SGP4 PROPAGATION ERROR REDUCTION USING BIAS CORRECTION TECHNIQUES FOR CUBESATS

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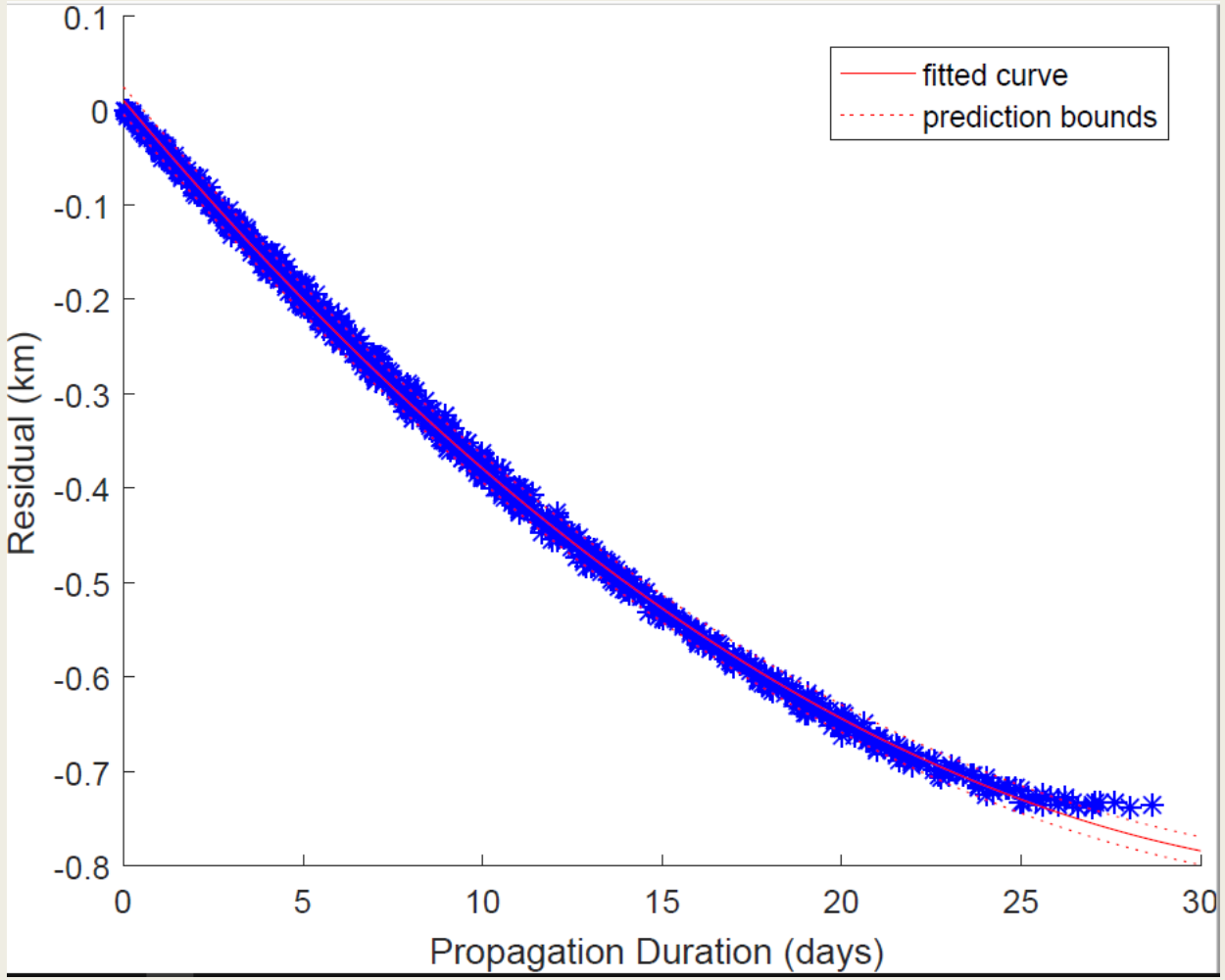
Simplified General Perturbations 4

- Analytical
- Extremely quick
- Computitonally efficient
- Updated and massive ephemeris source, Two Line Elements (TLE)

SGP4 Problems

- Initial Errors
- Lack of inaccuracy estimation
- Inefficient TLEs
- Rapid error growth

Systematic Error Growth



An example systematic error growth

Error Reduction Aims

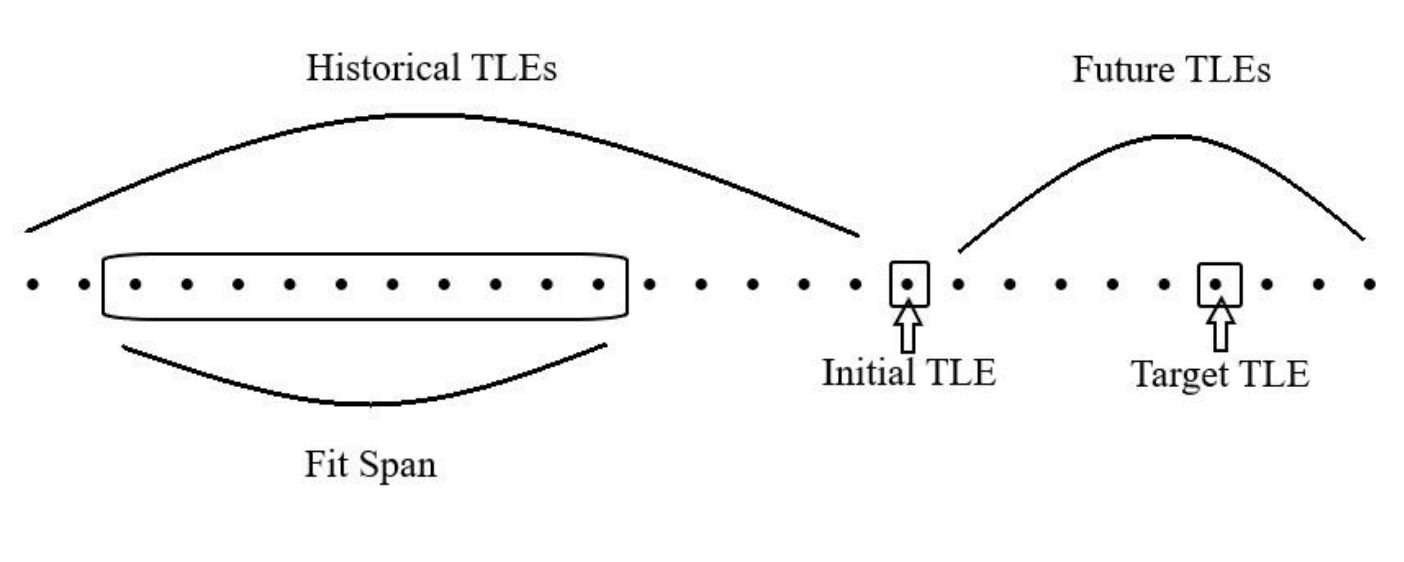
- Computitionally efficent (no orbit determination or numerical modelling)
- Requires no modification for different satellites
- Requires no outside data source

