Updated Centre of Mass Correction Tables for LAGEOS, Etalon, LARES, Starlette and Ajisai

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Context

SLR and VLBI scale difference ITRF2014 (1.37 ppb)

Allowing in the orbit solutions for the presence of observational errors reduces this difference by ~50%

Identifying the actual error sources is very hard:

Centre of mass corrections?
Timing devices?
Site surveys?
Operational inconsistencies?
Modelling deficiencies?
...other?

Context

SLR measurements are made to the reflecting surfaces of the satellites: an offset to their centre of mass (CoM) is required to solve the equations of motion

Time of flight measurements are only as good as the CoM values applied (among other things)

Station heights estimated from SLR will absorb errors in the observations by a ratio of ~1:1

Aims

Reassess centre of mass (CoM) models used by ILRS analysts for ITRF2014

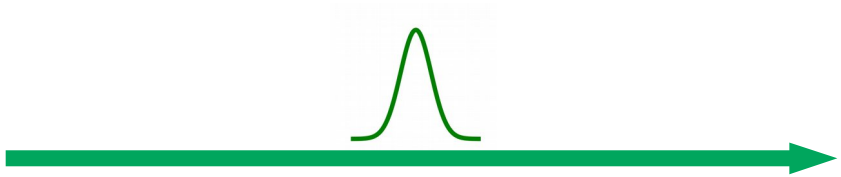
Improve current standards incorporating effects previously only approximated

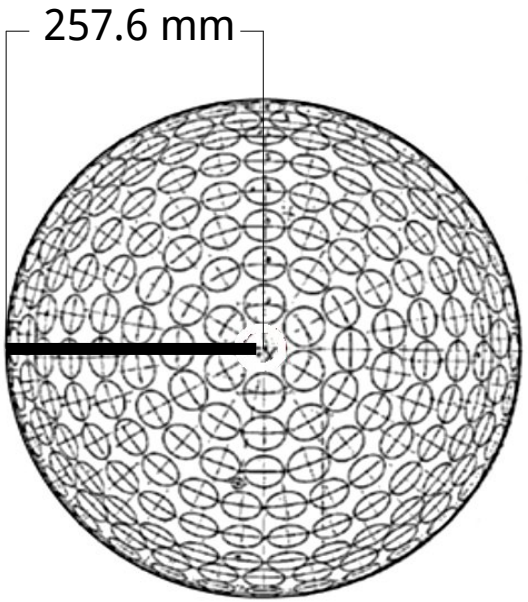
Recompute everything from scratch using the latest data available

Assess the impact on the overall errors estimated in the orbital solutions

If we had perfect CoM values, estimated range errors could be transferred to other targets

Question: Why don't you just read the technical drawings?





LAGEOS

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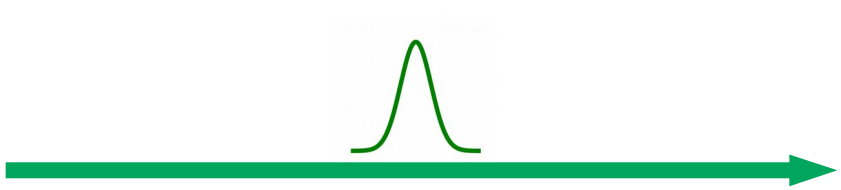

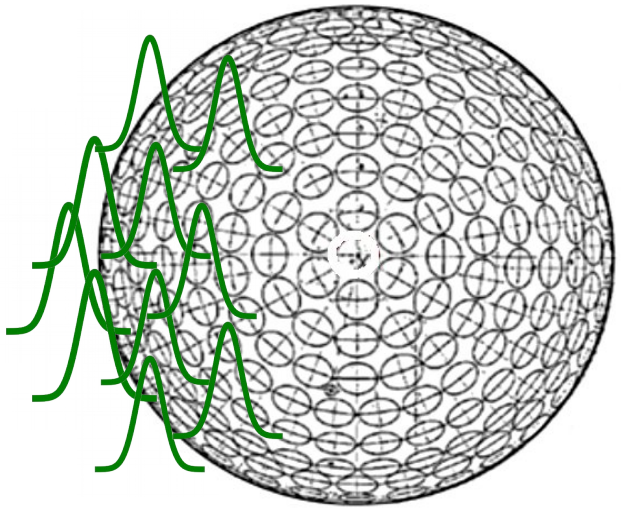

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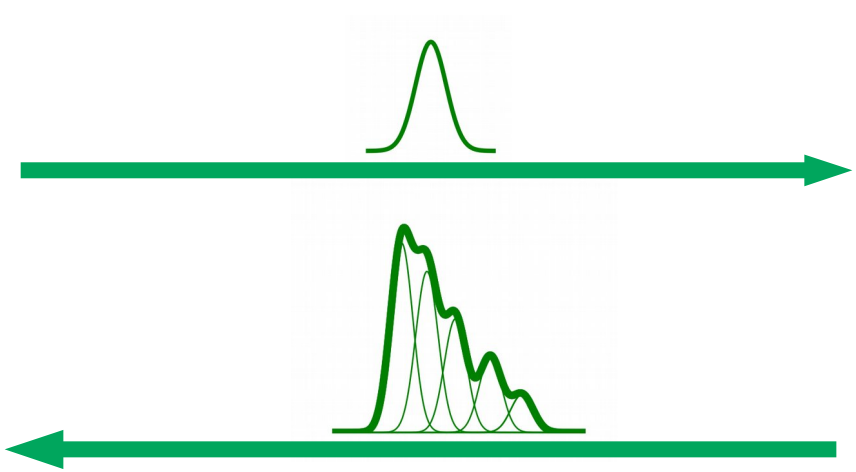
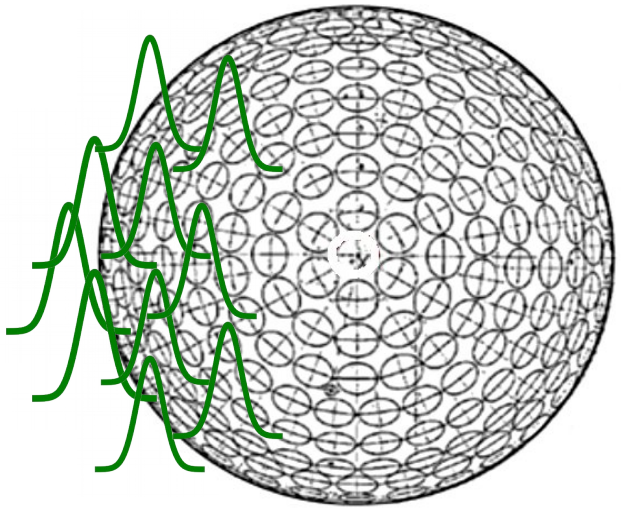
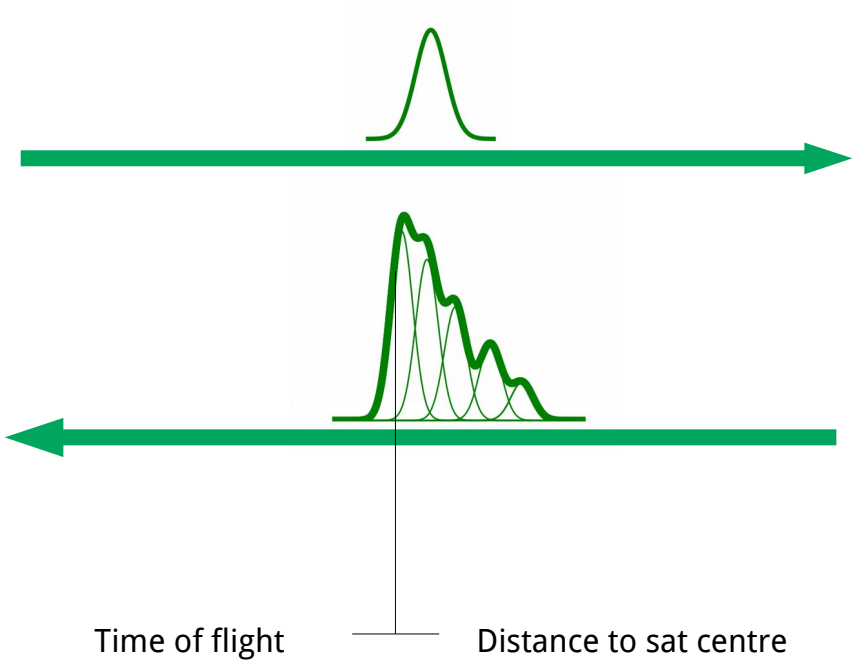


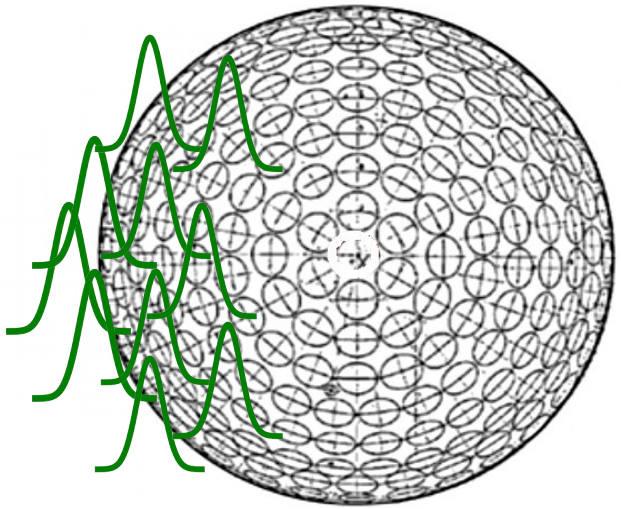


LAGEOS

Question: Why don't you just read the technical drawings?

