BALTIC+

Geodetic SAR for Baltic Height System Unification and Baltic Sea Level Research

Dataset User Manual

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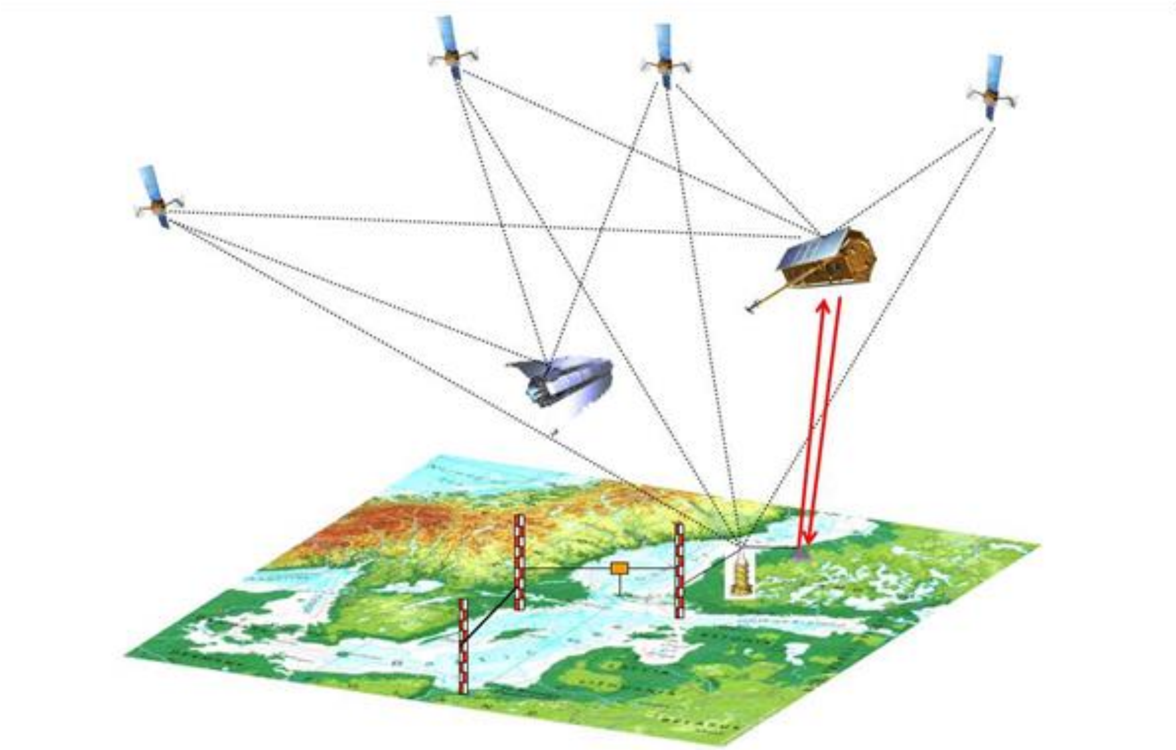

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Document Approval

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Abbreviations and Acronyms

CBK-PAN	Centrum Badań Kosmicznych Polskiej Akademii Nauk
CR	Corner Reflector
DLR	Deutsches Zentrum für Luft- und Raumfahrt
ECR	Electronic Corner Reflector
EUREF	Regional Reference Frame Sub-Commission for Europe
FGI	Finnish Geospatial Research Institute
GNSS	Global Navigation Satellite System
IERS	International Earth Rotation and Reference Systems Service
IGS	International GNSS Service
ITRF	International Terrestrial Reference Frame
LM	Lantmäteriet, Swedish Mapping, Cadastral and Land Registration Authority
SAR	Synthetic Aperture Radar
SAR-HSU	Geodetic SAR for Baltic Height System Unification and Baltic Sea Level Research
TUM	Technical University of Munich
TUT	Tallinn University of Technology

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1 INTRODUCTION

1.1 Purpose

The purpose of this technical note is a description of the datasets generated in the project and provided to the Agency.

1.2 Project Overview

Traditionally, sea level is observed at tide gauge stations, which usually also serve as height reference stations for national levelling networks and therefore define a height system of a country. Thus, sea level research across countries is closely linked to height system unification and needs to be regarded jointly. The project aims to make use of a new observation technique, namely SAR positioning, which can help to connect the GNSS basic network of a country to tide gauge stations and as such to link the sea level records of tide gauge stations to the geometric network. By knowing the geoid heights at the tide gauge stations in a global height reference frame with high precision, one can finally obtain absolute sea level heights of the tide gauge stations in a common reference system and can link them together. By this method, on the one hand national height systems can be connected and on the other hand the absolute sea level at the tide gauge stations can be determined. By analysing time series of absolute sea level heights their changes can be determined in an absolute sense in a global reference frame and the impact of climate change on sea level can be quantified (e.g. by ice sheet and glacier melting, water inflow, global warming).

The major scientific challenges to be addressed by this project then can be summarized as follows:

(1) Connection of the tide gauge markers with the GNSS network geometrically in order to determine the relative vertical motion and to correct the tide gauge readings. For this the new technique of SAR positioning is applied.
(2) Determination of a GOCE based high resolution geoid at tide gauge stations in order to deliver absolute heights of tide gauges with respect to a global equipotential surface as reference.
(3) Joint analysis of geometrical and physical reference frames to make them compatible, and to determine corrections to be applied for combined analysis of geometric and physical heights.

In order to provide answers to these challenges the project has been structured accordingly (Figure 1-1).

