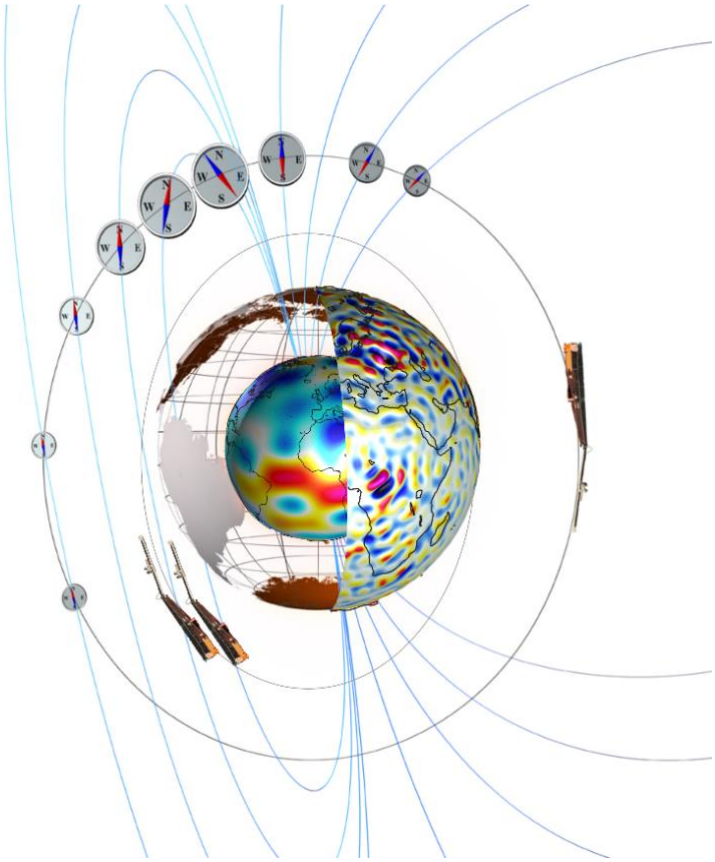
Data, Innovation, and Science Cluster

Swarm-TIRO Product Definition Document



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Record of Changes

Reason	Description	Rev	Date
Initial vers.	Released.	1 dA	03 Dec 2020
Signature		1	04 Dec 2020
Email from Klaus to Guram: 09.12.2020 18h11	Minor typos are corrected in some parts of the document.	2 dA	13 Jan 2021
Updated input from GFZ	GPS_Position, LEO_Position, GRACE_1_Position, GRACE_2_Position: (WGS84) is removed from the Description. Text in section 1.1 is updated. Several typos are corrected in some parts of the document.	2 dB	16 Feb 2021
Updated input from GFZ	Section 2.3: acronym IRI is added. Sections 4.2.1 and 4.2.2: Quality indicator description is updated. Section 4.2.2: typos are corrected from GFACE to GRACE-FO.	2 dC	20 May 2021
Updated input from GFZ	Degree is changed to deg. Data volume variable is updated for all products.	2 dD	01 Jun 2021
Email from Lars to Guram: 04.06.2021 09h22	Sections 4.2.1 and 4.2.2: GRACE and GRACE-FO position variables for 1 and 2 satellites are joined into one variable.	2 dE	07 Jun 2021
Signature		2	10 Jun 2021
Email from Lars to Guram: 11.06.2021 10h46	Sections 4.2.1 and 4.2.2: variable name "*GRACE_Position*" and "*GRACE-FO_Position*" changed to "*LEO_Position*". Dimension is set to 2x3.	3 dA	17 Jun 2021
Updated input from consortium	Sections 4.1.1, 4.1.2 and 4.1.3: C1_N0 and C2_N0 variables are added. Document text has been updated and corrected with minor changes.	3 dB	06 Dec 2021
Updated input from consortium	Sections 4.1.1, 4.1.2 and 4.1.3: C1_N0 and C2_N0 variable descriptions are updated.	3 dC	10 Jan 2022