Answer: Target signature effects





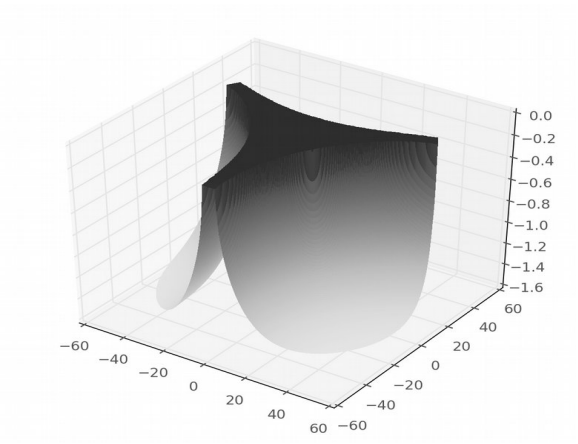
LAGEOS

CoM modelling steps

1. Compute ideal **optical response** of laser retroreflector arrays (LRA)

2. Determine **best fit** response using empirical data from distributions of single-photon detections

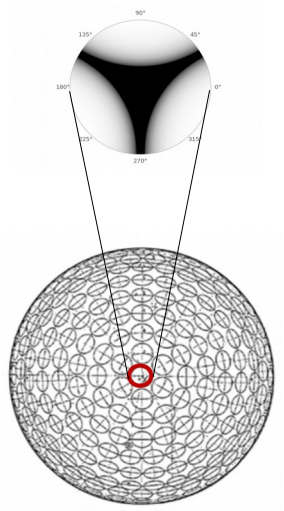
3. Compute CoM values using **system specifications**



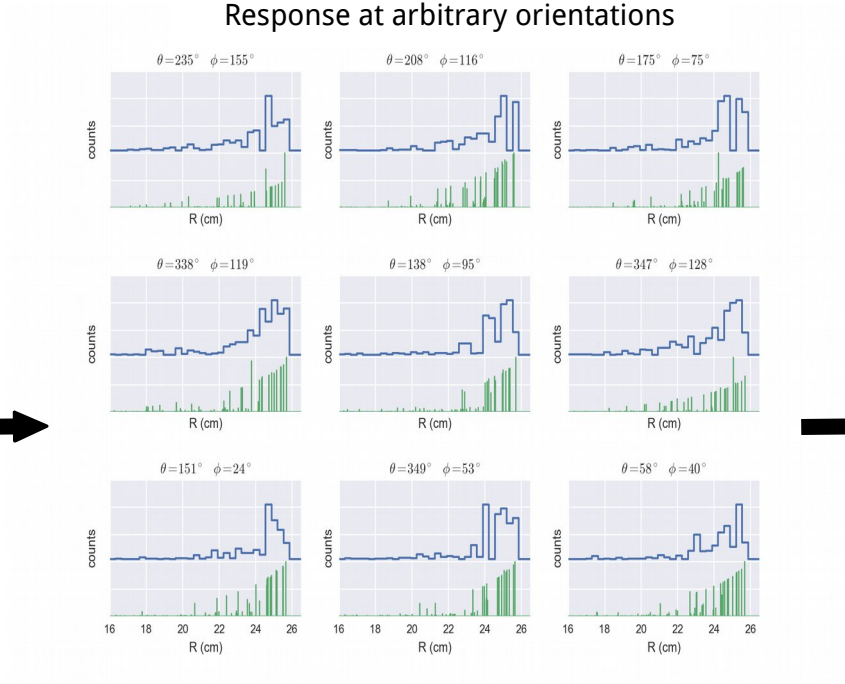
Otsubo & Appleby, System dependent CoM corrections for spherical satellites, 2003

1. Optical response function

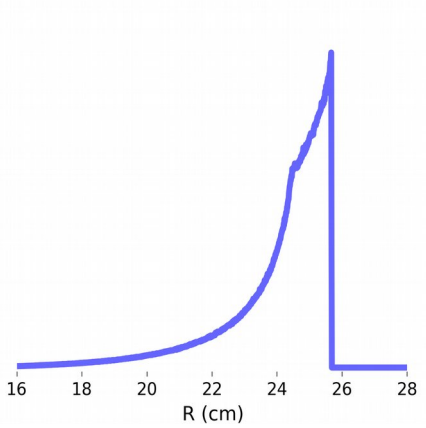
Reflectivity map



Response at arbitrary orientations



Average over 250K orientations



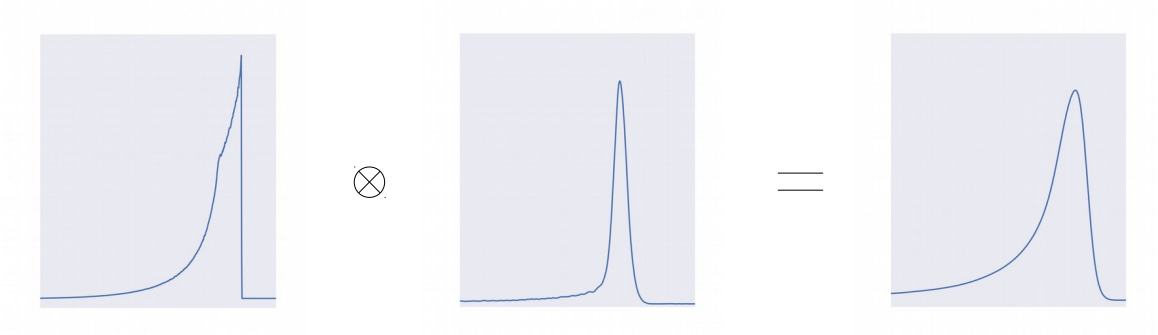
(family of functions)

2. Empirical fit

Accumulate single-photon detection data to obtain empirical distributions

We stacked full rate data from Herstmonceux station (2015-2018), selected, filtered and aligned

- ~ 15M LAGEOS obs.
- ~ 9.5M LAGEOS-2 obs.
- ~ 10.3M LARES obs.
- ~ 1.0M Etalon-1 + Etalon-2 obs
- ~ 4.5M Starlette obs.
- ~ 5.3M Ajisai obs.



Satellite optical response ⊗ System noise distribution = Empirical histogram

What theoretical function fits the data best?

3. CoM computation

Perform computation for all known system configurations

Input data: hardware parameters characterising system behaviour, average return rates and optical response functions

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Input data: hardware parameters characterising system behaviour, average return rates and optical response functions

Single-photon ranging

An analytical expression is available to compute distribution of returns

Solve numerically using calibration data provided by some stations (estimate from relevant system parameters otherwise)

3. CoM computation

Perform computation for all known system configurations

Input data: hardware parameters characterising system behaviour, average return rates and optical response functions

Single-photon ranging

An analytical expression is available to compute distribution of returns

Solve numerically using calibration data provided by some stations (estimate from relevant system parameters otherwise)

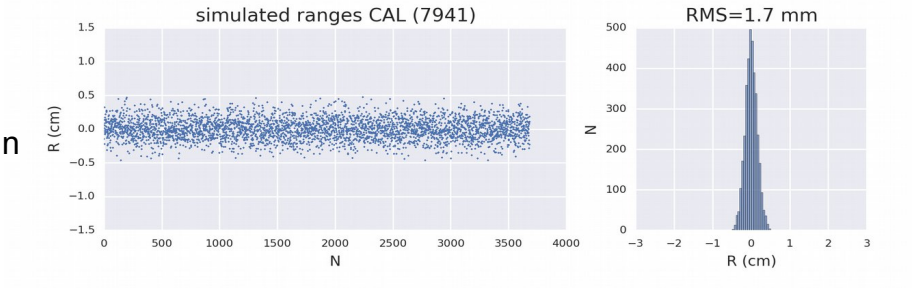
Multi-photon ranging

Monte Carlo numerical simulation of simplified, ideal detection process

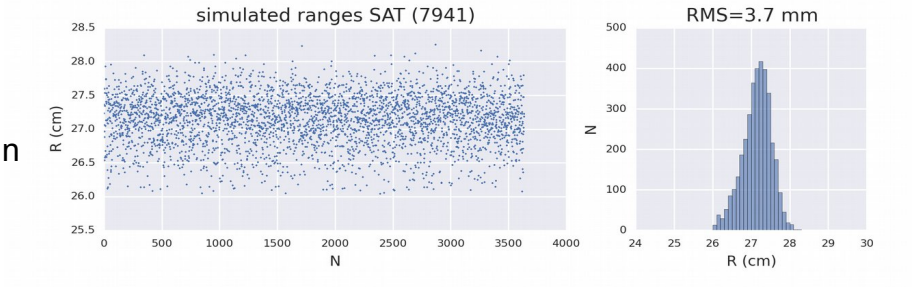
Dependent on some difficult-to-validate assumptions

3. CoM computation

CAL simulation



SAT simulation



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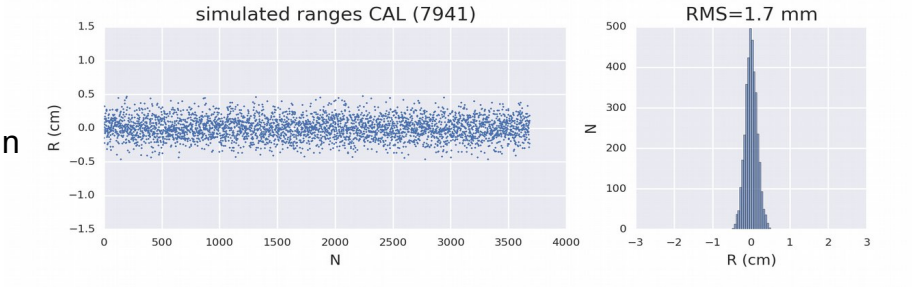