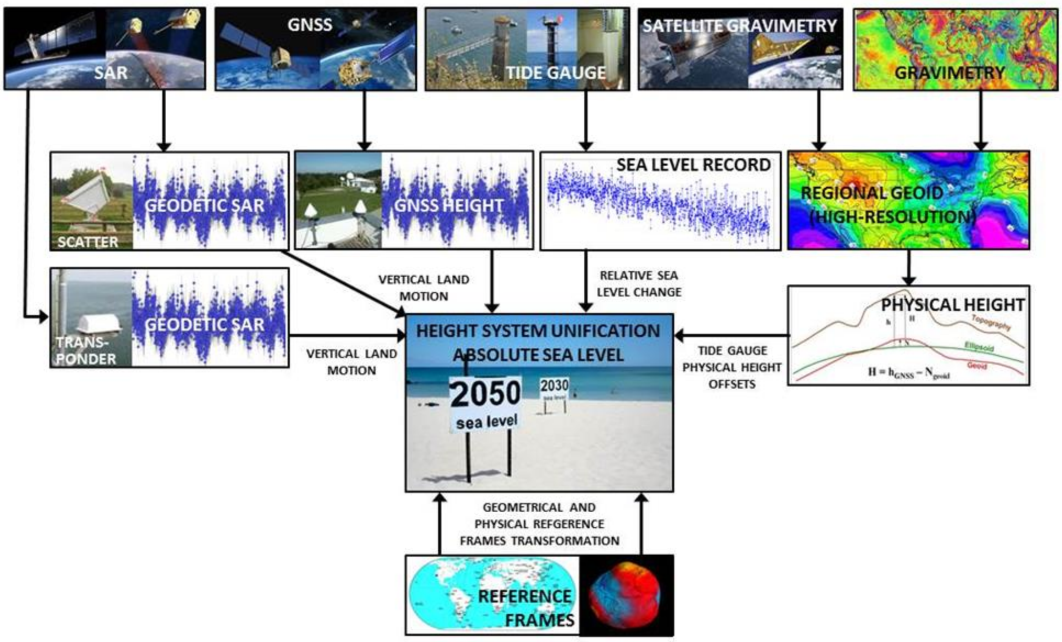

Figure 1-1: Overview of observations and their combination needed to reach the project goals. The boxes at the top line represent the observations needed to estimate the absolute sea level and its changes at tide gauge locations. All observations need to be processed consistently by applying common standards and reference frames in order to compute the absolute sea level at tide stations and its changes. Further-on this information then can be used for height system unification between different countries.

1.3 Applicable Documents

[AD-1] Final Report, SAR-HSU-FR-0022, Issue 1.1, dated 07.07.2021
[AD-2] Electronic Corner Reflector Station Description, Issue 1.1, dated 07.07.2021

1.4 References

Altamimi Z., P. Rebischung, L. Metivier, and X. Collilieux (2016) ITRF2014: A new release of the International Terrestrial Reference Frame modeling nonlinear station motions. Journal of Geophysical Research: Solid Earth 121(8), pp. 6109–6131, https://doi.org/10.1002/2016JB013098

Altamimi Z. (2018) EUREF Technical Note 1: Relationship and Transformation between the International and the European Terrestrial Reference Systems, Version June 28, 2018, http://etrs89.ensg.ign.fr/pub/EUREF-TN-1.pdf

Angermann D., Gruber T., Gerstl M., Heinkelmann R., Hugentobler U., Sánchez L., Steigenberger P. (2020): GGOS Bureau of Products and Standards: Inventory of standards and conventions used for the generation of IAG products. In: Poutanen, M., Rózsa, S. The Geodesist's Handbook 2020. J Geod 94, 109, https://doi.org/10.1007/s00190-020-01434-z

Boucher C. and Z. Altamimi (2011) Memo: Specifications for reference frame fixing in the analysis of a EUREF GPS campaign, http://etrs89.ensg.ign.fr/memo-V8.pdf

Gisinger, Christoph; Willberg, Martin; Balss, Ulrich; Klügel, Thomas; Mähler, Swetlana; Pail, Roland; Eineder, Michael (2017): Differential geodetic stereo SAR with TerraSAR-X by exploiting small multi-directional radar reflectors. In Journal of Geodesy 91 (1), pp. 53–67. https://doi.org/10.1007/s00190-016-0937-2

Petit G. and Luzum B. (Eds) (2010): IERS Conventions (2010). Verlag des Bundesamts für Kartographie und Geodäsie, Online: http://tai.bipm.org/iers/conv2010/conv2010.html.

2 OUTPUT DATASET DESCRIPTION

2.1 SAR Observations

2.1.1 Extracted Target Locations from Point Target Analysis (PTA-RES)

The files contain the extracted target location(s) from point target analysis. Multiple targets may be summarized in one file as noted by the header. Data blocks are repeated for each target. The file contains the following information.

File Name	
<ID>_PTA_Result.txt	<ID> = <AAA_BBB_XXXX_YYY_ZZZZ> [AAA] = BAL: Baltic Sea; [AAA] = MNC: Munich [BBB] = ASC: Ascending; [BBB] = DSC: Descending [XXXX] = Station Location Acronym (3 or 4 Letters) [YYY] = Reflector Acronym; ECR: Electronic Corner Reflector; CR: Corner Reflector [ZZZZ] = ECR Number or CR Station Acronym
Header	
NR OF SC :	Number of targets included in file
COORDINATES XYZ ITRF14 [m] :	List of approximate target coordinates in the ITRF14; XYZ in meters
Results SC ## : #	Number of extractions available for target ###
Data Block Columns Description (repeated per epoch)	
Col 01 = S_ID	Satellite ID for given acquisition, 4 digits, e.g. S1A1, S1B1, …
Col 02 to 04 = YYYY MM DD	Date of given acquisition, year, day, month
Col. 05 = t [SOD UTC]	Time of closest approach (azimuth) as seconds of day referring to UTC
Col. 06 = tau [s 2-way]	Signal round trip time (range) at zero Doppler, seconds
Col. 07 = PPower [dB]	Peak power as sigma0 integrated for 3dB peak width, decibel
Col. 08 = BPower [dB]	Background power inferred from the 4 quadrants surrounding the peak and scaled to 3dB peak area, decibel
Col. 09 = SCR [dB]	Signal-to-clutter ratio; difference of PPower minus BPower, decibel
Col. 10 = Rres [m]	Range resolution inferred from 3dB peak width
Col. 11 = Ares [m]	Azimuth resolution inferred from 3dB peak width
Col. 12 = sR [m]	Theoretical PTA standard deviation in range as inferred from SCR and Rres
Col. 13 = sA [m]	Theoretical PTA standard deviation in azimuth as inferred from SCR and Ares
Col. 14 = S	Number of the sub-swath containing the target location, e.g. 1 --> IW1, 2 --> IW2
Col. 15 = B	Number of the burst containing the target location, e.g. 1 --> Burst 1, …
Col. 16 = tPX [px]	Target azimuth location inside image in units of pixels; in case of burst modes, it means w.r.t. the burst
Col. 17 = tauPX [px]	Target range location inside image in units of pixels; in case of burst modes, it means w.r.t. the burst
Col. 18 = BAC [s]	Correction for bistatic azimuth effects not considered in the S-1 SAR image processor, seconds
Col. 19 = AFMC [s]	Correction for azimuth FM-rate mismatch shifts still present in S-1 SAR images, seconds
Col. 20 = DRC [s]	Correction for Doppler shifts in the range pulses, seconds two-way
Col. 21 = IPFv	Version of the S-1 SAR processor that processed the S-1 SAR image
Col. 22 = SWST [s 2-way]	Sampling window start time bias applied by the S-1 SAR processor during image generation, seconds two-way

