IGS contribution to ITRF2020

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The IGS contribution to ITRF2020 consists of the daily combined terrestrial frame (SINEX) solutions from the third IGS reprocessing campaign (repro3). Those were obtained by combining the contributions from 10 Analysis Centers (ACs) listed in the table below.

AC	Institution	GNSS	From	Till
COD	Center for Orbit Determination in Europe	GPS	1994-01-02	2020-12-31
		GLONASS	2002-01-01	2020-12-31
		GALILEO	2013-01-01	2020-12-31
ESA	European Space Operations Center	GPS	1995-01-01	2020-12-31
		GLONASS	2009-01-01	2020-12-31
		GALILEO	2015-01-01	2020-12-31
GFZ	GeoForschungsZentrum	GPS	1994-01-02	2020-12-31
		GLONASS	2012-01-01	2020-12-31
		GALILEO	2013-12-21	2020-12-31
GRG	Groupe de Recherche en Géodésie Spatiale	GPS	2000-05-03	2020-12-31
		GLONASS	2008-11-04	2020-12-31
		GALILEO	2016-12-31	2020-12-31
JPL	Jet Propulsion Laboratory	GPS	1994-01-02	2020-12-26
MIT	Massachusetts Institute of Technology	GPS	2000-01-02	2020-12-31
		GALILEO	2017-01-01	2020-12-31
NGS	National Geodetic Survey	GPS	1994-01-02	2020-12-31
TUG	Graz University of Technology	GPS	1994-01-02	2020-12-31
		GLONASS	2009-01-01	2020-12-31
		GALILEO	2013-01-01	2020-12-31
ULR	Université de la Rochelle	GPS	2003-01-01	2020-12-31
WHU	Wuhan University	GPS	2008-01-01	2019-12-31
		GLONASS	2010-09-28	2019-12-31

Available products

The IGS repro3 combined SINEX products follow the new IGS long file name convention. They are prefixed "IGS1R03SNX". The available products are listed in the table below, where ${yyyy} stands for the 4-character year and ${doy} for the 3-character day of year (first day of the week in case of weekly files). Note that the opportunity of repro3 was taken to change the style of the SINEX combination residual and summary files and to make them additionally available in YAML format.

File name	Content
IGS0R03SNX_${yyyy}${doy}0000_01D_01D_SOL.SNX	Daily combined SINEX solution
IGS0R03SNX_${yyyy}${doy}0000_01D_01D_CRD.SNX	id., without covariance matrices
IGS0R03SNX_${yyyy}${doy}0000_01D_01D_RES.RES	Daily combination residuals
IGS0R03SNX_${yyyy}${doy}0000_01D_01D_RES.YML	id., in YAML format
IGS0R03SNX_${yyyy}${doy}0000_07D_07D_SOL.SNX	Weekly combined SINEX solution
IGS0R03SNX_${yyyy}${doy}0000_07D_07D_CRD.SNX	id., without covariance matrices
IGS0R03SNX_${yyyy}${doy}0000_07D_01D_ERP.ERP	Weekly ERP file
IGS0R03SNX_${yyyy}${doy}0000_07D_07D_SUM.SUM	Weekly combination summary
IGS0R03SNX_${yyyy}${doy}0000_07D_07D_SUM.YML	id., in YAML format

At present, those products are publicly available at the following URLs, where ${wwww} stands for the 4-character GPS week number:

- https://cddis.nasa.gov/archive/gnss/products/${wwww}/repro3
- ftp://igs.ign.fr/pub/igs/products/${wwww}/repro3
- ftp://igs-rf.ign.fr/pub/repro3/${wwww}

Main modeling updates since repro2

Compared to the previous IGS reprocessing campaign and to current IGS operational products, a number of new models and conventions have been adopted in repro3. The main updates are detailed below together with their (expected) impact on terrestrial frame solutions.