Method Structure

- Use historical TLEs as a data source
- Clear inefficient TLEs
- Create error estimation equations at different coordinate systems
- Seperate seemingly random errors and systematic (biased) errors
- Edit original SGP4 propagation output

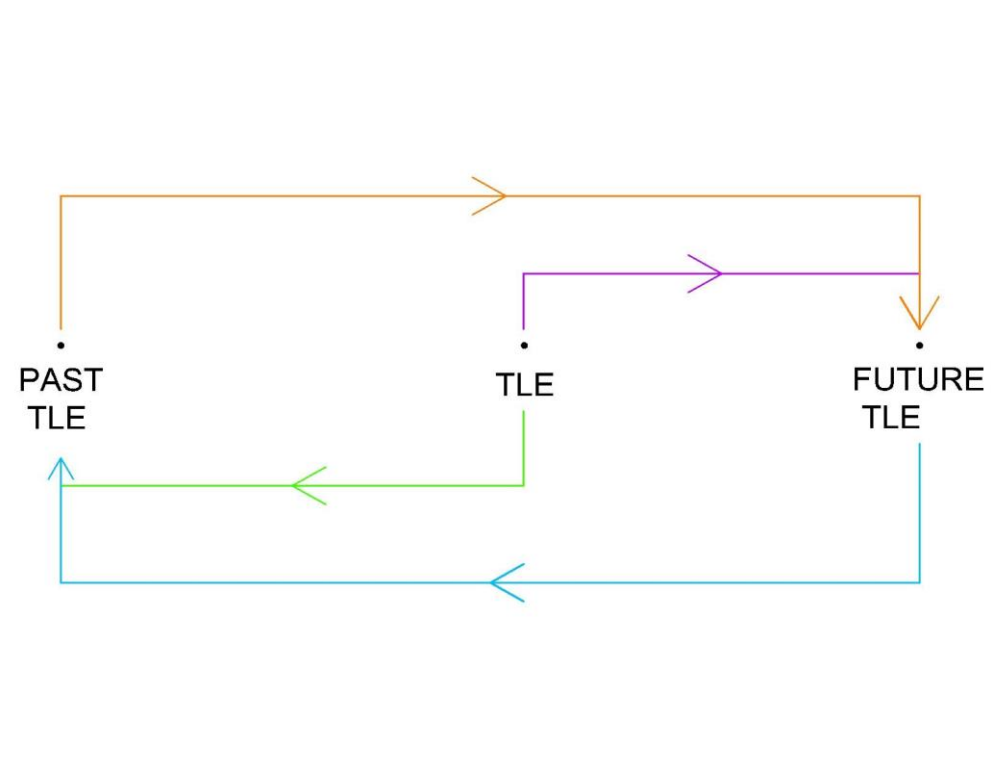
Test pool

- All cubesats that were in space between December 2015 and August 2017 (82 satellites)
- 135 TLEs for each satellite at three different time spans
- Combinative test cases



