Further improvements in mitigating systematics in geodetic laser ranging

José Rodríguez[1], Graham Appleby[1], Toshimichi Otsubo[2],

[1]BGS Space Geodesy Facility, UK

[2]Hitotsubashi University, Japan

Context

SLR and VLBI scale difference ITRF2014 (1.37 ppb)

Allowing for the presence of errors in SLR observations 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, therefore an offset to their centre of mass (CoM) is required to solve the equations of motion

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

Station heights estimated from SLR will absorb errors in the ranging measurements by a ratio of approximately 1:1

Aims

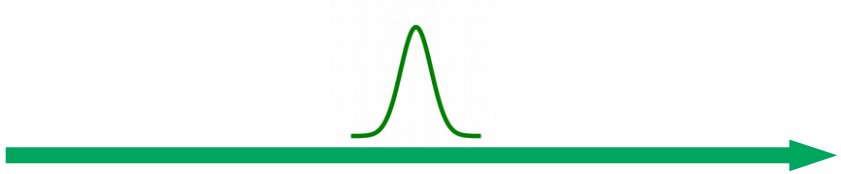
Reassess current centre of mass (CoM) models as used by ILRS analysts for ITRF2014

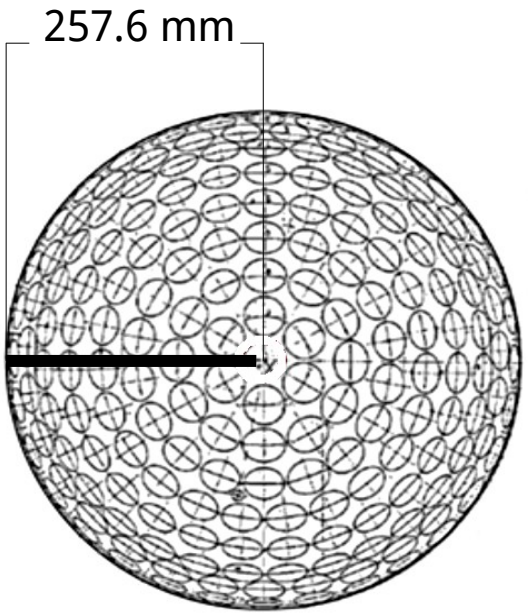
Attempt to improve current standards incorporating effects previously only approximated

Recompute all steps of the computation from scratch using the latest data available

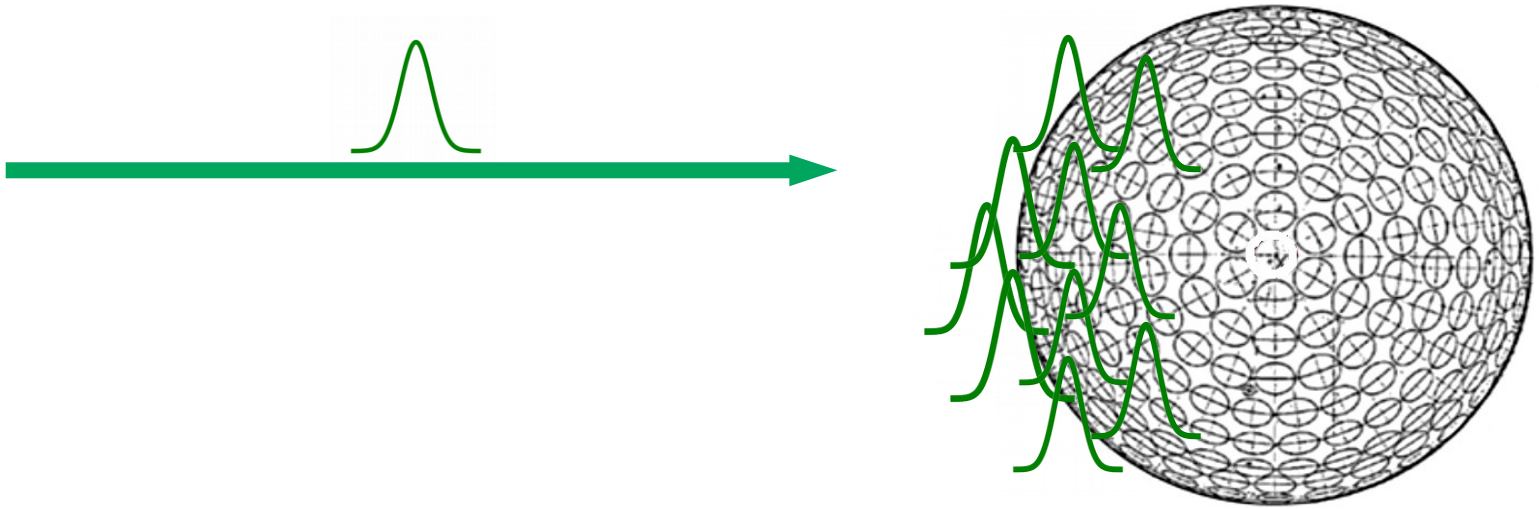
Assess the impact on the overall errors estimated in the orbital solutions

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





LAGEOS



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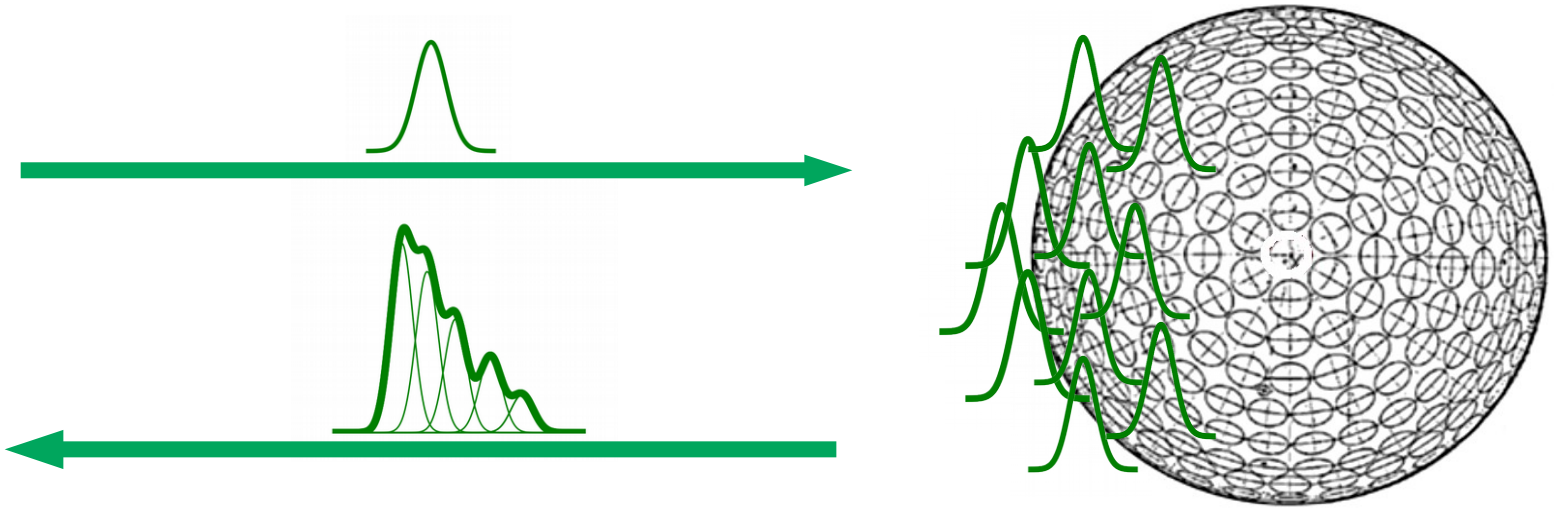

