Systematic Errors in Estimation of GPS Clock States

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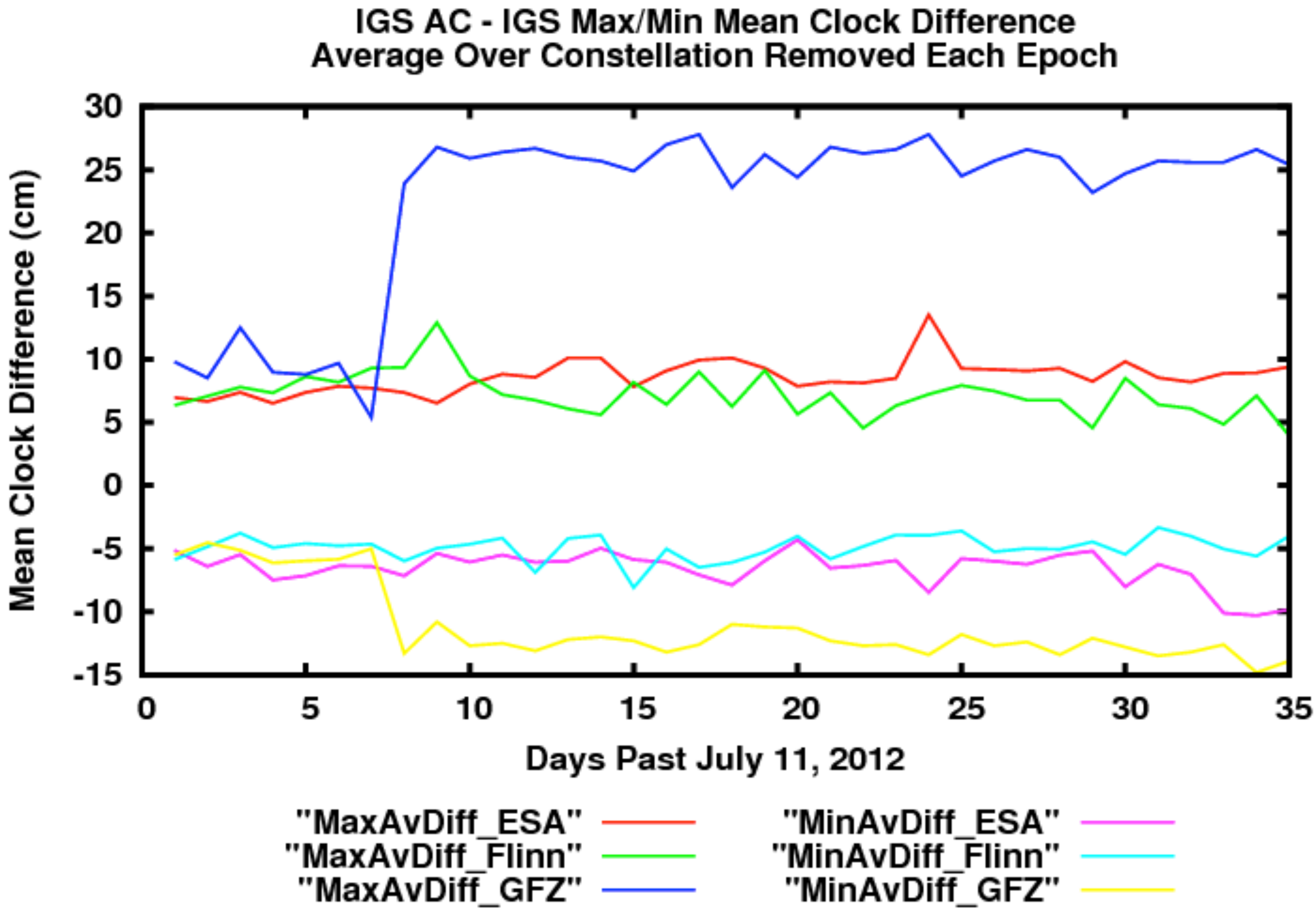
Motivation – the Quest for Truth