Reason	Description	Rev	Date
	Sections 4.1.1, 4.1.2 and 4.1.3: C1_N0 and C2_N0 variable names are changed to S1_C_N0 and S2_C_N0, respectively.		
Updated input from consortium	Sections 4.2.1 and 4.2.2: variables "*Iono_Corr*" and "*Flag*" are removed; Quality indicator description is updated.	3 dD	17 Mar 2022
Signature		3	17 Mar 2022

Table of Contents

1 Introduction

1.1 Scope and applicability

This document comprises the description of Swarm-TIRO Level 2 (L2) products Total Electron Content (TEC) and electron density (Ne) derived from the K-band Ranging (KBR) system using measurements from multi-satellite missions in response to the requirements of [AD-1]. TIRO TEC product from CHAMP mission and TIRO TEC and Ne from GRACE and GRACE-FO missions.

Current or updated version of this document is available in the SVN folder: https://smart-svn.spacecenter.dk/svn/smart/SwarmDISC/DISC_Projects/ITT3_3_TIRO/Deliverables/.

2 Applicable and Reference Documentation.

2.1 Applicable Documents

The following documents are applicable to the definitions within this document.

[AD-1] SW-OF-GFZ-GS-126_3-3_TIRO, Proposal for Swarm DISC ITT 3.3, Swarm-TIRO – Topside Ionosphere Radio Observations from multiple LEO-missions, https://smart-svn.spacecenter.dk/svn/smart/SwarmDISC/DISC_Projects/ITT3_3_TIRO/Proposal/.

[AD-2] SW-DS-DTU-GS-0001_Product_Specification, Product specification for L2 Products and Auxiliary Products, https://earth.esa.int/documents/10174/1514862/Swarm_L2_Product_Specification.

[AD-3] CDF User's Guide, Version 3.7.1, February 20, 2019, Space Physics Data Facility, NASA / Goddard Space Flight Center, Greenbelt, Maryland 20771 (U.S.A.) available at https://spdf.gsfc.nasa.gov/pub/software/cdf/doc/cdf371/cdf371ug.pdf.

[AD-4] SW-DS-GFZ-GS-012_3-3_TIRO_DPA, Swarm-TIRO Description of the Processing Algorithms.

2.2 Reference Documents

The following documents contain supporting and background information to be taken into account during the activities specified within this document.

[RD-1] Noja, M., Stolle, C., Park, J., Lühr (2013), Long-term analysis of ionospheric polar patches based on CHAMP TEC data, Radio Sci., 48, 289–301, doi: 10.1002/rds.20033.

[RD-2] Yue, X., Schreiner, W. S., Hunt, D. C., Rocken, C., Kuo, Y.-H. (20), Quantitative evaluation of the low Earth orbit satellite based slant total electron content determination, Space Weather, 9, S09001, doi: 10.1029/2011SW000687.

[RD-3] Xiong, C., Park, J., Lühr, H., Stolle, C., Ma, S.Y. (2010), Comparing plasma bubble occurrence rates at CHAMP and GRACE altitudes during high and low solar activity, Ann. Geophys., 28, 1647–1658, doi: 10.5194/angeo-28-1647-2010.

[RD-4] GRACE Level 1B Data Product User Handbook, https://podaac-tools.jpl.nasa.gov/drive/files/allData/grace/docs/Handbook_1B_v1.3.pdf.

2.3 Abbreviations

A list of acronyms and abbreviations used by Swarm partners can be found here. Any acronyms or abbreviations not found on the online list but used in this document can be found below.

Acronym *or abbreviation*	***Description***
CHAMP	CHAllenging Minisatellite Payload
DCB	Differential Code Bias
GPS	Global Positioning System
GRACE	Gravity Recovery and Climate Experiment
GRACE-FO	GRACE Follow-On
Ne	electron density
IRI-2016	International Reference Ionosphere 2016
KBR	K-band Ranging
LEO	Low Earth Orbit
MP	Multipath
RINEX	Receiver Independent Exchange Format
TIRO	Topside Ionosphere Radio Observations from multiple LEO-missions
TMS	time series

3 Product Summary

The Swarm-TIRO [AD-1] product package consists of two independent groups of L2 products for three satellite missions with the following product identifiers:

- CHAMP: **TEC_TMS_2F**;
- GRACE: **TEC1TMS_2F**, **TEC2TMS_2F**, and **NE__KBR_2F**;
- GRACE-FO: **TEC1TMS_2F**, **TEC2TMS_2F**, and **NE__KBR_2F**.

