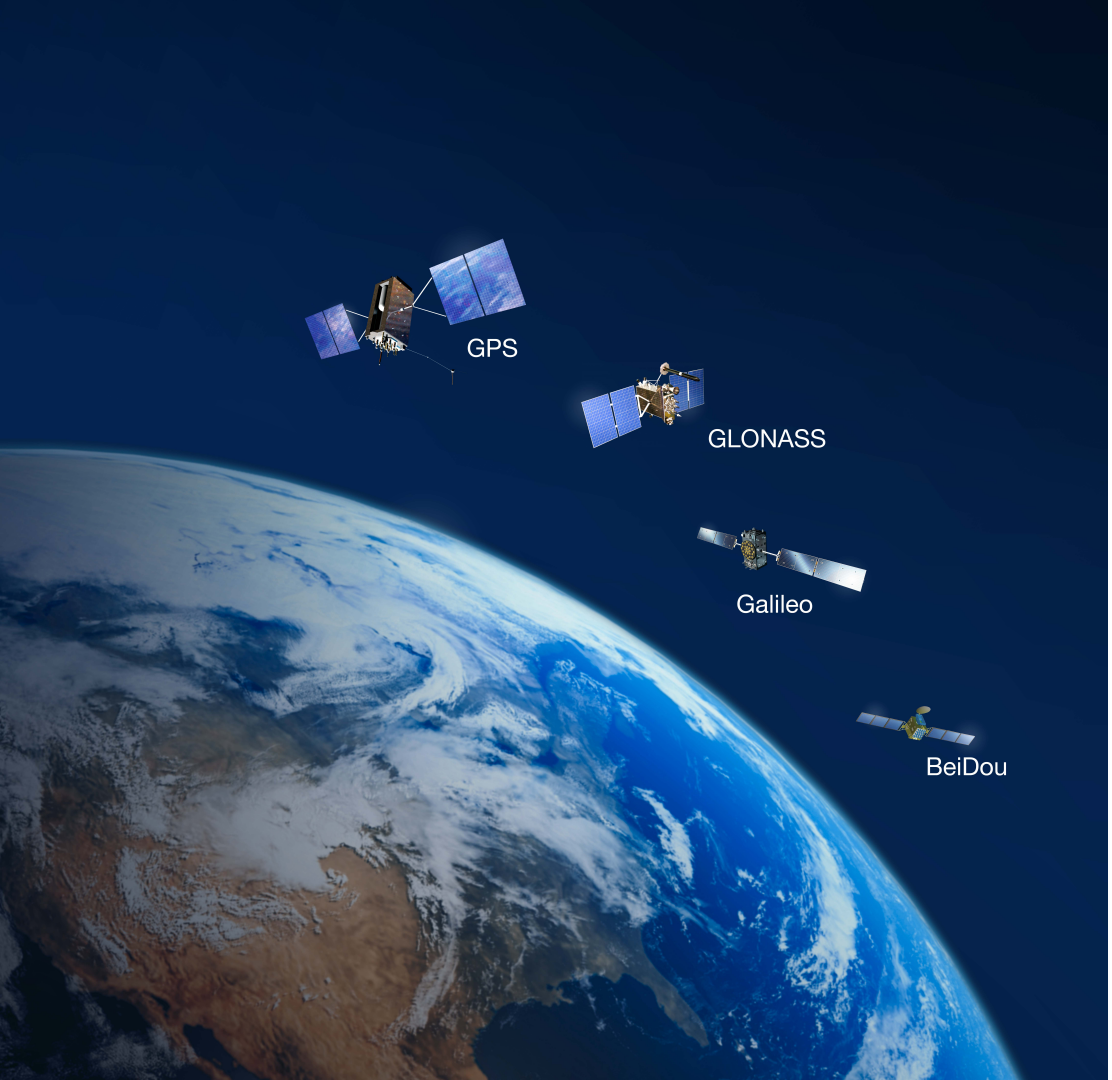

Multi-GNSS Ultras (≥ 4 constellation)

Achievability = Timeliness + Quality

Ant Sibthorpe
and
The GDGPS Team

Jet Propulsion Laboratory
California Institute of Technology

GDGPS
Jet Propulsion Laboratory

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Outline

Achievability

- Motivation
- Data
- Timeliness
- Quality
  - Orbits and Clocks
  - PPP
- Summary

