Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
Technische Universität München

Results of tests of the Earth‘s mean time-variable gravity field model CNES_GRGS.RL05MF_combined_GRACE_SLR_DORIS using precise orbit determination of TOPEX/Poseidon and Jason satellites

Sergei Rudenko[1], Riva Alkahal[1], Mathis Bloßfeld[1], Jean-Michel Lemoine[2]

[1] Deutsches Geodätisches Forschungsinstitut, Technische Universität München (DGFI-TUM), Munich, Germany
[2] Centre National d’Etudes Spatiales (CNES)/Groupe de Recherches de Géodésie Spatiale (GRGS), Toulouse, France

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Outline

Earth‘s mean time-variable gravity field models tested:
CNES_GRGS.RL05MF_combined_GRACE_SLR_DORIS (RL05, Lemoine, private communication, 2023) and EIGEN-GRGS.RL04.MEAN-FIELD (RL04, Lemoine, J.M. et al, 2019). Degree 1 terms are set to 0 in both models.

Precise orbit determination (POD) using Satellite Laser Ranging (SLR) observations.

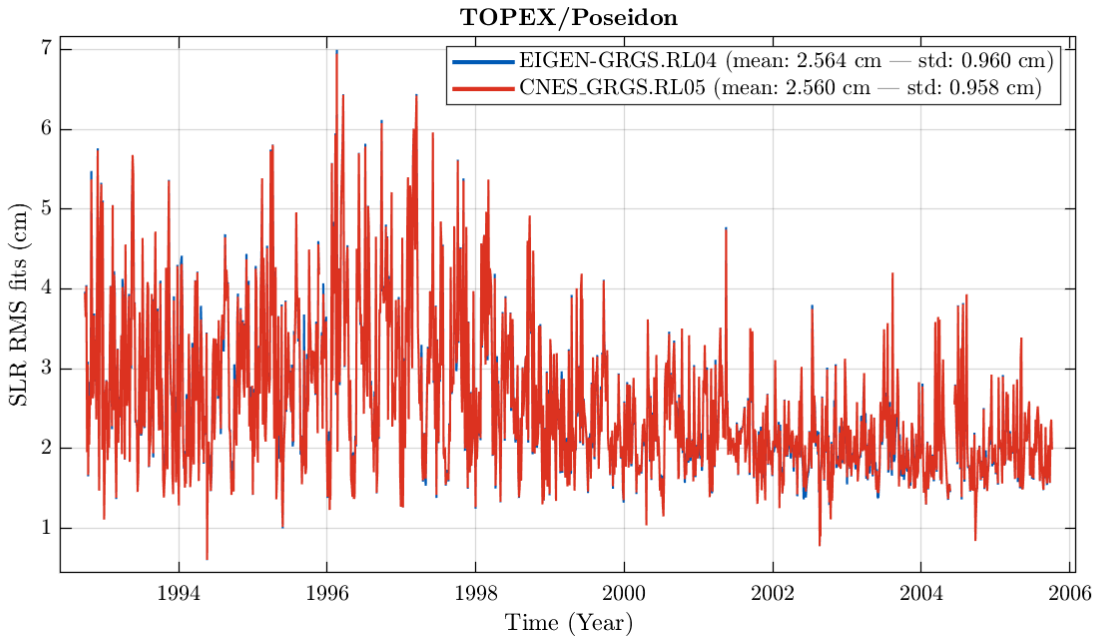
Satellites and time spans used: TOPEX/Poseidon (27.09.1992 – 09.10.2005), Jason-1 (13.01.2002 – 30.06.2013), Jason-2 (20.07.2008 – 02.10.2019), and Jason-3 (17.02.2016 – 24.10.2021)

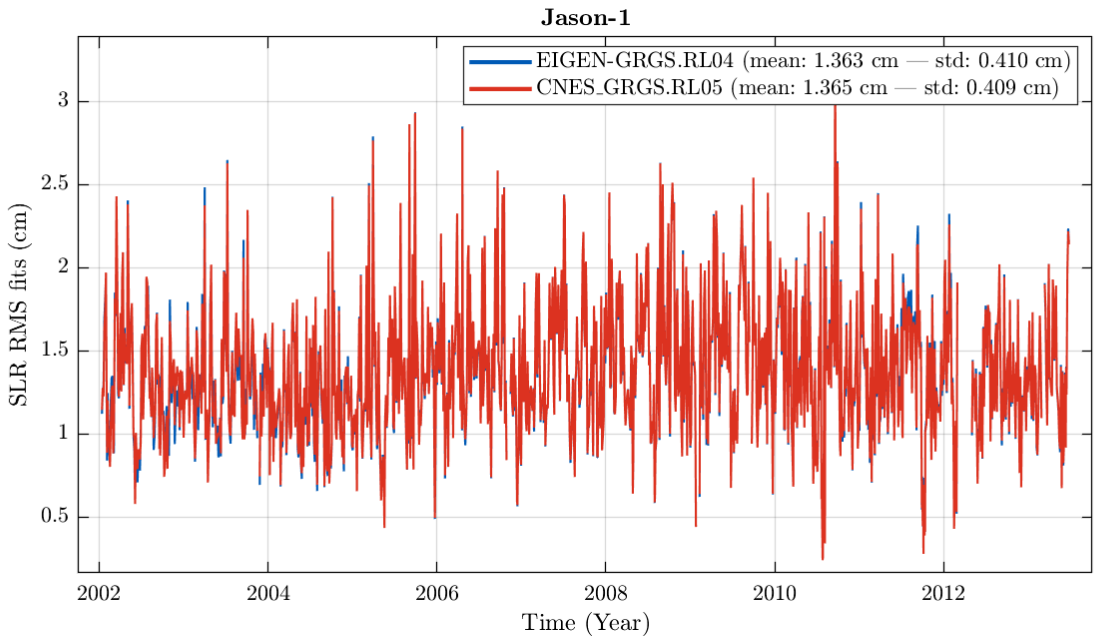
Background models for POD: as for the DGFI-TUM DSO1 orbits (Rudenko et al., 2023a, 2023b).

Reference frame realization for the orbits: SLRF2014.

Impact on the following parameters has been investigated:
- RMS fits of SLR observations,
- scaling factors of solar radiation pressure, Earth‘s albedo, atmospheric drag,
- empirical accelerations in the transverse and normal directions,
- SLR range biases (estimated once per a 3.5-day orbital arcs),
- orbit differences in the radial, transverse and normal directions.

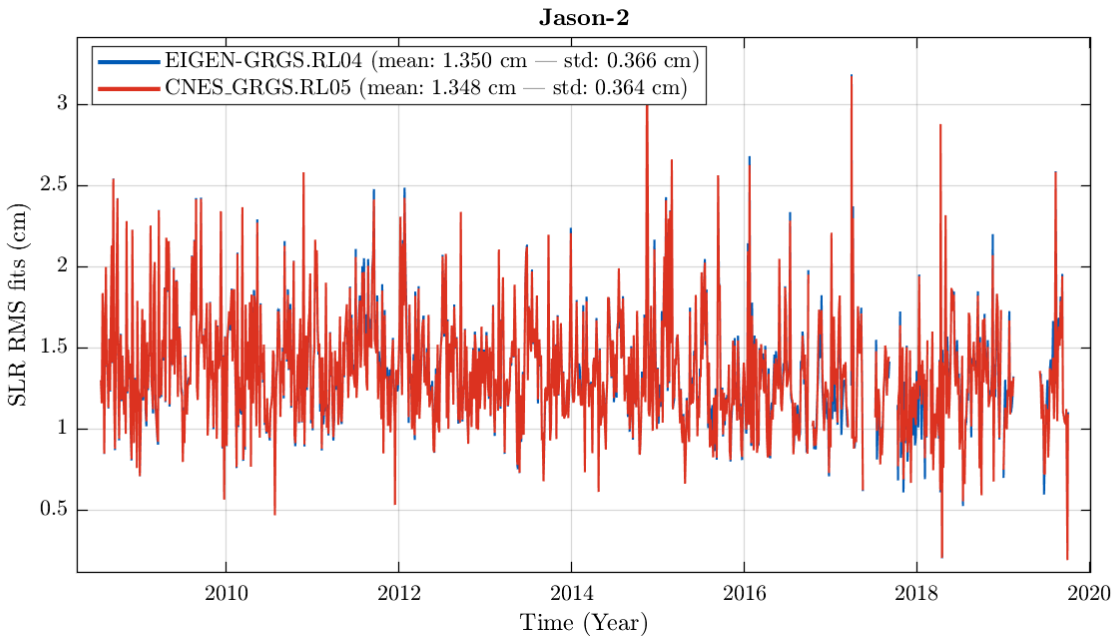
RMS fits of SLR observations: TOPEX/Poseidon and Jason-1