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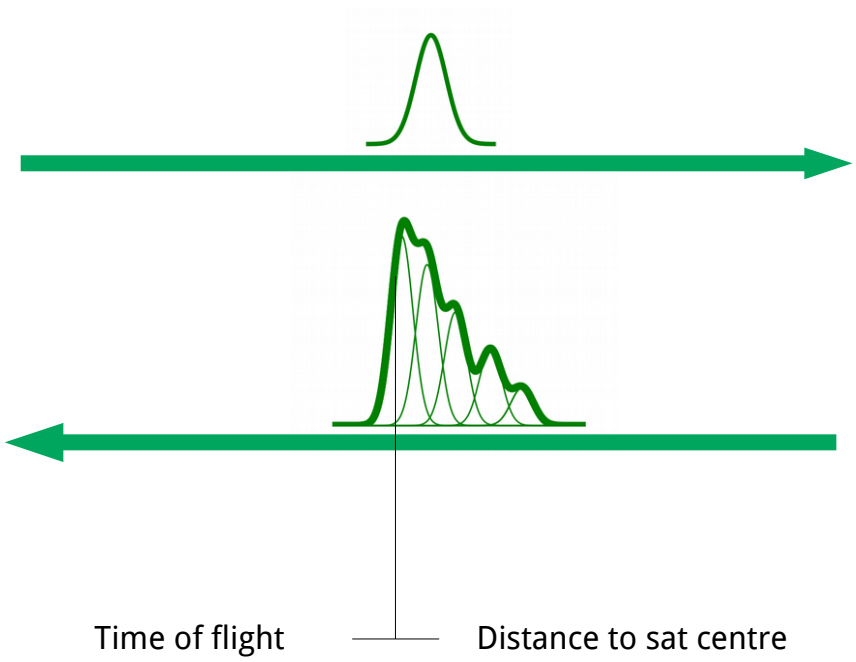
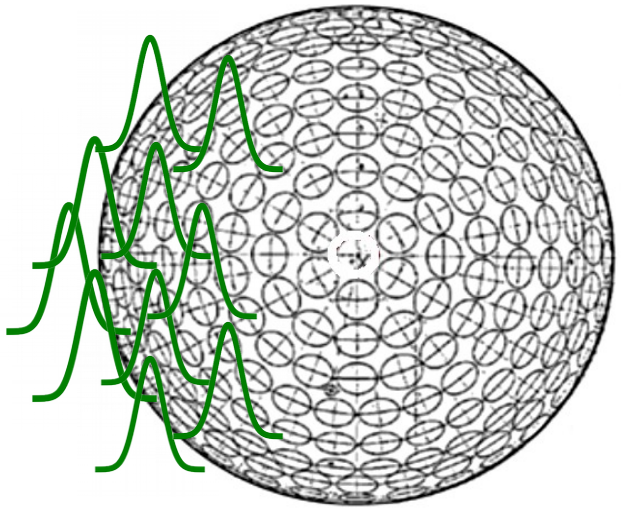




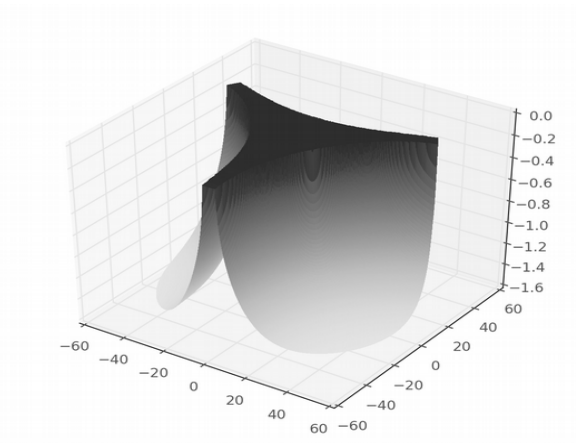
LAGEOS

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

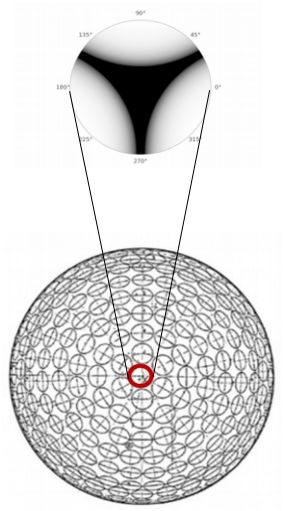
3. Compute CoM values using **system specifications**



