Long-term stability of ionospheric GIM corrections in satellite altimetry data sets

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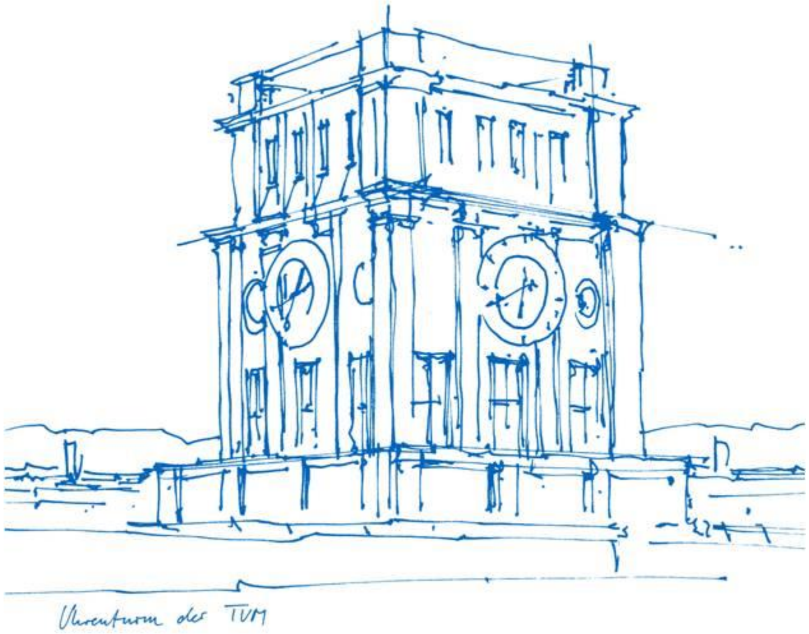
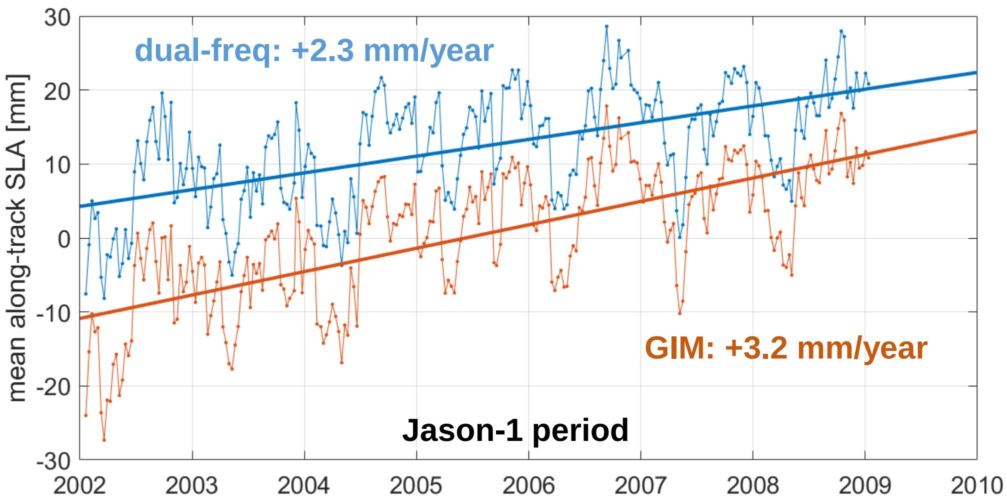


OSTST 2022, 03.11.2022, Venice

Motivation

It turned out that sea level trends differ when computed with different ionospheric corrections.