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Motivation

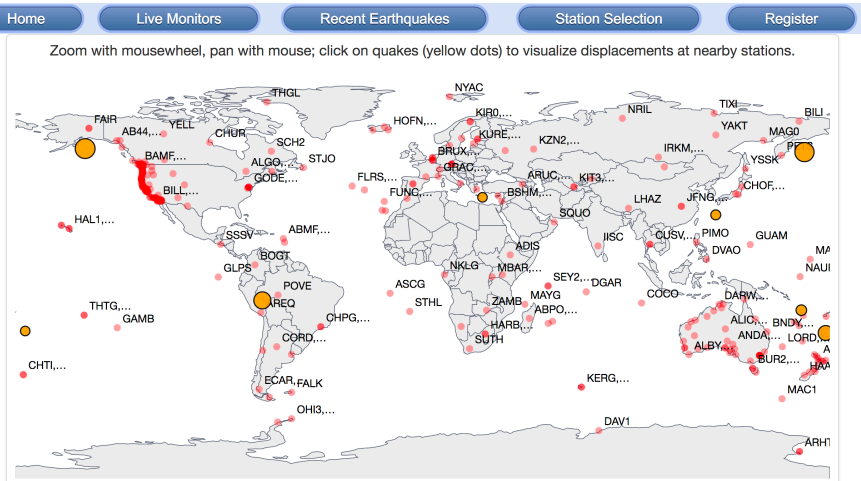
The need for speed … ?

Ultra products are intended to be:

- "Precise" (smoothed)
- Low-latency (1-2 hours), often leads to smaller station network (~50?)

Typically used for:

- Real-time (filter-only) QC
- Natural hazard monitoring, e.g. earthquake



Magnitude	Place	Time	ID
5	South of the Fiji Islands	Mon, 17 Sep 2018 09:32:41 GMT	us2000hfru
5.1	166km E of Nago, Japan	Mon, 17 Sep 2018 02:32:10 GMT	us2000hfp0
5	South of Tonga	Mon, 17 Sep 2018 02:01:42 GMT	us2000hfnm
5.3	36km ENE of Luganville, Vanuatu	Mon, 17 Sep 2018 00:24:15 GMT	us2000hfmc
5	80km SE of Makry Gialos, Greece	Mon, 17 Sep 2018 00:24:10 GMT	us2000hfm5
6.5	South of the Fiji Islands	Sun, 16 Sep 2018 21:11:48 GMT	us2000hfjk
7.1	138km WNW of Iberia, Peru	Fri, 24 Aug 2018 09:04:06 GMT	us1000ggj4
7.9	280km SE of Kodiak, Alaska	Tue, 23 Jan 2018 09:31:40 GMT	us2000cmy3
7.7	202km ESE of Nikol'skoye, Russia	Mon, 17 Jul 2017 23:34:13 GMT	us20009x42

https://ga.gdgps.net

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Data

The never-ending search for perfect observations …

- Processing 30 days from January 2018
  - Simulated ops environment, i.e. no special treatment
  - One 30-hour arc centered at noon for each day
- RINEX3 dual frequency ionosphere-free combinations:

	Phase & Range
BDS (C)	2I, 7I
GAL (E)	1C, 5Q
GPS (G)	1W, 2W
GLO (R)	1C, 2P

ftp://cddis.gsfc.nasa.gov

ftp://igs.bkg.bund.de

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Timeliness

Does a watched POD ever boil … ?

- Intel(R) Xeon(R) Gold 6144 CPU @ 3.50GHz, 16 physical cores (32 virtual), 128Gb RAM
- 30s data edited down to 5-mins
- POD GPS data are currently native W only!

	Duration(s)
Observation assembly/editing (~185 stations)	220
Make broadcast orbits/clocks	130
Input data QA (incl. PPP)	340
POD (~90 satellites, 50 stations)	2340
Total	3030

Total	~50 minutes

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Quality

Assessed using products from IGS MGEX ACs

- Orbit and clock differences are computed pairwise over each of the following datasets:
  - MGEX vs MGEX (CNES, CODE, GFZ, WUH)
    - i.e. MGEX internal agreement
  - JPL vs MGEX
    - i.e. JPL's agreement with MGEX
- PPP repeatability

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Quality

Maximum number of satellites on any one day:

	BDS GEO	BDS IGSO	BDS MEO	GAL	GPS	GLO	STNS
CNES	0	0	0	16	31	23	~115
CODE	0	6	3	16	32	23	~130
GFZ	5	6	3	16	31	23	~130
WUH	5	6	3	16	31	23	~130
JPL	5	6	3	14*	31	24	~50

* "unhealthy" broadcast satellites (i.e. E201, E202) excluded by default

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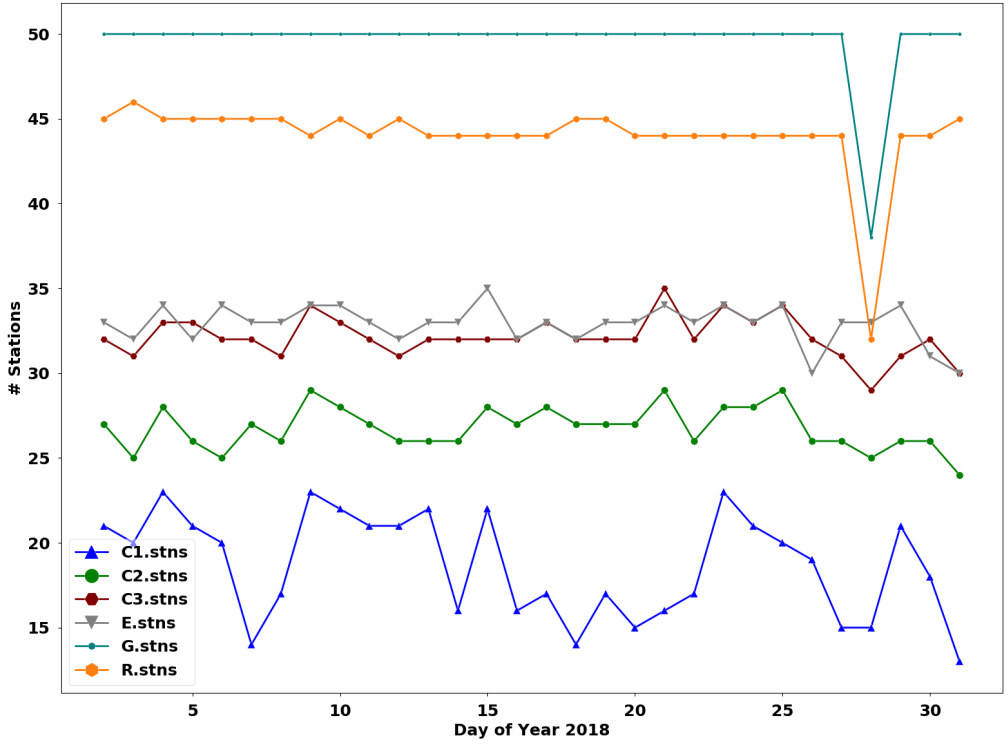
Quality

Per-satellite network breakdown:

C1 (GEO)
C2 (IGSO)
C3 (MEO)



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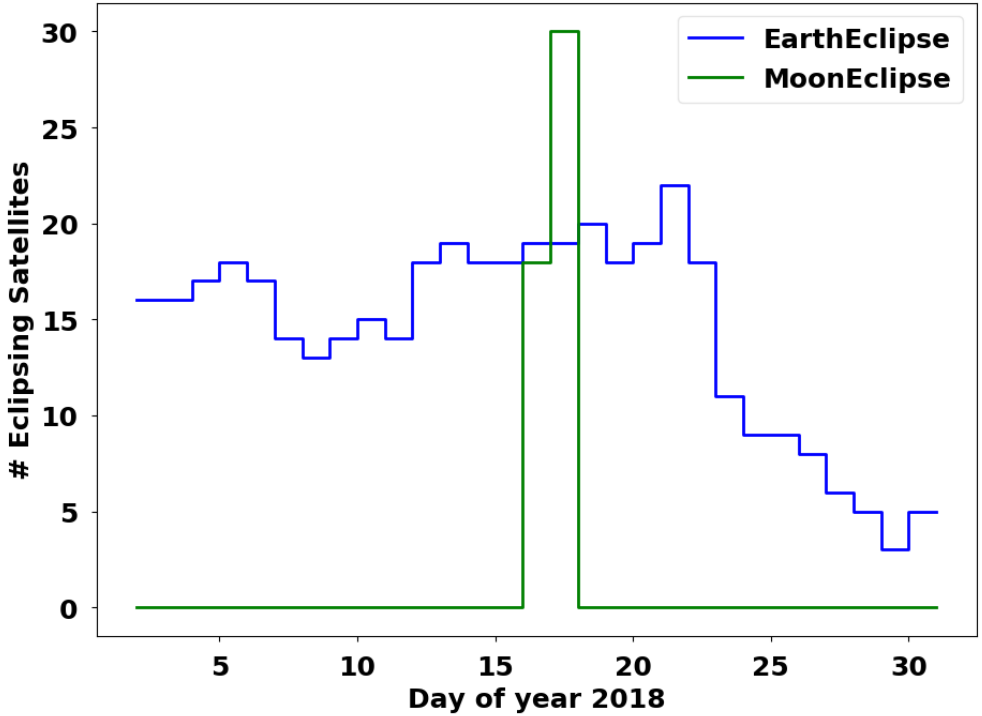
Quality