An example test case

TLE Consistency



TLE Consistency Check

	Perfect	Acceptable	Bad
Number	10078	815	177
Percentage	91.03	7.36	1.60

Outlier TLEs

	Normal	Repeating
Number	10804	266 (133 Couples)
Percentage	98.60	2.40

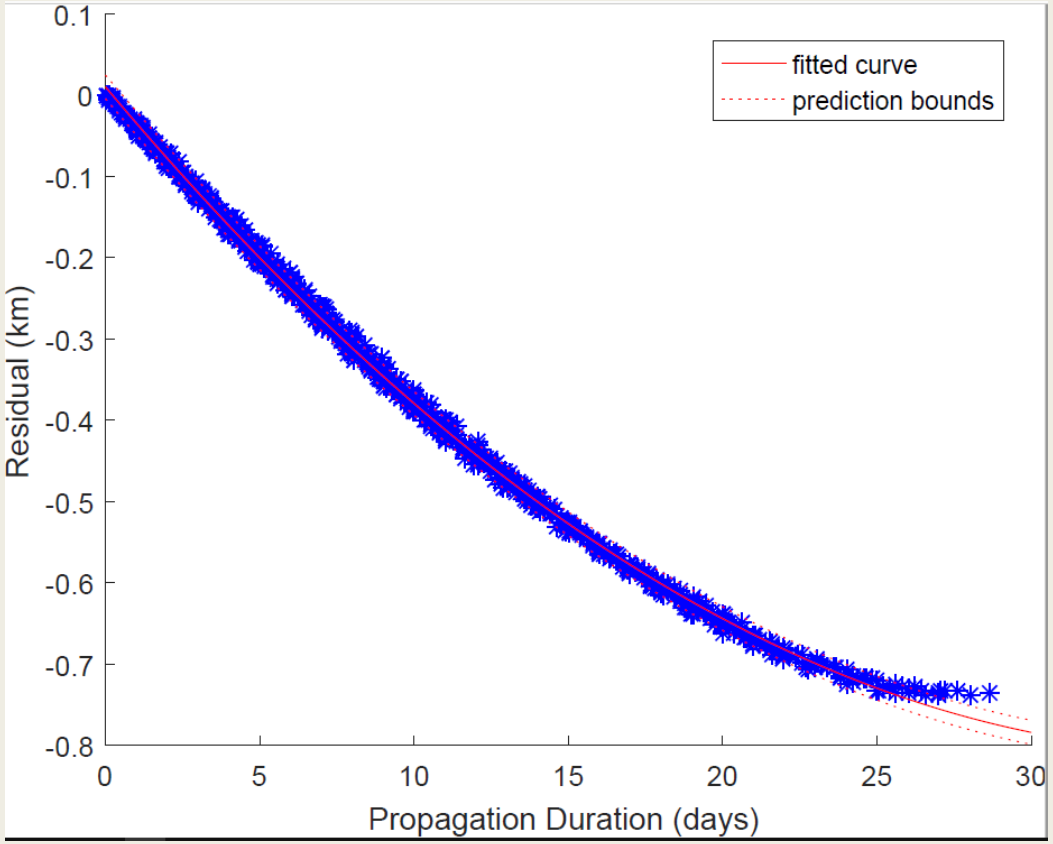
Repeated TLEs

Error Estimation Equations

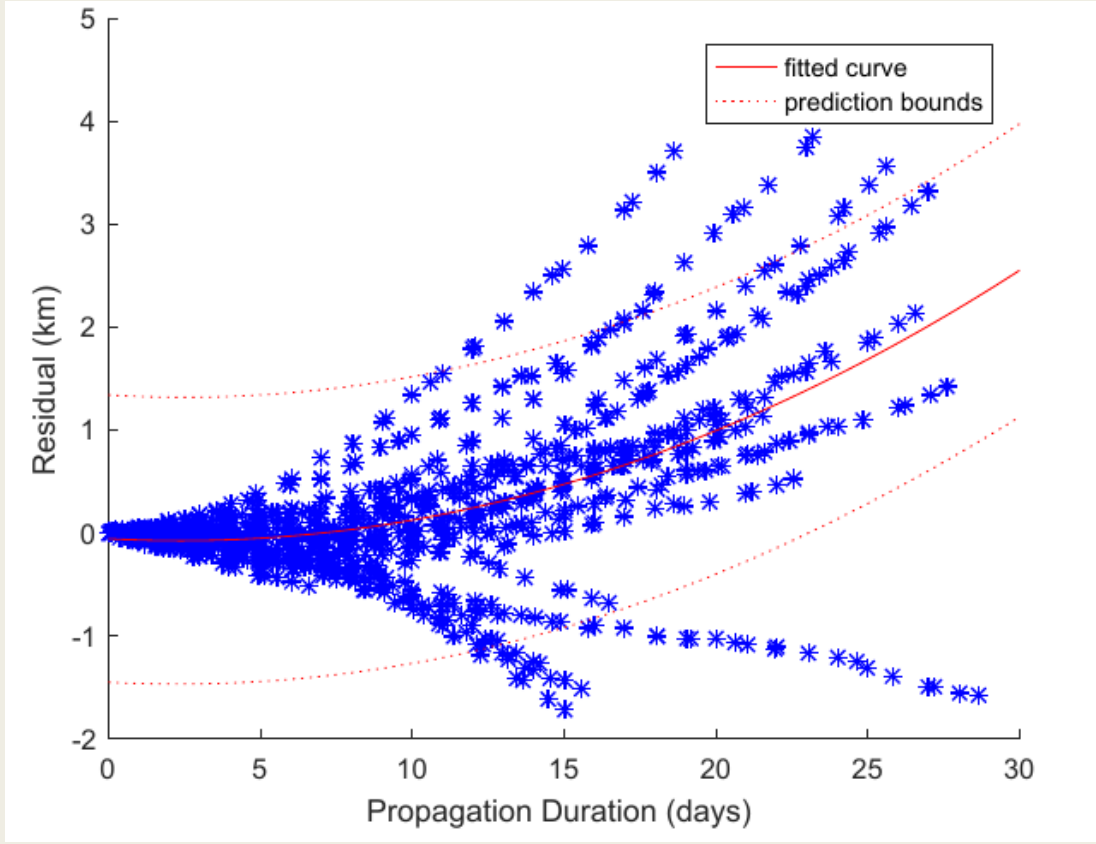
- Least squares regression to three equations
- Function of time (t)
- $E = A + B * t, \quad E = A + B * t + C * t^2, \quad E = A * e^{bt}$
- Root mean squared error comparison
- 36 different coordinate elements from RSW, NTW, PQW, TEME, classical orbital, equinoctial and flight elements.