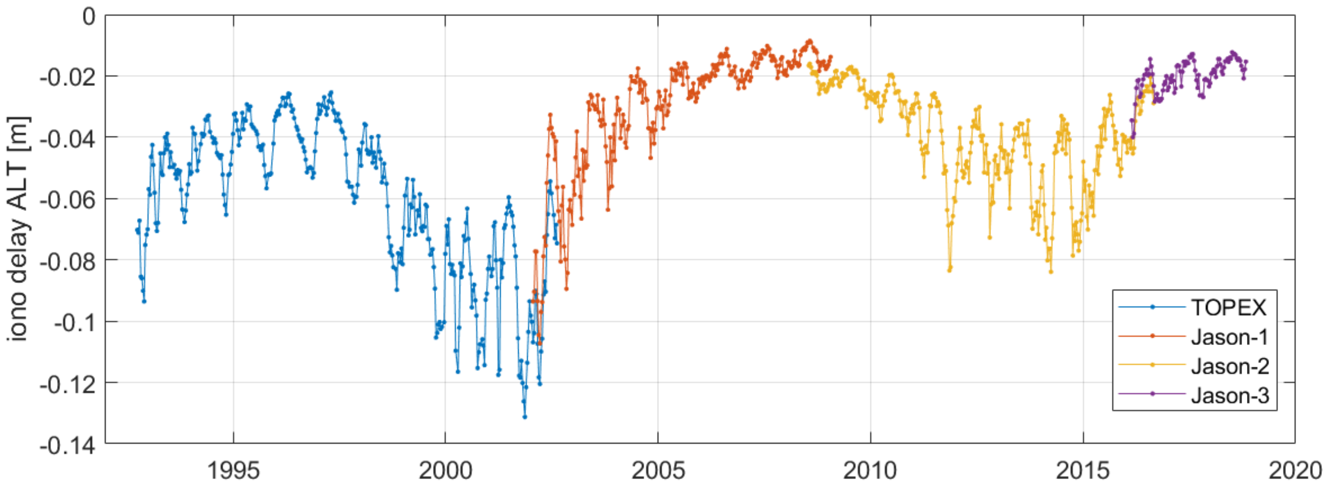
Why?
How to avoid this?

➢ GIM model is frequently used to correct single-frequency altimeter missions as well as for inland applications and in coastal regions.

Ionospheric delay correction from dual-frequency altimetry

NASA/CNES missions TOPEX and Jason-1, Jason-2, Jason-3 provide ionospheric delay corrections from dual-frequency observations for each measurement location.

Average ionospheric delay per 10-day repeat cycle (global coverage without polar areas)

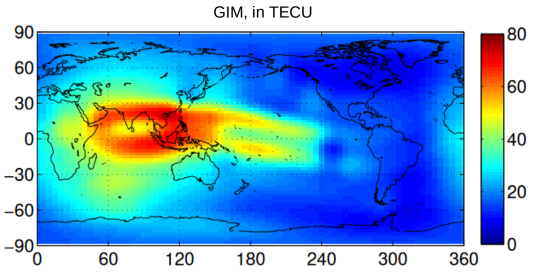


- inter-mission offsets
- 11-years solar cycle
- seasonal effects

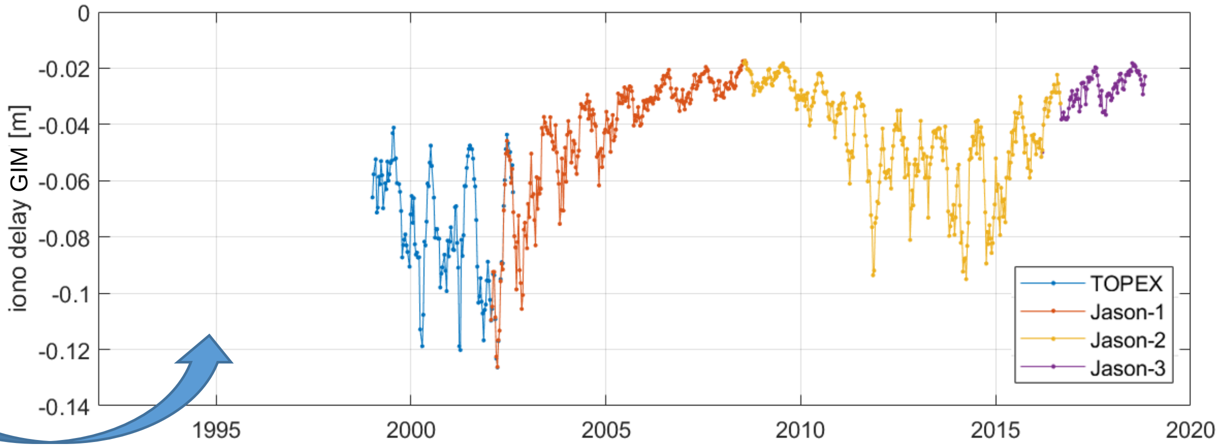
Estimated offsets
TP/J1: -1.4 cm
J1/J2: 0.7 cm
J2/J3: -0.9 cm