Eclipse – possible attitude issues…?



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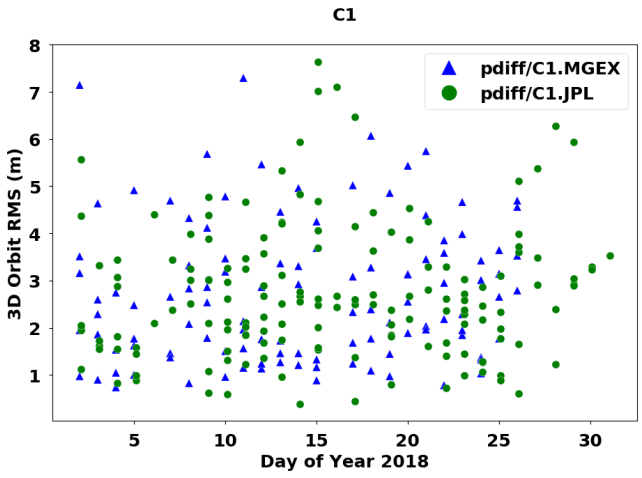
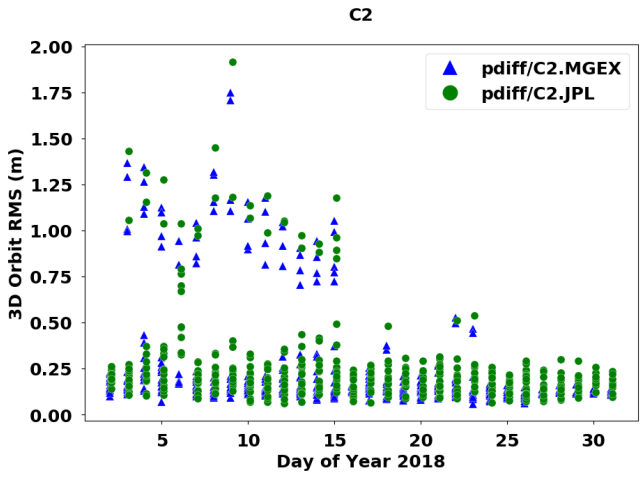
Quality

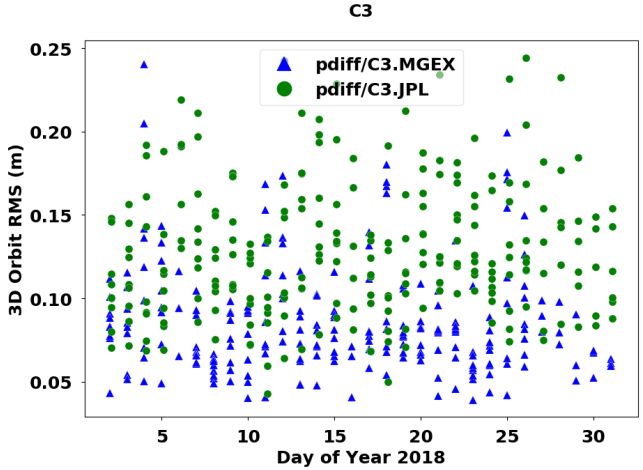
Orbits

All units are in meters





	Type	#	RMS(m)	StDev(m)
C1 (GEO)	MGEX	110	3.114	1.479
	JPL	156	3.083	1.413
C2 (IGSO)	MGEX	456	0.383	0.292
	JPL	463	0.346	0.239
C3 (MEO)	MGEX	228	0.092	0.033
	JPL	249	0.134	0.039