Secular pole The new IERS secular pole model was adopted in repro3. It replaces the previous mean pole model of the original IERS 2010 Conventions, which was used in repro2 and is still used in the IGS operational products. The repro3 terrestrial frame solutions thus show a degree-2, order-1 deformation pattern with respect to repro2/operational solutions, but also ITRF2014/IGS14, whose amplitude is relatively small until ~2010, but then increases linearly. It reaches ~3 mm in vertical and ~1 mm in horizontal in 2020.

Satellite z-PCOs Compared to igs14.atx, the radial phase center offsets (z-PCOs) of all GPS and GLONASS satellites have been updated in the ANTEX file used in repro3, igsR3.atx. While the GPS and GLONASS satellite z-PCOs in igs14.atx had been estimated based on the ITRF2014 terrestrial scale, they were corrected in igsR3.atx to become consistent with the Galileo satellite z-PCOs measured and published by the European GNSS Agency. Details about these corrections can be found in the 2019 technical reports of the IGS Antenna and Reference Frame working groups and in the header of igsR3.atx. As a consequence, the terrestrial scale of the IGS repro3 solutions is independent of ITRF2014, and is instead based on the Galileo satellite antenna calibrations. It shows an offset of ~1.2 ppb at epoch 2010.0 and a drift of ~0.03 ppb/yr with respect to the ITRF2014 scale.

Ground antenna calibrations In order to enable the processing of Galileo data in repro3, the L1/L2-only calibrations of several ground antenna types in igs14.atx were replaced by new multi-GNSS calibrations in igsR3.atx (see details in the 2019 technical report of the IGS Antenna working group and in the header of igsR3.atx). As usual, such ground antenna calibration updates induce antenna type- and station-dependent position offsets of a few mm in horizontal / up to ~1 cm in vertical. Those offsets were estimated for all affected stations that are part of the IGSR3 reference frame (see below). The results can be found at: ftp://igs-rf.ign.fr/pub/IGSR3/igs14_to_igsR3_2077.txt

IGSR3 reference frame Because of the updates mentioned above, the repro3 solutions could not have been aligned to the IGS14 reference frame without systematic errors. A particular reference frame called IGSR3, consistent with the new IERS secular pole model, the igsR3.atx satellite PCOs and the igsR3.atx ground antenna calibrations, was thus used in repro3. It is available at:

- ftp://igs-rf.ign.fr/pub/IGSR3/IGSR3_2077.snx
- ftp://igs-rf.ign.fr/pub/IGSR3/IGSR3_2077.ssc (without covariance matrix)

Details about its computation can be found in the comment section of the SINEX file. Note that the daily and weekly repro3 solutions are aligned in orientation and origin to IGSR3, but not in scale. Their scale is a weighted average of those of the contributing AC solutions, and is thus based on the igsR3.atx satellite z-PCOs.

PCO/PCV rotations for antennas not oriented North Although certain ground GNSS antennas are not oriented North, the IGS practice until repro3 had been to ignore these mis-orientations and use the phase center corrections from the IGS ANTEX files as if all antennas were oriented North. In

repro3 however, the phase center corrections from igsR3.atx have been rotated when necessary to match the actual antenna orientations reported in the site logs. These PCO/PCV rotations have impacts of up to a few cm in horizontal / a few mm in vertical on the estimated positions of the affected stations. Antenna orientations, extracted from the site logs, are reported in an extra column in the SITE/ANTENNA blocks of the repro3 SINEX files.

Inclusion of GLONASS and Galileo While only two ACs had processed GLONASS data in repro2, a majority of ACs have processed GLONASS and also Galileo data in repro3. This may have a positive impact, which remains to be quantified, on the background noise in the repro3 station position time series. On the other hand, this leads to additional spurious signals at periods around 8 and 10 days.