Context: assess the accuracy of a GPS orbit/clock determination process based on a small global network

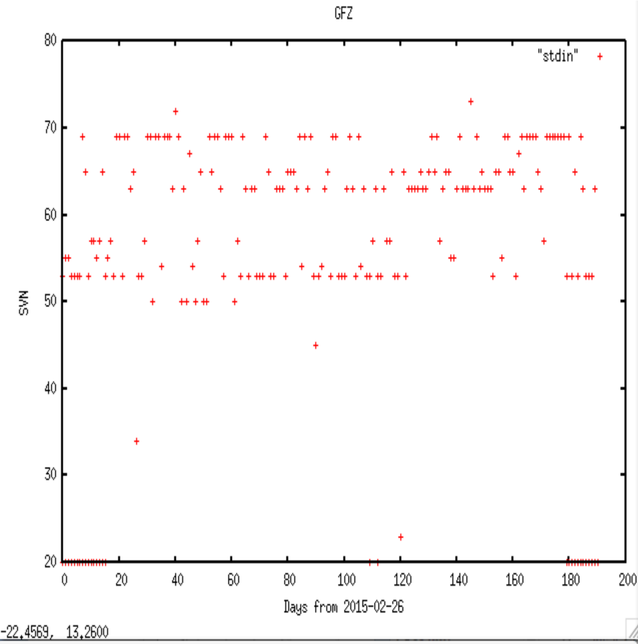
Challenge: tight error metrics, some in terms of *maximum value* for individual satellites (as opposed to *constellation RMS*)

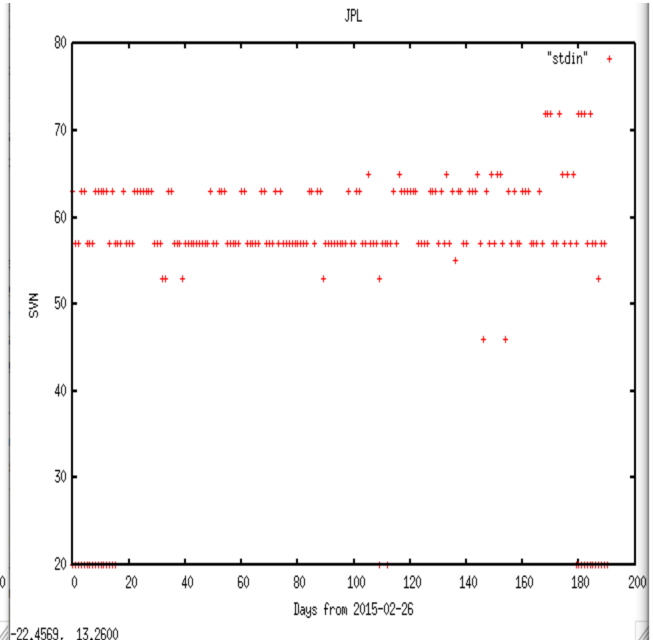
IGS AC's Final solutions showed large clock biases relative to the IGS Final Combined

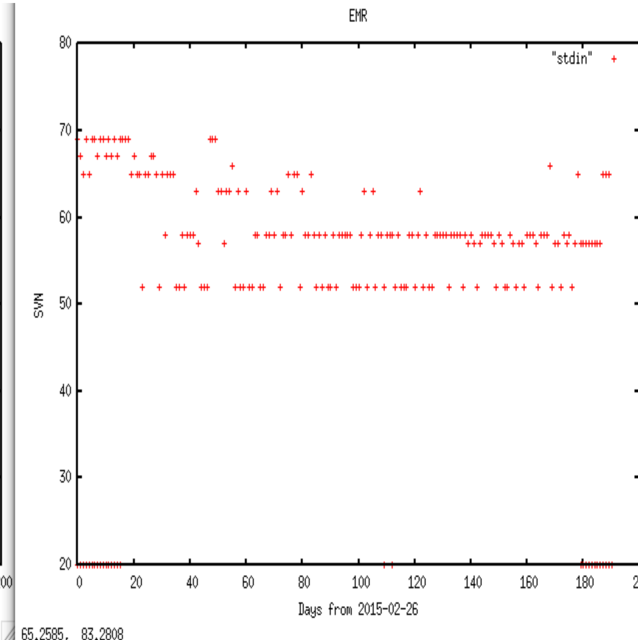
IGS AC's Final Clock Solutions Differ Systematically When Using a Maximum Error Metric