Bias Detection

- 95% confidence intervals



Systematic (biased) error growth



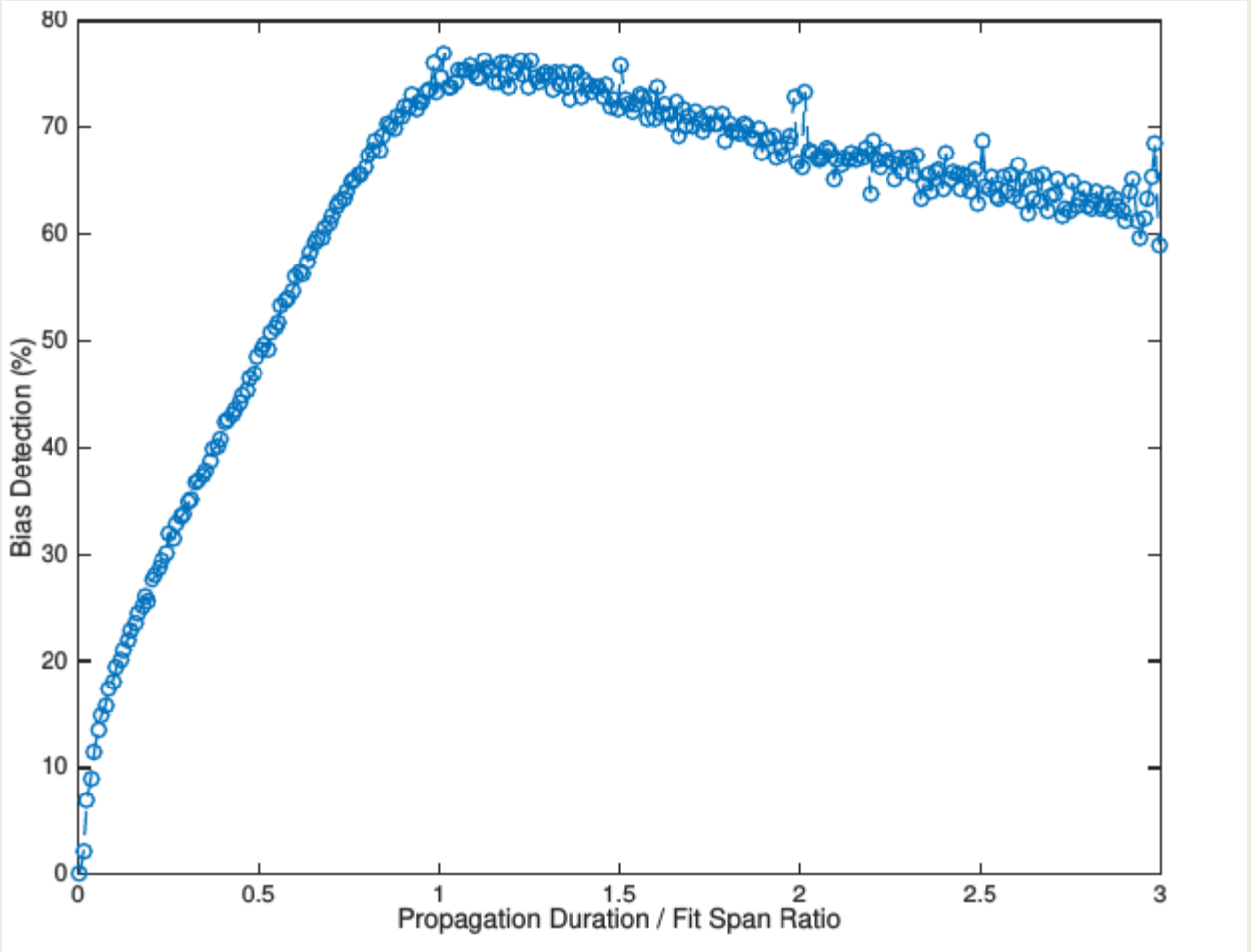
Random error growth

Trend Analysis

- Three criteria: Bias detection, success of operation and error reduction

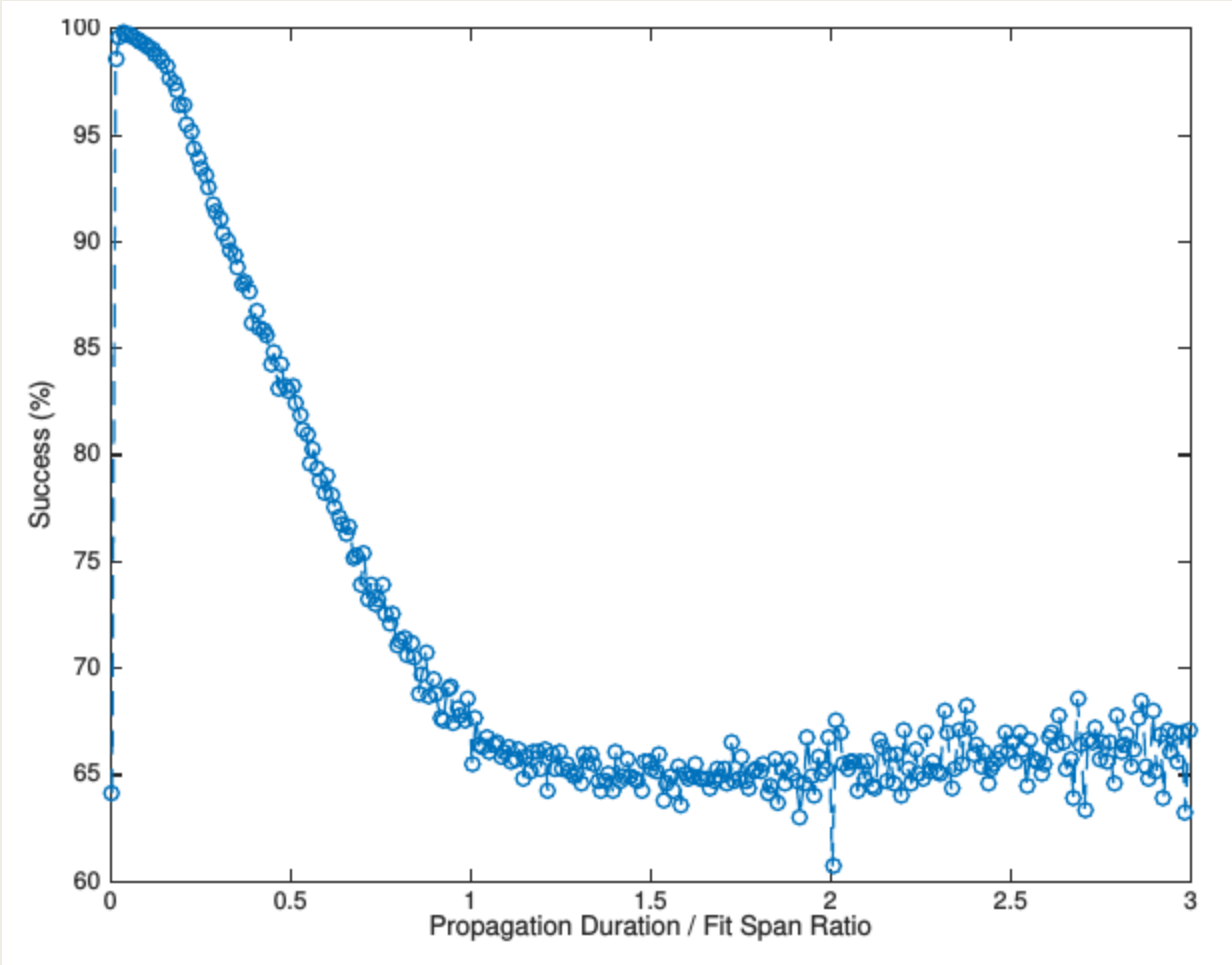
- Propagation duration / fit span duration ratio
- Adjusted R^2
- Propagation duration
- Number of TLEs used in fit span
- Coordinate element
- Satellite

Trend Analysis – Propagation / Fit Ratio



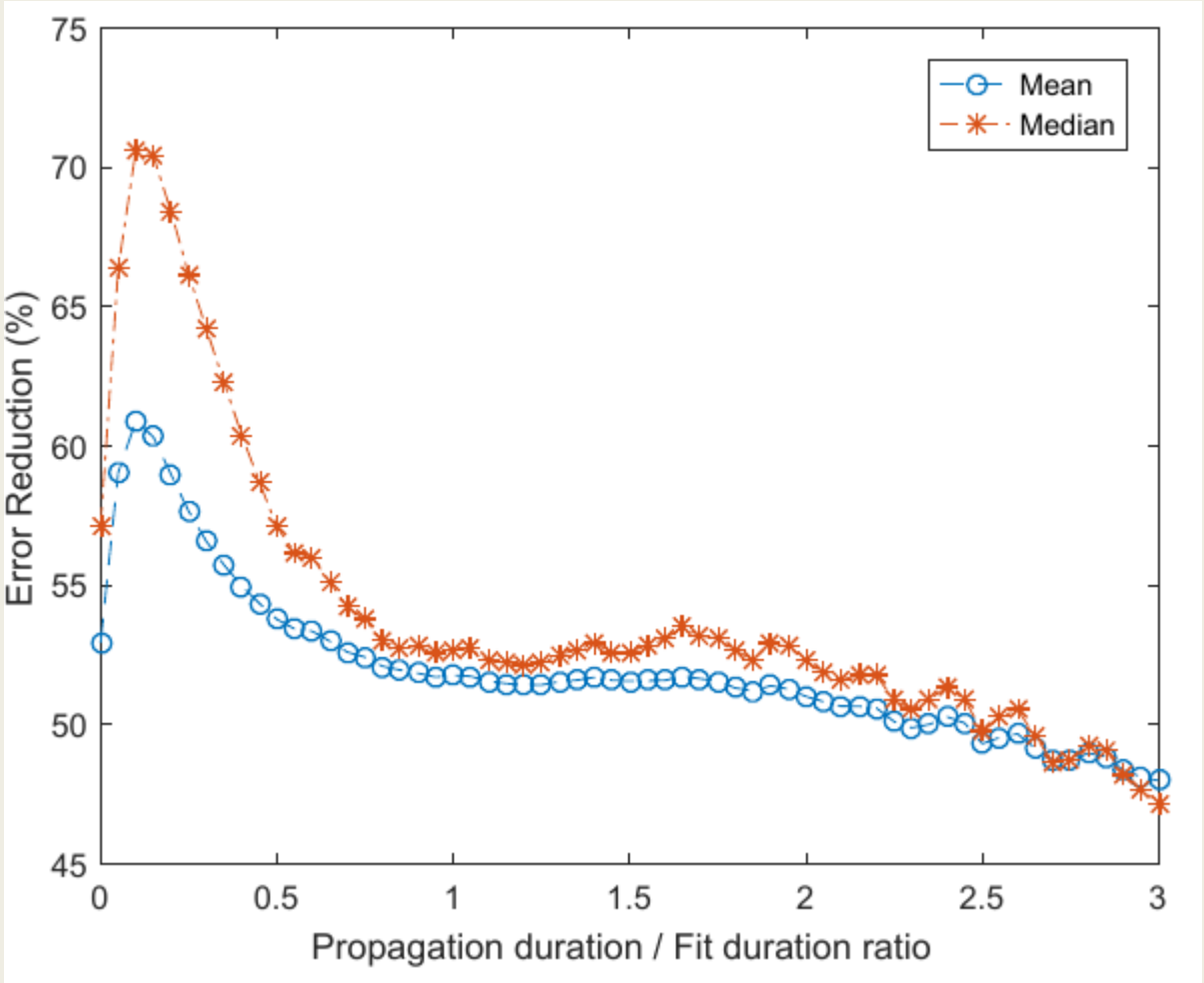
Propagation Duration / Fit Span Ratio and Bias Detection