GNSS-derived GIMs

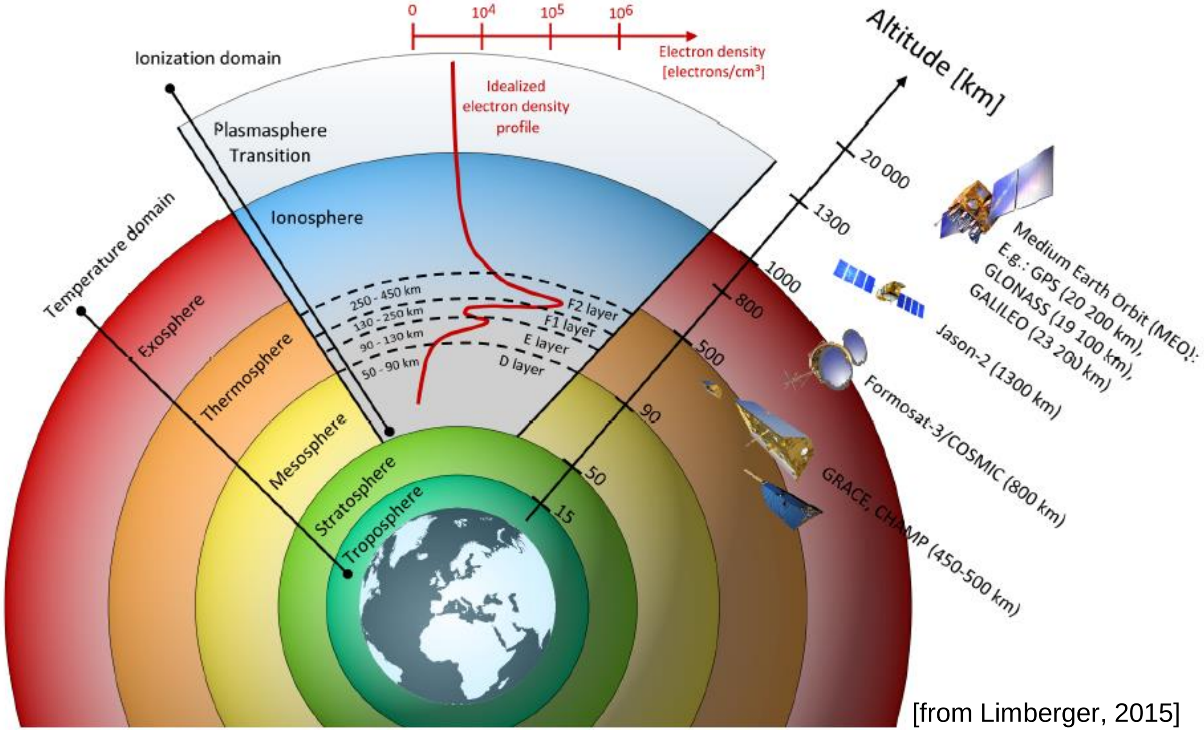
- GIM: Global Ionospheric Maps based on GNSS measurements
- Available since late 1998
- Routinely processed by various IGS processing centers
- Commonly used in altimetry: final global maps of JPL => JPLG
- GIM contain vertical electron content (VTEC) up to GNSS orbit height (~20.200km)



Interpolation to altimetry tracks



Impact of orbit height (plasmaspheric effect)



[from Limberger, 2015]

Order of magnitude:

- relative contribution of the plasmaspheric effect: **~10%-60%**
- largest in the equatorial regions