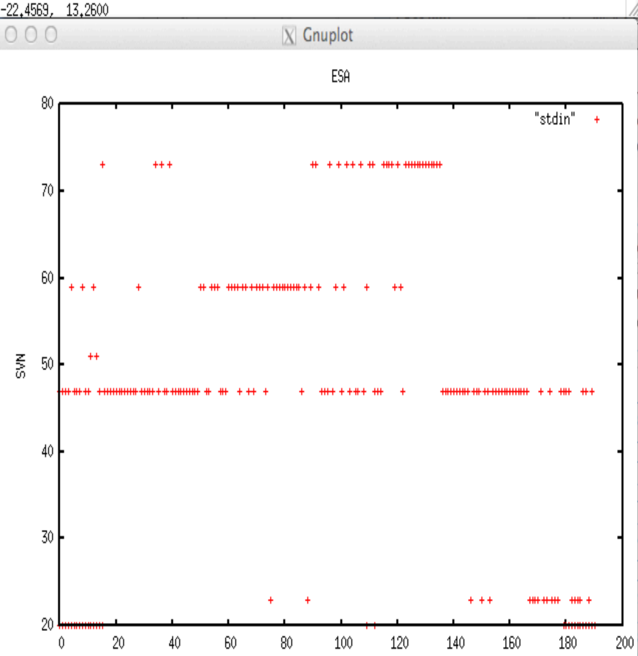


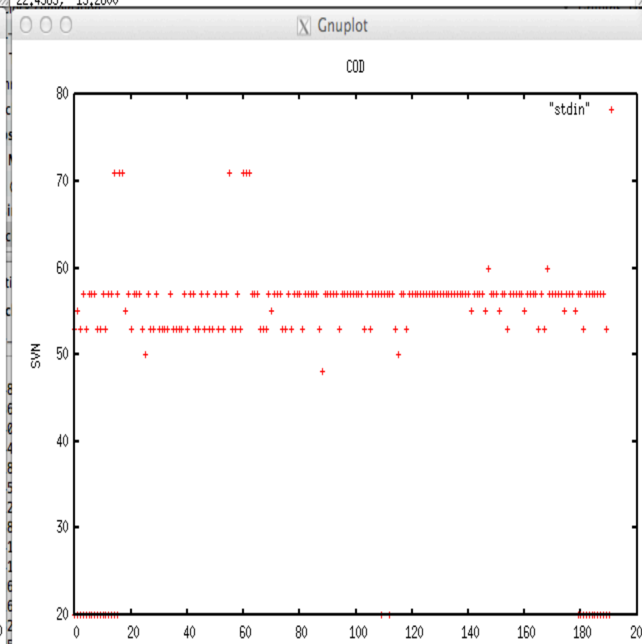
The Maximum Clock Biases are Systematically Satellite-Specific and AC-Specific











From IGS ACC Weekly Final Combination:

For each AC, denote the GPS Satellites with maximal clock bias relative to the IGS Final Combination