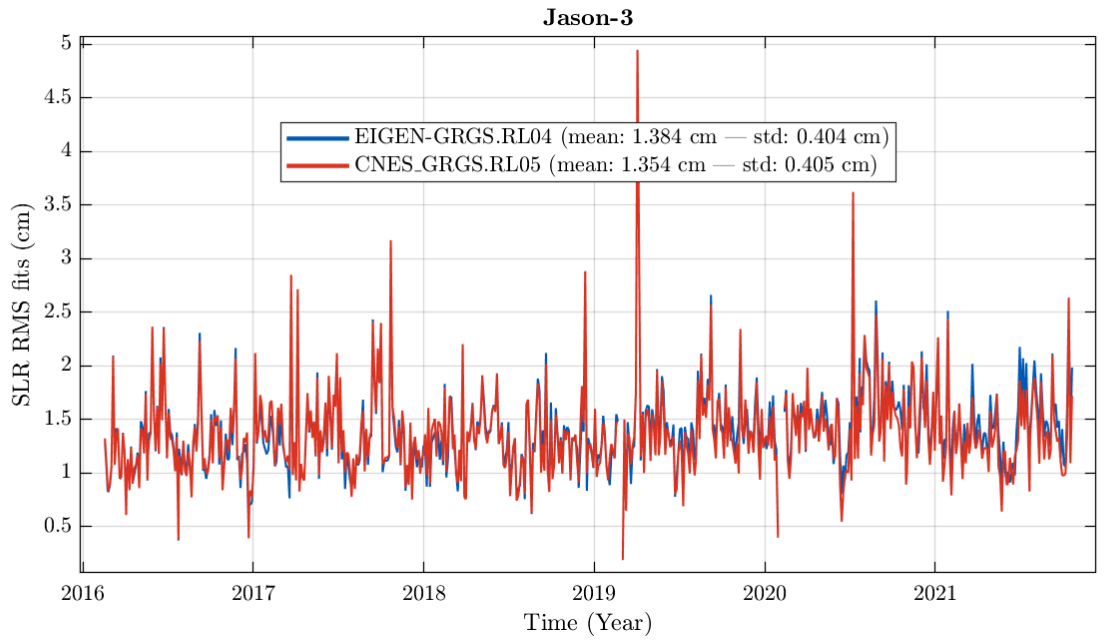




About 0.2% enhancement for TOPEX/Poseidon and
about a 0.2% degradation for Jason-1
with the RL05 model, as compared to the RL04 model.

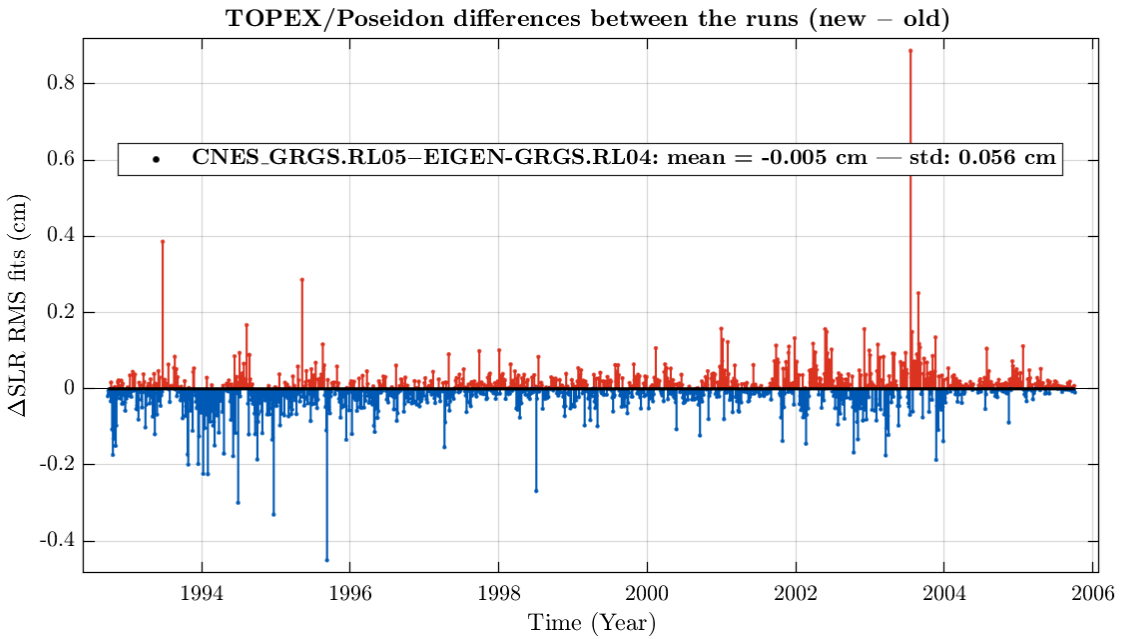
RMS fits of SLR observations: Jason-2 and Jason-3

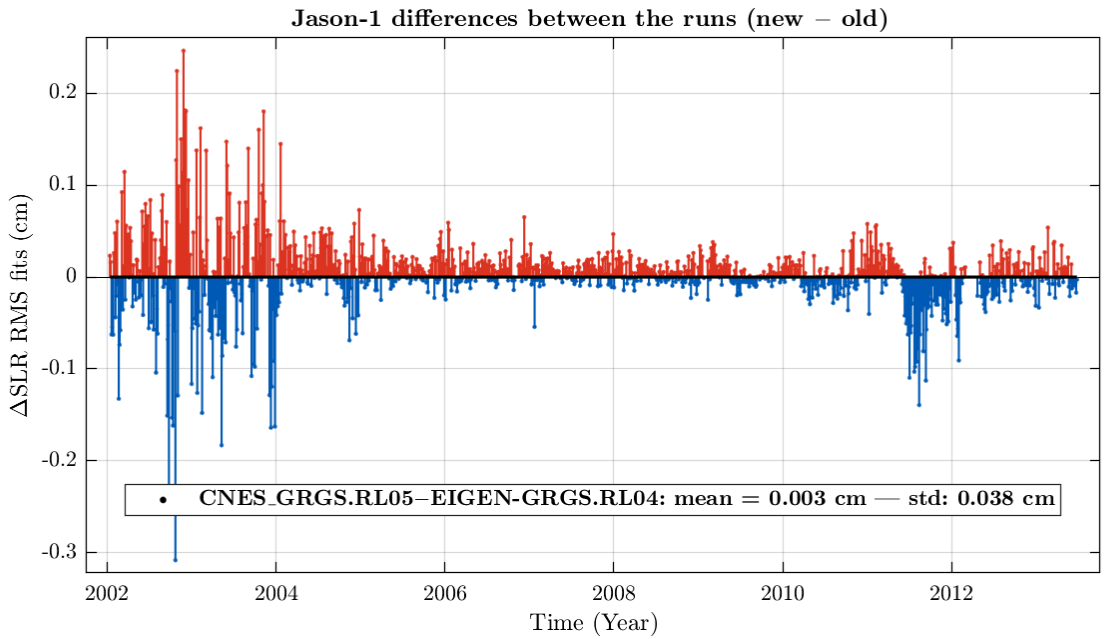




About a 0.2% enhancement for Jason-2 and
about a 2% enhancement for Jason-3
with the RL05 model, as compared to the RL04 model.