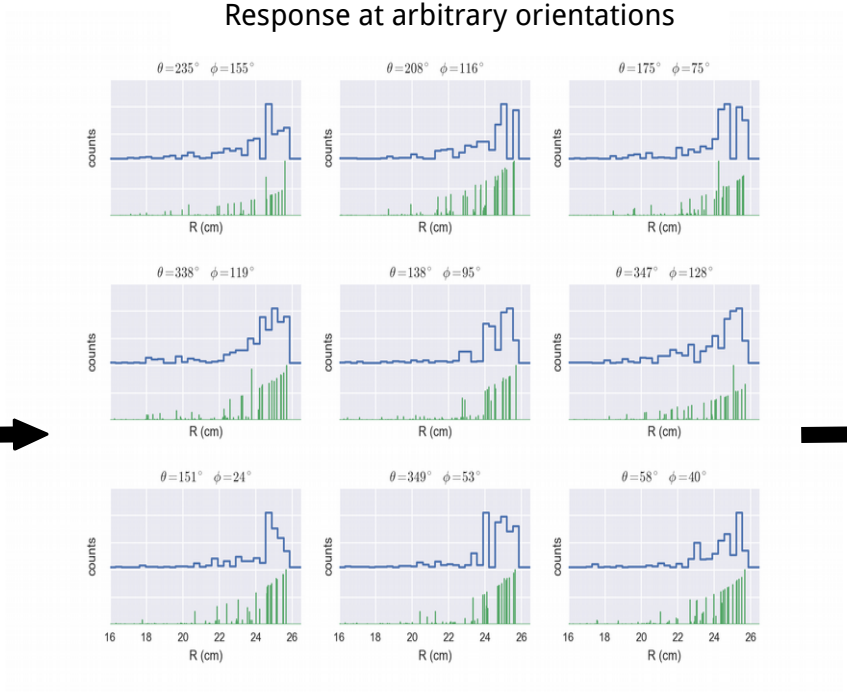
Otsubo & Appleby, System dependent CoM corrections for spherical satellites, 2003

1. Optical response function

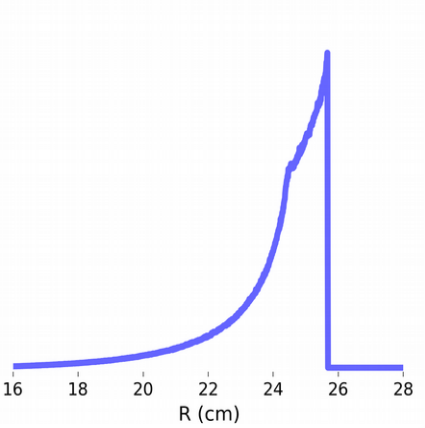
Reflectivity map



Response at arbitrary orientations



Average over 250K orientations

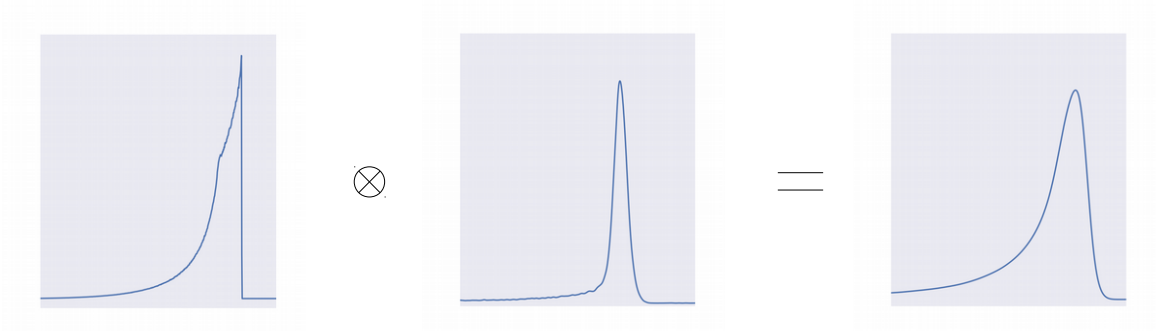


2. Empirical fit

Accumulate single-photon detection data to obtain empirical distributions

We stacked full rate data from Herstmonceux station (2015-2017)

- ~ 9.6M LAGEOS observations
- ~ 6.1M LAGEOS-2 observations
- ~ 5.9M LARES observations
- ~ 1.0M Etalon-1 + Etalon-2 observations



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 and periods of applicability

Input data consists of hardware parameters that determine system behaviour, average return rates and optical response functions

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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)

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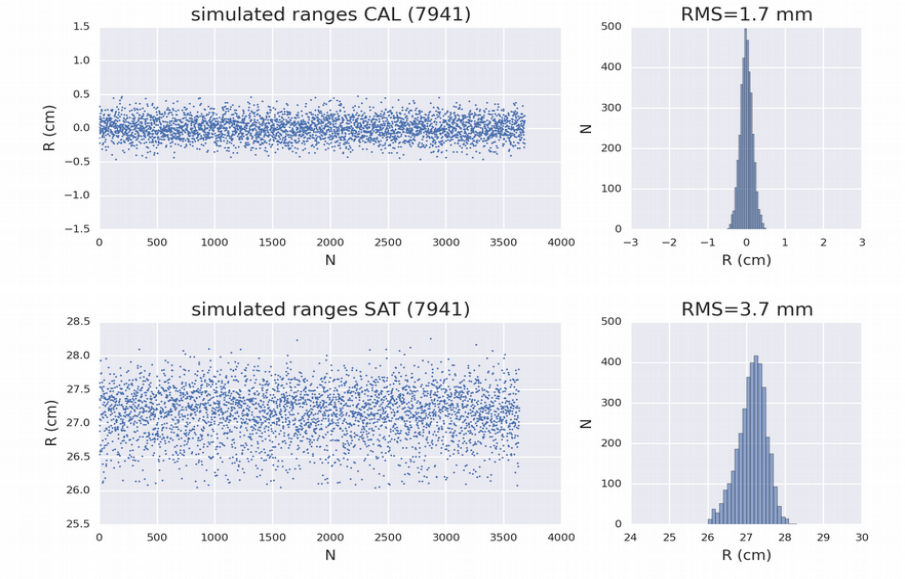
Solve numerically using calibration data provided by some stations (estimate from relevant system parameters otherwise)