Trend Analysis – Propagation / Fit Ratio



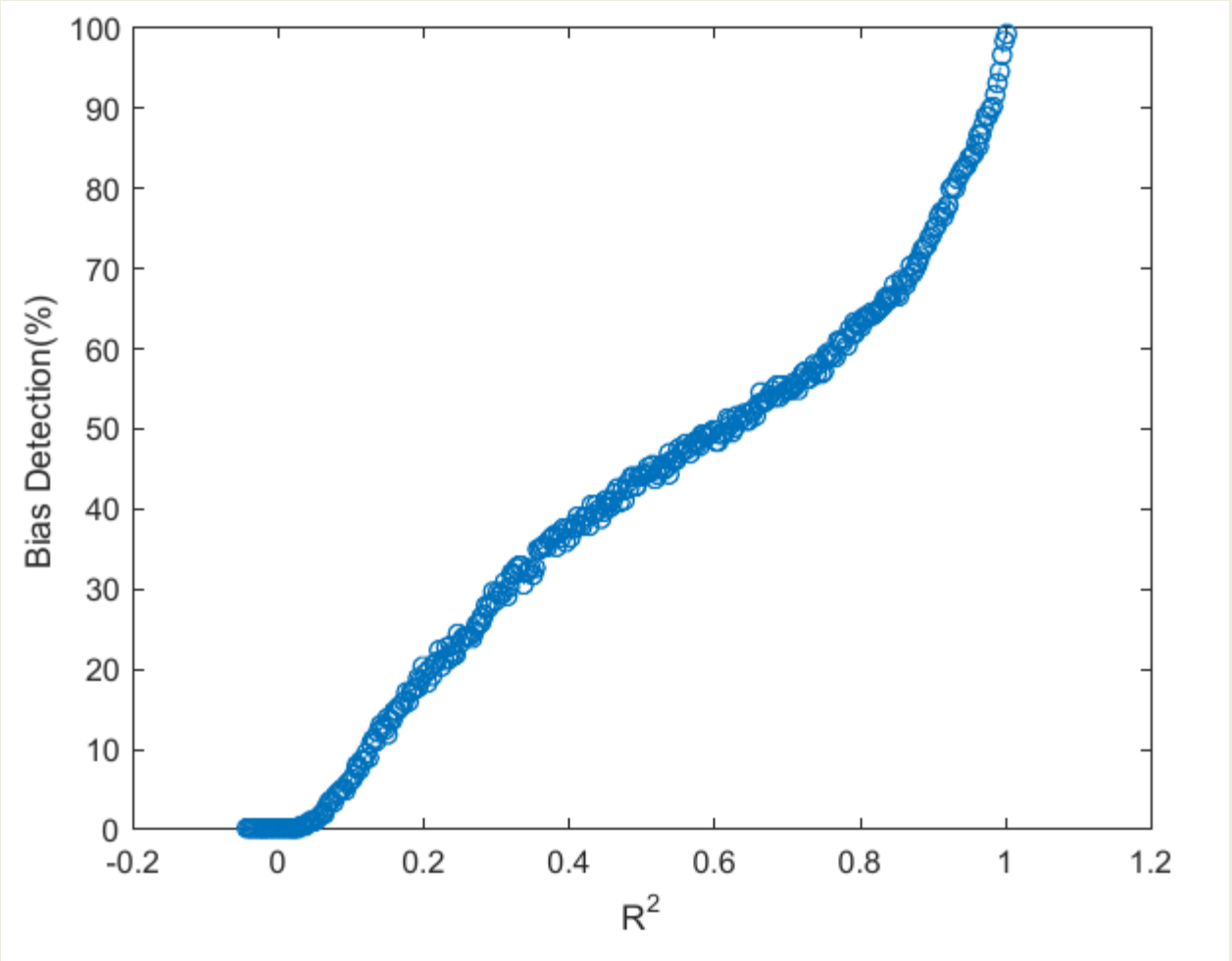
Propagation Duration / Fit Span Ratio and Success of Operation