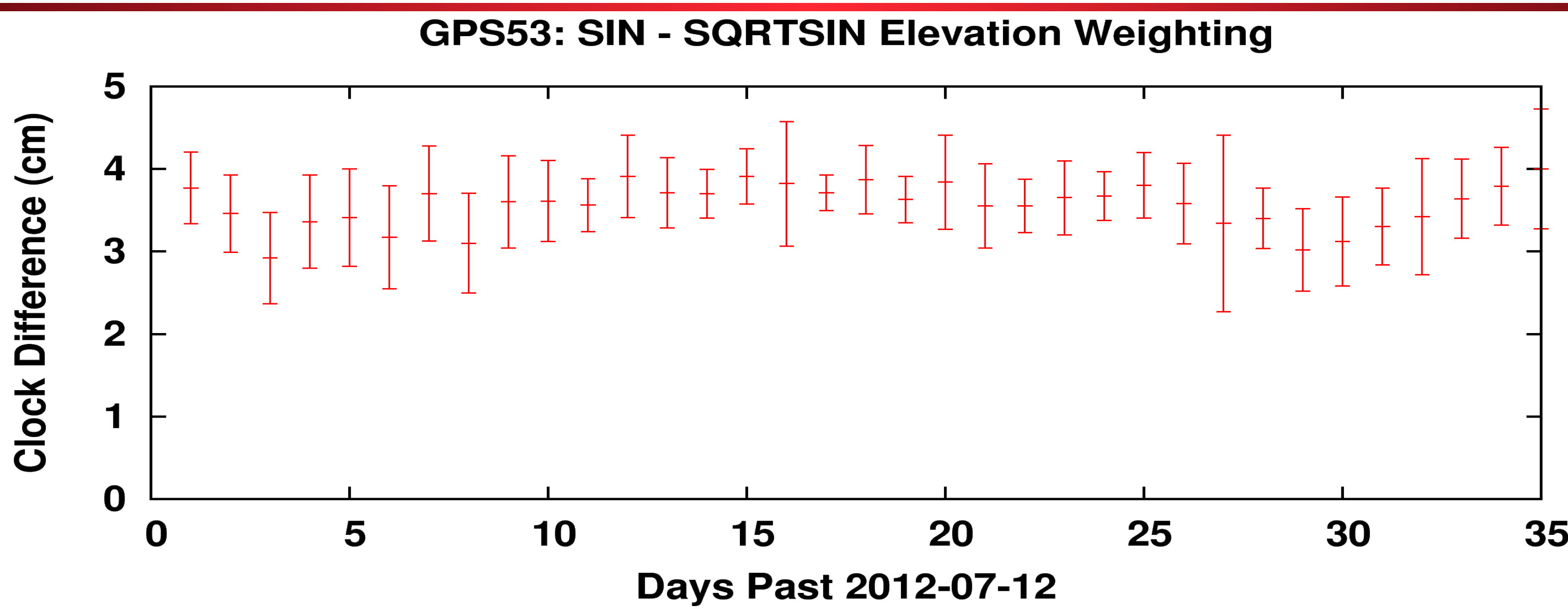
- AC-specific patterns emerge

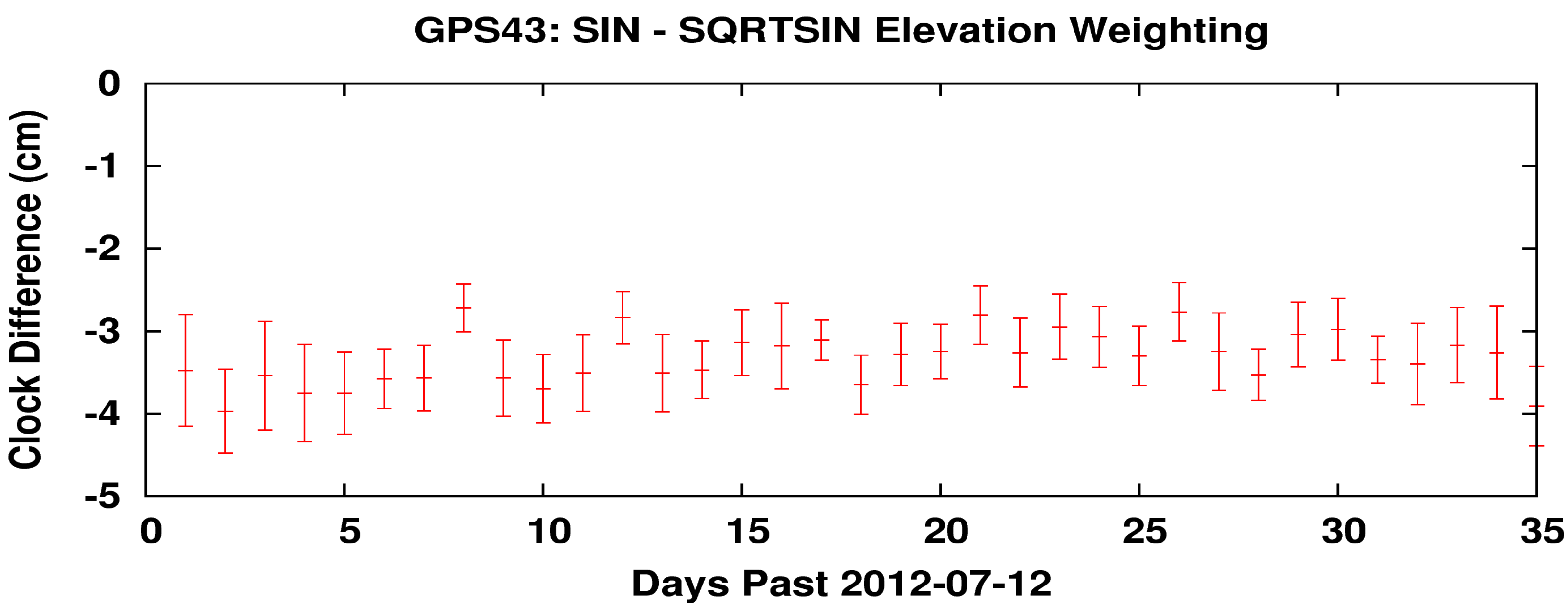
Jake's Table provides a Clue

AC's models for Repro-2

		CODE (COF)	EMR	ESA	GFZ	GRG	JPL	MIT
??EDITS COMPLETE??		YES	YES	YES	YES	YES	YES	
Measurement Models	**GNSS**	GPS, GLO	GPS, GLO	GPS, GLO	GPS, GLO	GPS, GLO	GPS	GPS
	Clock Products Provided (& sampling int.)	GPS: BRDC (SP3) GLO: None	GPS: 30s (SP3 & CLK) GLO: 15m (SP3)	GPS: 30s (SP3 & CLK) GLO: 30s (SP3 & CLK)	GPS: 30s (SP3 & CLK) GLO: 15m (SP3)	GPS: 30s (SP3 & CLK-SV and STA) GLO: 15m (SP3)	GPS: 30 s & 5m (SP3 & CLK)	GPS: 30s (SP3 & CLK)
	Observable Type	DbDiff (weak redundant)	UnDiff	UnDiff	Undiff	UnDiff	UnDiff	DbDiff (weak redundant)
	Data Rate	3 min	5 min	5 min +30 sec for clocks	5 min	15 min (30s for clocks)	5 min	2 min
	RHC phase rotation corr.	Yes (Wu et al., 1993)	Yes (Wu et al., 1993)	Yes (Wu et al., 1993)	Yes (Wu et al., 1993)	Yes (Wu et al., 1993)	Yes (Wu et al., 1993)	Yes (Wu et al., 199
	Elevation Cutoff	3 deg	10 deg	10 deg	7 deg	12 deg	7 deg	10 deg
	Elevation-dependent Inverse Weights ($sigma^2$ =)	$1 / \cos^2(z)$	$1/\sin(e)$	$1 / \sin^2(e)$	$1 / 2\sin(e)$ for $e < 30$ deg	none	$1/\sin(e)$	$a^2 + (b^2 / \sin^2(e))$ a,b from site residuals