Multi-photon ranging

Numerical simulation of simplified, ideal detection process

Dependent on some difficult-to-validate assumptions

3. CoM computation



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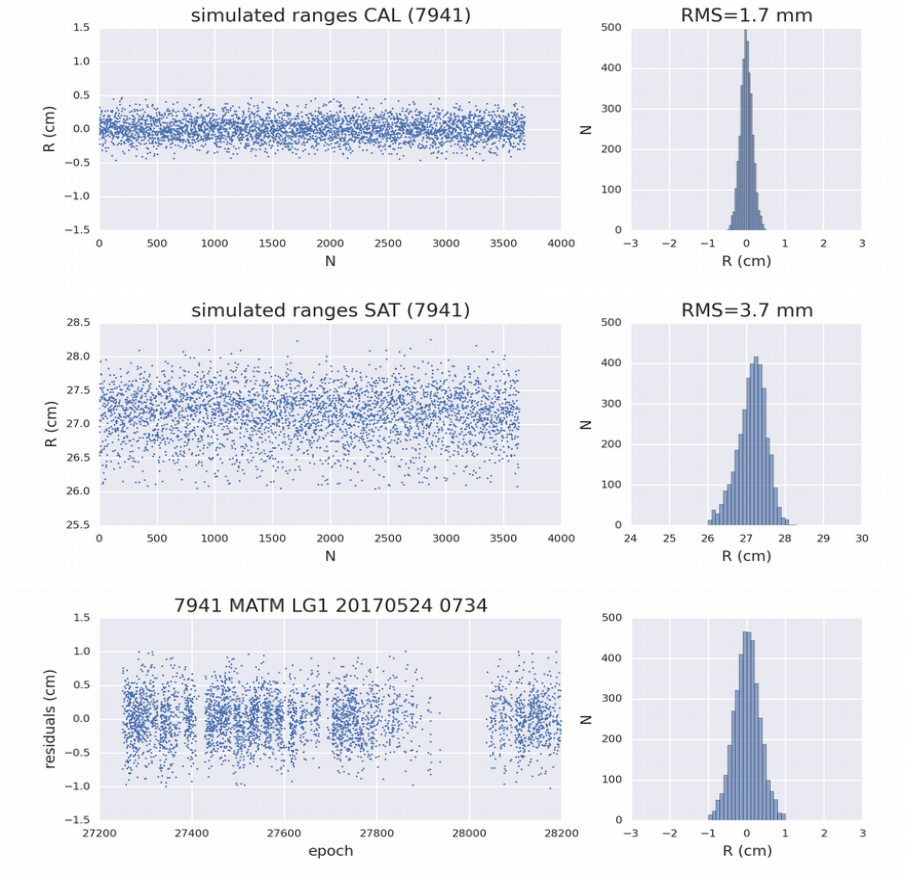

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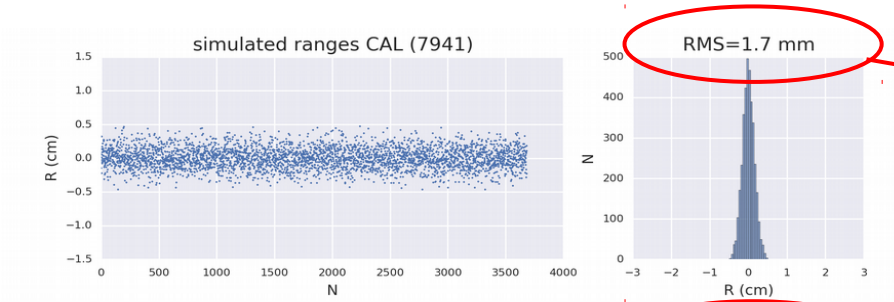
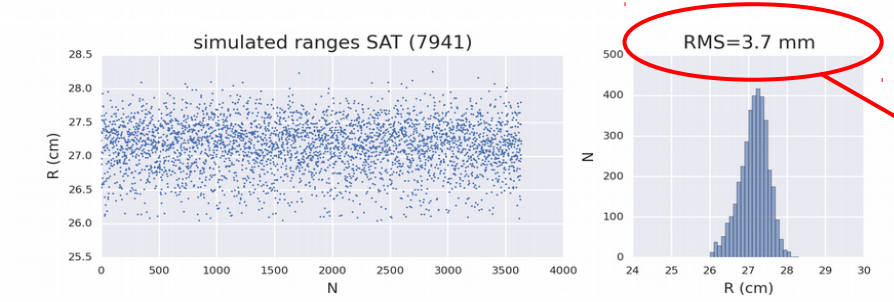
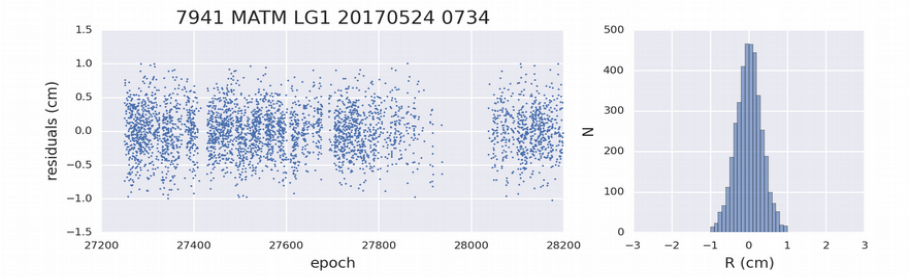
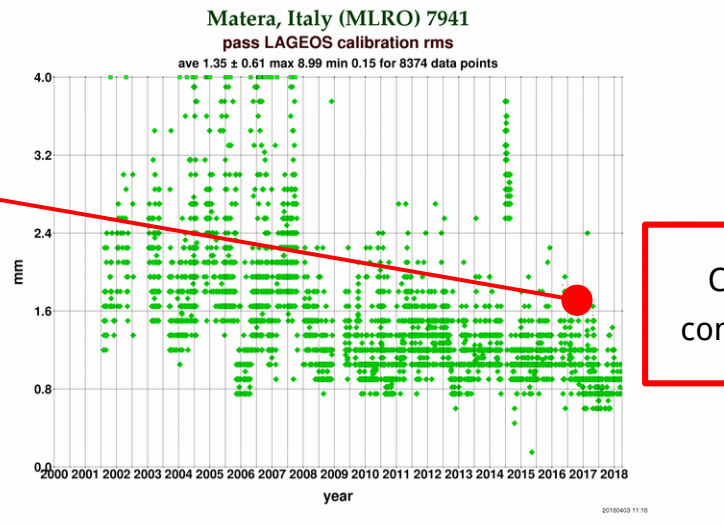
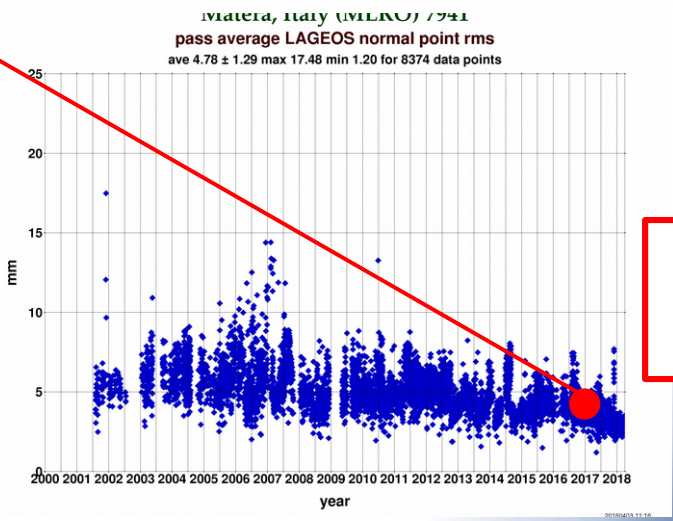








CAL RMS consistency?