The general information about how to derive TEC and KBR-Ne products from satellite measurements can be found in [RD-1] [RD-3] and [RD-2] [RD-4], respectively.

TEC1TMS_2F and TEC2TMS_2F products from GRACE-FO mission will be delivered on operational bases as daily files. The NE__KBR_2F product from GRACE-FO mission will not be operational products but will be updated regularly. Products form CHAMP and GRACE missions (TEC_TMS_2F, TEC1TMS_2F, TEC2TMS_2F, and NE__KBR_2F) will be delivered as historical data.

The TIRO product name convention below follows the Swarm L2 product name convention and product classification [AD-2]:

- MS_OPER_FFFxDDD_2F_YYYYMMDDThhmmss_YYYYMMDDThhmmss_nnnn.CDF

Here:

- MS = CH, GR, or GF for CHAMP, GRACE and GRACE-FO missions, respectively;
- OPER = routine operations;
- FFF = TEC or NE_;
- x = 1, 2, or _;
- DDD = TMS (time series) or KBR;
- 2 = Level 2;
- F = Fast Track products (the validation is performed by means of an internal quality check in the algorithms of each of these products and these products are released without a validation report [AD-2]);
- YYYYMMDDThhmmss – valid from;
- YYYYMMDDThhmmss – valid to;
- nnnn – file version number, e.g., 0101.
- CDF = Common Data Format [AD-3].

The filename example for TEC product from GRACE-FO (1) mission for the given time will be the following:

- GF_OPER_TEC1TMS_2F_20050505T000000_20050505T235959_0101.CDF

4 Specification of Products

This section contains a detailed description of the Swarm-TIRO product package for each product group separately and for all satellite missions. **TEC** product for **CHAMP**, **GRACE**, and **GRACE-FO** and **Ne** product for **GRACE**, and **GRACE-FO** are described in sections 4.1 and 4.2, respectively.

4.1 Total Electron Content (TEC)

4.1.1 CHAMP

Product identifier	**TEC_TMS_2F**
Definition	Time series of the ionospheric Total Electron Content (TEC) derived for the CHAMP satellite
Input Data	GPS satellite ephemeris (CODwwwwd.EPH) and transmitter biases (CODGddd0.yy): • ftp://ftp.aiub.unibe.ch/CODE CHAMP GPS observation data (CH-OG-1-SST+yyyy_ddd_00_x.v.rnx): • ftp://isdcftp.gfz-potsdam.de/champ/OG/Level1/SST CHAMP satellite position (CH-OG-3-RSO+CTS-CHA_yyyy_ddd_hh.dat): • ftp://isdcftp.gfz-potsdam.de/champ/OG/Level3/RSO
Input Time Span	3 days
Spatial representation	The line of sight from CHAMP to GPS satellites
Time representation	10-s time series for TEC and 1-day for DCB
Units	TECU (10^{16} electrons m^{-2})
Resolution	10^{-8} TECU[1]
Uncertainty	< 3 TECU (for absolute slant TEC): code leveling error < 0.97 TECU (95% quantile) and DCB error < 2.06 TECU (95% quantile)
Quality indicator	Relative_STEC_RMS[2] and DCB_Error (see output data variable)
Data volume	Up to 7 MB per day
Data format	CDF

Output Data

Variable Name	Type	Dim	Unit	Description
Timestamp	CDF_EPOCH	1	ms	Time of observation, UTC
Latitude	CDF_DOUBLE	1	deg	CHAMP position in ITRF – Geocentric latitude
Longitude	CDF_DOUBLE	1	deg	CHAMP position in ITRF – Geocentric longitude
Radius	CDF_DOUBLE	1	m	CHAMP position in ITRF – Geocentric radius (from the Earth centre)
GPS_Position	CDF_DOUBLE	3	m	X-, Y-, Z-coordinates of the GPS satellite
LEO_Position	CDF_DOUBLE	3	m	X-, Y-, Z-coordinates of the CHAMP satellite