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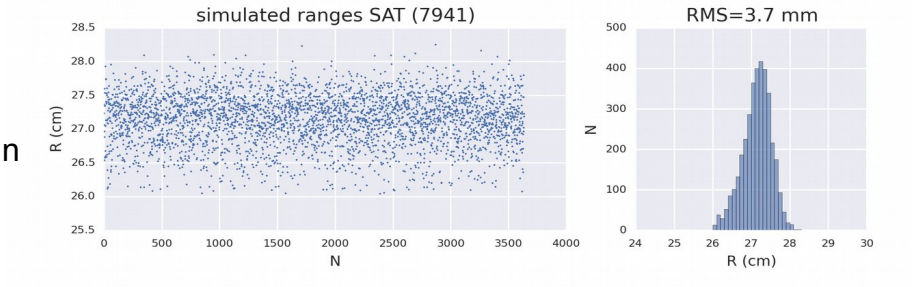
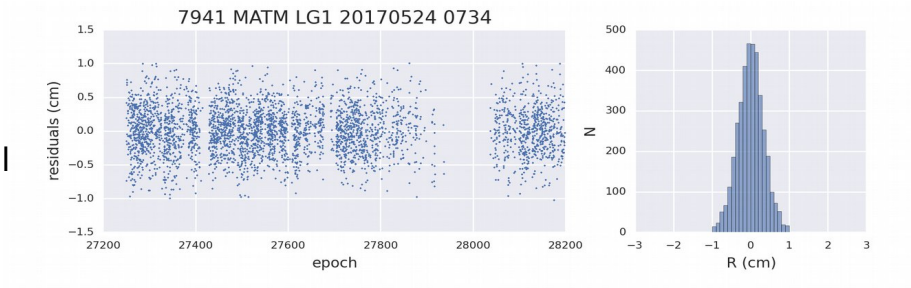


SAT empirical



3. CoM computation

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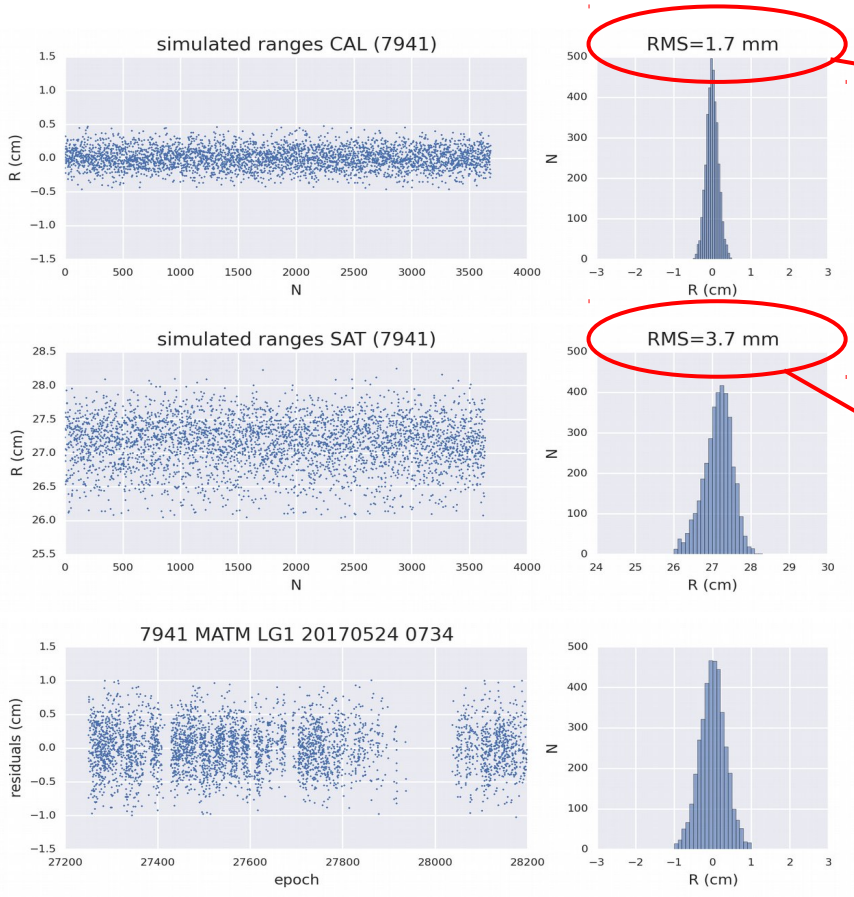
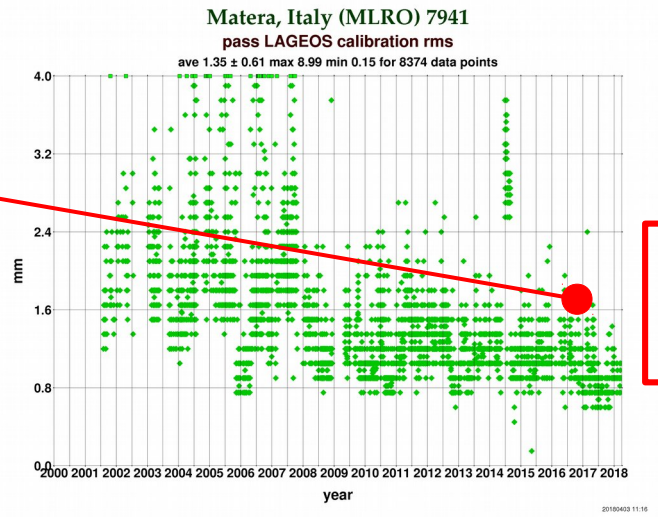
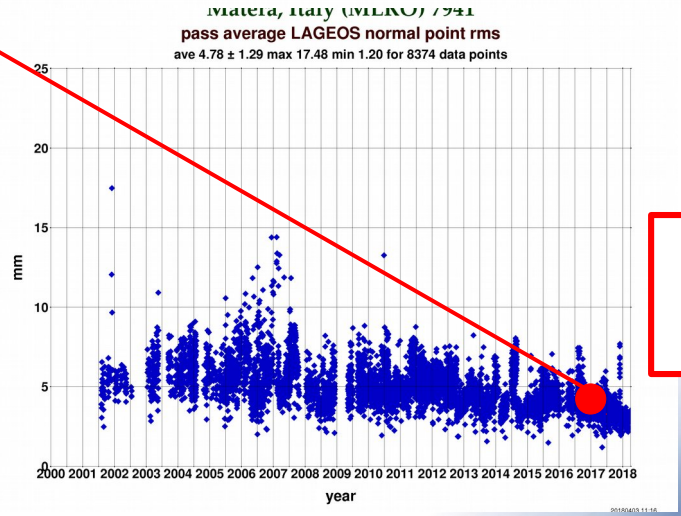




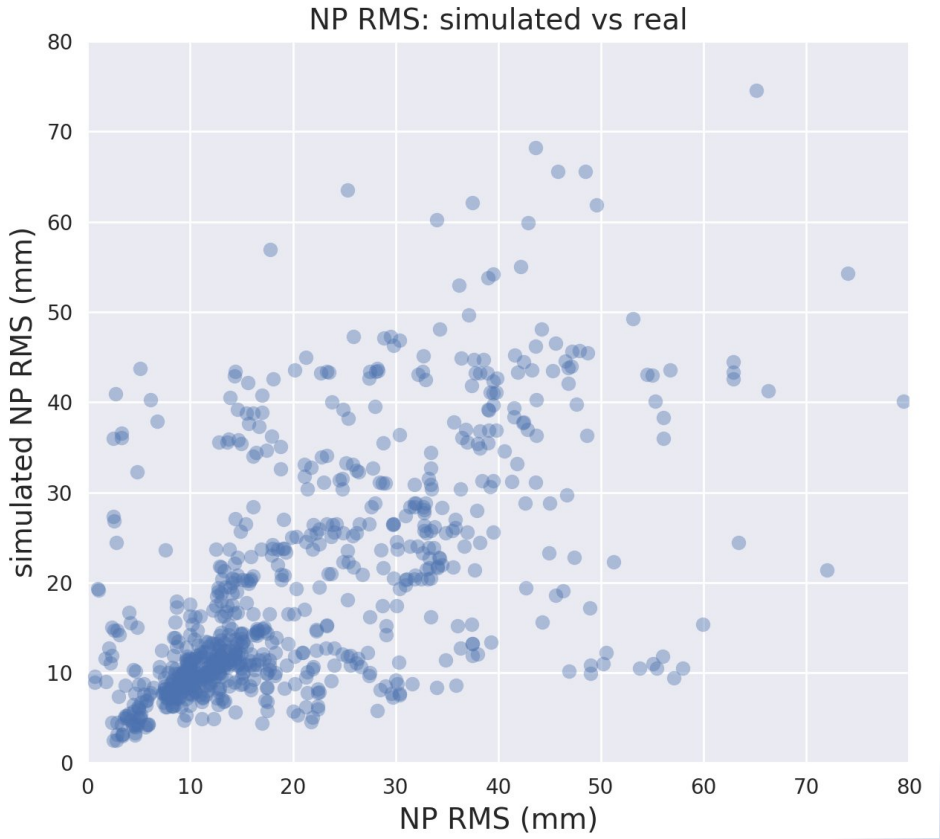
CAL RMS consistency?



SAT RMS consistency?

Model validation/performance

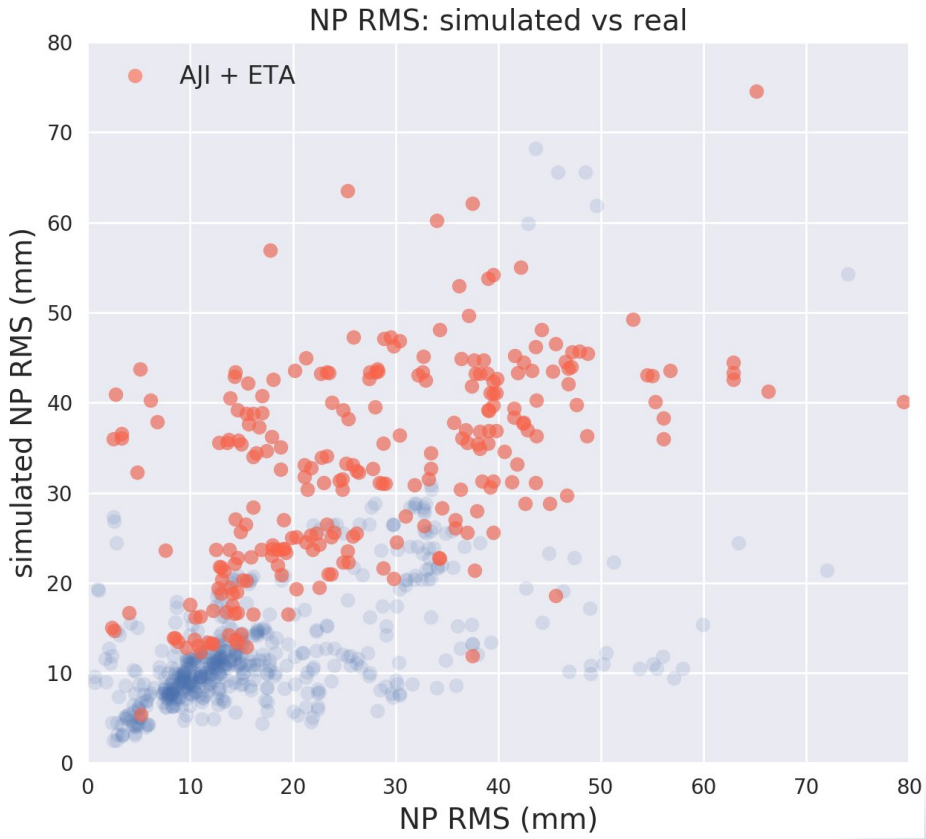
Comparison of predicted NP RMS with actual NP RMS provides a measure of model performance