SAT RMS consistency?

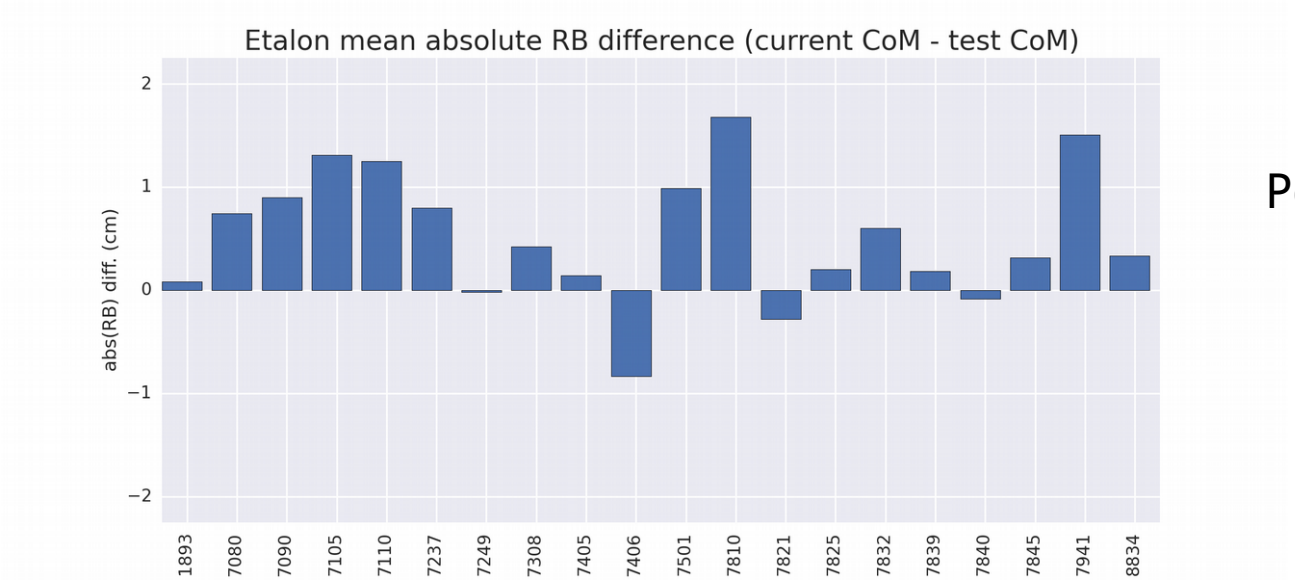
Results

Centre of mass values computed for all stations of the network for LAGEOS and Etalon satellites

We made comparisons of the estimated range errors obtained with the test and current CoM values applied

Not possible to separate between range errors and CoM mismodelling: this exercise only informs about the changes imparted by using different sets of corrections

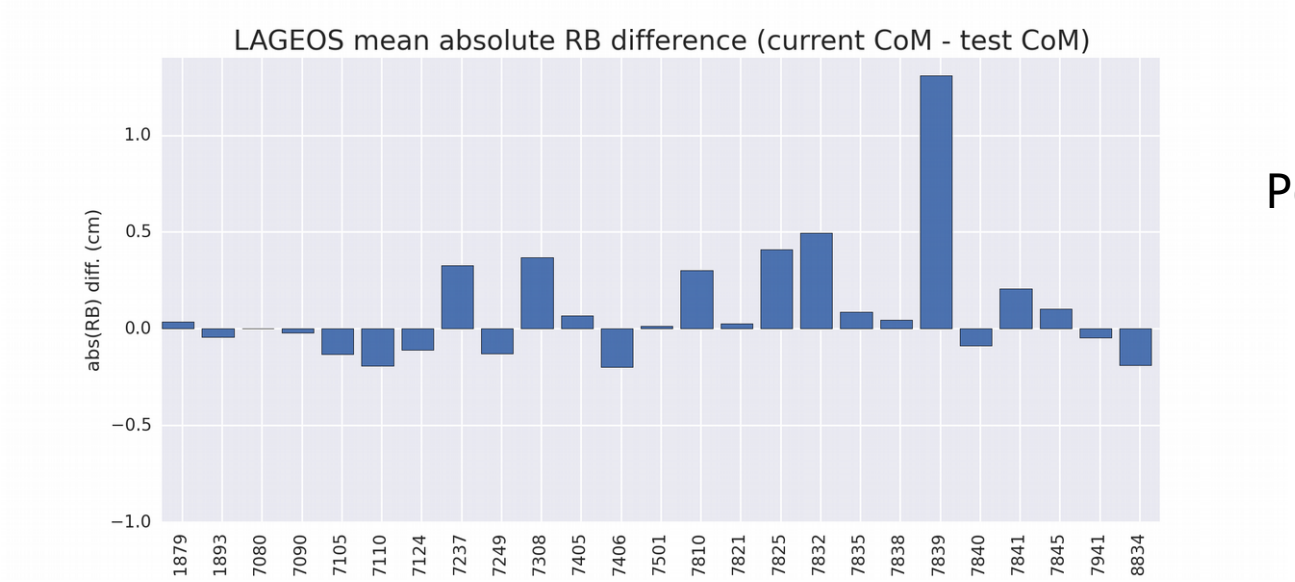
Assessed effect on station heights/frame scale