Product identifier	TEC_TMS_2F				
	PRN	CDF_UINT2	1	-	Pseudorandom noise (PRN) code of GPS satellite
	L1	CDF_DOUBLE	1	m	GPS L1C (L1 in RINEX v.2.10) carrier phase observation
	L2	CDF_DOUBLE	1	m	GPS L2W (L2 in RINEX v.2.10) carrier phase observation
	P1	CDF_DOUBLE	1	m	GPS C1W (P1 in RINEX v.2.10) code phase observation
	P2	CDF_DOUBLE	1	m	GPS C2W (P2 in RINEX v.2.10) code phase observation
	S1_C_N0	CDF_DOUBLE	1	dB-Hz	GPS S1 carrier-to-noise density C/N0 [AD-4] (Sect. 3.1.2.2)
	S2_C_N0	CDF_DOUBLE	1	dB-Hz	GPS S2 carrier-to-noise density C/N0 [AD-4] (Sect. 3.1.2.2)
	Absolute_STEC	CDF_DOUBLE	1	TECU	Absolute slant TEC
	Absolute_VTEC	CDF_DOUBLE	1	TECU	Absolute vertical TEC
	Elevation_Angle	CDF_DOUBLE	1	deg	Elevation angle
	Relative_STEC	CDF_DOUBLE	1	TECU	Relative slant TEC
	Relative_STEC_RMS	CDF_DOUBLE	1	TECU	Root mean square of relative slant TEC[2]
	DCB	CDF_DOUBLE	1	TECU	GPS receiver differential code bias (DCB[3]) (P2–P1)
	DCB_Error	CDF_DOUBLE	1	TECU	Post fit RMS of the least square system using pairs of mapped slant TEC
Output time span	1 day				
Update rate	N/A (historical data set)				
Latency	< 5 minutes				
Notes	[1] This is a digital resolution; the precision is worse than 0.01 TECU. [2] To estimate the accuracy of the relative slant TEC, the RMS between relative slant TEC from (a) code-phase, P2-P1, and (b) cycle slip corrected and code levelled, L1-L2,				

Product identifier	TEC_TMS_2F
	observations are calculated for each arc of continuous tracking of a single GPS satellite. The RMS value of each arc is then assigned to all GPS observations of that arc. [3] DCB is assumed to be constant during a single day.

4.1.2 GRACE

Product identifier	TECxTMS_2F
Definition	Time series of the ionospheric Total Electron Content (TEC) derived for GRACE 1 and 2 satellites
Input Data	GPS satellite ephemeris (CODwwwwd.EPH) and transmitter biases (CODGddd0.yy): • ftp://ftp.aiub.unibe.ch/CODE GRACE A and B GPS observation data (GPS1B_yyyy-mm-dd_n_02.rnx): • ftp://isdcftp.gfz-potsdam.de/grace/Level-1B/JPL/INSTRUMENT/RL02/ GRACE A and B satellite positions (GNV1B_yyyy-mm-dd_n_02.dat): • ftp://isdcftp.gfz-potsdam.de/grace/Level-1B/JPL/INSTRUMENT/RL02/
Input Time Span	3 days
Spatial representation	The line of sight from GRACE to GPS satellites
Time representation	10-s time series for TEC and 1-day for DCB
Units	TECU (10^{16} electrons m^{-2})
Resolution	10^{-8} TECU[1]
Uncertainty	< 3 TECU (for absolute slant TEC): code leveling error < 0.97 TECU (95% quantile) and DCB error < 2.06 TECU (95% quantile)
Quality indicator	Relative_STEC_RMS[2] and DCB_Error (see output data variable)
Data volume	Up to 7 MB per day and per satellite
Data format	CDF

Output Data

Variable Name	Type	Dim	Unit	Description
Timestamp	CDF_EPOCH	1	ms	Time of observation, UTC
Latitude	CDF_DOUBLE	1	deg	GRACE position in ITRF – Geocentric latitude
Longitude	CDF_DOUBLE	1	deg	GRACE position in ITRF – Geocentric longitude
Radius	CDF_DOUBLE	1	m	GRACE position in ITRF – Geocentric radius (from the Earth centre)
GPS_Position	CDF_DOUBLE	3	m	X-, Y-, Z-coordinates of the GPS satellite
LEO_Position	CDF_DOUBLE	3	m	X-, Y-, Z-coordinates of the GRACE satellite