Trend Analysis – Propagation / Fit Ratio



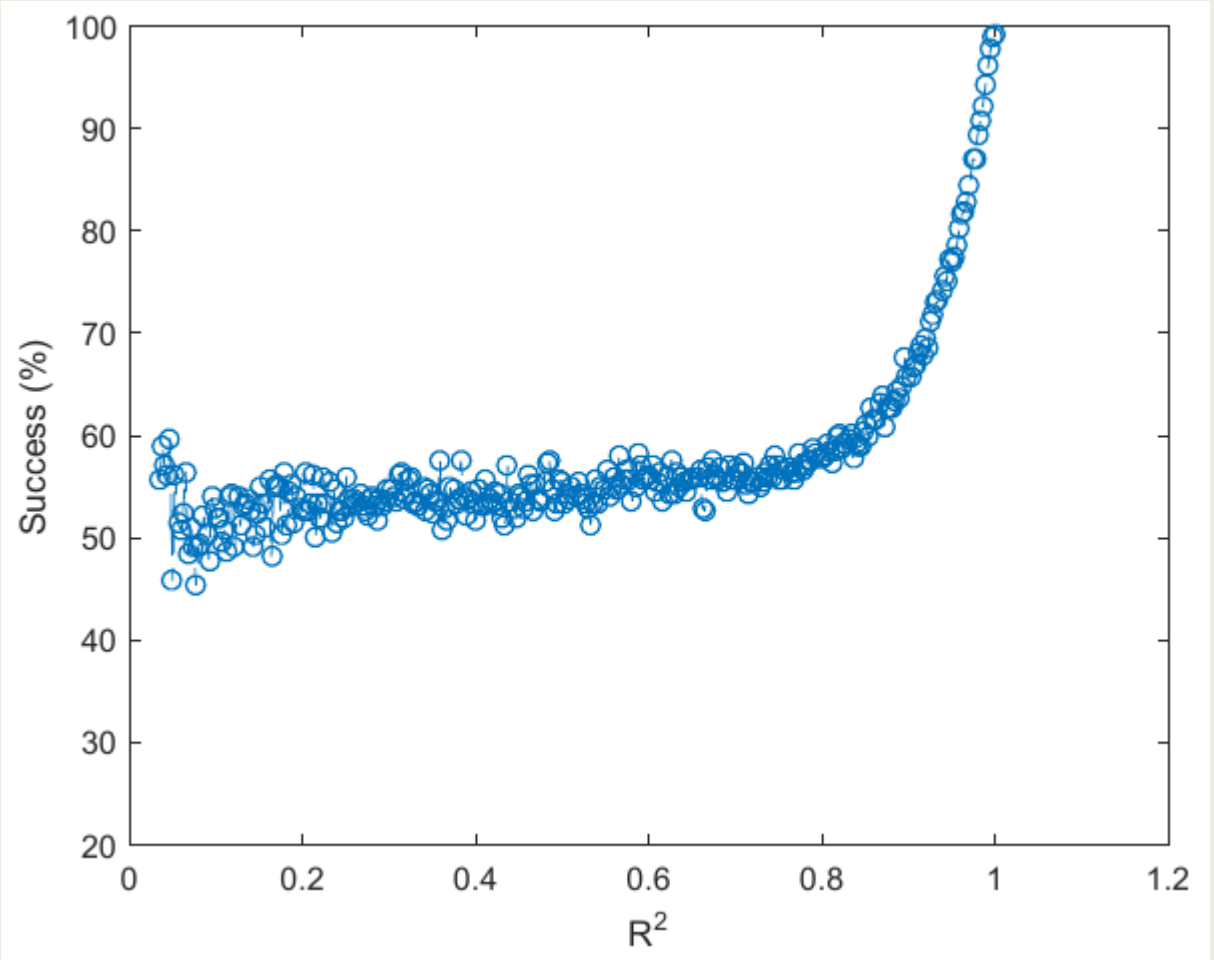
Propagation Duration / Fit Span Ratio and Error Reduction