Differences of RMS fits of SLR observations: TOPEX/Poseidon and Jason-1

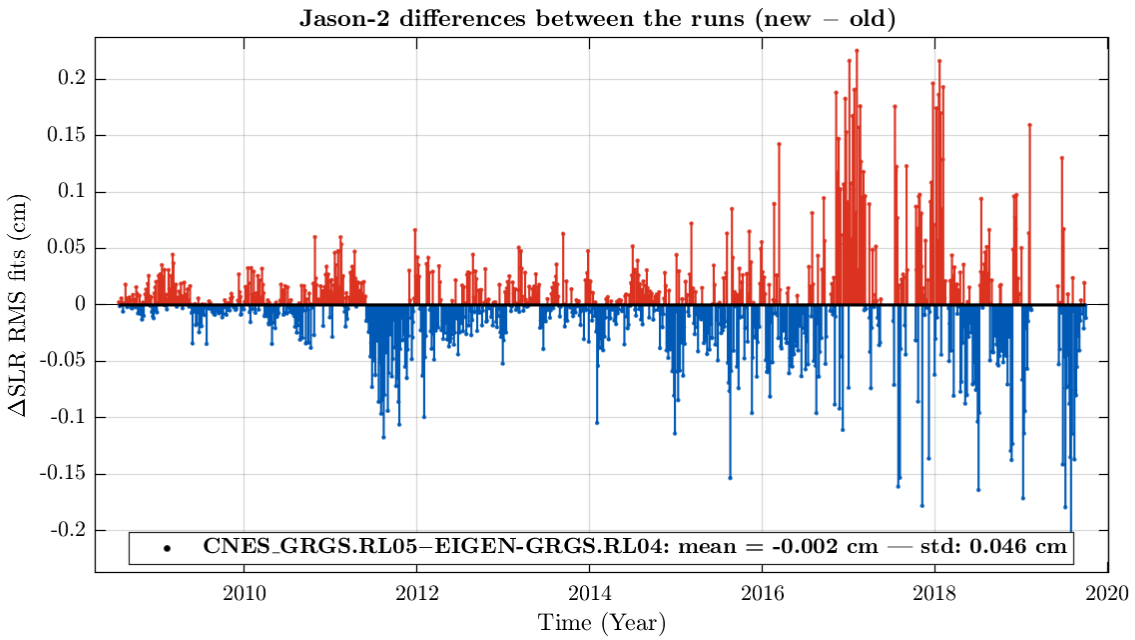


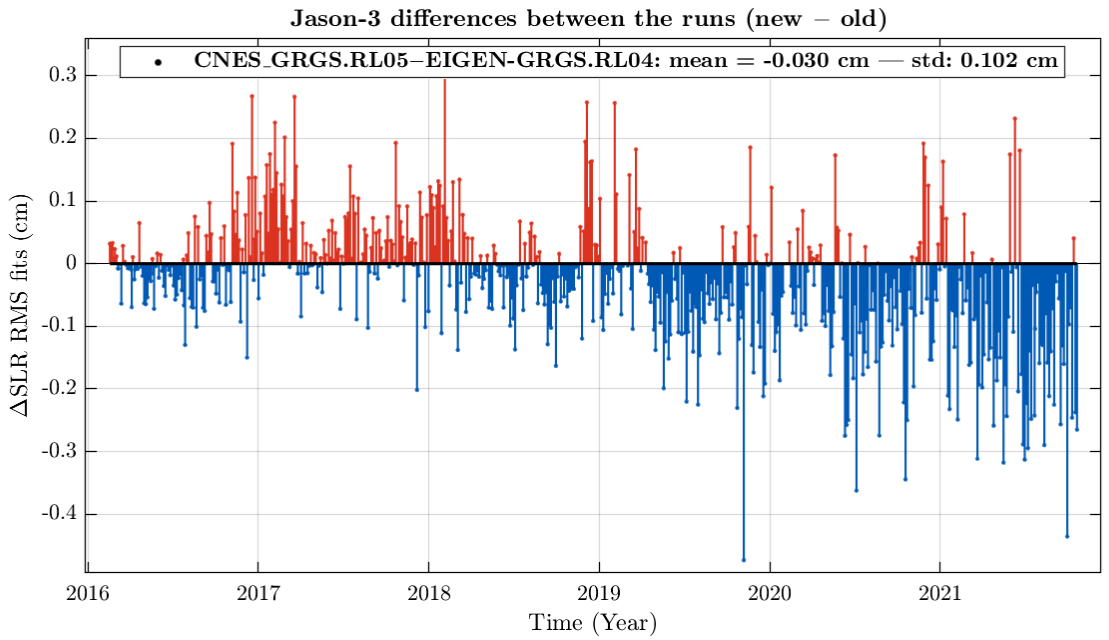


Red: degradation of the new (RL05) model.
Blue: enhancement of the new (RL05) model.

An enhancement for TOPEX/Poseidon in 1992-1998 and Jason-1 in 2011-2012.
Larger scatter of the differences in years 2002 and 2003 for both satellites.

Differences of RMS fits of SLR observations: Jason-2 and Jason-3

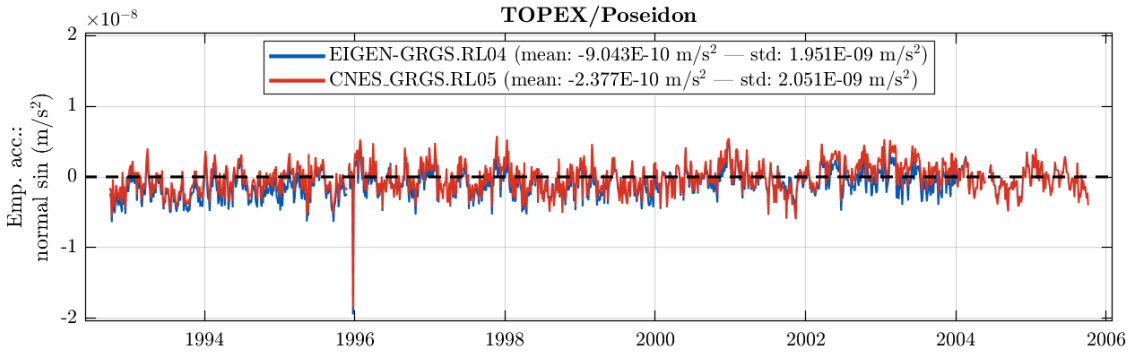


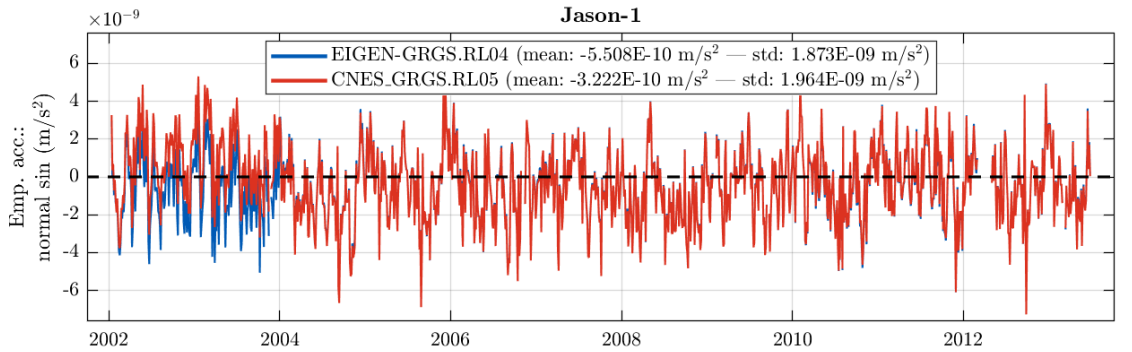


Red: degradation of the new (RL05) model.
Blue: enhancement of the new (RL05) model.

An enhancement for Jason-2 in years 2011-2016.5 and from 2018.3 to 2019.8 (end of the mission),
a degradation from about 2016.5 to about 2018.3.
Clear enhancement for Jason-3, except the period from about 2016.5 to about 2018.3.

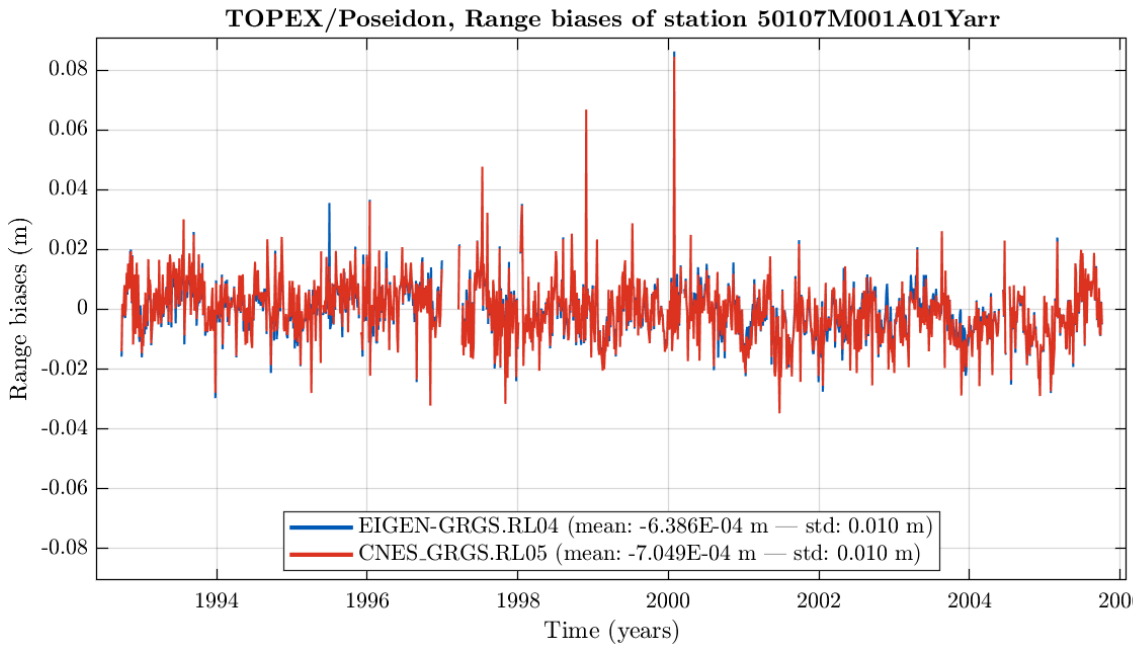
Empirical acceleration: amplitude of the normal sine term (TOPEX/Poseidon and Jason-1)