Others

- ACs have used "modern" ocean tidal loading models in repro3 (FES2014 or equivalent). This can be expected to reduce spurious aliased tidal signals in the repro3 station position time series to some extent.
- ACs have refined their solar radiation pressure models since repro2. This may be expected to reduce draconitic signals in the repro3 station position time series to some extent.
- The sub-daily EOP tide model from Desai & Sibois (2016) was adopted in repro3 in replacement of the current IERS model. This has been shown to have practically no impact on station position estimates, but should reduce spurious aliased tidal signals in the repro3 polar motion [rate] time series to some extent (Sibois, 2019).
- Contrary to repro2, all ACs have used time-variable gravity field models in repro3. The expected impact on terrestrial frame solutions is sub-millimetric (Amiri et al., 2016).

Combination strategy

The daily combinations of the AC repro3 SINEX solutions follow essentially the same strategy as the one used in repro2 and described in Rebischung et al. (2016). Some minor changes are detailed below.

Terrestrial scale In the repro2 daily combinations, no scale factors were estimated between the AC solutions and the combined solutions. In repro3, the estimation of such scale factors was restored to study possible subtle differences between the terrestrial scales realized by the different AC solutions. The terrestrial scale is in practice handled in a similar way as geocenter coordinates during the repro3 daily combinations. Scale factors with respect to the IGSR3 reference frame are first made explicit in the unconstrained AC normal equations, by a similar re-parameterization as for geocenter coordinates. The preprocessed AC normal equations are then inverted using no-net-rotation, translation or scale (NNR+NNT+NNS) constraints with respect to IGSR3 (instead of NNR+NNT only in repro2). The AC scale factors are then combined together with station positions, ERPs and geocenter coordinates, and scale residuals are in particular provided in the combination residual files. The combined solution is at this step obtained using NNR+NNT+NNS constraints with respect to IGSR3 and includes combined geocenter coordinates as well as a combined scale factor with respect to IGSR3. In a last post-processing step, the combined normal equation is re-inverted with NNR+NNT constraints only while fixing the combined scale factor to 0. By doing so, the combined scale information (based on the igsR3.atx satellite z-PCOs) is brought back into station coordinates.

Station metadata errors Like in repro2, care has been taken to exclude from the repro3 combinations AC station position estimates for which incorrect metadata were reported in the AC SINEX files. The policy adopted in repro3 was to confront metadata in the AC SINEX files with site logs collected from different sources and systematically reject stations with either:

- an incorrect antenna type,

- an eccentricity error larger than 1 mm in either East, North or Up,
- an antenna orientation error larger than 10°.

This lead in particular to reject all stations with antenna mis-orientations larger than 10° from the solutions of COD, NGS and WHU, as these ACs did not apply PCO/PCV rotations and reported 0 or no mis-orientations in their SINEX files. All detected metadata errors are reported in Section 6 of the combination summary files, while rejected stations are listed in Section 4.

AC weighting and outliers The weighting of AC solutions in the combinations was refined compared to repro2. The same unbiased variance component estimator is used, but it is now iteratively applied until all AC variance factors have converged to better than 10^{-3} in a relative sense. (This explains why the global variance factors reported in the daily combined SINEX files are very close to 1.) The criterion for rejecting outliers from the AC solutions was also changed compared to repro2. Now, any AC station position estimate with a *normalized* residual larger than 5 in either East, North or Up is considered as an outlier. The overall iterative repro3 combination procedure can be described as follows:

- Assign a priori AC variance factors in the same way as in repro2.
- Perform an initial combination and re-weight AC solutions using unbiased variance component estimates. No outliers are rejected yet.
- Iteratively combine AC solutions. After each iteration, reject outliers and re-weight AC solutions again.
- Iterate until no outlier remains and AC variance factors have converged.

Weekly combined solutions The weekly combined repro3 solutions are obtained by iteratively stacking the 7 daily combined solutions of the week. The daily solutions are given a uniform a priori variance factor of 1, and a single common corrective variance factor is estimated. After each iteration, station position estimates with normalized residuals larger than 5 are removed from the corresponding daily solutions. Iterations are performed until no such outlier remains.