2.1.2 SAR Raw Measurements (PTA-OBS)

The observation file is generated from the point target analysis file (PTA-RES). Processor specific corrections are applied to range and azimuth during file generation, representing the raw SAR measurements. Multiple targets may be summarized in one file. Data blocks for different targets are placed side by side organized by dates. If a target is unavailable or detected an outlier (low SCR), the entries are set to 9.

Note on SWST: differential corrections are applied if the SWST became updated in the S-1 SAR processor, i.e. range measurements based on previous configurations are corrected in order to match the latest value applied in processing.

File Name	
<ID>_SAR_Observations.cfg	<ID> = <AAA_BBB_XXXX_YYY_ZZZZ> [AAA] = BAL: Baltic Sea; [AAA] = MNC: Munich [BBB] = ASC: Ascending; [BBB] = DSC: Descending [XXXX] = Station Location Acronym (3 or 4 Letters) [YYY] = Reflector Acronym; ECR: Electronic Corner Reflector; CR: Corner Reflector [ZZZZ] = ECR Number or CR Station Acronym
Header	
IGS GNSS RX TS : [XXXX]	Optional list of IGS stations that can be used to correct the tropospheric delay, [XXXX] = 4 digit IGS IDs

IGS GNSS RX IS : [XXXX]	Optional list of IGS stations that can be used to correct the ionospheric delay, [XXXX] = 4 digit IGS IDs
NR OF SC :	Number of targets included in file
COORDINATES XYZ ITRF14 [m] :	List of approximate target coordinates in the ITRF14; XYZ in meters
Data Block Columns Description (repeated per epoch)	
Col 01 = S_ID	Satellite ID for given acquisition, 4 digits, e.g. S1A1, S1B1, …
Col 02-04 = YYYY MM DD	Date of given acquisition, year, day, month
Col 05 = AZIMUTH [SOD UTC]	Target 1 time of closest approach (azimuth); corrected for BAC & AFMC; seconds of day referring to UTC
Col 06 = RANGE [s]	Target 1 signal round trip time (range) at zero Doppler; corrected for DRC (& SWST); seconds two-way
Col 07 = AZIMUTH [SOD UTC]	Target 2 time of closest approach (azimuth); corrected for BAC & AFMC; seconds of day referring to UTC
Col 08 = RANGE [s]	Target 2 signal round trip time (range) at zero Doppler; corrected for DRC (& SWST); seconds two-way
…	Target 3 …

2.2 SAR Corrections

The external corrections are derived from spatiotemporal interpolation of geophysical models w.r.t. date and time of the SAR image acquisition. The effects are converted into slant range and azimuth radar geometry to be applied to the raw SAR observations contained in the observation files (PTA-OBS). Corrections are generated using the observation files (PTA-OBS), hence sorting matches original files. Additional matching may be performed by comparing satellite ID and azimuth date & time also listed in the correction files.

2.2.1 Tropospheric Delays (COR-TD)

The tropospheric correction files are generated from PTA-OBS and VMF3. Tropospheric delays are stored as 1-way path delay in units of meters. In order to apply them to the range observations, they need to be scaled by 2/c, with c denoting speed of light in vacuum. Multiple targets may be summarized in one file. Data blocks for different targets are placed side by side organized by dates. If a target is unavailable or detected an outlier (low SCR), the entries are set to 9.

File Name	
<ID>_D_Troposphere.txt	<ID> = <AAA_BBB_XXXX_YYY_ZZZZ> [AAA] = BAL: Baltic Sea; [AAA] = MNC: Munich [BBB] = ASC: Ascending; [BBB] = DSC: Descending [XXXX] = Station Location Acronym (3 or 4 Letters) [YYY] = Reflector Acronym; ECR: Electronic Corner Reflector; CR: Corner Reflector [ZZZZ] = ECR Number or CR Station Acronym
Header	
NR OF SC :	Number of targets for which corrections are included in file
Data Block Columns Description (repeated per epoch)	
Col 01 = ID	Satellite ID for given acquisition, 4 digits, e.g. S1A1, S1B1, …
Col 02-04 = YYYY MM DD	Date of given acquisition, year, day, month
Col 05 = SOD UTC	Target 1 time of closest approach (azimuth) as seconds of day referring to UTC
Col 06 = d_tro [m]	Target 1 tropospheric delay in units of meters, one-way
Col 07 = s_d_tro [+-m]	Target 1 standard deviation of tropospheric delay if provided by underlying method; meters
Col 08 = SOD UTC	Target 2 time of closest approach (azimuth) as seconds of day referring to UTC
Col 09 = d_tro [m]	Target 2 tropospheric delay in units of meters, one-way
Col 10 = s_d_tro [+-m]	Target 2 standard deviation of tropospheric delay if provided by underlying method; meters
…	Target 3 …

2.2.2 Ionospheric Delays (COR-ID)

The ionospheric correction files are generated from PTA-OBS and IGS-TEC. Ionospheric delays are stored as 1-way path delay in units of meters. In order to apply them to the range observations, they need to be scaled by 2/c, with c denoting speed of light in vacuum. Multiple targets may be summarized in one file. Data blocks for different targets are placed side by side organized by dates. If a target is unavailable or detected an outlier (low SCR), the entries are set to 9.