Model validation/performance

Comparison of predicted NP RMS with actual NP RMS provides a measure of model performance

Bigger targets (AJI, ETA) are harder to model



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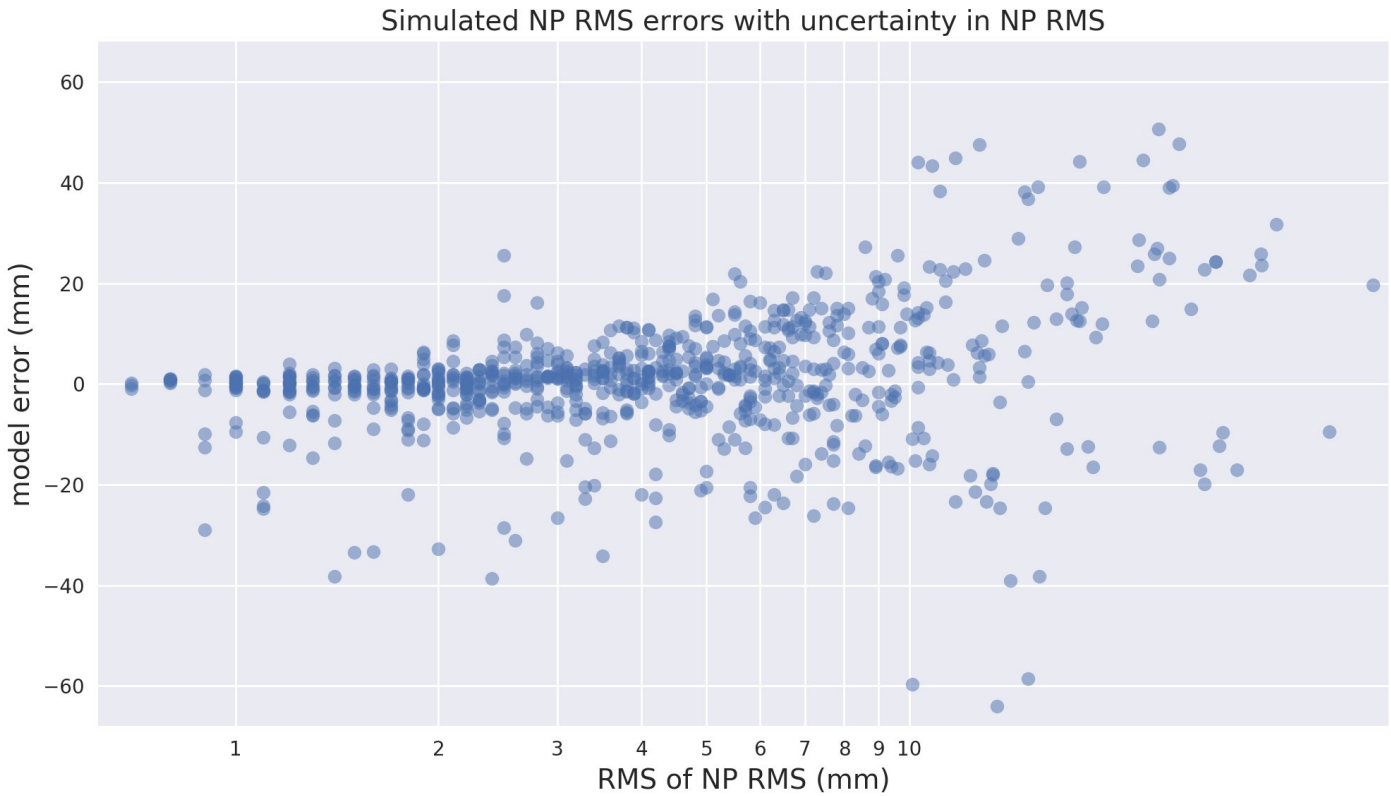

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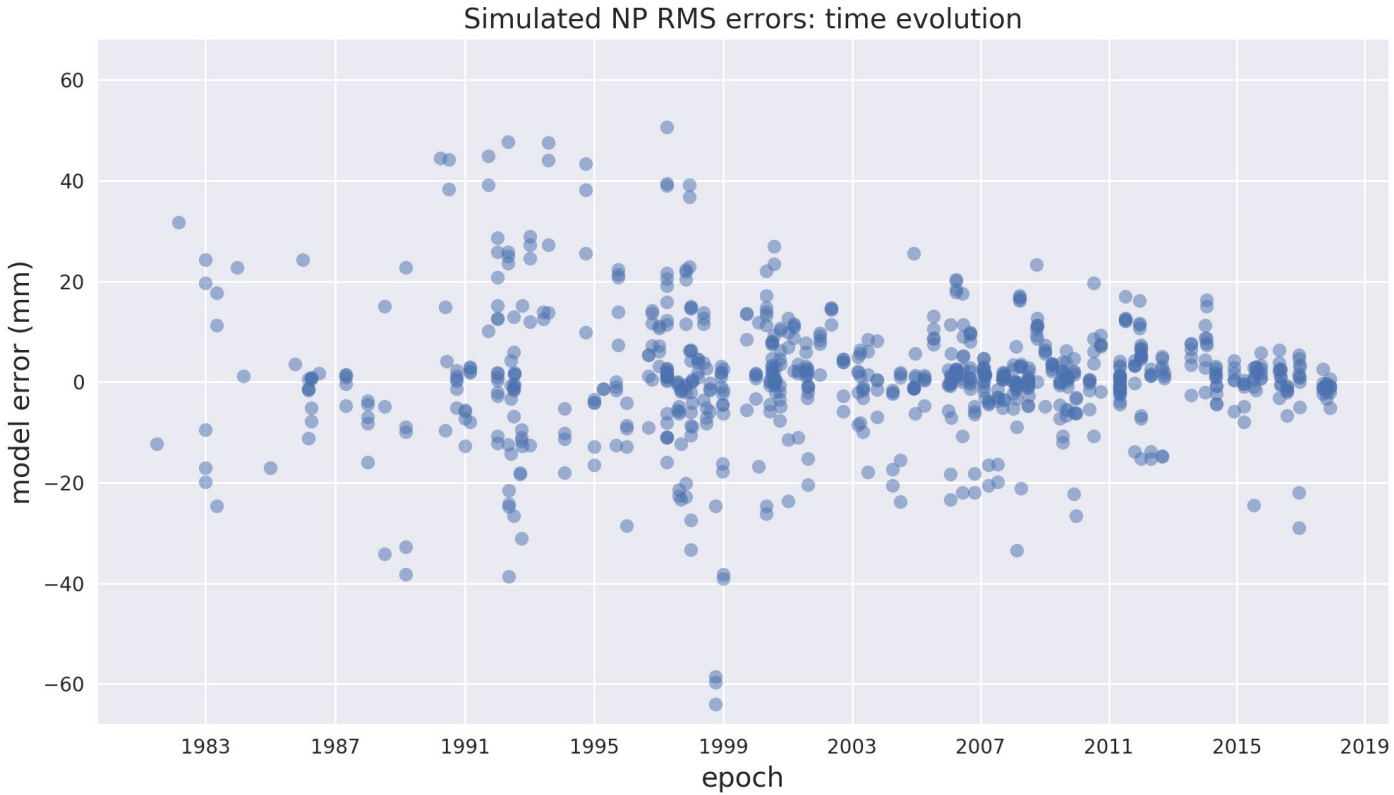
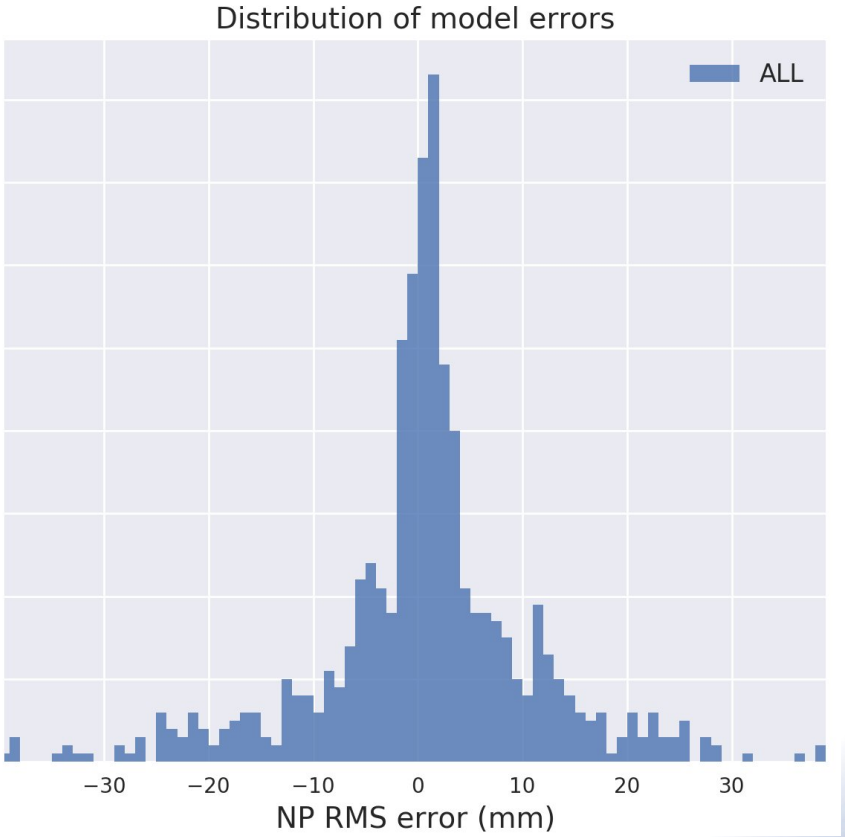