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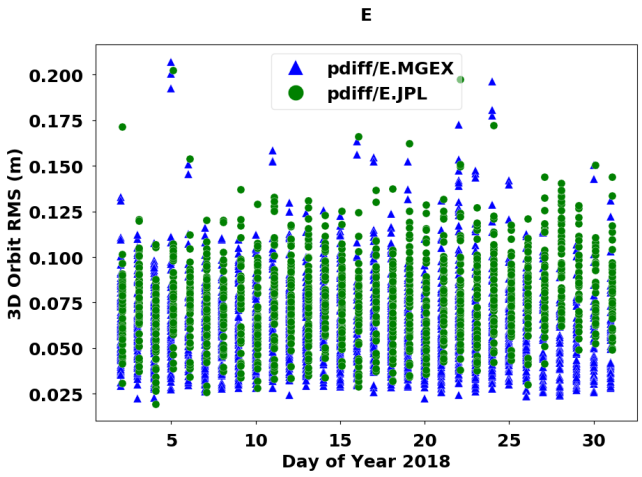
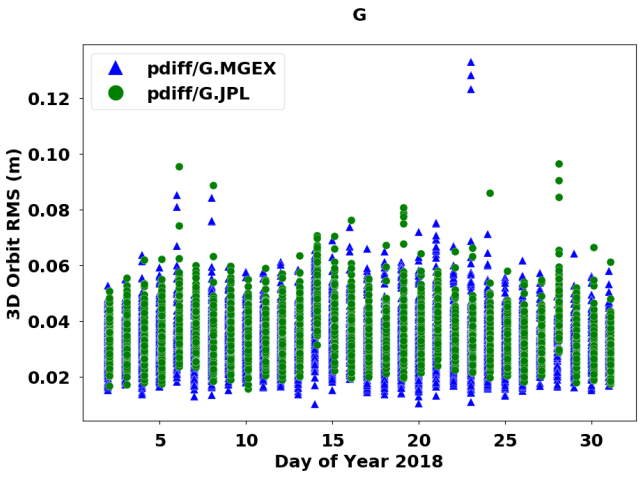
Quality

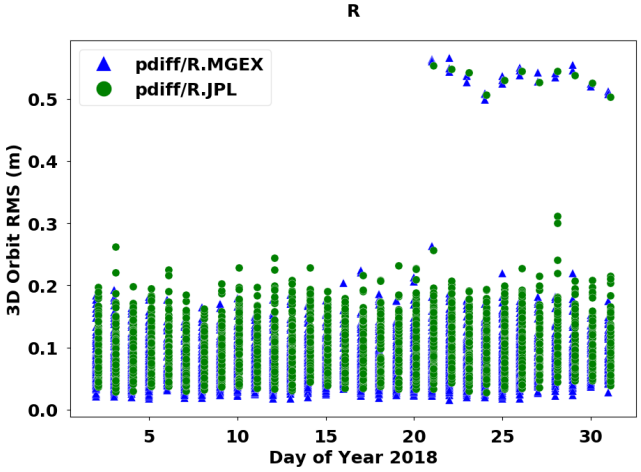
Orbits

All units are in meters





	Type	#	RMS(m)	StDev(m)
E	MGEX	2538	0.065	0.023
	JPL	1509	0.081	0.022
G	MGEX	4893	0.034	0.010
	JPL	3407	0.038	0.009
R	MGEX	3584	0.091	0.053
	JPL	2448	0.118	0.051



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Quality

Clocks

"Different satellite antenna PCOs and PCVs are used by the MGEX analysis centers processing BeiDou:"

Analysis center	BDS PCOs/PCVs
CODE	MGEX conventional
GFZ	Dilssner et al. (2014)
Wuhan Univ.	Guo et al. (2016)

http://mgex.igs.org/IGS_MGEX_Products.php

For now, like CODE, JPL's multi-GNSS ultras also use "MGEX conventional"