File Name	
<ID>_D_Ionosphere.txt	<ID> = <AAA_BBB_XXXX_YYY_ZZZZ> [AAA] = BAL: Baltic Sea; [AAA] = MNC: Munich [BBB] = ASC: Ascending; [BBB] = DSC: Descending [XXXX] = Station Location Acronym (3 or 4 Letters) [YYY] = Reflector Acronym; ECR: Electronic Corner Reflector; CR: Corner Reflector [ZZZZ] = ECR Number or CR Station Acronym
Header	
NR OF SC :	Number of targets for which corrections are included in file
Data Block Columns Description (repeated per epoch)	

Col 01 = ID	Satellite ID for given acquisition, 4 digits, e.g. S1A1, S1B1, …
Col 02-04 = YYYY MM DD	Date of given acquisition, year, day, month
Col 05 = SOD UTC	Target 1 time of closest approach (azimuth) as seconds of day referring to UTC
Col 06 = d_iono [m]	Target 1 ionospheric delay in units of meters, one-way
Col 07 = s_d_iono [+-m]	Target 1 standard deviation of ionospheric delay if provided by underlying method; meters
Col 08 = SOD UTC	Target 2 time of closest approach (azimuth) as seconds of day referring to UTC
Col 09 = d_tro [m]	Target 2 ionospheric delay in units of meters, one-way
Col 10 = s_d_tro [+-m]	Target 2 standard deviation of ionospheric delay if provided by underlying method; meters
…	Target 3 …

2.2.3 Geodynamic Corrections (COR-GC)

The geodynamic effects are computed from PTA-OBS and IERS-2010, following the definitions of the ITRF as outlined in the IERS conventions (version 2010, chapter 7, displacements of reference points).

The cumulative impact on range and azimuth are stored in the correction file. The range corrections are available in units of meters 1-way. In order to apply them to the range observations, they need to be scaled by 2/c, with c denoting speed of light in vacuum. The azimuth corrections are in units of seconds and can be used as is.

The following geodynamic corrections are comprised in values listed in the file:

- Solid Earth tidal deformations caused by Sun & Moon; note that the model is computed as "conventional tide free" to match geodetic conventions.
- Ocean loading stemming from water mass redistribution by tides weighing on the coastlines using the FES2004 tidal model. The model coefficients were specifically requested for the installation sites at: http://holt.oso.chalmers.se/loading/.
- Atmospheric pressure loading induced by diurnal heating of the atmosphere (S1 and S2 components).
- Rotational deformation due to polar motion.
- Ocean pole tide loading.
- Secular trends as inferred from nearby IGS reference site located on same tectonic plate (https://itrf.ign.fr/ITRF_solutions/2014/more_ITRF2014.php); differential correction w.r.t. to 1st of January 2020 (2020.0). The IGS station used to compute the trend as well as the site velocity are annotated in the header section.

Multiple targets may be summarized in one file. Data blocks for different targets are placed side by side organized by dates. If a target is unavailable or detected an outlier (low SCR), the entries are set to 9.

File Name	
<ID>_D_Geodynamics.txt	<ID> = <AAA_BBB_XXXX_YYY_ZZZZ> [AAA] = BAL: Baltic Sea; [AAA] = MNC: Munich [BBB] = ASC: Ascending; [BBB] = DSC: Descending [XXXX] = Station Location Acronym (3 or 4 Letters) [YYY] = Reflector Acronym; ECR: Electronic Corner Reflector; CR: Corner Reflector [ZZZZ] = ECR Number or CR Station Acronym
Header	
NR of SC :	Number of targets for which corrections are included in file
ITRF Epoch YYYY MM DD :	Fixed to 2020 01 01; the ITRF epoch for which the secular trends are corrected for in the measurements.
Nearest IGS Stations :	IGS 4 digits Station ID which was used to compute the trend
ITRF Velocity VxVyVz [m/y] :	IGS site velocity vector as given in the ITRF solution in meters per year
Data Block Columns Description (repeated per epoch)	
Col 01 = ID	Satellite ID for given acquisition, 4 digits, e.g. S1A1, S1B1, …
Col 02-04 = YYYY MM DD	Date of given acquisition, year, day, month
Col 05 = SOD UTC	Target 1 time of closest approach (azimuth) as seconds of day referring to UTC
Col 06 = d_geod_R [m]	Target 1 cumulative displacement effects in range in units of meters, one-way
Col 07 = d_geod_A [s]	Target 1 cumulative displacement effects in azimuth in units of seconds
Col 08 = SOD UTC	Target 2 time of closest approach (azimuth) as seconds of day referring to UTC
Col 09 = d_geod_R [m]	Target 2 cumulative displacement effects in range in units of meters, one-way
Col 10 = d_geod_A [s]	Target 2 cumulative displacement effects in azimuth in units of seconds
…	Target 3 …

2.2.4 Sentinel-1 Systematic Effects Corrections (COR-SC)

Sensor specific calibration constants (S1A, S1B) are stored in dedicated calibration files. The numbers need to be applied to the raw range and azimuth observations to ensure unbiased observations. The numbers primarily account for SAR payload internal signal delays and have been inferred from S1A and S1B measurements of the long term stable corner reflector installed at Metsähovi geodetic observatory.

File Name	
D_Sys_<ID>_IFT.txt	<ID> = S1A or S1B (for Sentinel-1A or 1B respectively)

Data Block Columns Description	
Col 01 = Azimuth_delay [s]	Azimuth calibration constant in units of seconds
Col 02 = Range_delay [s]	Slant range calibration constant in units of seconds, 2-way

2.2.5 ECR System Corrections (COR-EC1, COR-EC2)

ECR Antenna Geometric Phase Center Location Correction (COR-EC1)

The different locations of ECR antennas as well as the signal delay introduced by ECR electronics have to be taken into account. Depending on the orbit geometry, the phase center of the ECR is shifted with respect to the estimated position. This offset is added as a correction to the observations as a function of the incidence angle. Note: Phase Center variation maps are not yet available for the ECRs. Therefore, this data file is not available as a result of the project.