Positive better: reduced RB

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

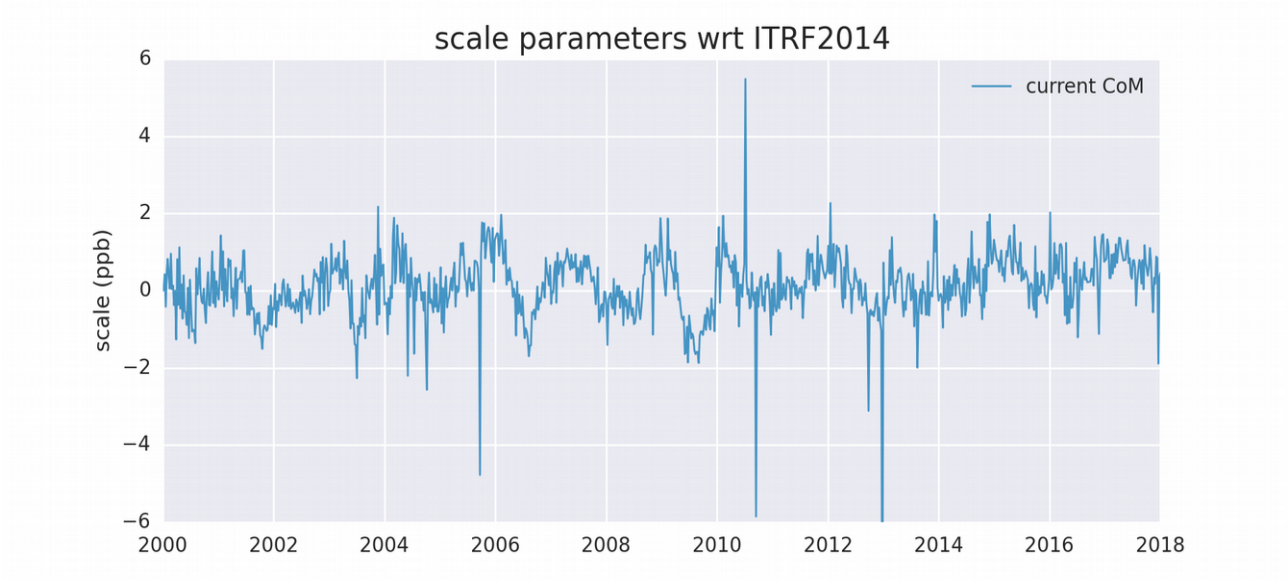
Very few stations see an increase in RB

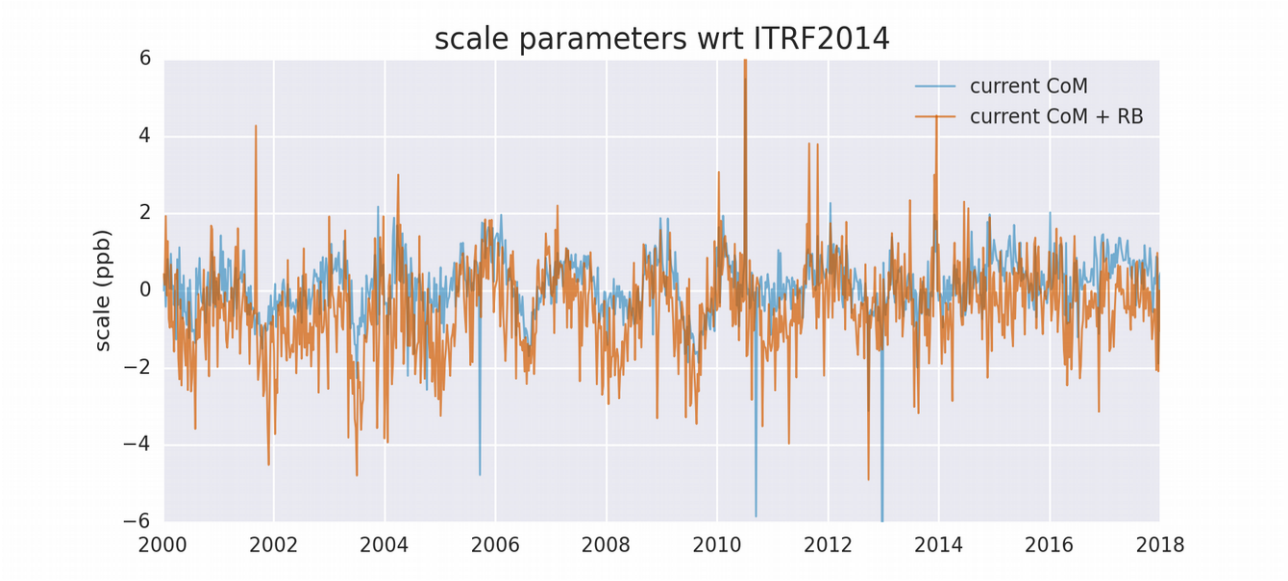


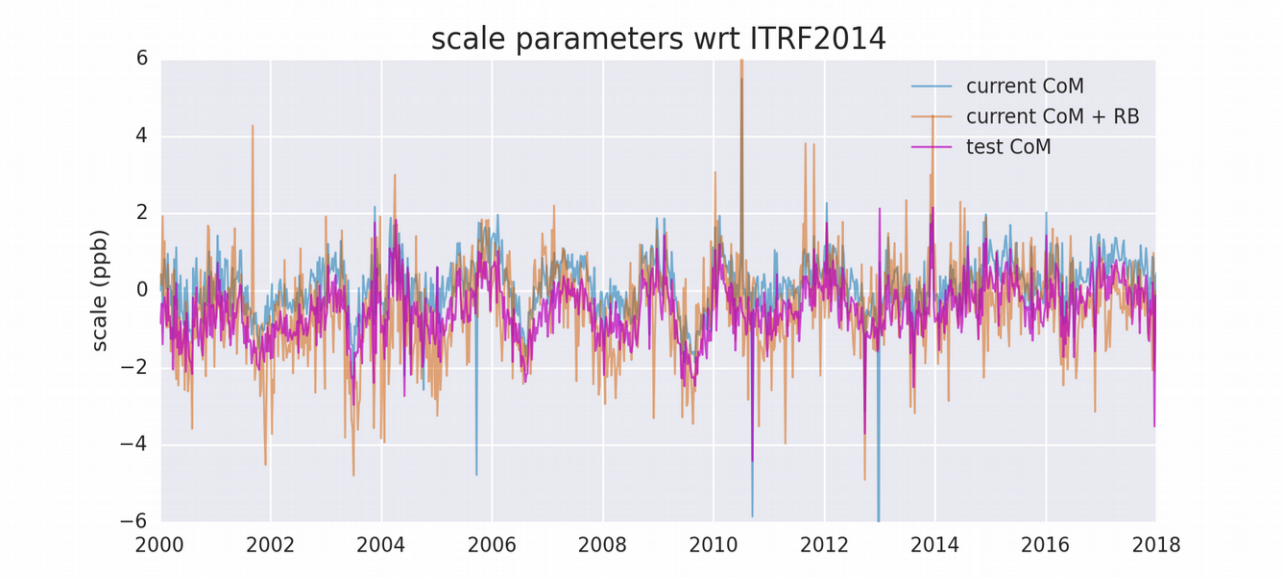
Positive better: reduced RB

More mixed picture for LAGEOS, although “gains” probably outweight “losses”