Scaling approach used in GDR data sets

- Ionospheric model to account for free electrons above satellite altimeter orbit height, e.g. International Reference Ionosphere (IRI)
- Iijlima et al. (1999) => usage of model relation instead of model values itself

$$\mathrm{TEC}_{<800\ \mathrm{km}}(t, \lambda, \phi) = \mathrm{TEC}_{\mathrm{GIM}}(t, \lambda, \phi) \frac{\mathrm{TEC}_{\mathrm{IRI\text{-}95}<800\ \mathrm{km}}(t, \lambda, \phi)}{\mathrm{TEC}_{\mathrm{IRI\text{-}95}<1400\ \mathrm{km}}(t, \lambda, \phi)}$$

altitude of altimeter satellite

IRI-95: old model; without plasmaspheric extension; only valid up to 1400km

- ➢ This approach is still used within the latest GDR data sets!
- ➢ Plasmaspheric electron content above 1400 km is completely neglected!

Alternative scaling approach

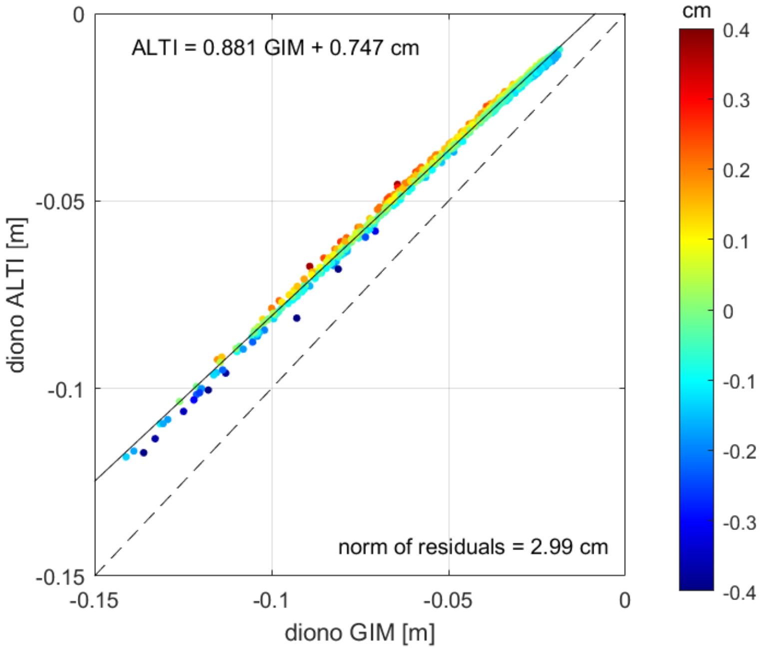
- Assume linear relationship between both VTEC values
- First used for NIC09 (Scharroo and Smith, 2010)

$$TEC_{ALTI}(t,\lambda,\phi) = TEC_{GIM}(t,\lambda,\phi) \cdot scale + offset$$

➢ Can be empirically estimated if both data sets are available (ALTI and GIM) => Jason satellites

Estimation of scale factors for Jason satellites

1999-2021 (TOPEX/Jason-1/Jason-2/Jason-3)



Average of all along-track value (open-ocean only; without sea-ice areas)

- offset = 0.747 cm
- scale = 0.881

- relationship is not fully linear
- scale differs from NIC09 scale (0.925)

Impact of different scaling approaches on long-term stability

=> sea level trends

Comparison of three different solutions (scaling approaches):

- unscaled GIM version (electron content up to GNSS orbit height)
- GDR GIM version (scaled by the approach of Iijima et al. (1999))
- GIM scaled by empirical estimated factor (optimal scaling)

All are compared to the dual-frequency altimetry time series, which is assumed to be stable in time (no drift)

Impact of different scaling approaches on long-term stability

=> sea level trends

0.280 ± 0.014 mm/year

0.033 ± 0.006 mm/year

Impact of different scaling approaches on long-term stability

=> sea level trends

Trend difference strongly depends on the observation period (due to correlation with solar activity)