File Name	
<ID>_D_Phasecenter.txt	<ID> = <AAA_BBB_XXXX_YYY_ZZZZ> [AAA] = BAL: Baltic Sea; [AAA] = MNC: Munich [BBB] = ASC: Ascending; [BBB] = DSC: Descending [XXXX] = Station Location Acronym (3 or 4 Letters) [YYY] = Reflector Acronym; ECR: Electronic Corner Reflector [ZZZZ] = ECR Number
Header	
NR of SC :	Number of targets for which corrections are included in file
Data Block Columns Description (repeated per epoch)	
Col 01 = ID	Satellite ID for given acquisition, 4 digits, e.g. S1A1, S1B1, ...
Col 02-04 = YYYY MM DD	Date of given acquisition, year, day, month
Col 05 = SOD UTC	Target 1 time of closest approach (azimuth) as seconds of day referring to UTC
Col 06 = d_ECR_R [m]	Target 1 geometric phase center offset effects in range in units of meters, one-way
Col 07 = d_ECR_A [s]	Target 1 geometric phase center offset effects in azimuth in units of seconds

ECR Electronic Delay Correction (COR-EC2)

The ECR electronics causes a signal delay which has to be corrected in the SAR measurements. The effect was calibrated with a set of reference ECR, yielding a model that describes the delay as a function of orbit geometry and incidence angle. The model is evaluated for each acquisition and the results are stored the in dedicated correction files as described below.

File Name	
<ID>_D_ECR_Delay.txt	<ID> = <AAA_BBB_XXXX_YYY_ZZZZ> [AAA] = BAL: Baltic Sea; [AAA] = MNC: Munich [BBB] = ASC: Ascending; [BBB] = DSC: Descending [XXXX] = Station Location Acronym (3 or 4 Letters) [YYY] = Reflector Acronym; ECR: Electronic Corner Reflector [ZZZZ] = ECR Number
Header	
NR of SC :	Number of targets for which corrections are included in file
Data Block Columns Description (repeated per epoch)	
Col 01 = ID	Satellite ID for given acquisition, 4 digits, e.g. S1A1, S1B1, ...
Col 02-04 = YYYY MM DD	Date of given acquisition, year, day, month
Col 05 = SOD UTC	Target 1 time of closest approach (azimuth) as seconds of day referring to UTC
Col 06 = d_ECR_R [m]	Target 1 ECR electronic delay impact on range in units of meters, one-way
Col 07 = d_ECR_A [s]	Target 1 ECR electronic delay impact on azimuth in units of seconds

2.3 SAR Positioning

The results of the parameter estimation include:

- the X, Y, Z target coordinates in the ITRF2014.
- the uncertainties $\sigma_X, \sigma_Y, \sigma_Z, \sigma_{XY}, \sigma_{XZ}, \sigma_{YZ}$, derived from the variance-covariance matrix $\Sigma(\hat{\mathbf{x}})$.
- the confidence ellipsoid, which can be obtained by performing eigenvalue and eigenvector decomposition of $\Sigma(\hat{\mathbf{x}})$ scaled to a 95% confidence level as described in (Gisinger et al. 2017).
- In case external reference coordinates for the same target are also available (e.g. from a terrestrial survey), the $\Delta X_{x,y,z}$ coordinate differences are computed.
- The range and azimuth standard deviations σ_r and σ_a, provided by the variance component estimation.
- The observation residuals.

2.3.1 SAR Positioning Solution (SAR-POS)

Time series of coordinates of the SAR target as X, Y, Z coordinates in the ITRF2014 and uncertainties $\sigma_X, \sigma_Y, \sigma_Z, \sigma_{XY}, \sigma_{XZ}, \sigma_{YZ}$, derived from the variance-covariance matrix $\Sigma(\hat{\mathbf{x}})$. Confidence ellipsoid from eigenvalue and eigenvector decomposition of $\Sigma(\hat{\mathbf{x}})$ scaled to a 95% confidence level. In case external reference coordinates for the same target are also available (e.g. from a terrestrial survey), the $\Delta X_{x,y,z}$ coordinate differences are computed.

File Name	
<ID>_<temp_res> _summary_results.txt.	<ID> = <AAA_BBBB_XXXX_YYY_ZZZZ> [AAA] = BAL: Baltic Sea; [AAA] = MNC: Munich [BBBB] = AS__: Ascending; [BBBB] = DS__: Descending; [BBBB] = ASDS: Ascending and Descending [XXXX] = Station Location Acronym (3 or 4 Letters) [YYY] = Reflector Acronym; ECR: Electronic Corner Reflector; CR: Corner Reflector [ZZZZ] = ECR Number or CR Station Acronym <temp_res>=Temporal resolution of Observation intervals (e.g. 1M, 2M, 3M, 4M, All). “All” means average solution with all data
Header	
<XXXX> - <BBBB>	XXXX] = Station Location Acronym (3 or 4 Letters) [BBBB] = AS__: Ascending; [BBBB] = DS__: Descending, [BBBB] = ASDS: Ascending and Descending
<Temporal Resolution> time series	<temp_res>=Temporal resolution of Observation intervals (e.g. 1M, 2M, 3M, 4M, All). “All” means average solution with all available data.
Reference Epoch ITRF14	Reference epoch of the reference Coordinates yyyy mm dd
Coordinates XYZ ITRF14 [m] :	List of reference target coordinates in the ITRF14; XYZ in meters
ITRF Epoch YYYY MM DD :	Fixed to 2020 01 01; the ITRF epoch for which the secular trends are corrected for in the measurements.
Nearest IGS Stations :	IGS 4 digits Station ID which was used to compute the trend
ITRF Velocity VxVyVz [m/y] :	IGS site velocity vector as given in the ITRF solution in meters per year
Data Block Columns Description (repeated per temporal interval)	
Col 01 = Solution Epoch [YYYY MM DD]	Epoch of the Solution yyyy mm dd <temp_res>-mean date
Col 02 = DTs_A[#]	Number of valid data takes in azimuth
Col 03 = DTs_R[#]	Number of valid data takes in range
Col 04 = X[m]	Target X coordinate in ITRF14 in meters
Col 05 = Y[m]	Target Y coordinate in ITRF14 in meters
Col 06 = Z[m]	Target Z coordinate in ITRF14 in meters
Col 07-09 = { s_x [+-m], s_y [+-m], s_z [+-m] }	Standard deviations $\sigma_X, \sigma_Y, \sigma_Z$ from variance-covariance matrix $\Sigma(\hat{\mathbf{x}})$ ITRF14
Col 10-12 = { s_xy [m²], s_xz [m²], = s_yz [m²] }	Covariance $\sigma_{XY}, \sigma_{XZ}, \sigma_{YZ}$,, from variance-covariance matrix $\Sigma(\hat{\mathbf{x}})$ ITRF14
Col 13-21 = { Eig_V1(N); Eig_V1(E), Eig_V1(H); Eig_V2(N); Eig_V2(E), Eig_V2(H); Eig_V3(N); Eig_V3(E), Eig_V3(H)}	Three Eigenvectors from $\Sigma(\hat{\mathbf{x}})$ decomposition in Local reference frame with North East, Height components
Col 22-24 = { Eig_a1[m], Eig_a2[m], Eig_a3[m]}	Three Eigenvalues from $\Sigma(\hat{\mathbf{x}})$ decomposition of the respective Eigenvectors
Col 25-27 = { dX[m], dY[m], dZ[m] }	the $\Delta X_{x,y,z}$ coordinate differences to reference coordinates ITRF14
Col 28-30 = { dN[m], dE[m], dH[m] }	the $\Delta X_{N,E,H}$ coordinate differences to reference coordinates in local frame (North, East, Up)
Col 31-33 = { s_N [+-m], s_E [+-m], s_H [+-m] }	Confidence intervals $\sigma_N, \sigma_E, \sigma_H$ from variance-covariance matrix $\Sigma(\hat{\mathbf{x}})$ in local frame (North, East, Up)