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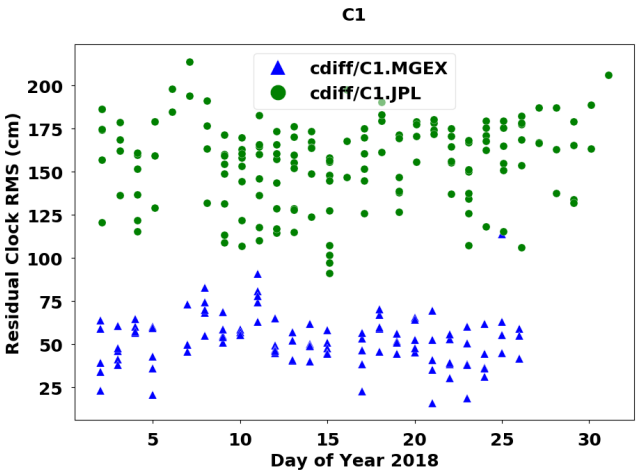
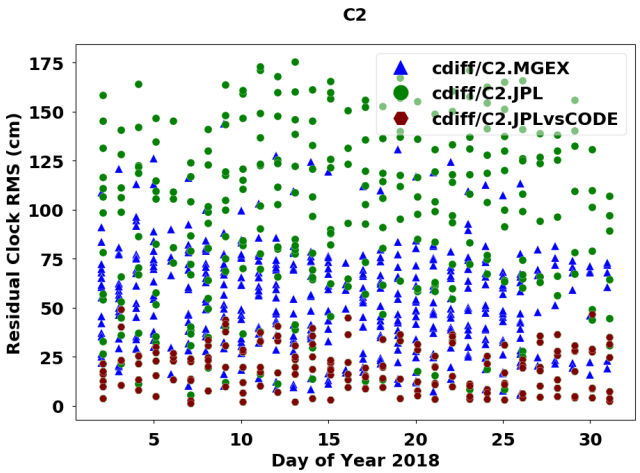
Quality

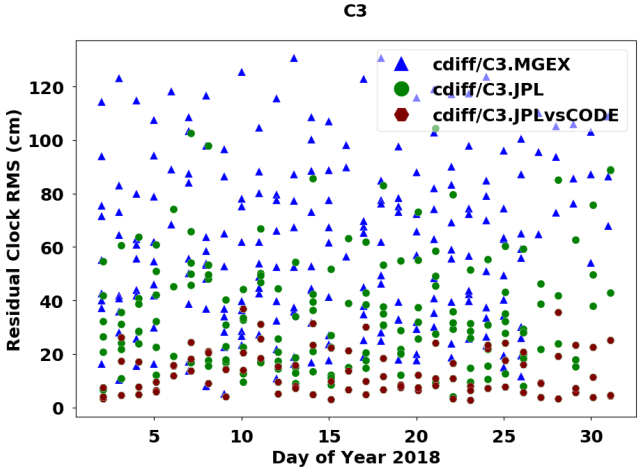
Clocks





C1 (GEO)	C2 (IGSO)	C3 (MEO)

No stats reported here. They don't make much sense due to the strong dependence of the clock solutions on PCOs.



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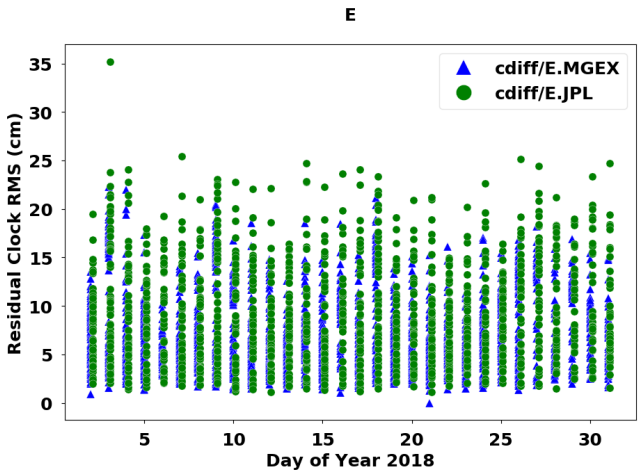
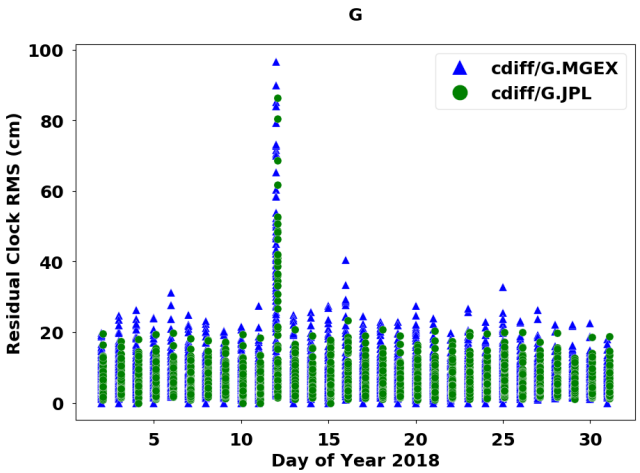
Quality