Model validation/performance

Despite expected caveats models performs reasonably well most of the time



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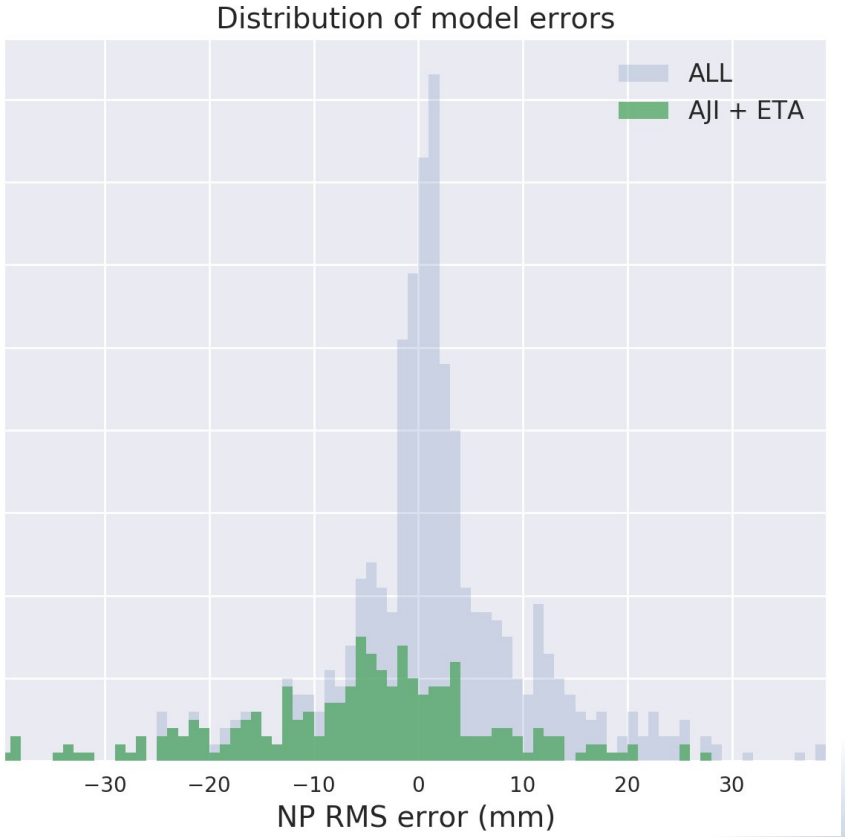

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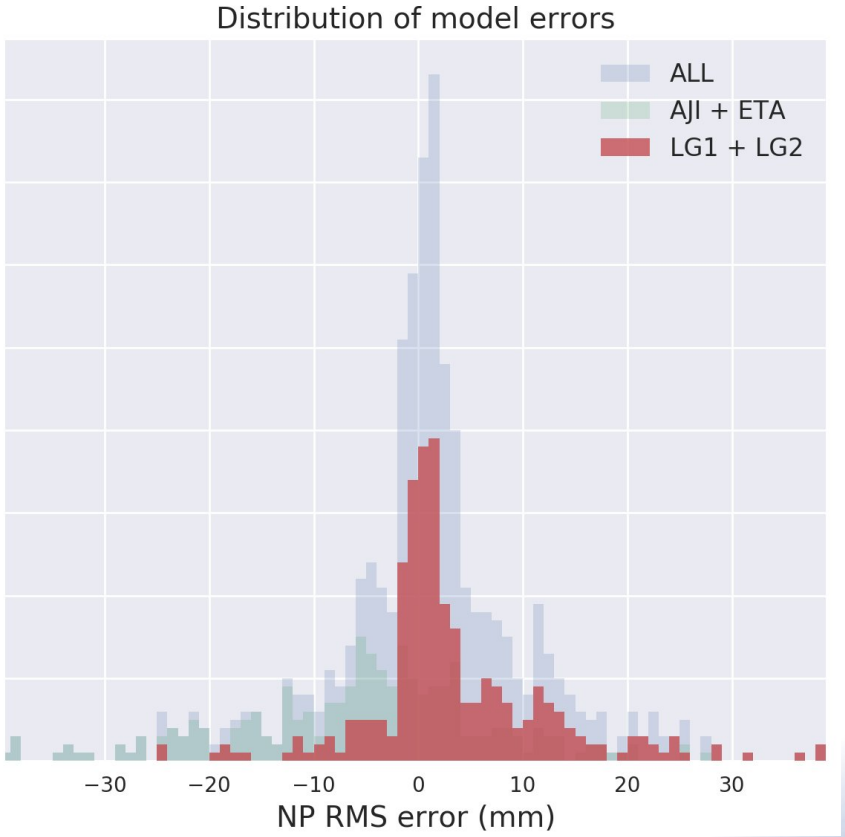
Most systems well predicted for smaller targets



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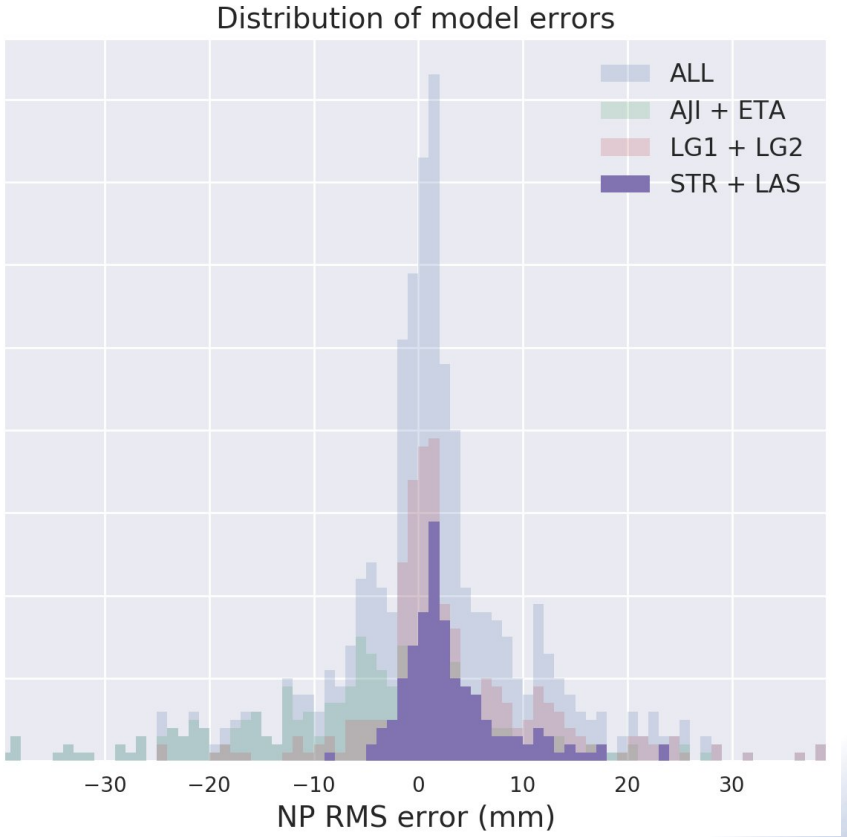