2.3.2 SAR Observation Solution (SAR-OBS)

Time series of range and azimuth standard deviations σ_r and σ_a, provided by the variance component estimation and observation residuals.

File Name	
<ID>_<temp_res>_Observation_summary_Quality_Statistics.txt.	<ID> = <AAA_BBBB_XXXX_YYY_ZZZZ> [AAA] = BAL: Baltic Sea; [AAA] = MNC: Munich [BBBB] = AS__: Ascending; [BBBB] = DS__: Descending; [BBBB] = ASDS: Ascending and Descending [XXXX] = Station Location Acronym (3 or 4 Letters)

	[YYY] = Reflector Acronym; ECR: Electronic Corner Reflector; CR: Corner Reflector [ZZZZ] = ECR Number or CR Station Acronym <temp_res>=Temporal resolution of Observation intervals (e.g. 1M, 2M, 3M, 4M, All). “All” means average solution with all available data.
Header	
<XXXX> - <BBBB>	[XXXX] = Station Location Acronym (3 or 4 Letters) [BBBB] = AS__: Ascending; [BBBB] = DS__: Descending; [BBBB] = ASDS: Ascending and Descending
<Temporal Resolution> time series	<temp_res>=Temporal resolution of Observation intervals (e.g. 1M, 2M, 3M, 4M, All). “All” means average solution with all available data.
Reference Epoch ITRF14	Reference epoch of the reference Cordinates yyyy mm dd
Coordinates XYZ ITRF14 [m] :	List of reference target coordinates in the ITRF14; XYZ in meters
Data Block Columns Description	
Col 01 = Solution Epoch [YYYY MM DD]	Epoch of the Solution yyyy mm dd <temp_res>-mean date
Col 02 = Input DTs [#]	Number of Observation dates inputted in the processor
Col 03 = Valid DTs_A[#]	Number of valid data takes in azimuth
Col 04 = Valid DTs_R[#]	Number of valid data takes in range
Col 05 = s_0^2	Variance unit weight
Col 06 – (5+ #in_angle) = sR [+-m]	Standard deviation σ_r in range direction per incidence angle (#in_angle=number of incidence angles)gle
Col (6+ #in_angle) -(5+2* #in_angle) = sA [+-m]	Standard deviation σ_a in azimuth direction per incidence angle (#in_angle=number of incidence angles)ngle

number of incidence angles= #in_angle

2.3.3 Bias Correction

The incident depending bias in the residuals of the positioning is accounted for as a correction in the repeated 3D stereo SAR iteration. This file is generated during SAR Positioning and only used internally during this process.

File Name	
<ID>_Angle_Bias.txt	<ID> = <AAA_BBB_XXXX_YYY_ZZZZ> [AAA] = BAL: Baltic Sea; [AAA] = MNC: Munich [BBBB] = AS__: Ascending; [BBBB] = DS: Descending; BBBB] = ASDS: Ascending and Descending [XXXX] = Station Location Acronym (3 or 4 Letters) [YYY] = Reflector Acronym; ECR: Electronic Corner Reflector; CR: Corner Reflector [ZZZZ] = ECR Number or CR Station Acronym
Data Block Columns Description (repeated per epoch)	
Col 01-06 = YYYY MM DD hh mm ss	Date of given acquisition, year, day, month, hour, minute, second
Col 07 = d_ECR_R [m]	Target 1 cumulative displacement effects in range in units of meters, one-way
Col 08 = d_ECR_A [s]	Target 1 cumulative displacement effects in azimuth in units of seconds

2.4 GNSS Positioning

2.4.1 GNSS Positioning Solution (GNSS-POS)

Coordinates of the GNSS stations as X, Y, Z coordinates in the ITRF2014 and uncertainties and derived geographical coordinates with respect to the chosen reference ellipsoid.

File Name	
<ID> _GNSS_coordinates.txt.	<ID> = <AAA> [AAA] = BAL: Baltic Sea Network
Header	
Data Period: <Temporal Coverage>	<temporal Coverage>=Temporal coverage of observation intervals [yyyy mm dd – yyyy mm dd] = averaging period
Reference Ellipsoid:	Name of reference ellipsoid for geographic coordinates
Data Description	
Col 01 = Station Location Acronym (3 or 4 Letters)	GNSS station acronym
Col 02 = Solution Epoch [YYYY.XX]	Epoch of the Solution yyyy.xx - mean date in decimal year
Col 03 = X[m]	X coordinate in ITRF14 in meters
Col 04 = Y[m]	Y coordinate in ITRF14 in meters
Col 05 = Z[m]	Z coordinate in ITRF14 in meters
Col 06 = RMS_X [m]	RMS of X coordinate
Col 07 = RMS_Y [m]	RMS of Y coordinate

Col 08 = RMS_Z [m]	RMS of Z coordinate
Col 09 = Latitude [dd mm ss]	Latitude wrt. reference ellipsoid in [dd mm ss]
Col 10 = Longitude [dd mm ss]	Latitude wrt. reference ellipsoid in [dd mm ss]
Col 11 = Height [m]	Height above reference ellipsoid in [m]

2.5 Tide Gauge Data Analysis

2.5.1 Corrected Sea Surface Height at Tide Gauge Stations (TG-SSH)

Corrected sea surface heights observed at tide gauges with respect to the tide gauge benchmark with hourly temporal resolution.