<table>
<tr><td>Product identifier</td><td colspan="5">TECxTMS_2F</td></tr>
<tr><td></td><td colspan="5"><table>
<tr><td>PRN</td><td>CDF_UINT2</td><td>1</td><td>-</td><td>Pseudorandom noise (PRN) code of GPS satellite</td></tr>
<tr><td>L1</td><td>CDF_DOUBLE</td><td>1</td><td>m</td><td>GPS L1C (LA in RINEX v.2.20) carrier phase observation</td></tr>
<tr><td>L2</td><td>CDF_DOUBLE</td><td>1</td><td>m</td><td>GPS L2W (L2 in RINEX v.2.20) carrier phase observation</td></tr>
<tr><td>P1</td><td>CDF_DOUBLE</td><td>1</td><td>m</td><td>GPS C1W (P1 in RINEX v.2.20) code phase observation</td></tr>
<tr><td>P2</td><td>CDF_DOUBLE</td><td>1</td><td>m</td><td>GPS C2W (P2 in RINEX v.2.20) code phase observation</td></tr>
<tr><td>S1_C_N0</td><td>CDF_DOUBLE</td><td>1</td><td>dB-Hz</td><td>GPS S1 carrier-to-noise density C/N0 [AD-4] (Sect. 3.1.2.2)</td></tr>
<tr><td>S2_C_N0</td><td>CDF_DOUBLE</td><td>1</td><td>dB-Hz</td><td>GPS S2 carrier-to-noise density C/N0 [AD-4] (Sect. 3.1.2.2)</td></tr>
<tr><td>Absolute_STEC</td><td>CDF_DOUBLE</td><td>1</td><td>TECU</td><td>Absolute slant TEC</td></tr>
<tr><td>Absolute_VTEC</td><td>CDF_DOUBLE</td><td>1</td><td>TECU</td><td>Absolute vertical TEC</td></tr>
<tr><td>Elevation_Angle</td><td>CDF_DOUBLE</td><td>1</td><td>deg</td><td>Elevation angle</td></tr>
<tr><td>Relative_STEC</td><td>CDF_DOUBLE</td><td>1</td><td>TECU</td><td>Relative slant TEC</td></tr>
<tr><td>Relative_STEC_RMS</td><td>CDF_DOUBLE</td><td>1</td><td>TECU</td><td>Root mean square of relative slant TEC[2]</td></tr>
<tr><td>DCB</td><td>CDF_DOUBLE</td><td>1</td><td>TECU</td><td>GPS receiver differential code bias (DCB[3]) (P2–P1)</td></tr>
<tr><td>DCB_Error</td><td>CDF_DOUBLE</td><td>1</td><td>TECU</td><td>Post fit RMS of the least square system using pairs of mapped slant TEC</td></tr>
</table></td></tr>
<tr><td>Output time span</td><td colspan="5">1 day</td></tr>
<tr><td>Update rate</td><td colspan="5">N/A (historical data set)</td></tr>
<tr><td>Latency</td><td colspan="5">< 5 minutes</td></tr>
<tr><td>Notes</td><td colspan="5">[1] This is a digital resolution; the precision is worse than 0.01 TECU.

[2] To estimate the accuracy of the relative slant TEC, the RMS between relative slant TEC from
(a) code-phase, P2-P1, and
(b) cycle slip corrected and code levelled, L1-L2,</td></tr>
</table>

Product identifier	TECxTMS_2F
	observations are calculated for each arc of continuous tracking of a single GPS satellite. The RMS value of each arc is then assigned to all GPS observations of that arc. [3] DCB is assumed to be constant during a single day.