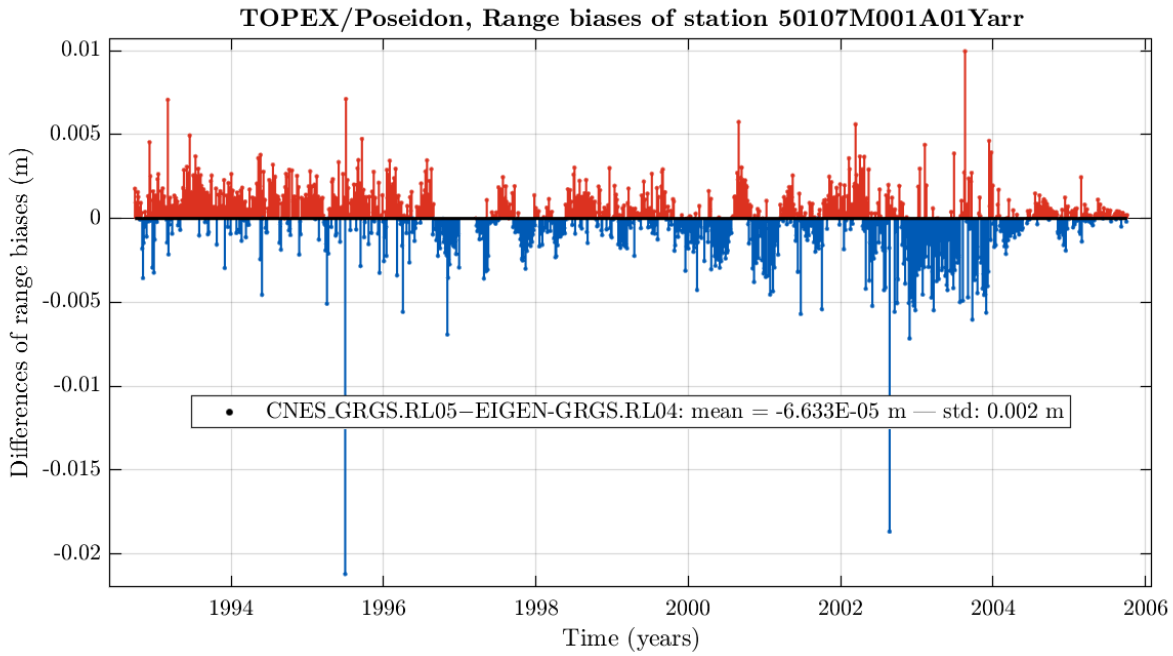




Reduction of the mean of the amplitude of the normal sine term using the RL05 model, compared to the RL04 model.

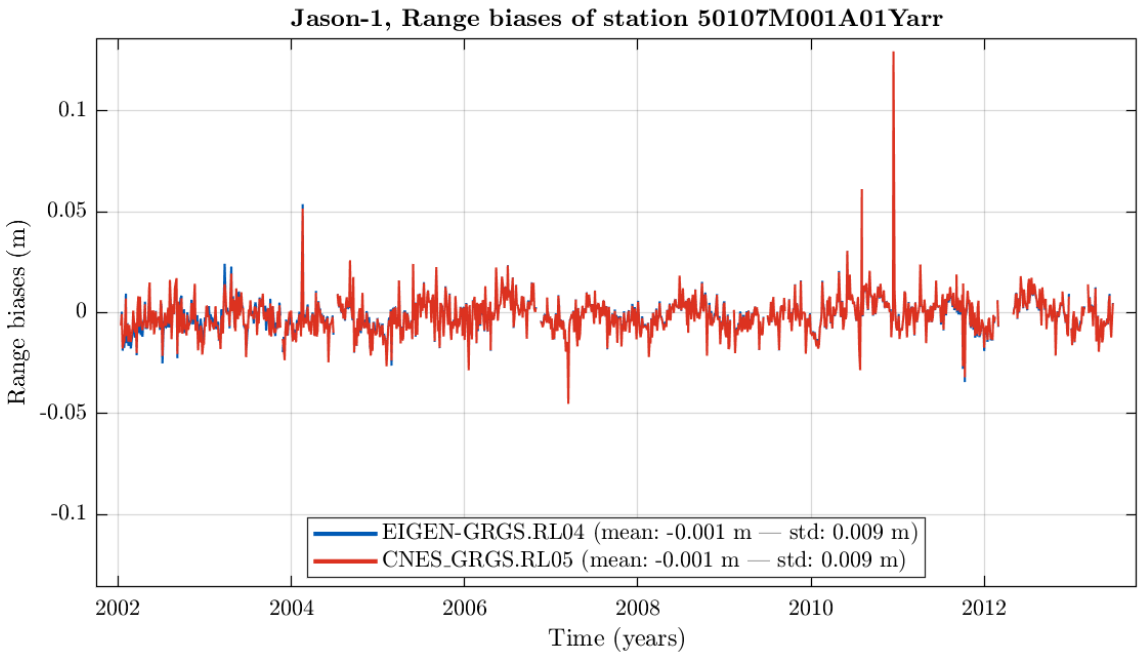
Yarragadee SLR station range biases: TOPEX/Poseidon

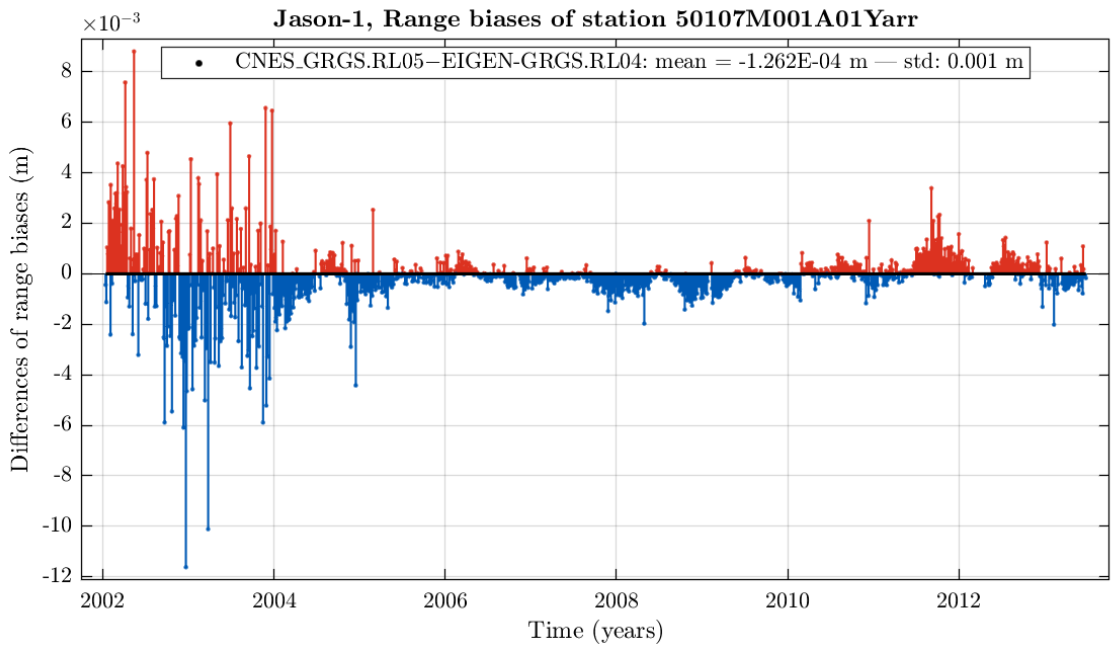




A reduction of the estimated range bias in 2002 and 2003.