File Name	
<ID> _Tide_Gauge_heights.txt.	<ID> = <AAA> [AAA] = BAL: Baltic Sea Network
Header	
Data Period: <Temporal Coverage>	<temporal Coverage>=Temporal coverage of observation interval [yyyy mm dd – yyyy mm dd] = averaging period
Reference Height:	Height Reference System
Data Description	
Col 01 = Tide Gauge Name	Name of tide gauge station
Col 02 = Solution Epoch [YYYY.XX]	Epoch of the Solution yyyy.xx - mean date in decimal year
Col 03 = Tide Gauge Height [m]	Average sea level height in meters
Col 04 = Standard Deviation of Tide Gauge Height [m]	Standard deviation of tide gauge time series

2.6 GOCE based Geoid Computation

2.6.1 Geoid Heights (GEO-HGT)

Geoid heights or height anomalies for ECR and tide gauge stations.

File Name	
<ID> _Geoid_heights.txt.	<ID> = <AAA> [AAA] = BAL: Baltic Sea Network
Header	
Data Period: <Temporal Coverage>	<temporal Coverage>=Temporal coverage of observation interval [yyyy mm dd – yyyy mm dd] = averaging period
Reference Ellipsoid:	Reference Ellipsoid (Normal Potential Field)
Data Description	
Col 01 = Station Name	Name of station
Col 02 = Solution Epoch [YYYY.XX]	Epoch of the Solution yyyy.xx - mean date in decimal year
Col 03 = Geoid Height [m]	Geoid height above reference ellipsoid in meters

2.7 Reference Frames and Joint Standards

2.7.1 Numerical Standards (STD-NUM)

Numerical standards relevant for the project and collected from literature (GRS80, EGM2008, IERS Conventions 2010, IAG). Detailed descriptions are provided in Angermann D., Gruber T., Gerstl M., Heinkelmann R., Hugentobler U., Sánchez L., Steigenberger P. GGOS Bureau of Products and Standards: Inventory of standards and conventions used for the generation of IAG products, In: (Eds:. Poutanen, M., Rózsa, S). The Geodesist's Handbook 2020. J Geod 94, 109 (2020). https://doi.org/10.1007/s00190-020-01434-z

Applicable numerical standards and conventions and system transformations are summarized in [AD-1]. No specific dataset is produced for this purpose.

2.7.2 Non-linear Station Motions (STD-NLSM)

Non-linear motions of ECR and GNSS stations due to periodic signals given by ITRF2014 or DTRF2014 results and by geophysical models for the atmospheric, hydrological and oceanic loading.

File access and description see: https://www.iers.org/IERS/EN/DataProducts/data.html and https://www.dgfi.tum.de/en/science-data-products/dtrf2014/

2.7.3 Extrapolation of ITRF Coordinates (STD-ITRF)

Extrapolation parameters for geometric coordinates (SAR, GNSS) from reference epoch 2010.0. to observation time (2020).

The mathematical model for extrapolating geometric coordinates to the observation epoch is provided in the IERS Conventions 2010 (Petit and Luzum, 2010). In the conventional secular approach, the regularized station position is parameterized by a linear model describing the position at any observation epoch ti by the position at the reference epoch t0 plus a constant velocity multiplied by the time difference $t_i - t_0$.

The ITRF2014 is generated with an enhanced modelling of non-linear station motions, including seasonal (annual and semi-annual) signals of station positions and post-seismic deformations (PSD) for sites that were subject to major earthquakes. In case of ITRF2014 and for stations subject to PSD, the user should add the sum of all PSD corrections to the linearly propagated position, using equation 4.16 of the most recent update of Chapter 4 of the IERS Conventions (https://iers-conventions.obspm.fr/content/chapter4/icc4.pdf). The ITRF PSD parametric models, together with all equations allowing users to compute the PSD corrections and Fortran subroutines are available at the ITRF2014 website https://itrf.ign.fr/ITRF_solutions/2014/. Periodic signals are available on request

2.7.4 Geocenter Coordinates (STD-ORI)

Geocenter motion needed for the combination of geometric heights (SAR, GNSS) with gravimetric geoid heights. The center of mass needs to be described in the geometric center of figure for in the ITRF2014 system. A time series of geocenter coordinates in the ITRF2014 reference system are available at the ITRF2014 website https://itrf.ign.fr/ITRF_solutions/2014/. The amplitudes and phases of the annual and semi-annual signals of the geocenter coordinates are published in Altamimi et al. (2016). The annual amplitudes are 2.6 mm, 2.9 mm and 5.7 mm for the x-, y- and z-component, respectively.

2.7.5 Transformation between ITRF2014 and ETRS89 (STD-EUREF)

Transformation formulae allowing to link the ETRS89 to the ITRF2014, for both station positions and station velocities are needed. The formulas to be applied are published for example in Boucher and Altamimi (2011) and Altamimi (2018). When transforming station coordinates from ITRS to ETRS89 at a specific epoch t, the users are advised to validate their obtained station coordinates in their preferred ETRS89 frame, by using the web-based tool available at the EUREF Permanent Network (EPN) website at http://epncb.oma.be/_productsservices/coord_trans/ .

2.8 Height System Unification and Absolute Sea Level

2.8.1 Unified Tide Gauge Heights (TG-HGT)

Physical heights of tide gauge stations involved in the project.

File Name	
<ID> _Physical_heights.txt.	<ID> = <AAA> [AAA] = BAL: Baltic Sea Network
Header	
Data Period: <Temporal Coverage>	<temporal Coverage>=Temporal coverage of observation interval [yyyy mm dd – yyyy mm dd] = averaging period
Reference Height System:	Reference Height System (Geoid Solution)
Data Description	
Col 01 = Station Name	Name of station
Col 02 = Solution Epoch [YYYY.XX]	Epoch of the Solution yyyy.xx - mean date in decimal year
Col 03 = Physical Height [m]	Physical height above geoid in meters

2.8.2 Absolute Sea Level Heights (SL-ABS)

Absolute sea level heights of tide gauge stations involved in the project.