	TOPEX 01/1999-08/2002	Jason-1 01/2002-01/2009	Jason-2 07/2008-09/2016	Jason-3 02/2016-06/2021
GIM unscaled	-1.122 ± 0.116	1.074 ± 0.046	-0.541 ± 0.054	0.477 ± 0.052
GIM SGDR	-	0.985 ± 0.041	-0.519 ± 0.050	0.465 ± 0.051
GIM optimal scaled	-0.533 ± 0.102	0.079 ± 0.028	-0.016 ± 0.018	0.104 ± 0.018
GIM NIC scaled	-0.577 ± 0.101	0.353 ± 0.025	-0.232 ± 0.028	0.329 ± 0.033

Comparing different scaling approaches for Jason-1

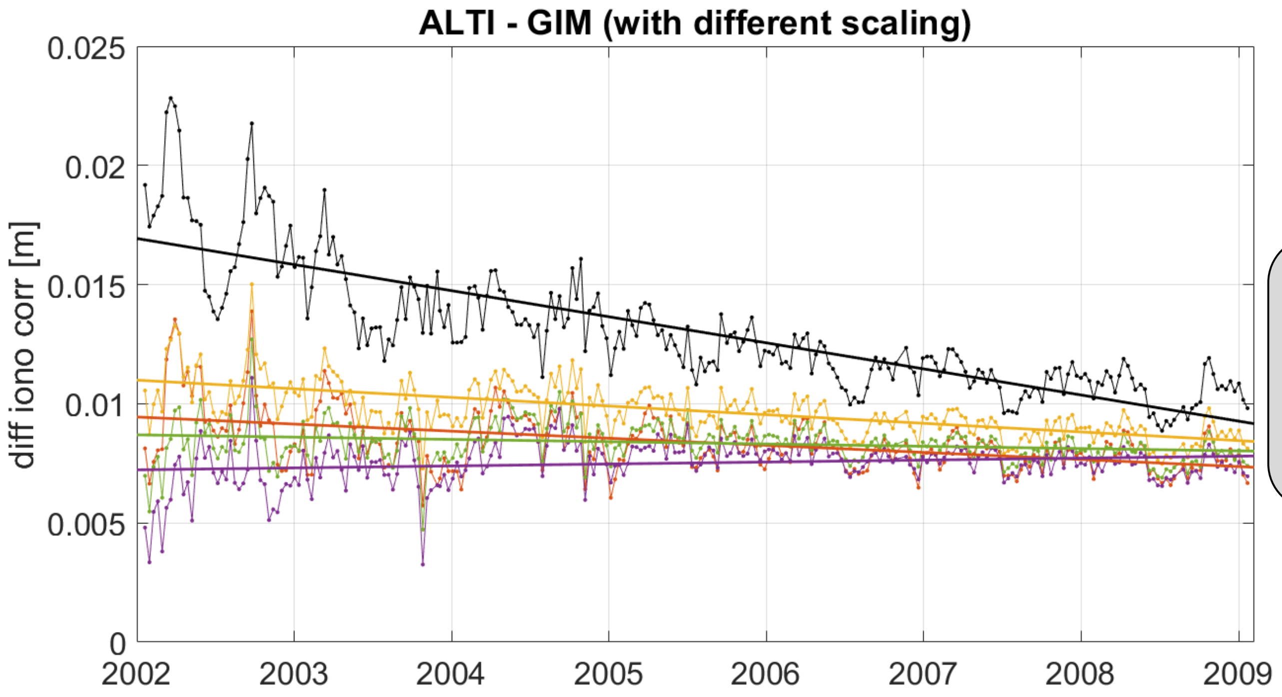
Compare factor-based scaling with scaling using dedicated ionosphere/plasmasphere models

A) IRI-Plas
B) NeQuick2

Both valid up to 20000 km altitude (GNSS orbit height)

C) 0.881 (const)