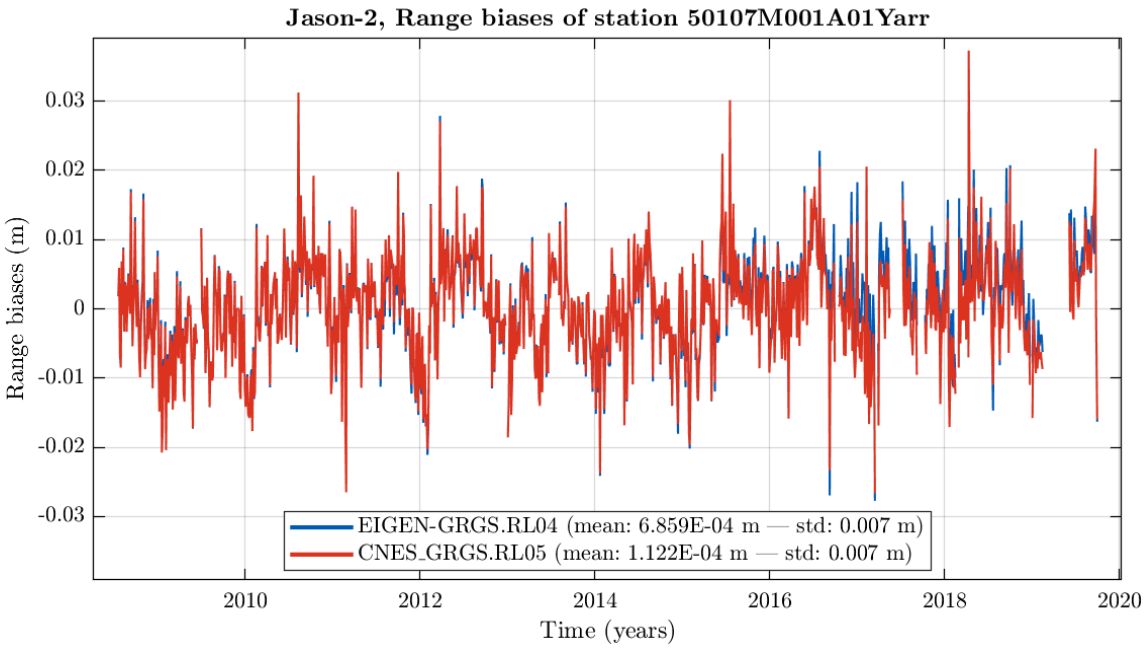
Yarragadee SLR station range biases: Jason-1

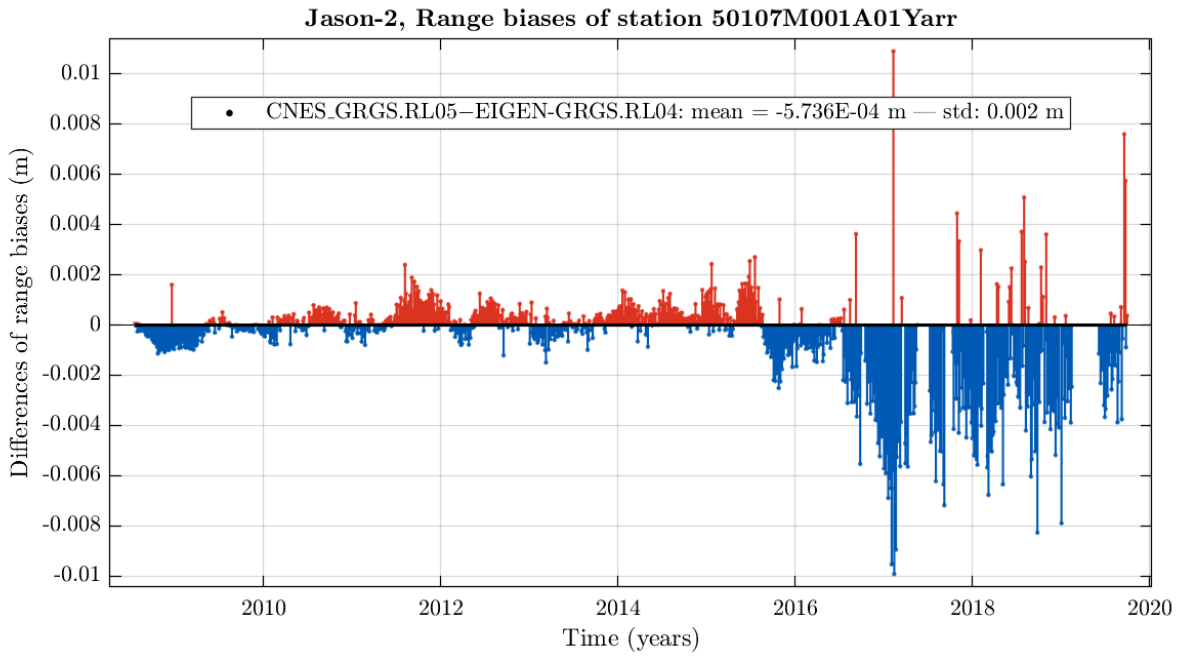




An increased scatter of the differences of the estimated range biases in 2002 and 2003.

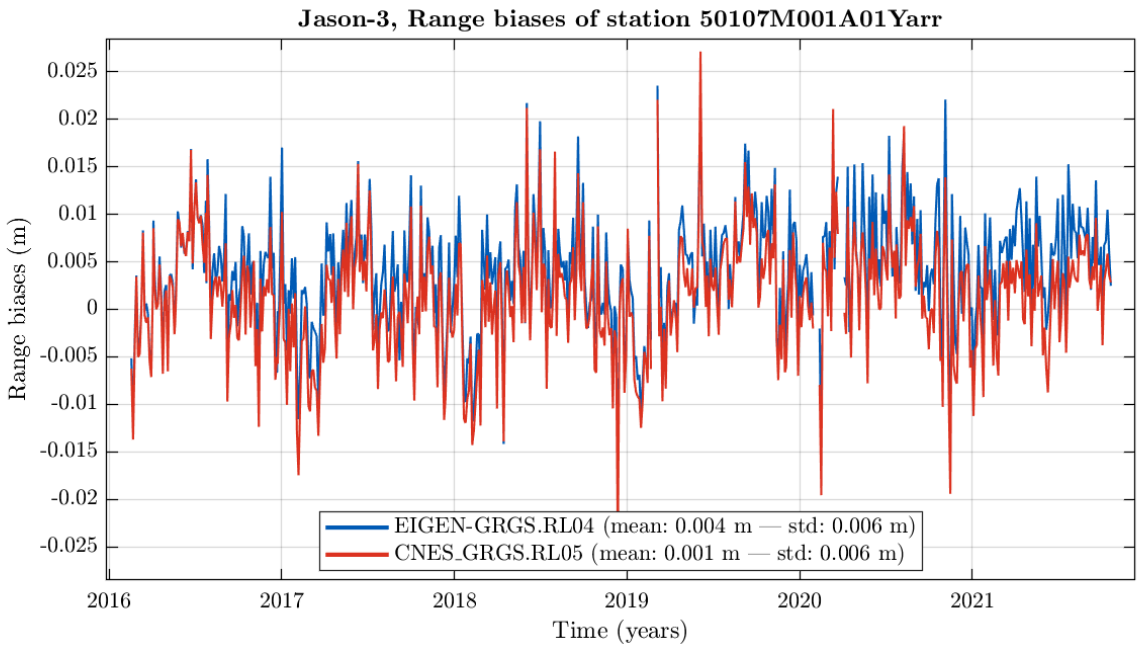
Yarragadee SLR station range biases: Jason-2