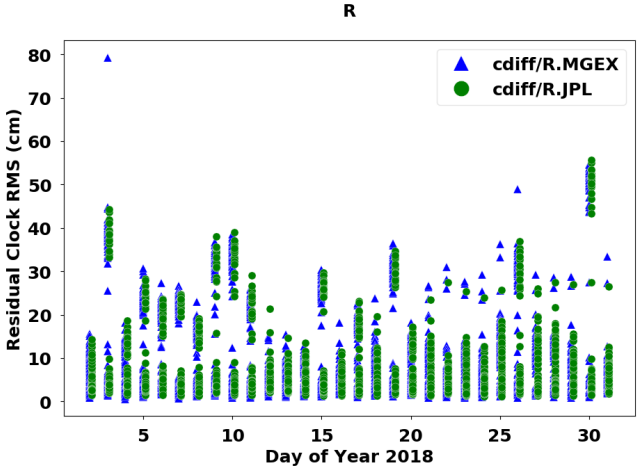
Clocks

All units are in centimeters





	Type	#	RMS(cm)	StDev(cm)
E	MGEX	2538	8.16	4.05
	JPL	1509	10.36	5.23
G	MGEX	4891	10.18	6.89
	JPL	3406	7.57	4.93
R	MGEX	3584	15.54	10.79
	JPL	2359	11.62	8.57



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Quality

PPP

- >730 station days (some overlap with POD)
- Traditional CA-P (DCB) range adjustment allowed
- Non-ambiguity resolved – software issue (now fixed) prevented writing of WLPB files when post-smooth editing
- No editing of results
- GPS-only. Checking for direct degradation vs current "best" solution

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Quality

PPP

- Bertiger, . et al. (2010) Single receiver phase ambiguity resolution with GPS data. J Geod 84: 327. https://doi.org/10.1007/s00190-010-0371-9

Table 6. 2008-06-01 to 2008-11-30 using 106 IGS05 frame definition stations

	E stdev (mm)	N stdev (mm)	V stdev (mm)
Unresolved/VMF1	2.9	2.1	6.0

- Consider what might affect reproducibility given different data period / network

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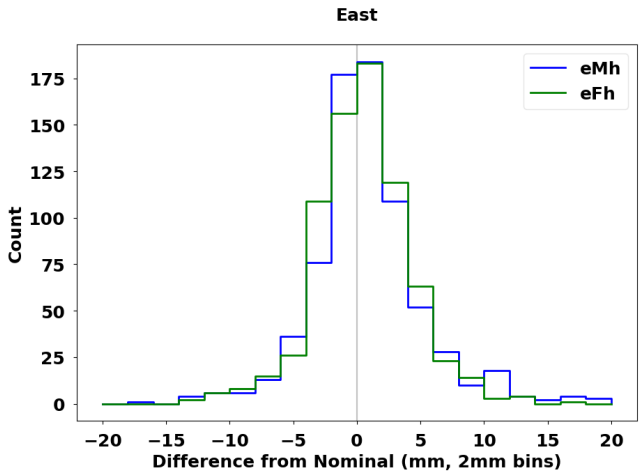
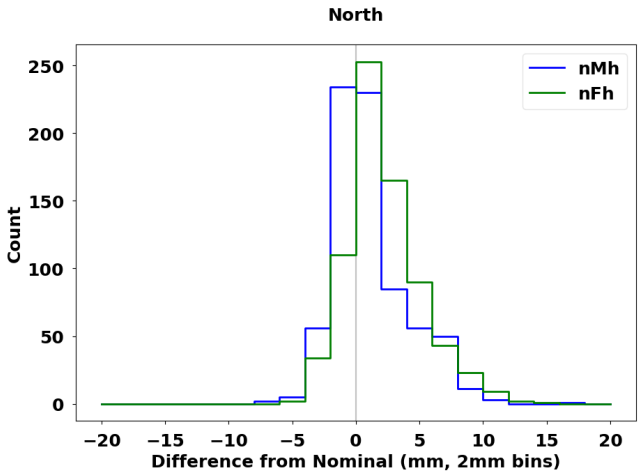
Quality