File Name	
<ID> _Absolute_Sea_Level_heights.txt.	<ID> = <AAA> [AAA] = BAL: Baltic Sea Network
Header	
Data Period: <Temporal Coverage>	<temporal Coverage>=Temporal coverage of observation interval [yyyy mm dd – yyyy mm dd] = averaging period
Reference Height System:	Reference Height System (Geoid Solution)
Data Description	

Col 01 = Station Name	Name of station
Col 02 = Solution Epoch [YYYY.XX]	Epoch of the Solution yyyy.xx - mean date in decimal year
Col 03 = Geoid Height [m]	Absolute sea level height above geoid in meters

3 INPUT AND AUXILIARY DATASET DESCRIPTION

3.1 SAR Data

3.1.1 Sentinel-1 Level 1 Single Look Complex Images (S1-L1-SLC)

Sentinel-1 images acquired for the Baltic sea area in the Interferometric Wide-Swath mode; single-look complex level 1 products from ESA Copernicus open access hub in SAFE format.

File access and description see: https://scihub.copernicus.eu

3.1.2 Sentinel-1 Precise Orbit Product (S1-PSO)

Sentinel-1 precise state vectors (position & velocity) with 10s sampling; provided as daily files spanning 26 hours (1 hour daily boundary overlaps) from ESA PDGS, Sentinel-1 Quality Control in XML format.

File access and description see: https://aux.sentinel1.eo.esa.int/

3.2 Geophysical Data

3.2.1 Global TEC Maps (IGS-TEC)

Global total electron content (TEC) maps with 5° by 5° spatial resolution and 1 hour temporal resolution; files provide daily data cubes from IGS, Center for Orbit Determination in Europe in IONEX format.

File access and description see: https://www.igs.org/products

3.2.2 VMF3 Gridded Products (VMF3)

Global gridded parameter data for Vienna mapping function model; 1° by 1° spatial resolution and 6 hours temporal resolution; one file per timestamp (00h, 06h, 12h, 18h) from Technical University Vienna in ASCII format.

File Access and description see: https://vmf.geo.tuwien.ac.at/

3.2.3 IERS Conventions 2010 (IERS-2010)

Solid Earth tidal deformations; Ocean loading; Atmospheric pressure loading; Rotational deformation due to polar motion; Ocean pole tide loading from International Earth Rotation and Reference System Service (IERS).

File access and description see: https://www.iers.org/IERS/EN/DataProducts/data.html

3.3 Site Location Data

3.3.1 Approximate Locations of ECR Stations (ECR-LOC-A)

Approximate coordinates of all the installed ECRs to download the applicable SAR image. Approximate ECR positions (1 meter or better) determined during installation.

Details see [AD-2].

3.4 GNSS Data

3.4.1 GNSS Observations (GNSS-OBS)

GNSS observation files in RINEX v2.11 or 3.02 format for GNSS stations used for the regional network adjustment. Data with lowest possible elevation angle to be used. Data acquired from International GNSS Service (IGS), see https://www.igs.org/products, and from regional network operators.

3.4.2 GNSS Precise Orbits (GNSS-ORB)

Orbit files of GNSS satellites (positions and velocities) in SP3 from International GNSS Service (IGS), see: https://www.igs.org/products.

3.4.3 GNSS Clock Corrections (GNSS-CLK)

Satellites clock corrections in CLK format from International GNSS Service (IGS), see: https://www.igs.org/products.

3.4.4 Background Models for GNSS Positioning (GNSS-BM)

Background models required for GNSS processing. Station velocities, Solid and ocean pole tides, Permanent tides, Center of mass corrections for tidal loading, Geopotential model, Earth orientation parameters, Pole coordinates, Planetary ephemeris, Receiver antenna phase center offsets and variations, Sun radiation pressure model, Nutation model, Troposphere for GNSS.

File access and description are provided in the following table:

Parameter	**Background Model**	**File Access**
Station velocities	ITRF2014	IERS-2010 (see section 3.2.3)
Solid/Ocean Pole Tides, Permanent Tides	TIDE2000	IERS-2010 (see section 3.2.3)
Ocean Tidal Loading	OT_FES2004	IERS-2010 (see section 3.2.3)
Centre of mass corrections for loading	Header of the tidal loading file	IERS-2010 (see section 3.2.3)
Geopotential model	EGM2008	GEO-EGM (see section 3.6.3)
Earth orientation Param./ Pole Coord.	IERS C04 EOP	IERS-2010 (see section 3.2.3)
Planetary Ephemeris	DE405	https://ssd.jpl.nasa.gov/?planet_eph_export
Receiver antenna phase centre offsets and variations	ANTEX files	http://www.epncb.oma.be/_documentation/equipment_calibration/
Sun radiation pressure model	SATELLIT.IYY	GNSS Satellite Information File
Nutation model	IAU2000R06	IERS-2010 (see section 3.2.3)
Troposphere:	GMF/GPT and VMF1 for GNSS	https://vmf.geo.tuwien.ac.at/

3.5 Tide Gauge Data

3.5.1 Tide Gauge Raw Data (TG-RAW)

Sea surface height with respect to zero marker of tide gauge station with hourly resolution including information about applied corrections (e.g. ocean and Earth tides). Data acquired from national tide gauge authorities in their original format.

3.5.2 Tide Gauge Sensor Corrections (TG-COR)

Information about instrument corrections like drifts or sensor outages/problems as well as information about gross errors. Data acquired from national tide gauge authorities in their original format.

3.6 Gravity Data

3.6.1 Local Gravity Data (GEO-GRA)

Local terrestrial and/or airborne gravity data around tide gauge stations (at least 110 km around station) from NKG or national authorities in their original format.

3.6.2 Digital Elevation Model (GEO-DEM)

Digital elevation model NKG2015 DEM (called NKG_DEM2014) will be used for Sweden, Finland and Estonia. For Poland the global SRTM2gravity (computed by TUM) model may be used. Data access via NKG or TUM (for SRTM2gravity model: see: https://www.lrg.tum.de/iapg/forschung/schwerefeld/s2g/).

3.6.3 Global Gravity Field Model (GEO-EGM)

GOCE based Earth gravity field models. Files available in ICGEM format from http://icgem.gfz-potsdam.de/home.

3.6.4 Time-Variable Gravity Field (GEO-TVG)

Time-variable gravity due to land uplift in the Baltics from land-uplift model and/or GRACE Follow-On results. Models available from NGK (for NKG2016LU model) and from http://icgem.gfz-potsdam.de/home for GRACE monthly gravity field time series.