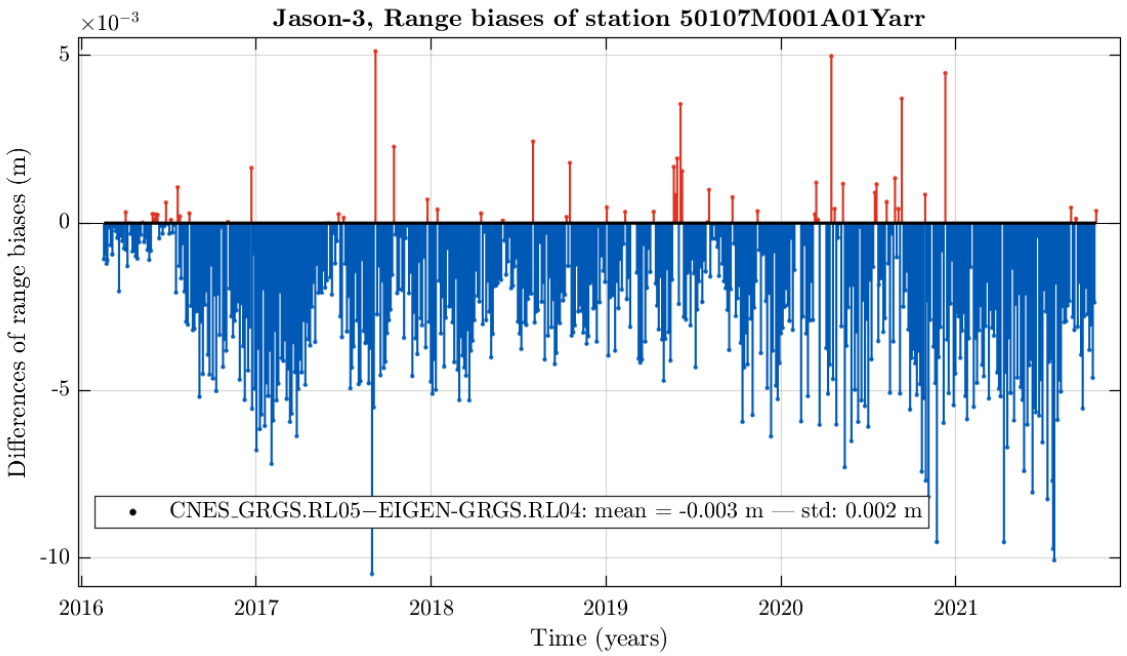




A reduction of the estimated range bias after about 2015.5, when using the RL05 model.

Yarragadee SLR station range biases: Jason-3





A clear about 3 mm reduction of the mean absolute value of the SLR range bias.

Average values of the parameters for TOPEX/Poseidon

Parameter	Mean RL04	Mean RL05	std RL04	std RL05
SLR RMS fit [cm]	2.5642	2.5595	0.9601	0.9580
mean SLR [cm]	-4. 1385E-06	5.3885E-07	-	-
Obs. used [%]	95.0511	95.0505	-	-
Solar radiation scale factor	0.9773	0.9768	0.0877	0.0877
Earth albedo scale factor	0.8857	0.8897	0.5766	0.5749
Atm. drag scale factor	1.0076	1.0099	0.4859	0.4848
Emp. Acc. T Cosine	2.1710E-10	1.6361E-10	1.7960E-09	1.8134E-09
Emp. Acc. T Sine	-8.7183E-11	-1.86012E-10	4.5590E-09	4.5882E-09
Emp. Acc. N Cosine	-3.2246E-11	-4.0663E-11	1.0369E-09	1.0348E-09
Emp. Acc. N Sine	-9.0429E-10	-2.3766E-10	1.9507E-09	2.0513E-09
Emp Acc T polygon	1.9482E-11	2.1985E-11	7.6461E-10	7.6227E-10
Emp Acc N polygon	-4.5519E-10	-6.3331E-10	6.2282E-09	6.2298E-09

Better result compared to a reference value (smaller RMS fits, closer to 1 for scale factors, and 0 for empirical acceleration, mean SLR fits and standard deviations (std)).

Average values of the parameters for Jason-1

Parameter	Mean RL04	Mean RL05	std RL04	std RL05
SLR RMS fit [cm]	1.3626	1.3654	0.4102	0.4093
mean SLR [cm]	2.3369E-05	2.3296E-05	-	-
Obs. used [%]	95.1382	95.1391	-	-
Solar radiation scale factor	0.9491	0.9490	0.0462	0.0462
Earth albedo scale factor	1.0268	1.0304	0.7192	0.7144
Atm. drag scale factor	0.9892	0.9899	0.4284	0.4285
Emp. Acc. T Cosine	-6.0396E-11	-1.0133E-10	1.9254E-09	1.9340E-09
Emp. Acc. T Sine	2.8737E-10	3.0072E-10	5.9009E-09	5.9159E-09
Emp. Acc. N Cosine	-2.9305E-11	-2.9943E-11	1.4870E-09	1. 4756E-09
Emp. Acc. N Sine	-5.5079E-10	-3.2216E-10	1.8734E-09	1.9641E-09
Emp Acc T polygon	-7.6297E-12	-6.9075E-12	7.4038E-10	7.3494E-10
Emp Acc N polygon	8.6640E-11	5.8940E-11	3.8605E-09	3.8602E-09

Better result compared to a reference value (smaller RMS fits, closer to 1 for scale factors, and 0 for empirical acceleration, mean SLR fits and standard deviations (std)).

Average values of the parameters for Jason-2

Parameter	Mean RL04	Mean RL05	std RL04	std RL05
SLR RMS fit [cm]	1.3499	1.3477	0.3656	0.3637
mean SLR [cm]	1.3331E-05	6.6641E-06	-	-
Obs. used [%]	96.1994	96.19941	-	-
Solar radiation scale factor	0.9922	0.9922	0.0371	0.0372
Earth albedo scale factor	1.2798	1.2888	0.6396	0.6407
Atm. drag scale factor	1.0075	1.0063	0.3538	0.3524
Emp. Acc. T Cosine	-3.2901E-11	-2.7951 E-11	1.6472E-09	1.6583E-09
Emp. Acc. T Sine	3.0346E-10	3.2551E-10	3.8671E-09	3.9060E-09
Emp. Acc. N Cosine	-6.5815E-11	-6.5819E-11	1.5138E-09	1.5094E-09
Emp. Acc. N Sine	-6.9024E-10	-6.9741E-10	1.9222E-09	1.9327E-09
Emp Acc T polygon	-1.0575E-10	-1.0716E-10	5.6914E-10	5.6885E-10
Emp Acc N polygon	2.1367E-10	8.1761E-11	3.9239E-09	3.9192E-09

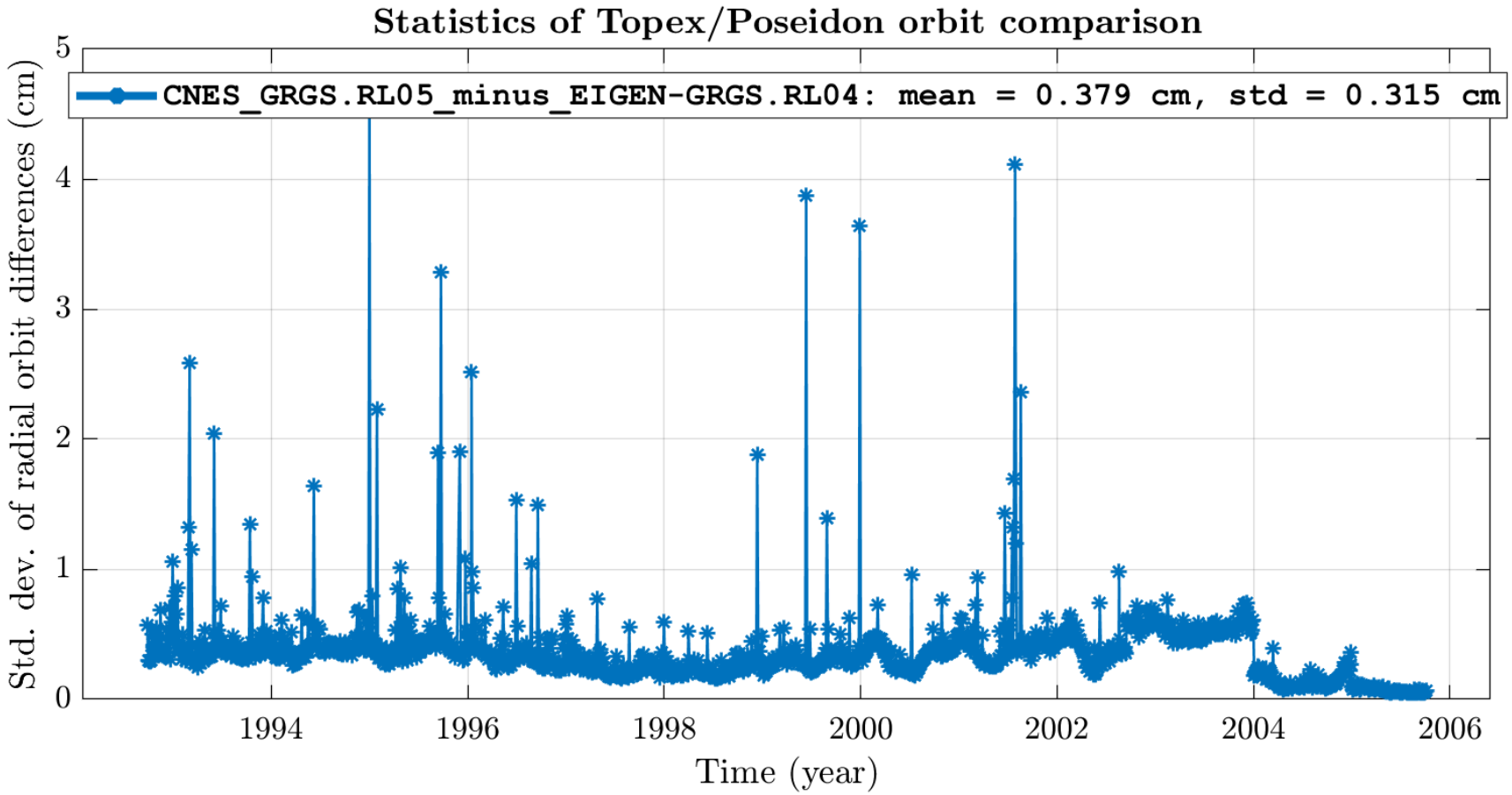
Better result compared to a reference value (smaller RMS fits, closer to 1 for scale factors, and 0 for empirical acceleration, mean SLR fits and standard deviations (std)).