4.1.3 GRACE-FO

Product identifier	TECxTMS_2F
Definition	Time series of the ionospheric Total Electron Content (TEC) derived for GRACE-FO 1 and 2 satellites
Input Data	GPS satellite ephemeris (CODwwwwd.EPH) and transmitter biases (CODGddd0.yy): • ftp://ftp.aiub.unibe.ch/CODE GRACE-FO C and D GPS observation data (GPS1B_yyyy-mm-dd_n_04.rnx): • ftp://isdcftp.gfz-potsdam.de/grace-fo/Level-1B/JPL/INSTRUMENT/RL04/ GRACE-FO C and D satellite positions (GNV1B_yyyy-mm-dd_n_04.dat): • ftp://isdcftp.gfz-potsdam.de/grace-fo/Level-1B/JPL/INSTRUMENT/RL04/
Input Time Span	3 days
Spatial representation	The line of sight from GRACE-FO to GPS satellites
Time representation	10-s time series for TEC and 1-day for DCB
Units	TECU (10^{16} electrons m^{-2})
Resolution	10^{-8} TECU[1]
Uncertainty	< 3 TECU (for absolute slant TEC): code leveling error < 0.97 TECU (95% quantile) and DCB error < 2.06 TECU (95% quantile)
Quality indicator	Relative_STEC_RMS[2] and DCB_Error (see output data variable)
Data volume	Up to 7 MB per day and per satellite
Data format	CDF

Output Data

Variable Name	Type	Dim	Unit	Description
Timestamp	CDF_EPOCH	1	ms	Time of observation, UTC
Latitude	CDF_DOUBLE	1	deg	GRACE-FO position in ITRF – Geocentric latitude
Longitude	CDF_DOUBLE	1	deg	GRACE-FO position in ITRF – Geocentric longitude
Radius	CDF_DOUBLE	1	m	GRACE-FO position in ITRF – Geocentric radius (from the Earth centre)
GPS_Position	CDF_DOUBLE	3	m	X-, Y-, Z-coordinates of the GPS satellite
LEO_Position	CDF_DOUBLE	3	m	X-, Y-, Z-coordinates of the GRACE-FO satellite

<table>
<tr><td>Product identifier</td><td colspan="5">TECxTMS_2F</td></tr>
<tr><td></td><td colspan="5"><table>
<tr><td>PRN</td><td>CDF_UINT2</td><td>1</td><td>N/A</td><td>Pseudorandom noise (PRN) code of GPS satellite</td></tr>
<tr><td>L1</td><td>CDF_DOUBLE</td><td>1</td><td>m</td><td>GPS L1C (LA in RINEX v.2.20) carrier phase observation</td></tr>
<tr><td>L2</td><td>CDF_DOUBLE</td><td>1</td><td>m</td><td>GPS L2W (L2 in RINEX v.2.20) carrier phase observation</td></tr>
<tr><td>P1</td><td>CDF_DOUBLE</td><td>1</td><td>m</td><td>GPS C1W (P1 in RINEX v.2.20) code phase observation</td></tr>
<tr><td>P2</td><td>CDF_DOUBLE</td><td>1</td><td>m</td><td>GPS C2W (P2 in RINEX v.2.20) code phase observation</td></tr>
<tr><td>S1_C_N0</td><td>CDF_DOUBLE</td><td>1</td><td>dB-Hz</td><td>GPS S1 carrier-to-noise density C/N0 [AD-4] (Sect. 3.1.2.2)</td></tr>
<tr><td>S2_C_N0</td><td>CDF_DOUBLE</td><td>1</td><td>dB-Hz</td><td>GPS S2 carrier-to-noise density C/N0 [AD-4] (Sect. 3.1.2.2)</td></tr>
<tr><td>Absolute_STEC</td><td>CDF_DOUBLE</td><td>1</td><td>TECU</td><td>Absolute slant TEC</td></tr>
<tr><td>Absolute_VTEC</td><td>CDF_DOUBLE</td><td>1</td><td>TECU</td><td>Absolute vertical TEC</td></tr>
<tr><td>Elevation_Angle</td><td>CDF_DOUBLE</td><td>1</td><td>deg</td><td>Elevation angle</td></tr>
<tr><td>Relative_STEC</td><td>CDF_DOUBLE</td><td>1</td><td>TECU</td><td>Relative slant TEC</td></tr>
<tr><td>Relative_STEC_RMS</td><td>CDF_DOUBLE</td><td>1</td><td>TECU</td><td>Root mean square of relative slant TEC[2]</td></tr>
<tr><td>DCB</td><td>CDF_DOUBLE</td><td>1</td><td>TECU</td><td>GPS receiver differential code bias (DCB[3]) (P2–P1)</td></tr>
<tr><td>DCB_Error</td><td>CDF_DOUBLE</td><td>1</td><td>TECU</td><td>Post fit RMS of the least square system using pairs of mapped slant TEC</td></tr>
</table></td></tr>
<tr><td>Output time span</td><td colspan="5">1 day</td></tr>
<tr><td>Update rate</td><td colspan="5">Daily</td></tr>
<tr><td>Latency</td><td colspan="5">< 5 minutes</td></tr>
<tr><td>Notes</td><td colspan="5">[1] This is a digital resolution; the precision is worse than 0.01 TECU.