This does not inform us about the sign of the changes…



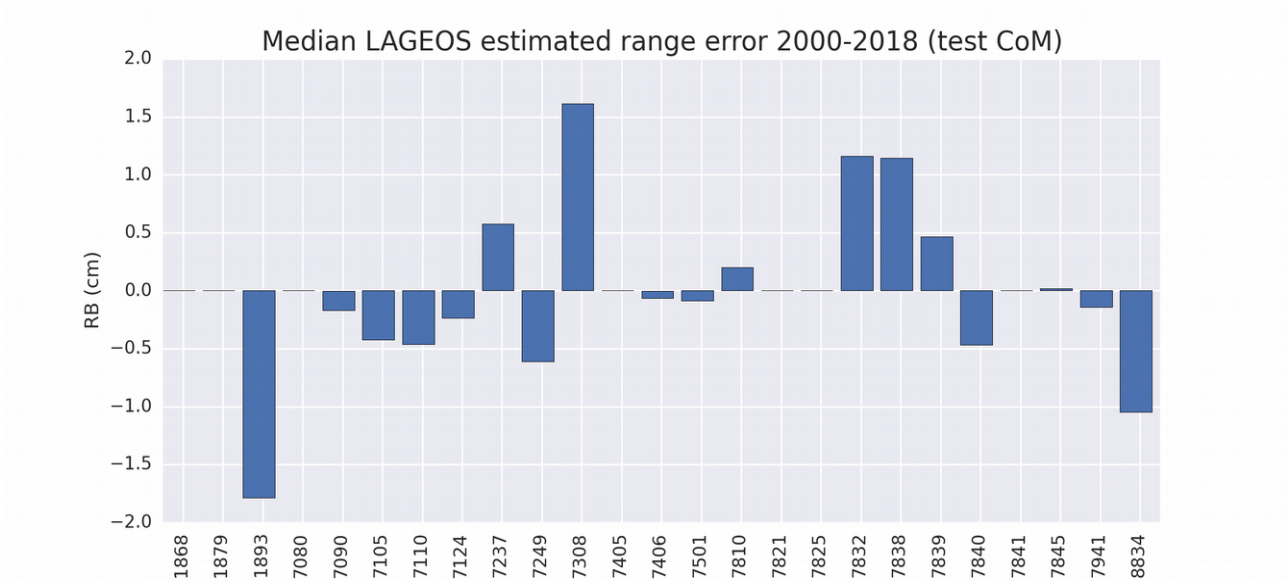




Similar average scale change when estimating RB and when using test CoM values: ~0.6 ppb

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

...is this all there is to it?



Landing in the “right” place, on average, does not mean absence of problems

Summary

We have attempted to improve the CoM modelling for the spherical geodetic satellites

Updated modelling takes into consideration more details about the measuring process

Results are encouraging for Etalon satellites (although their weight in the solutions is very low)

Significant consequences for LAGEOS, leading to a change in the frame scale

Caveats:

- not final values
- some model assumptions not checked/validated properly yet
- sensitivity analysis not done
- realistically, accuracy no better than ~2-3 mm for LAGEOS and ~6 mm for Etalon
- a few other issues currently under investigation

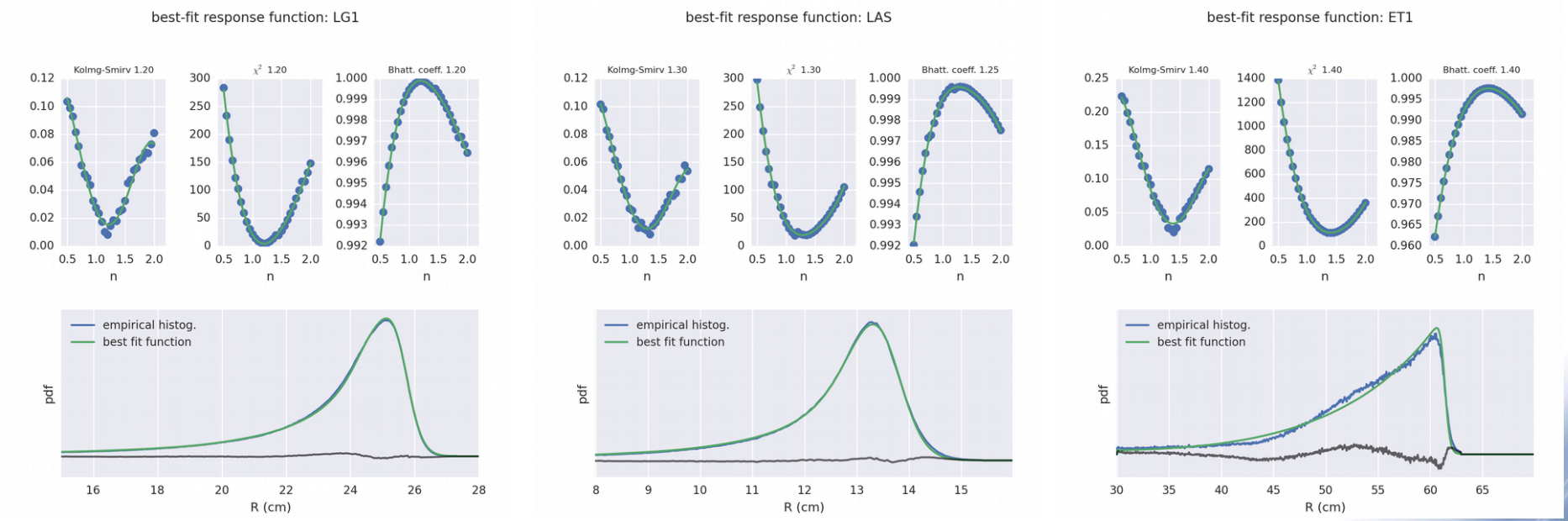
CoM alone **can not** possibly fix everything we see in the orbital solutions