Average values of the parameters for Jason-3

Parameter	Mean RL04	Mean RL05	std RL04	std RL05
SLR RMS fit [cm]	1.3838	1.3541	0.4041	0.4051
mean SLR [cm]	-5.1935E-05	-3.6179E-05	-	-
Obs. used [%]	98.8388	98.8358	-	-
Solar radiation scale factor	0.9885	0.9892	0.0274	0.0263
Earth albedo scale factor	1.3026	1.3505	0.5755	0.5608
Atm. drag scale factor	1.0001	0.9925	0.2704	0.2701
Emp. Acc. T Cosine	1.3318E-10	1.0417E-10	1.3245E-09	1.2746E-09
Emp. Acc. T Sine	-1.4244E-12	3.4939E-11	3.1785E-09	3.0494E-09
Emp. Acc. N Cosine	-1.6744E-11	-3.3681E-11	1.3469E-09	1.3103E-09
Emp. Acc. N Sine	-6.2628E-10	-5.4413E-10	1.7663E-09	1.7624E-09
Emp Acc T polygon	-8.7121E-11	-9.1348E-11	4.2512E-10	4.0733E-10
Emp Acc N polygon	4.6412E-10	1.2642E-10	4.0235E-09	3.9931E-09

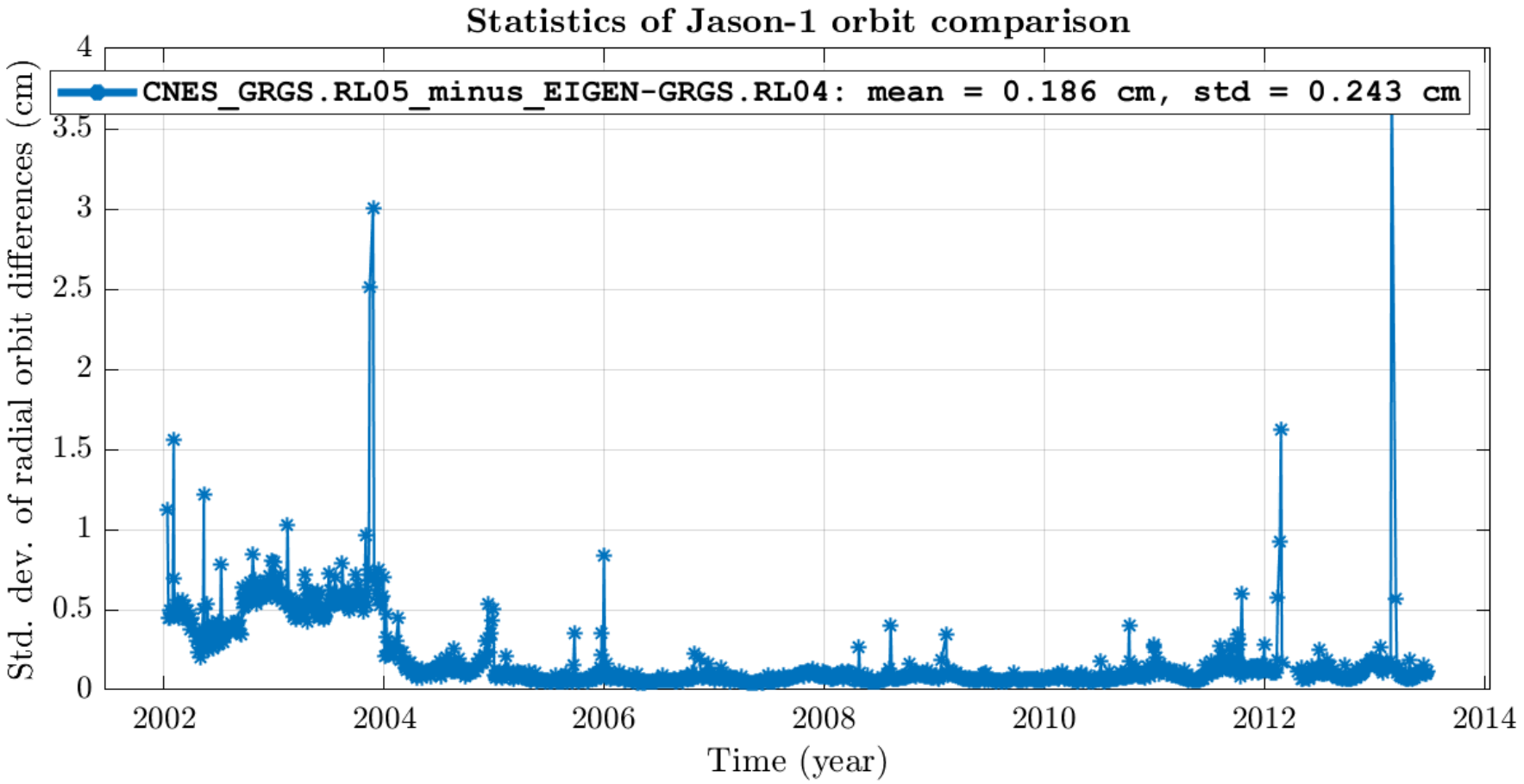
Better result compared to a reference value (smaller RMS fits, closer to 1 for scale factors, and 0 for empirical acceleration, mean SLR fits and standard deviations (std)).

Standard deviations of orbit differences (radial direction): TOPEX/Poseidon



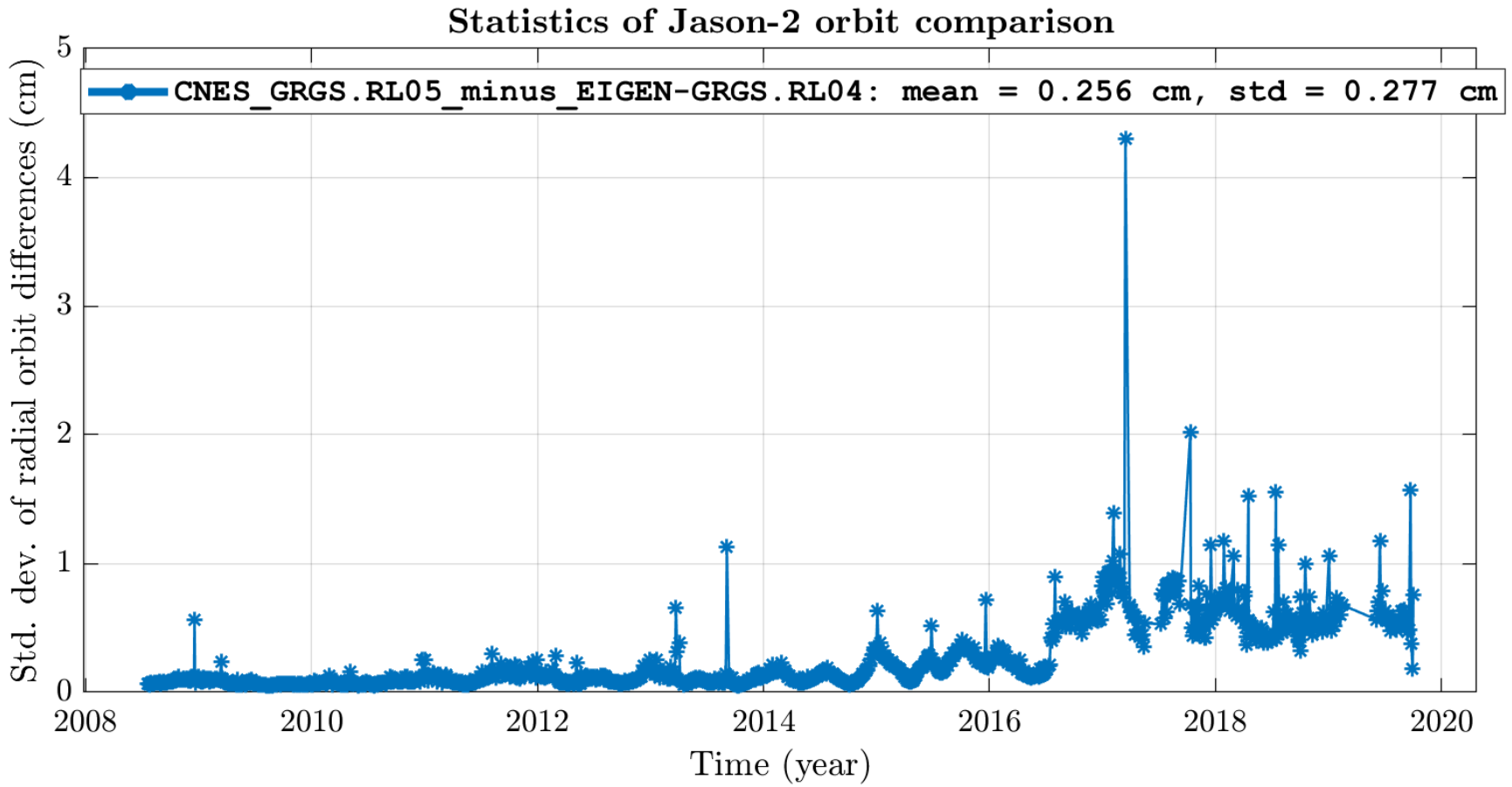
The mean is 0.4 cm, the standard deviation is 0.3 cm,
when comparing the RL05- and RL04-based orbits. A jump at year 2004.0 is clearly seen.