[2] To estimate the accuracy of the relative slant TEC, the RMS between relative slant TEC from
(a) code-phase, P2-P1, and
(b) cycle slip corrected and code levelled, L1-L2,</td></tr>
</table>

Product identifier	TECxTMS_2F
	observations are calculated for each arc of continuous tracking of a single GPS satellite. The RMS value of each arc is then assigned to all GPS observations of that arc. [3] DCB is assumed to be constant during a single day.

4.2 Electron Density (Ne)

4.2.1 GRACE

Product identifier	NE__KBR_2F
Definition	Time series of the averaged electron density (Ne) between GRACE 1 and 2 satellites
Input Data	GRACE 1 and 2 satellite positions (GNV1B) and ionospheric range correction between GRACE 1 and 2 satellites (KBR1B): • ftp://isdcftp.gfz-potsdam.de/grace/Level-1B/JPL/INSTRUMENT/RL03/
Input Time Span	1 day[1]
Spatial representation	The middle point of line of sight between GRACE 1 and 2 satellites
Time representation	5-s time series
Units	m^{-3}
Resolution	10^{-4} m^{-3} (this is a digital resolution; the precision is worse than 10^{7} m^{-3})
Uncertainty	Better than 1.5 10^{7} m^{-3} for relative Ne and 8.5 10^{10} m^{-3} for absolute Ne
Quality indicator	Magnitude of Absolute_Ne is calibrated against IRI-2016 model data. If Absolute_Ne = NaN then no calibration is performed.
Data volume	Up to 2 MB per day and per satellite
Data format	CDF
Output Data	

Variable Name	Type	Dim	Unit	Description
Timestamp	CDF_EPOCH	1	ms	Time of observation, UTC
Latitude	CDF_DOUBLE	1	deg	Middle point position between GRACE 1 and 2 satellites in ITRF – Geocentric latitude
Longitude	CDF_DOUBLE	1	deg	Middle point position between GRACE 1 and 2 satellites in ITRF – Geocentric longitude
Radius	CDF_DOUBLE	1	m	Middle point position between GRACE 1 and 2 satellites in ITRF – Geocentric radius (from the Earth centre)
LEO_Position	CDF_DOUBLE	2x3	m	X-, Y-, Z-coordinates of the GRACE 1 and 2 satellites

Product identifier	NE__KBR_2F				
	Distance	CDF_DOUBLE	1	m	Distance between GRACE 1 and 2 satellites
	Relative_Hor_ TEC	CDF_DOUBLE	1	TECU	Relative horizontal TEC between GRACE 1 and 2 satellites
	Relative_Ne[2]	CDF_DOUBLE	1	m^{-3}	Mean relative electron density of the area between GRACE 1 and 2 satellites
	Absolute_Ne	CDF_DOUBLE	1	m^{-3}	Electron density between GRACE 1 and 2 satellites
Output time span	1 day				
Update rate	N/A (historical data set)				
Latency	> 5 minutes (strongly depends on the arc length)[1]				
Notes	[1] The peculiarity of the processing is the handling of daily available data which are organized in arcs that can have a length of several minutes up to months. The information about the arc length is unknown at the beginning of the arc and full arcs are required to ensure consistent levelling. Thus, it is necessary to collect data until the current arc is completed, which can take up to a few months. [2] The electron density arcs are shifted by levelling the minimum value of this arc to zero (the first value of each arc is zero).				