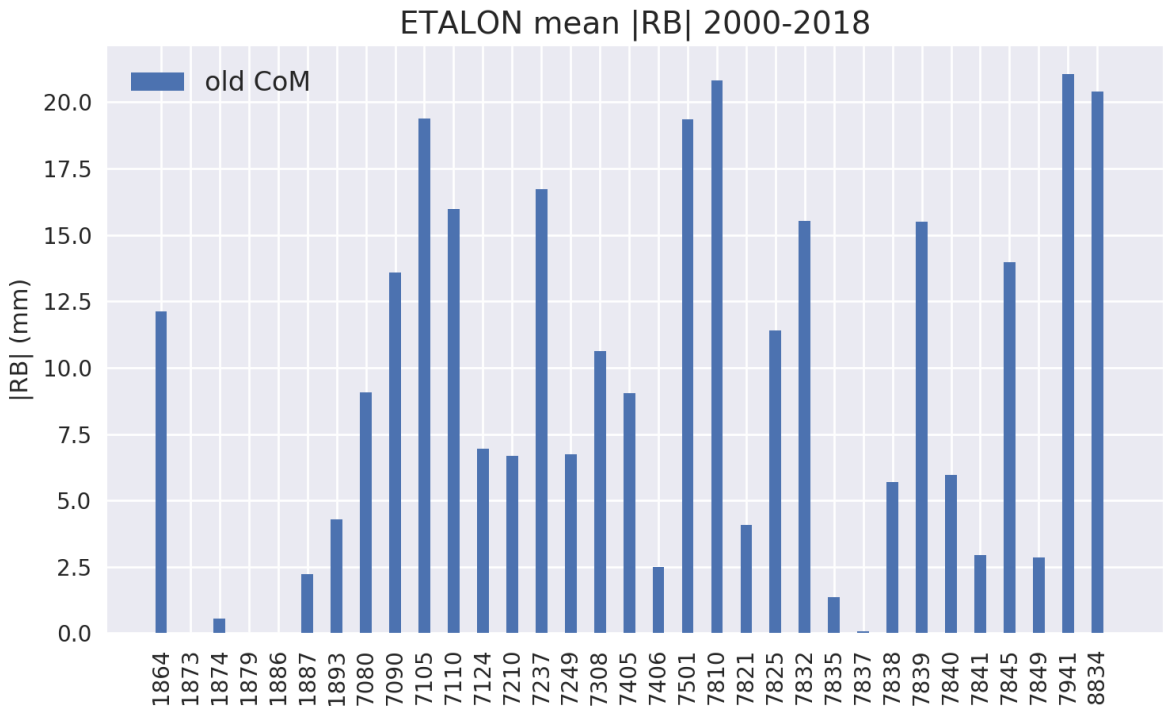
Results

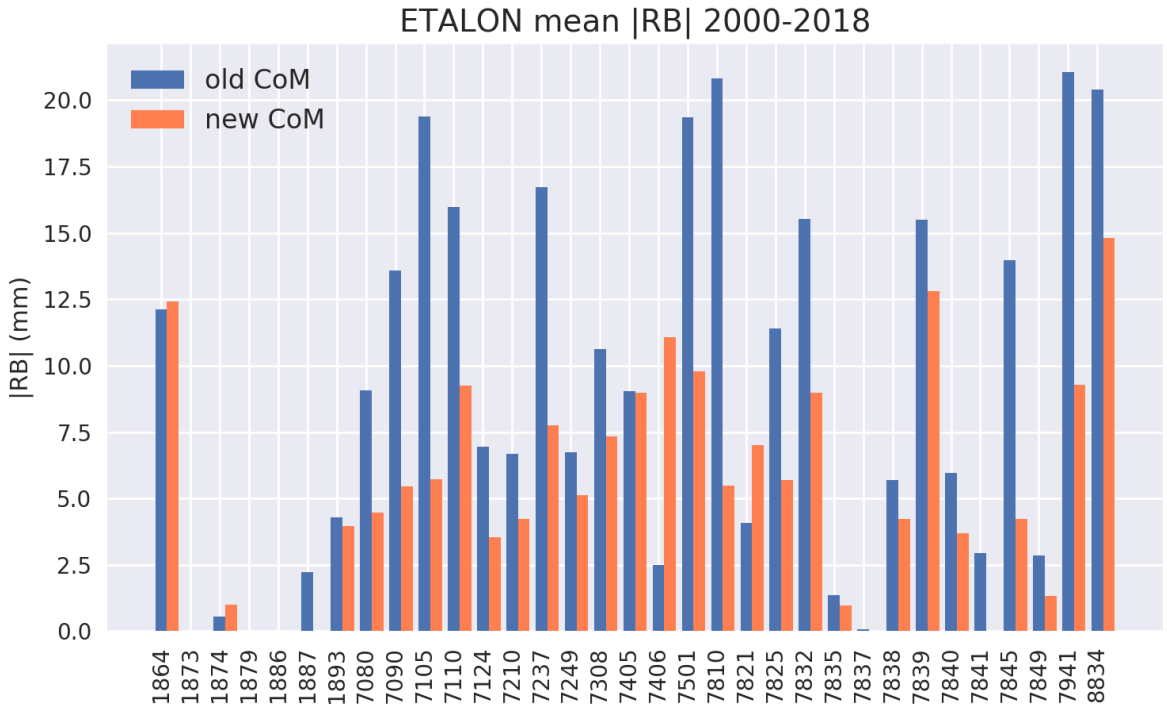
Centre of mass values computed for all stations of the network for 6 spherical satellites

We made comparisons of the estimated range errors obtained with the old and new CoM values

BUT: impossible to separate between range errors and CoM mismodelling

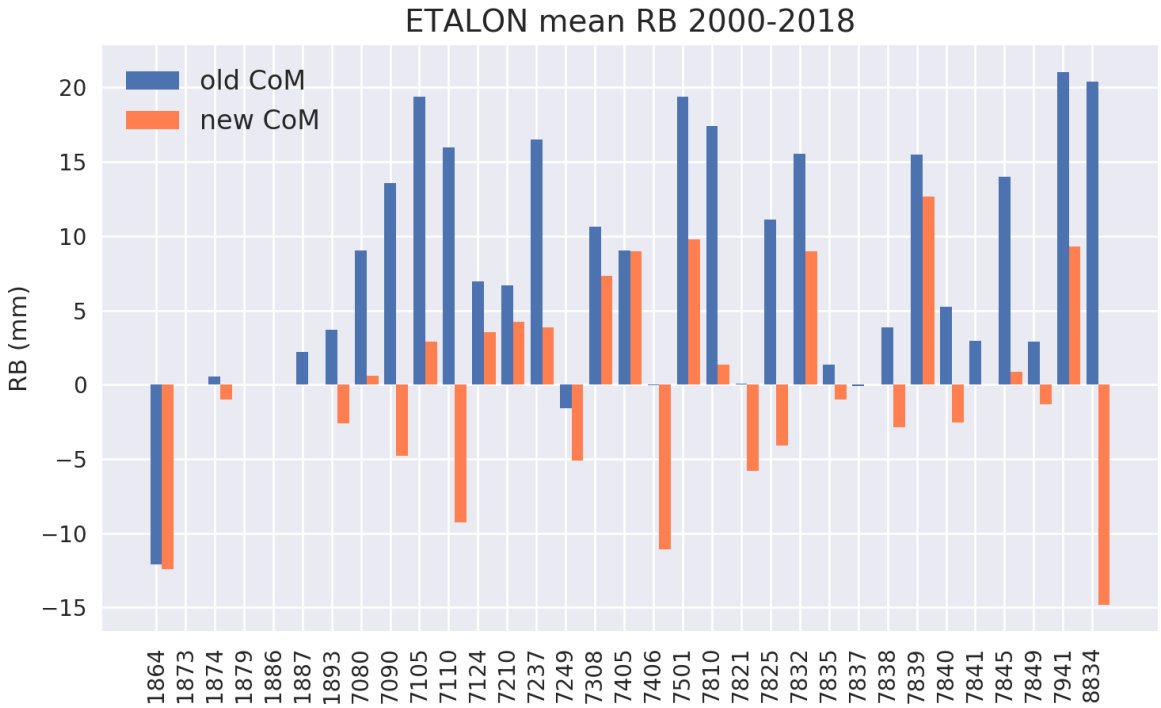
Assessed effect on station heights/frame scale





For Etalon, test CoM values remove about 1 cm biases from several stations

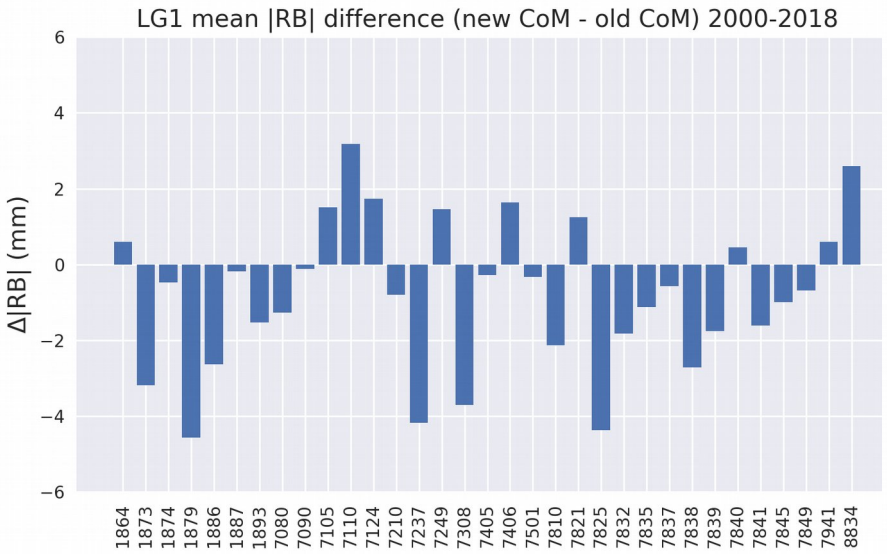
Very few stations see an increase in RB



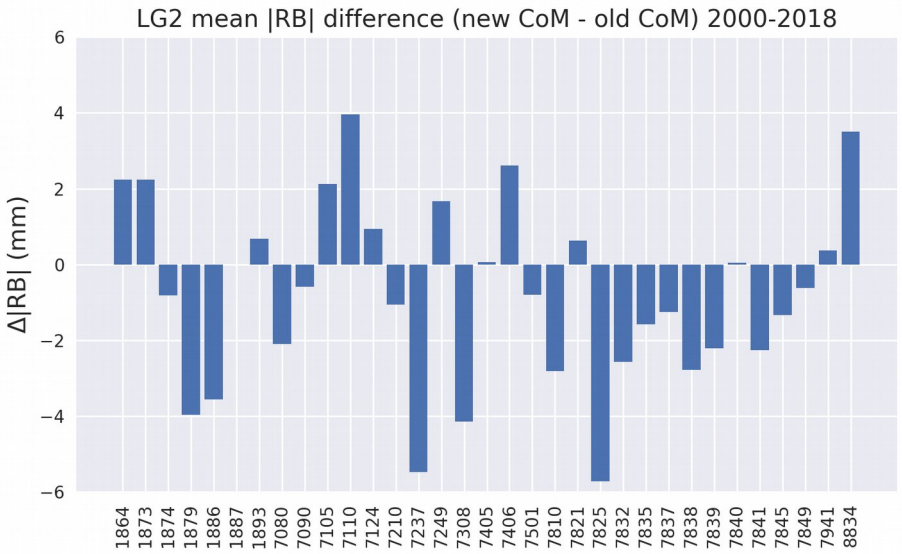
Actual differences are greater when considering the sign of the estimated biases

New CoM values remove to a large extent the predominant positive bias across the network