Standard deviations of orbit differences (radial direction): Jason-1



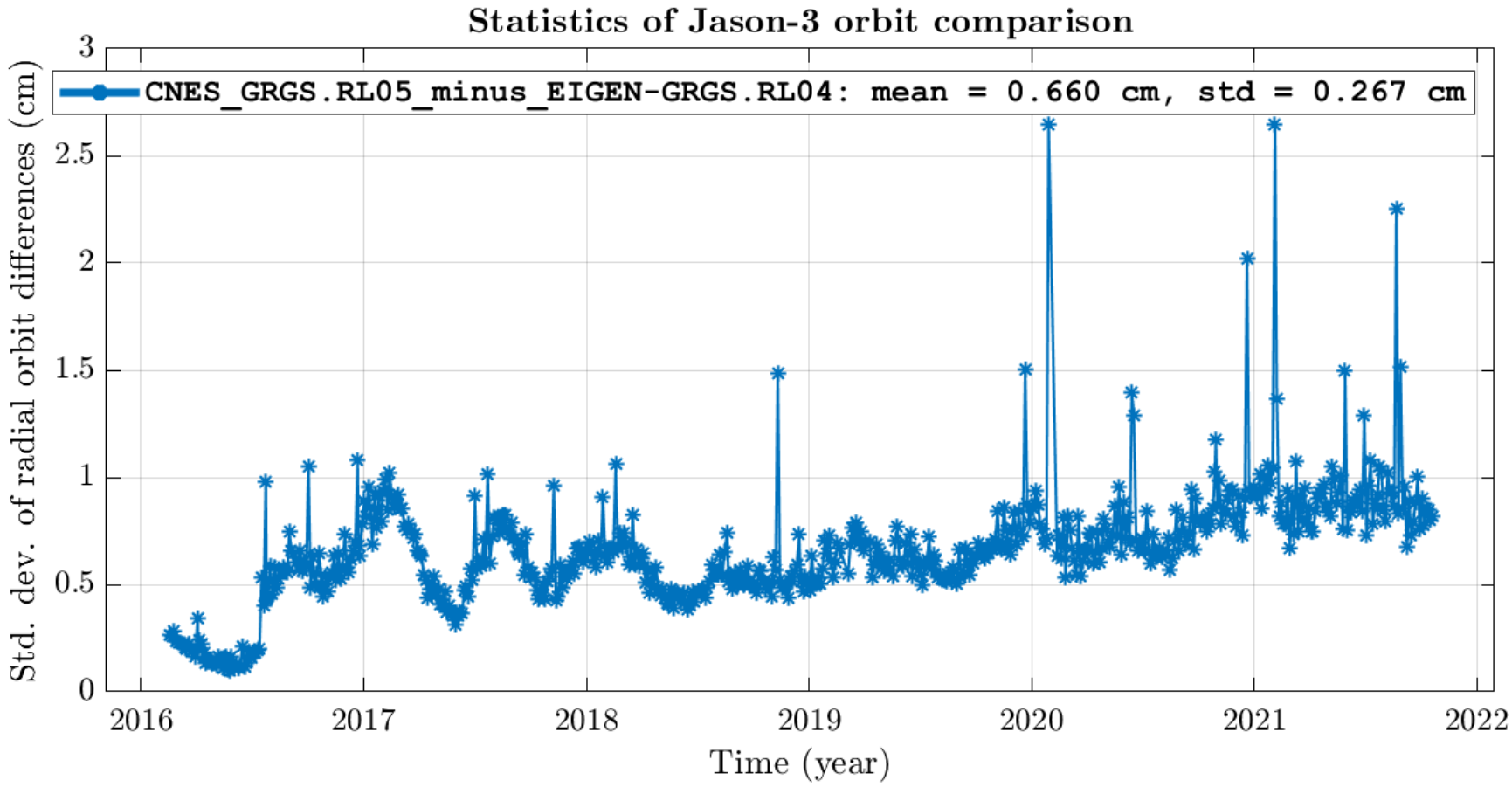
The mean is 0.2 cm, the standard deviation is 0.2 cm,
when comparing the RL05- and RL04-based orbits. A jump at year 2004.0 is clearly seen.

Standard deviations of orbit differences (radial direction): Jason-2



The mean is 0.3 cm, the standard deviation is 0.3 cm,
when comparing the RL05- and RL04-based orbits. A jump at year 2016.5 is clearly seen.

Standard deviations of orbit differences (radial direction): Jason-3



The mean is 0.7 cm, the standard deviation is 0.3 cm,
when comparing the RL05- and RL04-based orbits. A jump at year 2016.5 is clearly seen,
as well as a trend for the period from 2016.5.

Conclusions

The new Earth's mean time-variable gravity field **model** CNES_GRGS.RL05MF_combined_GRACE_SLR_DORIS **shows improved performance** (smaller values of RMS fits of SLR observations) at the time spans (years) **1992 – 1998, 2011 – 2016.5, and 2018.3 – 2021.9**, as compared to the EIGEN-GRGS.RL04.MEAN-FIELD gravity field model.

Larger scatter of orbit differences is observed **in years 2002 and 2003**, when comparing RL05-based and RL04-based orbits.

The RL05 model shows increased RMS fits of SLR observations **(a degradation**) at the **period from about 2016.5 to about 2018.3**, that is correlated with a gap between GRACE and GRACE-FO data. Probably, modelling of time-variable part of the new (RL05) model for this time interval should be verified and improved, if possible.

The use of the new (RL05) gravity field model causes **0.2 - 0.7 cm mean and 0.2 - 0.3 cm scatter of the standard deviation of the differences in satellite positions**, as compared to using the RL04 gravity field model. More significant differences are observed after 2016.5.

Some small changes have been observed in the Earth albedo scale factor and transverse empirical acceleration.

SLR station range biases seem to be sensitive to the gravity field model replacement. They were reduced, for example, for Yarragadee.

No significant differences were found in the following parameters, when using the new model instead of old one: solar radiation pressure scale factor, atmospheric drag scale factor.

References

Lemoine, J.M., Bourgogne, S., Biancale, R., Reinquin F., and Bruinsma, S.: EIGEN-GRGS.RL04.MEAN-FIELD – Mean Earth gravity field model with a time-variable part from CNES/GRGS RL04, doi: 10.5880/ICGEM.2019.010, 2019.

Rudenko S., Dettmering D., Zeitlhöfler J., Alkahal R., Upadhyay D., Bloßfeld M.: Radial orbit errors of contemporary altimetry satellite orbits. Surveys in Geophysics, doi: 10.1007/s10712-022-09758-5, 2023a.

Rudenko S., Zeitlhöfler J., Bloßfeld M.: DGFI-TUM DSO1 orbits of altimetry satellites TOPEX/Poseidon, Jason-1, Jason-2 and Jason-3 derived from SLR data in the SLRF2014 reference frame (data). Deutsches Geodätisches Forschungsinstitut, Zenodo, doi: 10.5281/zenodo.7441352, 2023b.

Acknowledgements

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