4.2.2 GRACE-FO

Product identifier	NE__KBR_2F
Definition	Time series of the averaged electron density (Ne) between GRACE-FO 1 and 2 satellites
Input Data	GRACE-FO 1 and 2 satellites positions (GNV1B) and ionospheric range correction between GRACE-FO 1 and 2 satellites (KBR1B): • ftp://isdcftp.gfz-potsdam.de/grace-fo/Level-1B/JPL/INSTRUMENT/RL04/
Input Time Span	1 day[1]
Spatial representation	The middle point of line of sight between GRACE-FO 1 and 2 satellites
Time representation	5-s time series
Units	m^{-3}
Resolution	10^{-4} m^{-3} (this is a digital resolution; the precision is worse than 10^{7} m^{-3})
Uncertainty	Better than 1.5 10^{7} m^{-3} for relative Ne and 8.5 10^{10} m^{-3} for absolute Ne
Quality indicator	Magnitude of Absolute_Ne is calibrated against IRI-2016 model data. If Absolute_Ne = NaN then no calibration is performed.
Data volume	Up to 2 MB per day and per satellite
Data format	CDF

<table>
<tr><td>Product identifier</td><td>NE__KBR_2F</td></tr>
<tr><td>Output Data</td><td>
<table>
<tr><th>Variable Name</th><th>Type</th><th>Dim</th><th>Unit</th><th>Description</th></tr>
<tr><td>Timestamp</td><td>CDF_EPOCH</td><td>1</td><td>ms</td><td>Time of observation, UTC</td></tr>
<tr><td>Latitude</td><td>CDF_DOUBLE</td><td>1</td><td>deg</td><td>Middle point position be-tween GRACE-FO 1 and 2 satellites in ITRF – Geocentric latitude</td></tr>
<tr><td>Longitude</td><td>CDF_DOUBLE</td><td>1</td><td>deg</td><td>Middle point position be-tween GRACE-FO 1 and 2 satellites in ITRF – Geocentric longitude</td></tr>
<tr><td>Radius</td><td>CDF_DOUBLE</td><td>1</td><td>m</td><td>Middle point position be-tween GRACE-FO 1 and 2 satellites in ITRF – Geocentric radius (from the Earth centre)</td></tr>
<tr><td>LEO_Position</td><td>CDF_DOUBLE</td><td>2x3</td><td>m</td><td>X-, Y-, Z-coordinates of the GRACE-FO 1 and 2 satellites</td></tr>
<tr><td>Distance</td><td>CDF_DOUBLE</td><td>1</td><td>m</td><td>Distance between GRACE-FO 1 and 2 satellites</td></tr>
<tr><td>Relative_Hor_ TEC</td><td>CDF_DOUBLE</td><td>1</td><td>TECU</td><td>Relative horizontal TEC between GRACE-FO 1 and 2 satellites</td></tr>
<tr><td>Relative_Ne[2]</td><td>CDF_DOUBLE</td><td>1</td><td>m^{-3}</td><td>Mean relative electron density of the area between GRACE-FO 1 and 2 satellites</td></tr>
<tr><td>Absolute_Ne</td><td>CDF_DOUBLE</td><td>1</td><td>m^{-3}</td><td>Electron density between GRACE-FO 1 and 2 satellites</td></tr>
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<tr><td>Output time span</td><td>1 day</td></tr>
<tr><td>Update rate</td><td>Up to several months[1]</td></tr>
<tr><td>Latency</td><td>> 5 minutes (strongly depends on the arc length)[1]</td></tr>
<tr><td>Notes</td><td>[1] The peculiarity of the processing is the handling of daily available data which are organized in arcs that can have a length of several minutes up to months. The information about the arc length is unknown at the beginning of the arc and full arcs are required to ensure consistent levelling. Thus, it is necessary to collect data until the current arc is completed, which can take up to a few months.
[2] The electron density arcs are shifted by levelling the minimum value of this arc to zero.</td></tr>
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