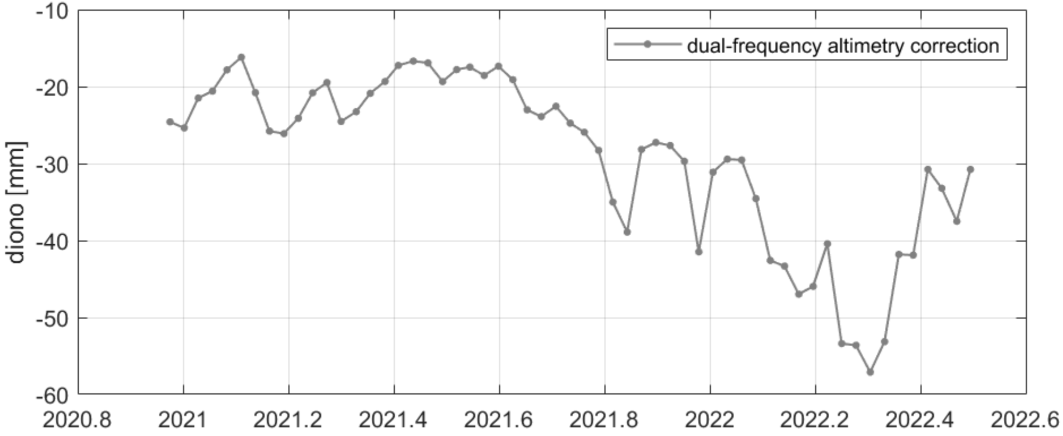
Comparing different scaling approaches for Jason-1



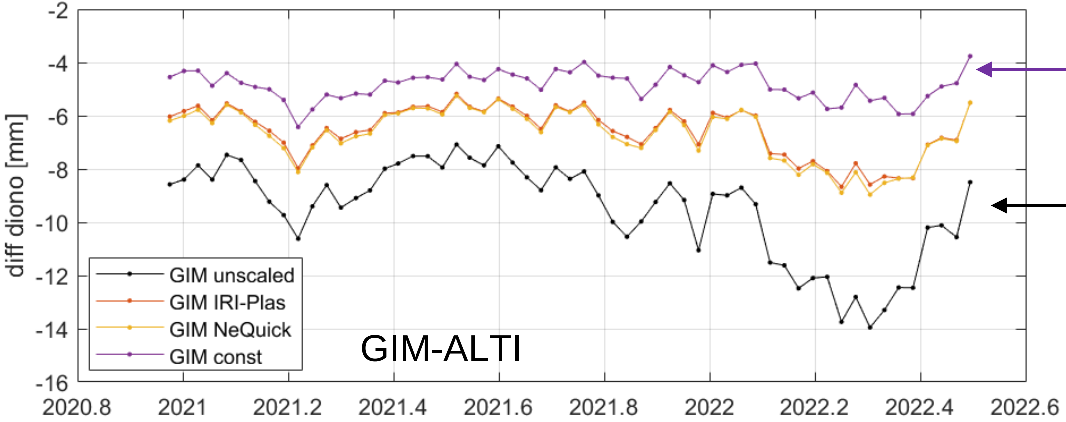
unscaled: -1.095 ± 0.045 mm/yr

IRI-Plas: -0.297 ± 0.034 mm/yr
NeQuick: -0.362 ± 0.025 mm/yr
const: -0.082 ± 0.028 mm/yr

Sentinel-6



- ~1.5 years of NTC L2 repro. data
- increasing solar activity



factor 0.881: -0.1 ± 0.2 mm/year

unscaled: -2.6 ± 0.4 mm/year

Which scaling approach to recommend for GDR products?

- Reference missions: scaling with constant factor (determined over full period) is recommend (0.881)
    - ➢ good long term stability (consistent with dual-frequency altimetry corrections)
    - ➢ easiest and fastest approach

- For other missions (==satellite altitudes): own scaling factors have to be computed

Summary

- GIM corrections in altimetry GDR data sets are not fully scaled to account for plasmaspheric electron content.
- Neglecting the plasmaspheric effect leads to trends of up to a few mm/year in GMSL estimates
- The application of a scale factor improves the consistency in trend with respect to dual-frequency satellite altimetry data.
- Scale factor estimated from TP/J1/J2/J3 data outperforms scaling by models and is also applicable to S6
- Of special importance when using single-frequency altimeters (ERS, Cryosat-2, …) or for coastal and inland applications

Dettmering and Schwatke (2022) https://doi.org/10.1029/2021EA002098
Dettmering and Schwatke (in review for Earth, Planets and Space)