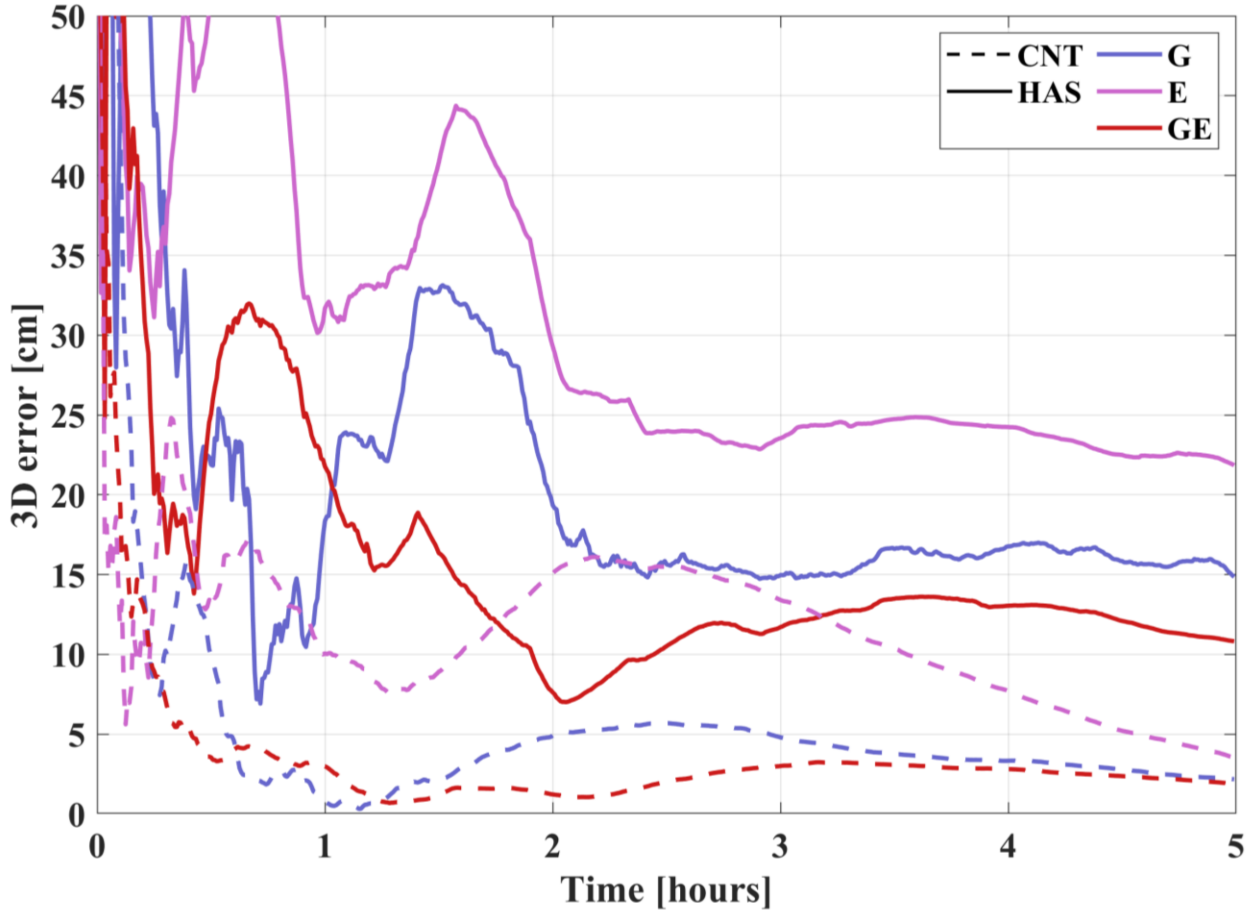
GALILEO HIGH ACCURACY SERVICE (HAS) "SNEEK PEAK"

- Initial testing signals; eventual GE PPP
- Station ALBH, Canada DOY 202, 2021
- HAS orbits/clocks; CNT orbits / clocks / biases



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KEY APPLICATIONS FOR PPP

Scientific:

Geodynamics, orbit determination, tides

Commercial:

Surveying/mapping, off-shore, precision agriculture

Mass market:

Autonomous vehicles, smartphones

CONCLUSIONS / FINAL THOUGHTS

- Numerous PPP enhancements
- Performance: minute initialization to <dm horizontal
- Performance: mm horizontal / cm 3D positioning
- Additional measurements allowing PPP usage to greatly expand
- PPP can be seen as s/w to augment mass-market h/w
- New constellation-based services such as Galileo HAS will provide direct PPP performance – perhaps making PPP natural mode of GNSS
- PPP can significantly benefit user performance (accuracy, availability, integrity, resilience)

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