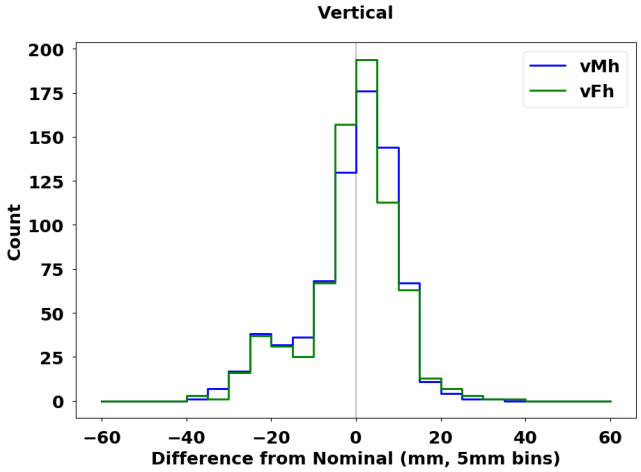
PPP





Not bias-fixed	E stdev (mm)	N stdev (mm)	V stdev (mm)
MultiGNSS	4.3	2.9	11.0
Flinn	3.7	2.9	10.7

For January 2018, repeatability of station standard deviations appears to be worse than in Bertiger et al. (2010). Why is it worse for both product types … ?



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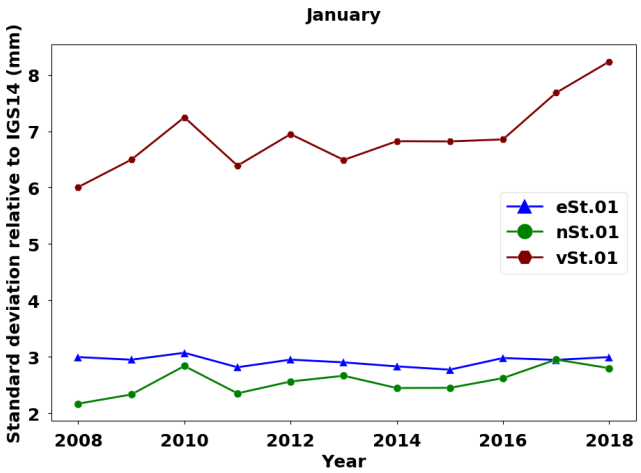
Quality

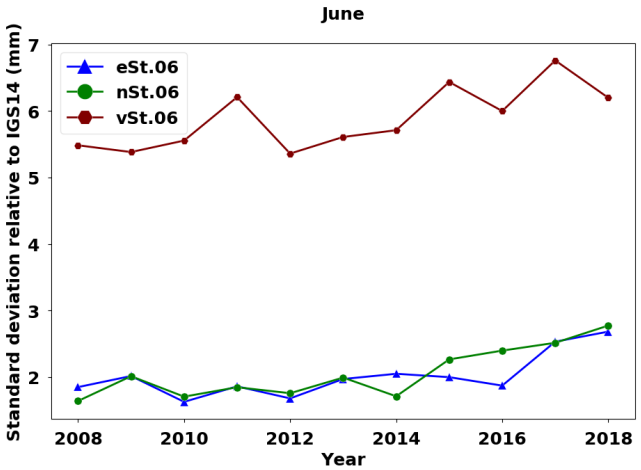
PPP – frame degradation & seasonality

E stdev (mm)	N stdev (mm)	V stdev (mm)
2.9	2.1	6.0

Bertiger et al. (2010)

- ITRF14 assimilated data from 1994-01 to 2015-02
- IGS14 – IGS realization of ITRF14
- Total of 48 stations common across 2008-2018
- PPP 48 stations for January & June, 2008-2018
- Unresolved / GPT2
- Scatter computed relative to IGS14 in ENV





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Quality

Achievability

Low-latency 4-constellation ultra-products are desirable for near-real-time monitoring of real-time processes and for rapid natural hazard response.

- A 30-hour, 90-satellite, 50-station run with data batches every 300s takes ~50 minutes from beginning to end
- Ultra products agree closely with MGEX, up to BDS PCOs
- GPS not degraded
- PPP results using multi products compare well with those using final GPS-only solutions

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