Thank you

2. Empirical fit

Choosing the best candidate according to some metric

Good agreement for LAGEOS pair and LARES, not so good for Etalon



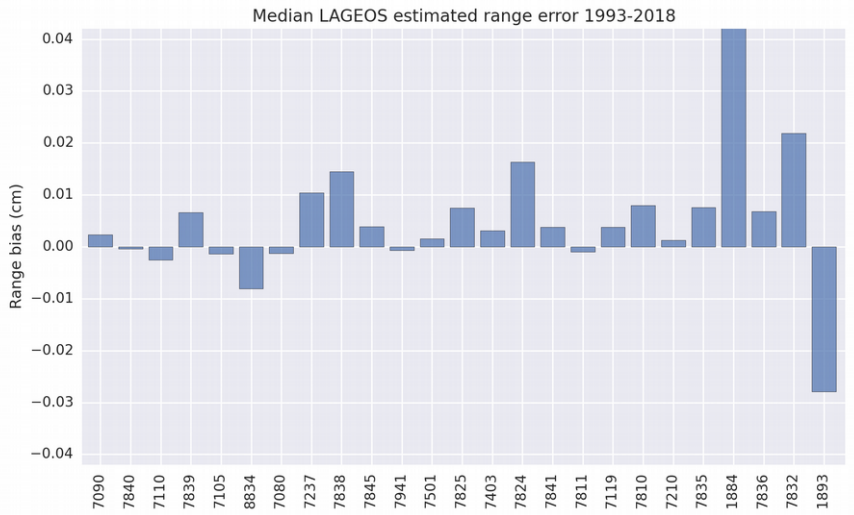
LAGEOS

LARES

Etalon

Estimated range biases alone do not tell us what the specific error sources are...

but they may offer some clues:



Why most biases appear to be positive over very long periods of time?

Why a group of stations present quite big biases for the Etalon satellites?

3. CoM computation (multi-photon systems)

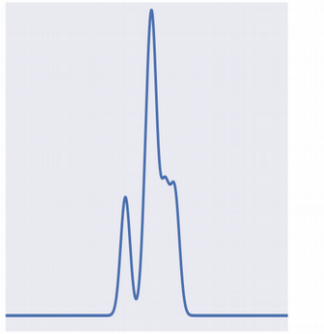
		mirror	laser				detector				timer		policy/reduc.	
Station	epochs	diam	wave	eng	width	rate	type/model	qe	rise	jitt	model	prec	cal	sat
7941 MATM	20100524 20500101	150	532	100	50	10	MCP PMT210	15	120	30	ET HTSI	2	MP	3.0 3.0

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

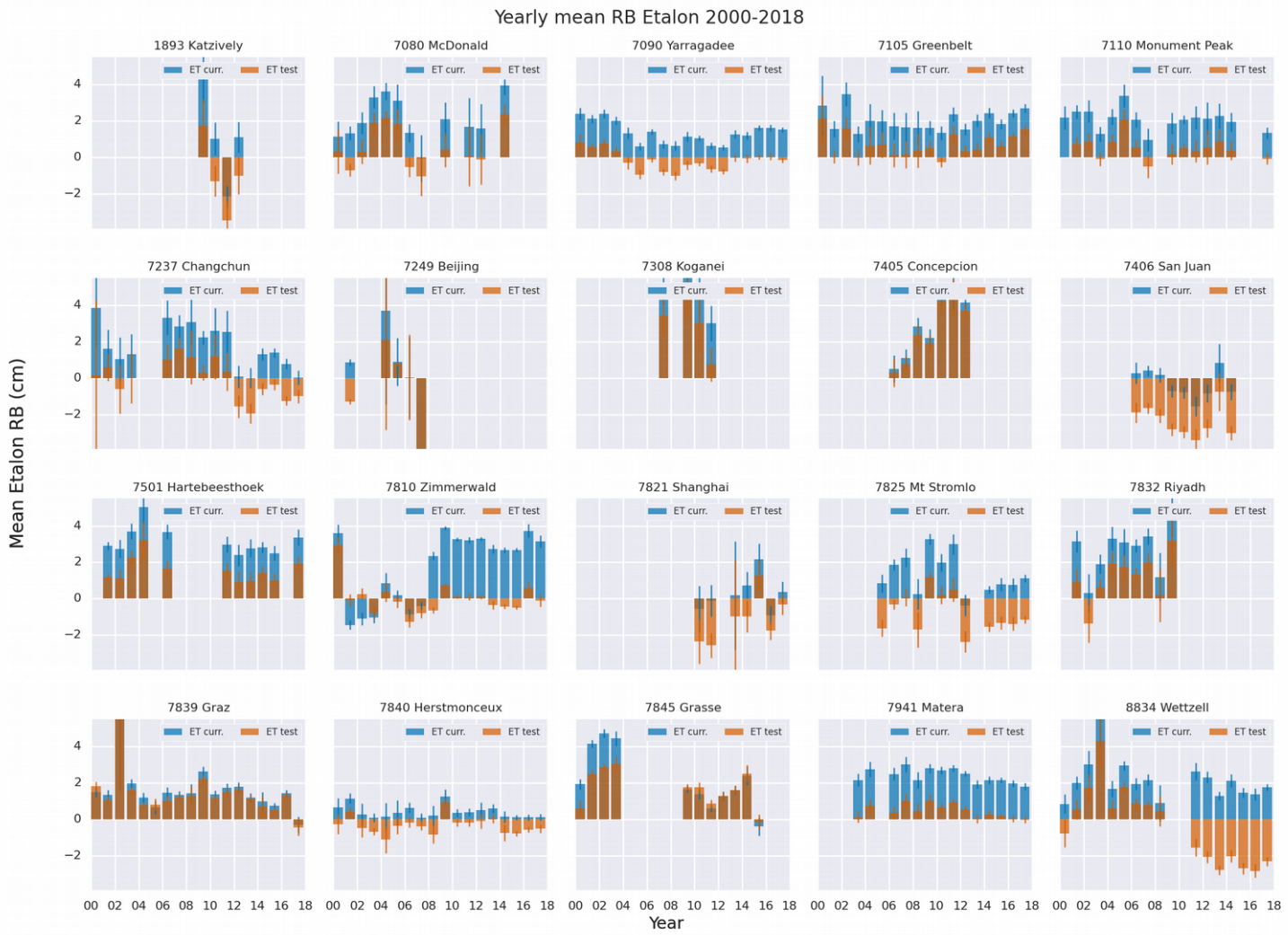
Repeat many times to generate ranging distribution

Reduce data according to rejection criteria

Etalon RB

Current CoM

Test CoM



LAGEOS RB

Current CoM

Test CoM