Trend Analysis – Adjusted R-square



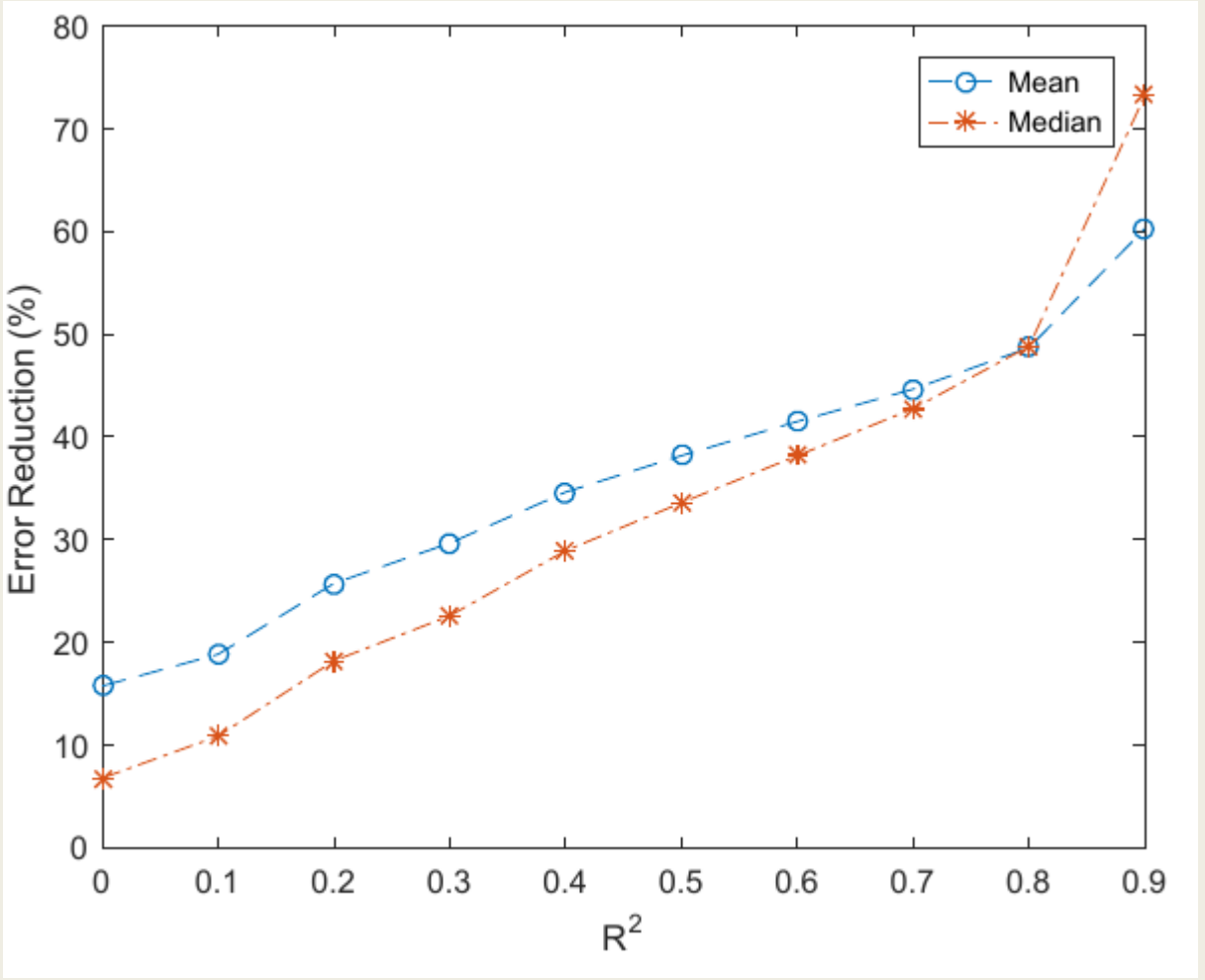
Adjusted R^2 and Bias Detection

Trend Analysis – Adjusted R-square



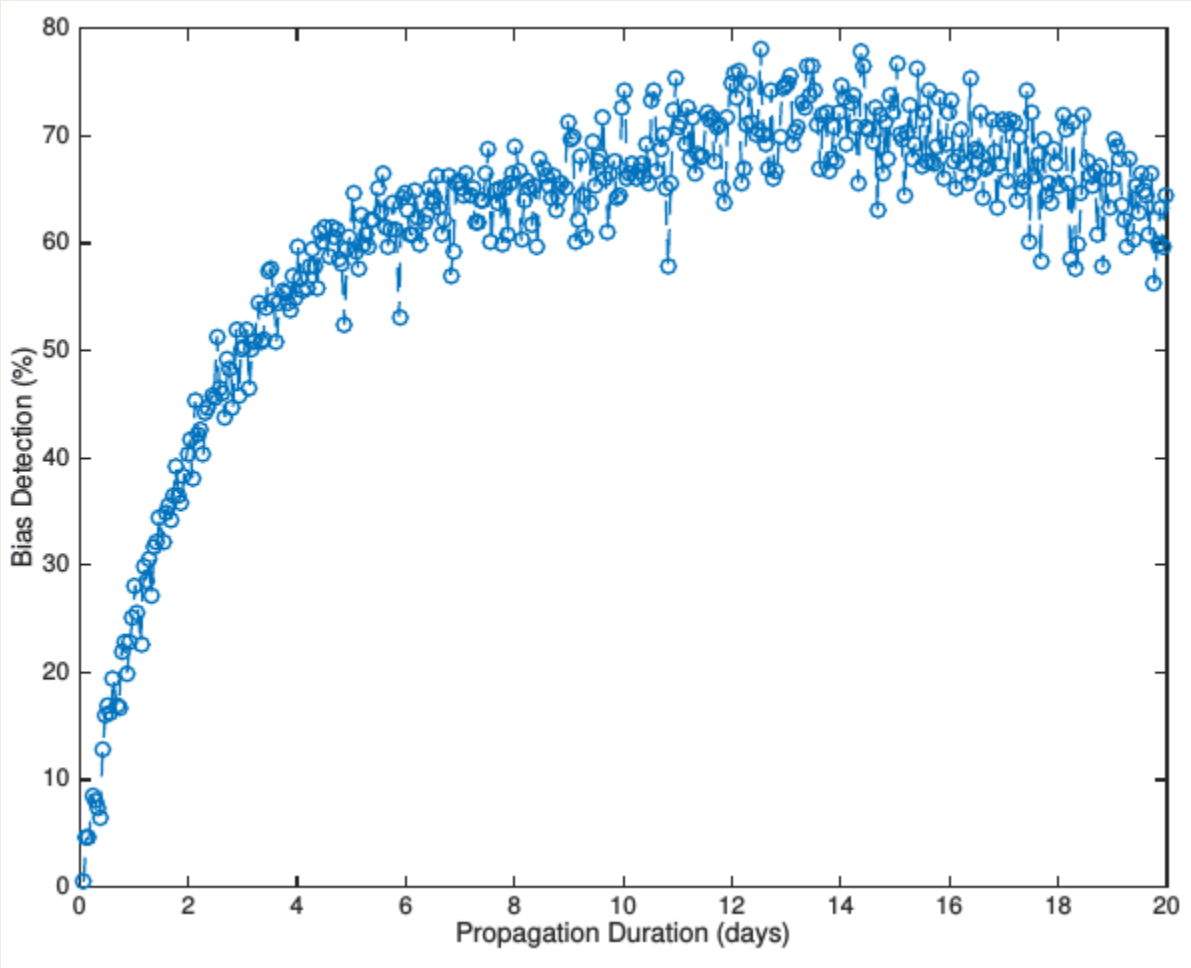
Adjusted R^2 and Success

Trend Analysis – Adjusted R-square



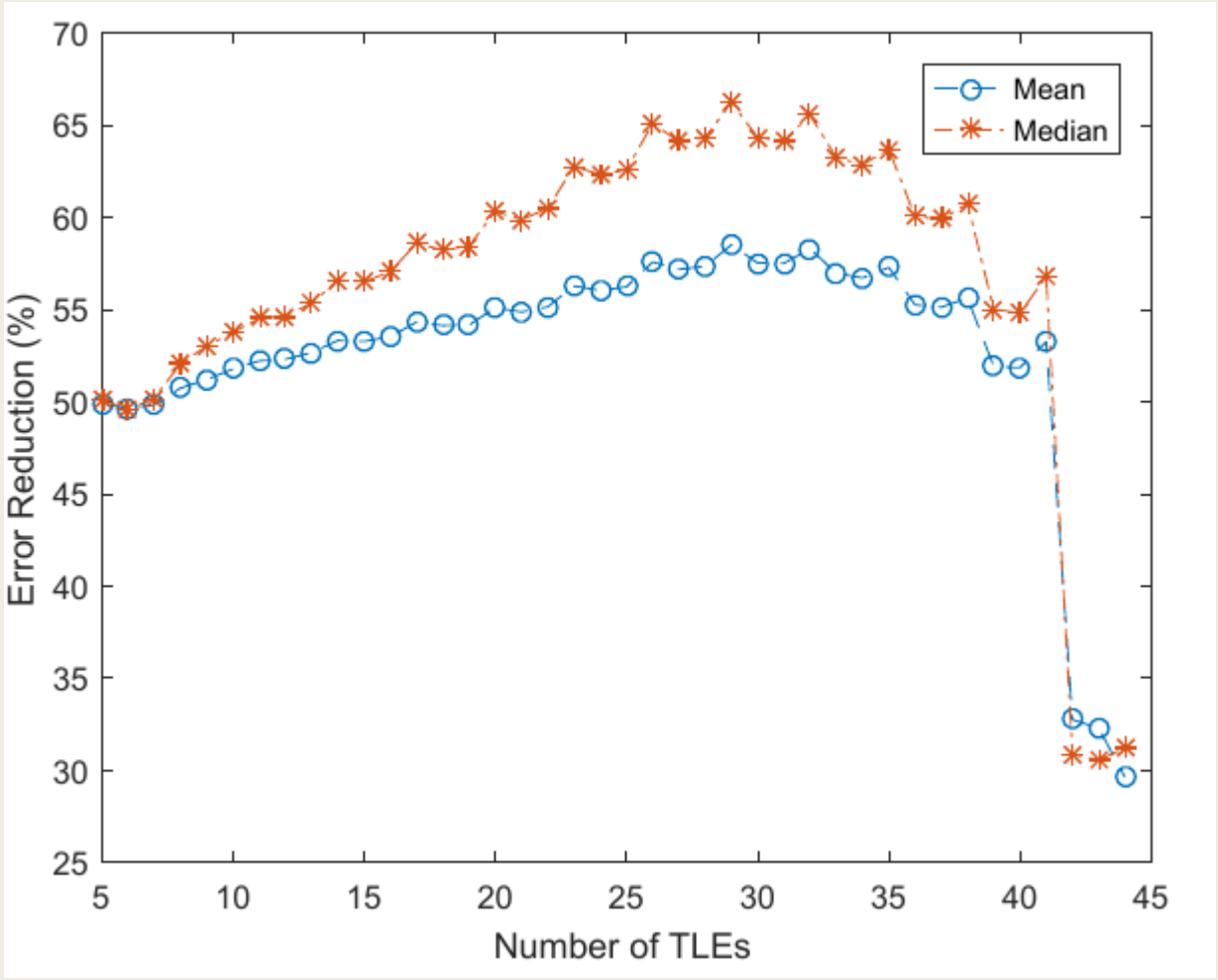
Adjusted R^2 and Error Reduction

Trend Analysis – Propagation Duration



Propagation Duration and Bias Detection

Trend Analysis – Number of TLEs



Number of TLEs and Error Reduction

Trend Analysis - Results

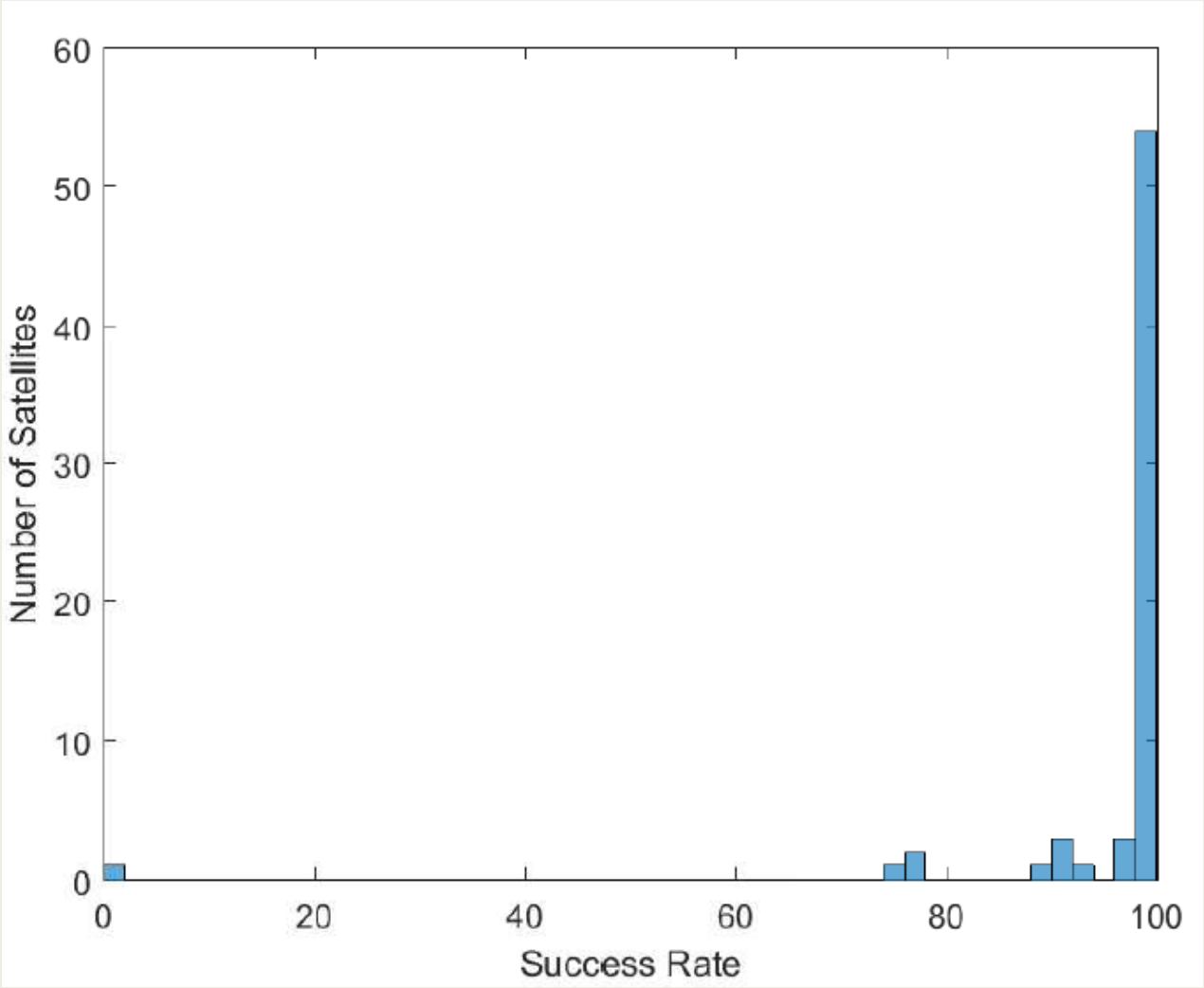
- Method is suitable for orbit predictions (propagations) longer than a day
- Propagation / Fit duration ratio and goodness of fit are extremely effective on all three criteria

Coordinate Elements

- $R^2 > 0.95$ and fit / propagation duration ratio is between 3 and 5
- Well fit: R, W, N, S (vel), T (vel), e, Ω, ω, v, M, n, $a_f, a_g,\ vmag$
- Sucessful: R, W, N, S (vel), T (vel), $\Omega, a_f, a_g, vmag$

Coord. El.	$R^2 > 0.95$ (%)	Bias Det (%)	Success (%)	Mean Error Red. (%)
R	53.77	99.84	99.73	78.13
W	30.98	99.63	98.19	62.83
N	54.61	99.62	99.63	77.35
S (velocity)	56.04	98.89	99.56	77.21
T (velocity)	55.06	99.75	99.74	78.27
Ω	31.71	99.63	98.20	62.80
a_f	48.00	98.41	98.84	59.53
a_g	44.98	98.75	98.39	61.37
$vmag$	55.65	99.92	99.71	77.80

Satellite



Success Rate Distribution over Satellites

Conclusions

- Bias correction method can be effectively used for cubesats
- TLE, as a data source, is accurate enough
- R, W, N, S (vel), T (vel), $\Omega, a_f, a_g, vmag$ are useful for bias detection and correction
- Success of bias correction is different for each Satellite
- Goodness of fit and fit span duration is crucial for high success and significant error reduction

- A quick, self sufficent method for error reduction is presented.