Clock Biases Driven by Elevation-Dependent Data Weighting





Impact of the Clock Biases Depends on Application Scenarios

One example, one case: static ppp of AMC2 on December 16, 2015

Perturbed the JPL Final GPS satellite clock solutions for December 16, 2015 to add 5 cm clock bias to GPS53, and subtract 5 cm clock bias from GPS43

Performed two static, ambiguity-resolved point-positioning of AMC2 with the unperturbed orbit/clocks and the purturbed orbits/clocks

- 10 degrees elevation custoff
- 1/sin (el) data weighting

Position difference was:

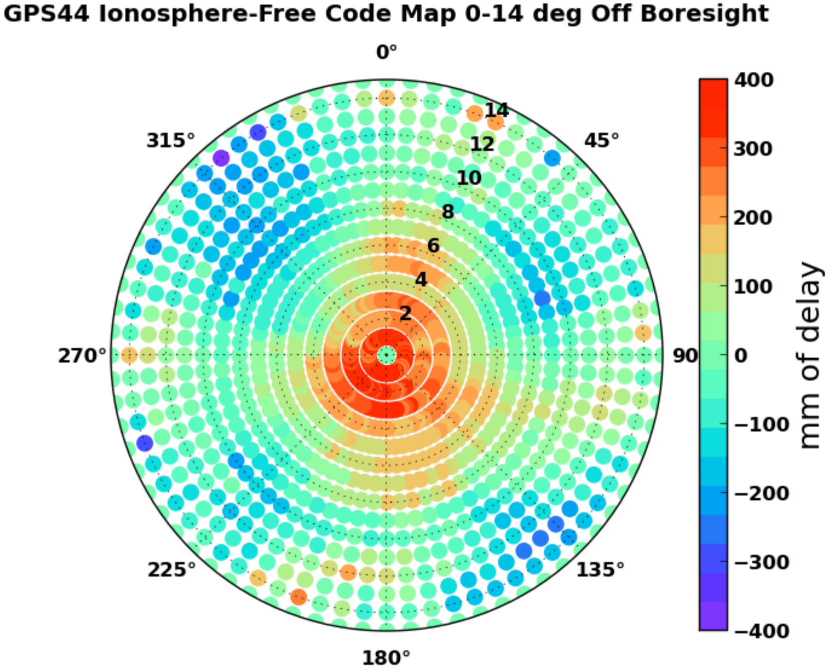
East: 5 mm
North: 0 mm
Vertical: 2 mm

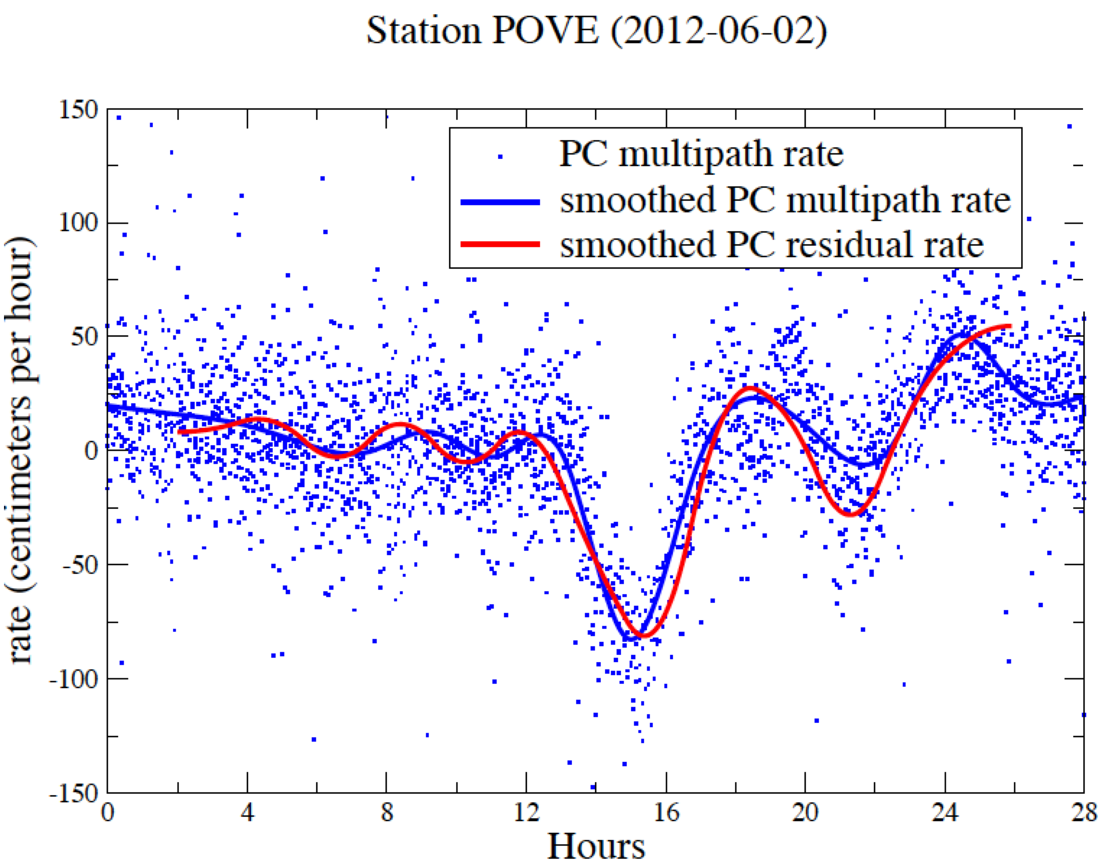
There are Other Sources of Systematic Clock Biases

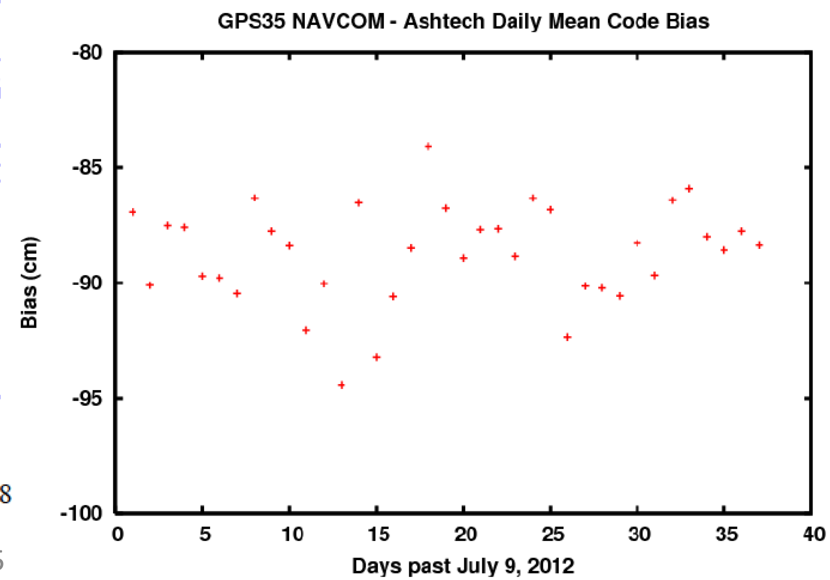
Antenna pseudorange variation maps

Satellite-receiver-specific code biases

Code phase wander







Conclusions

Systematic biases in satellite clock solutions can be explained by different *effective* modeling of the satellite pseudorange antenna patterns

Growth in the global tracking network has been accompanied by increase in anomalous receiver performance, and diversity in key receiver attributes

By addressing the key error sources contributing to systematic clock biases, we were able to construct a relative 'truth' solution (based on a 70-site tracking network) with a reduced level of clock biases

- ~7 cm reduction in spurious clock biases relative to the IGS Final Combined

Combined solutions remain problematic when it comes to tracing and diagnosing systematic modeling errors