LAGEOS



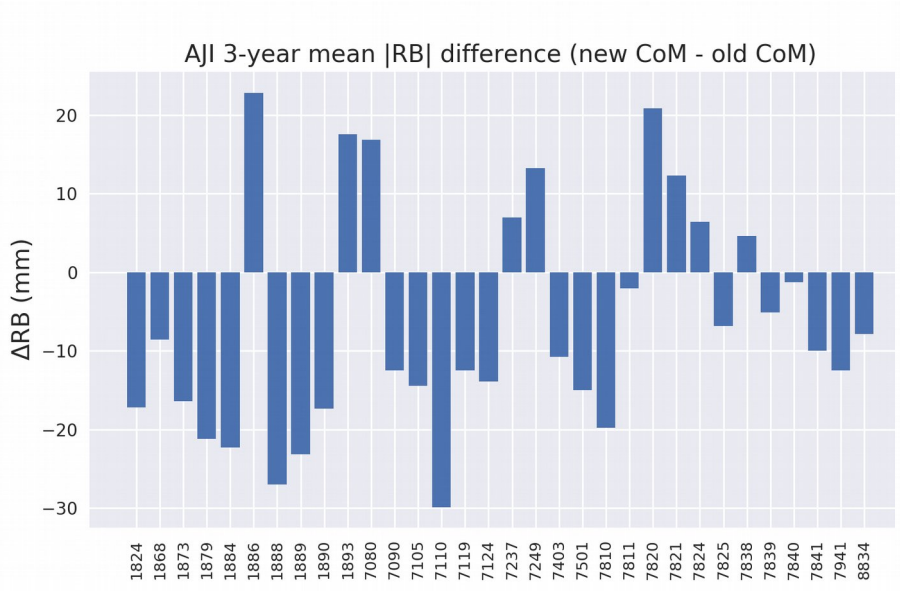
LAGEOS-2



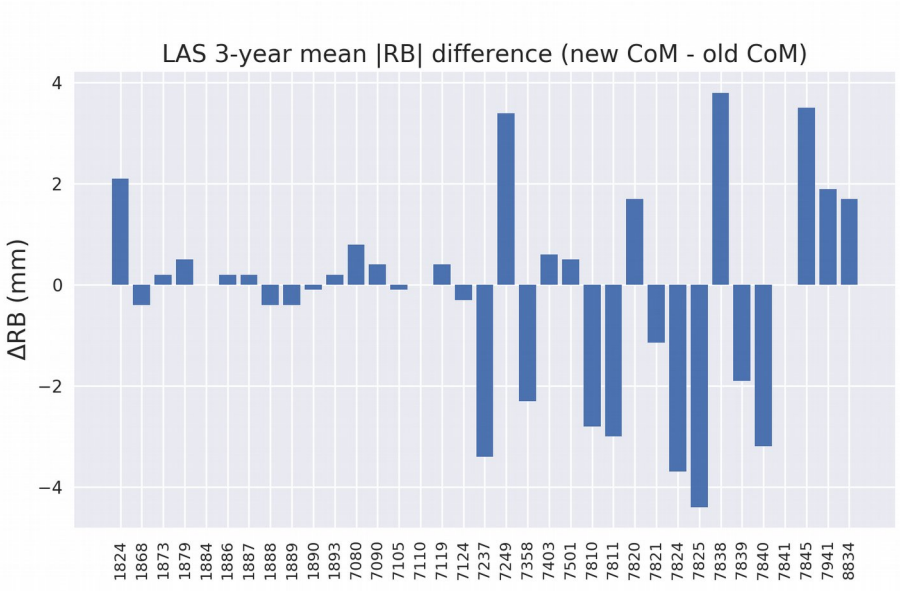
Negative is “good”: RB “removed” from stations

Positive is “bad”: RB “added” to stations

AJISAI



LARES



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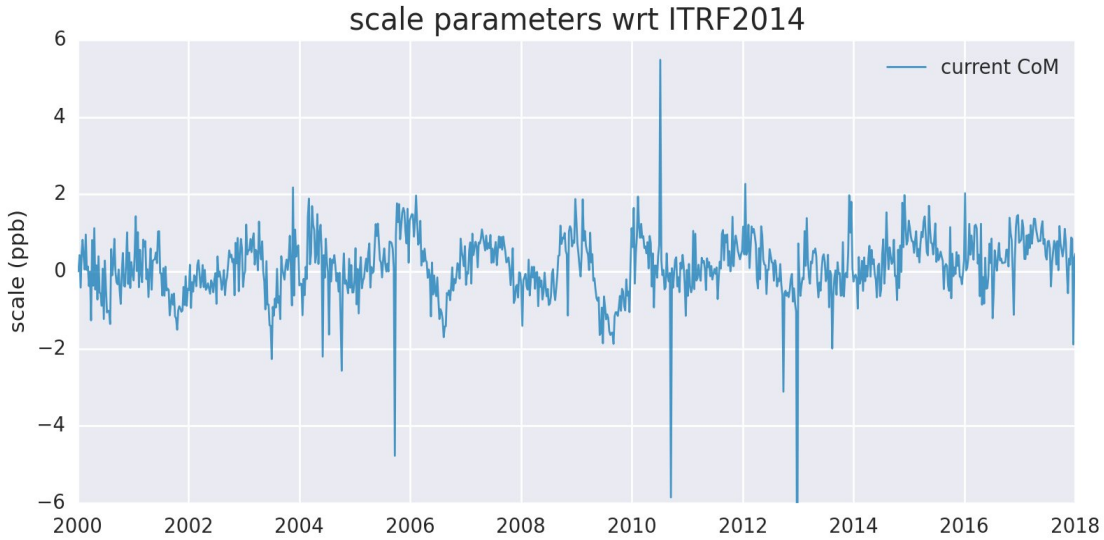
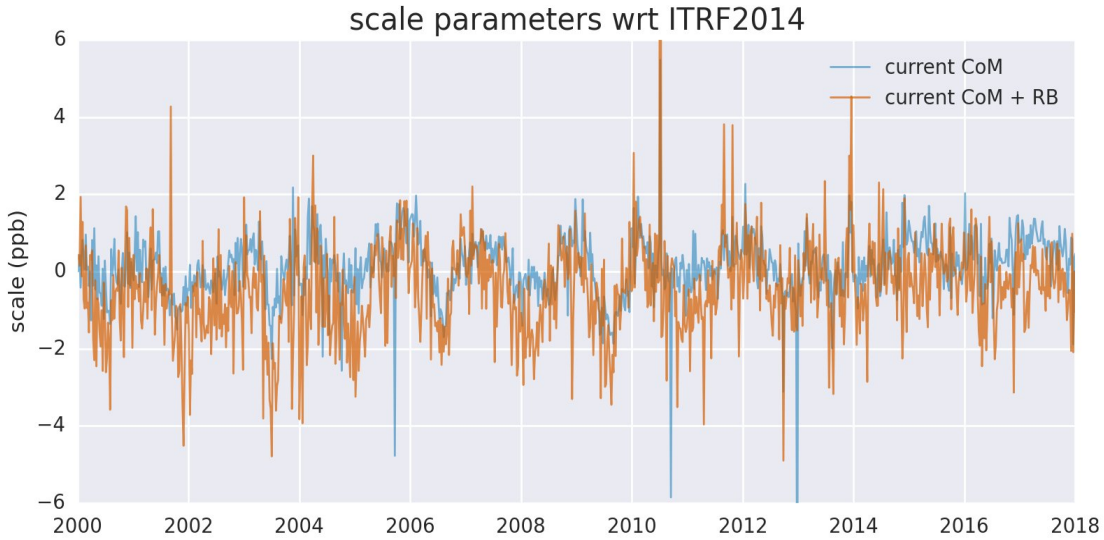
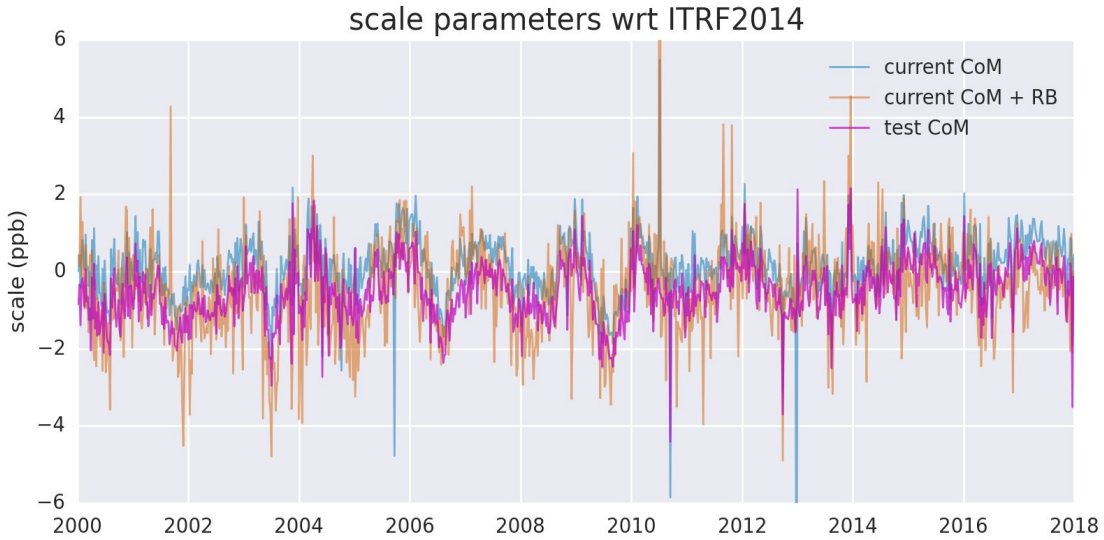






Similar average scale change when estimating RB and when using test CoM values: ~0.6 ppb

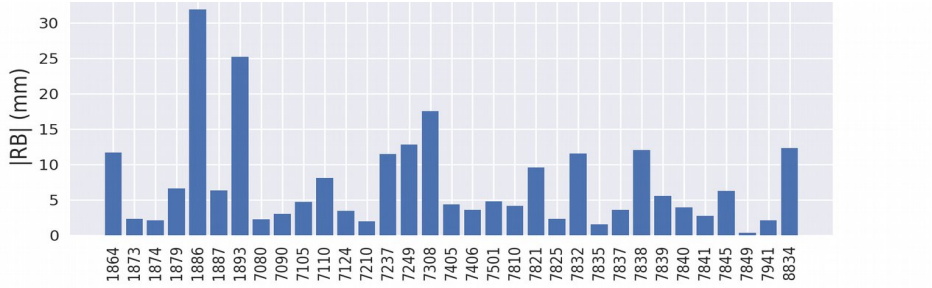
Or in other words: both solution types have **increased** station heights

Agreement between the scales realised by SLR and VLBI is improved

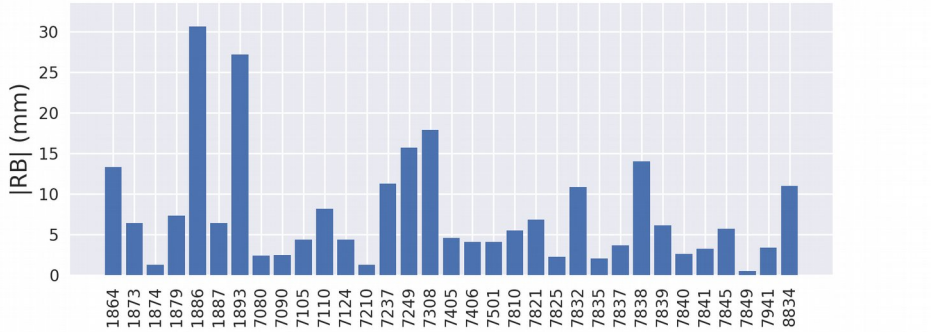
Have we solved the RB problems...?

|RB| remaining using new CoM values

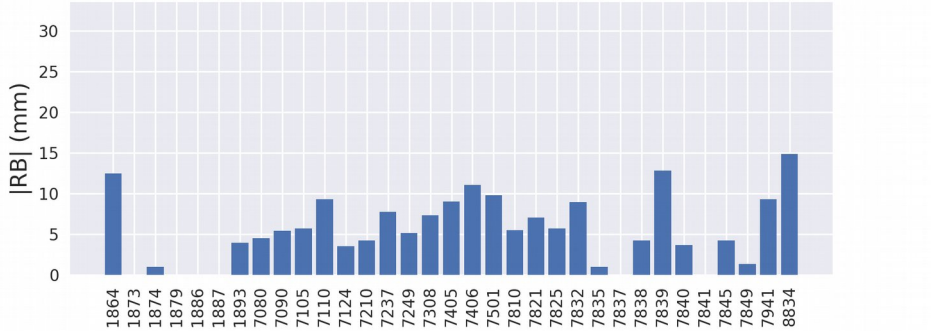
LAGEOS



LAGEOS-2



ETALON



Range biases do **NOT** disappear using the new CoM values

Summary

We have an improved CoM modelling for the spherical geodetic satellites

Updated modelling takes into consideration more details about the measuring process

Results introduce significant differences in the CoM offsets for LAGEOS, LAGEOS-2, Etalon and AJISAI

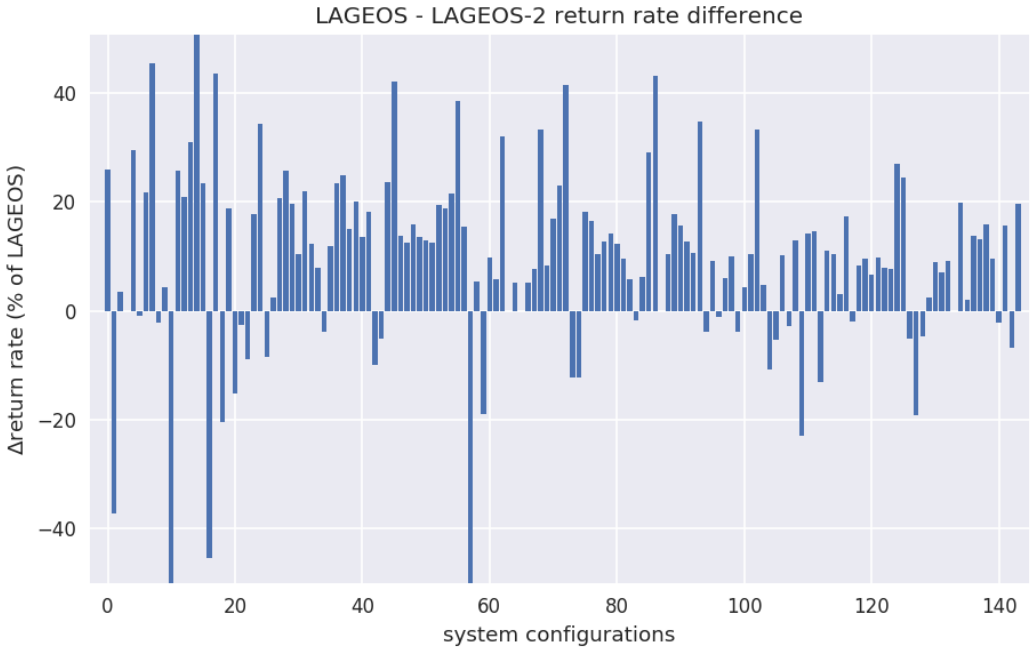
Differences for LAGEOS introduce a scale change in the SLR frame

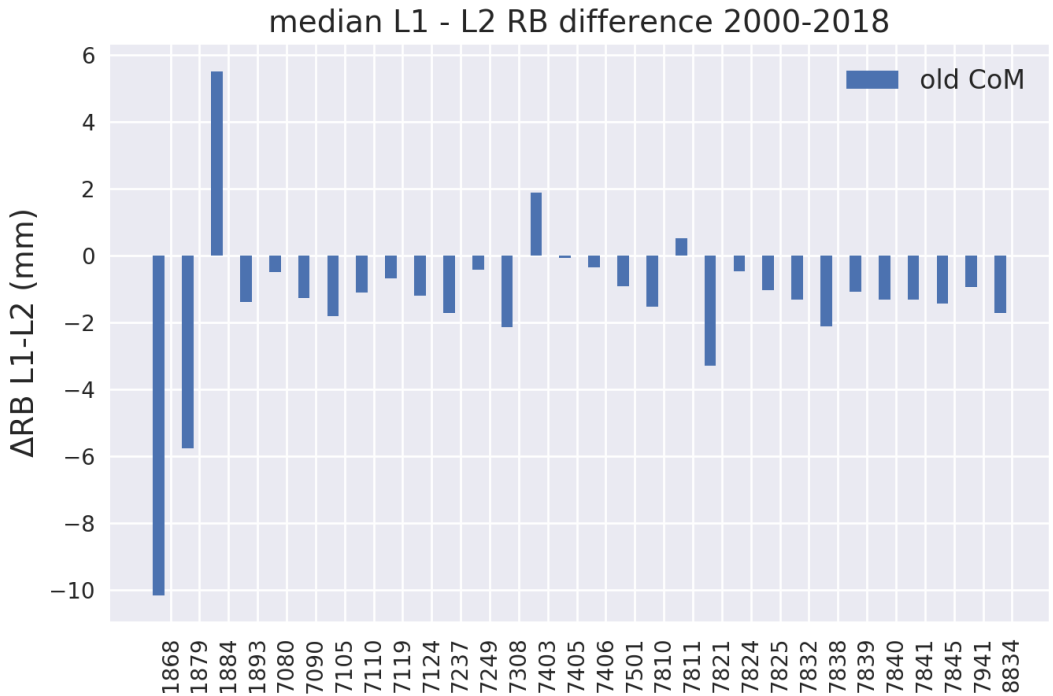
Caveats:

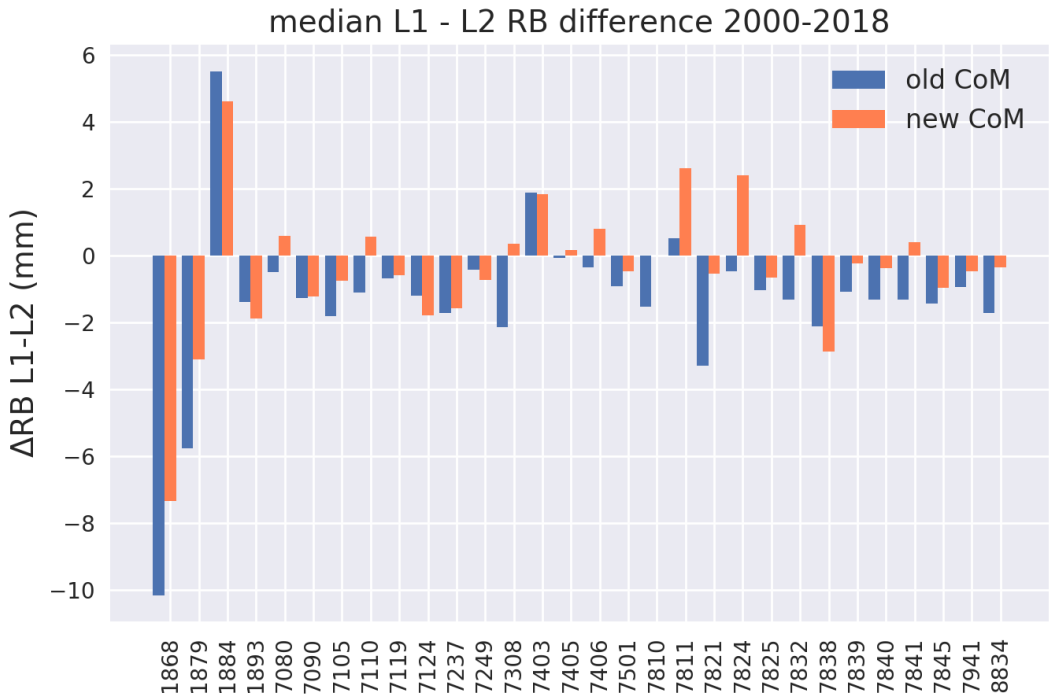
- incomplete knowledge of some systems details
- model only considers ideal, linear behaviour
- realistically, accuracy no better than ~2-3 mm for LAGEOS and ~6 mm for Etalon/AJISAI on average across the network; much worse for individual cases

CoM alone **can not** possibly fix everything we see in the orbital solutions

Thank you







3. CoM computation (multi-photon systems)

			mirror	laser				detector				timer		policy/reduc.	
Station		epochs	diam	wave	eng	width	rate	type/model	qe	rise	jitt	model	prec	cal	sat
7941	MATM	20100524 20500101	150	532	100	50	10	MCP PMT210	15	120	30	ET HTSI	2	MP	3.0	3.0

Determine mean detection rate for period **rr (%)**

Number of photoelectrons **Npe**

Draw sample from Poisson distribution with rate **Npe** **n=0,...k**

Draw **n** samples from average distribution of returned pulses

Simulated returned pulse

Convolve with system temporal response

Determine timing event

Repeat many times to generate ranging distribution

Reduce data according to rejection criteria