

Data, Innovation, and Science Cluster

TOLEOS

Product Definition Document

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Record of Changes

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1 Introduction

1.1 Scope

This document defines the contents and the format of the data products that are produced within the TOLEOS project in agreement with the requirements specified in [AD-1].

2 Applicable and Reference Documentation

2.1 Applicable Documents

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

- [AD-1] TOLEOS – Thermosphere Observations from Low-Earth Orbiting Satellites. Proposal for Swarm DISC ITT 4.3, SW-OF-DUT-GS-129, Revision 1
- [AD-2] Product specification for L2 Products and Auxiliary Products. Swarm Level 2 Processing System, SW-DS-DTU-GS-0001, Revision 2Y
- [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>

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] Doornbos, E. (2011) Thermosphere density and wind determination from satellite dynamics. Dissertation, Delft University of Technology. <http://resolver.tudelft.nl/uuid:33002be1-1498-4bec-a440-4c90ec149aea>
- [RD-2] Montenbruck, O., Gill, E. (2012) Satellite orbits – Models, Methods Applications (1st ed.). Springer. <http://doi.org/10.1007/978-3-642-58351-3>

2.3 Abbreviations

The following list defines the acronyms used within this document.

Acronym	Description
CDF	Common Data Format
CHAMP	Challenging Mini-satellite Payload
GOCE	Gravity field and Ocean Circulation Explorer
GRACE	Gravity Recovery and Climate Experiment
GRACE-FO	Gravity Recovery and Climate Experiment Follow-On
GRS80	Geodetic Reference System 1980
LTAN	Local Time of the Ascending Node

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<i>Acronym</i>	<i>Description</i>
N/A	Not Applicable
NED	North-East-Down
POD	Precise Orbit Determination
TOLEOS	Thermosphere Observations from Low-Earth Orbiting Satellites
UTC	Coordinated Universal Time
XML	Extensible Markup Language

3 Structure of the data products

The data products are provided as CDF files that mimic the already existing density data products of the Swarm mission (DNSxACC and DNSxPOD files), which are specified in [AD-2]. The density data products of the TOLEOS project are compatible in the sense that they contain the same variables as in the already existing Swarm density data product. Further, they contain additional variables as described in Section 4.

4 Specification of data products

4.1 File naming convention

The file naming convention follows closely the Swarm file naming convention. Files are named according to

`MS_TYPE_OBSxSRC_2__YYYYMMDDThhmmss_YYYYMMDDThhmmss_bbv.cdf`

where the parts of the file name are defined in [Table 4-1](#). It should be noted that the conjunction data product is not specific to a single mission, which is signified by using the letters “MM” for multi-mission.

Table 4-1: File naming convention

Part of filename	Explanation
MS	Mission <ul style="list-style-type: none"> • CH = CHAMP • GR = GRACE • GF = GRACE-FO • MM = multi-mission
TYPE	Type of processing <ul style="list-style-type: none"> • OPER = routine processing
OBS	Observation type <ul style="list-style-type: none"> • DNS = density • WND = crosswind • CON = conjunction
x	Satellite <ul style="list-style-type: none"> • CHAMP: _ (underscore) • GRACE: 1 or 2 (first or second satellite) • GRACE-FO: 1 or 2 (first or second satellite)
SRC	Source <ul style="list-style-type: none"> • ACC = accelerometer • EPH = satellite ephemeris
YYYYMMDDThhmmss	Start and end date and time of the period covered by the data product

Part of filename	Explanation
bb	Processing baseline (indicating a significant upgrade of the data product)
vv	File version (indicating a minor update of the data product)

4.2 Data products

Three kinds of data products will be produced during the TOLEOS project, namely thermosphere mass density, crosswind, and conjunction data products. The former two will be provided as daily data products, whereas the third will be provided as monthly data product.

In contrast to density observations, it will not always be possible to derive meaningful crosswind observations because the latter requires a significantly larger aerodynamic acceleration signal. Thus, the daily density data products will not all be paired with a matching crosswind data product.

4.2.1 Density data product

Product identifier	DNSxACC_2
Definition	Thermosphere mass density at the satellite location
Input Data	Calibrated accelerometer measurements, satellite aerodynamic and radiation pressure models, thermosphere models (temperature and composition, in-track wind), radiation flux data, satellite position and velocity, Earth orientation parameters, satellite mass, satellite inertial attitude
Input Time Span	1 day
Spatial representation	Time-series along satellite orbit
Time representation	UTC time
Units	See output data
Resolution	10–30 s time step (depending on the mission), equivalent to 76–228 km along the orbit
Uncertainty	30% of variance of orbit average of mass density or $5 \times 10^{-14} \text{ kg/m}^3$, whichever value is largest
Quality indicator	Quality flag (see output data)
Data volume	Few MB per day per satellite
Data format	CDF
Output Data	

Product identifier	DNSxACC_2																																																						
	<table border="1"> <thead> <tr> <th>Field name</th> <th>Type</th> <th>Dimension</th> <th>Unit</th> <th>Contents</th> </tr> </thead> <tbody> <tr> <td>time</td> <td>CDF_EPOCH</td> <td>1</td> <td>ms</td> <td>Observation time (UTC)</td> </tr> <tr> <td>altitude</td> <td>CDF_REAL8</td> <td>1</td> <td>m</td> <td>Observation altitude (GRS80)</td> </tr> <tr> <td>latitude</td> <td>CDF_REAL8</td> <td>1</td> <td>deg</td> <td>Observation geodetic latitude</td> </tr> <tr> <td>longitude</td> <td>CDF_REAL8</td> <td>1</td> <td>deg</td> <td>Observation longitude</td> </tr> <tr> <td>local_solar_time</td> <td>CDF_REAL8</td> <td>1</td> <td>h</td> <td>Local solar time</td> </tr> <tr> <td>density</td> <td>CDF_REAL8</td> <td>1</td> <td>kg/m³</td> <td>Mass density</td> </tr> <tr> <td>density_orbitmean</td> <td>CDF_REAL8</td> <td>1</td> <td>kg/m³</td> <td>Orbit average of mass density (implemented as moving average)</td> </tr> <tr> <td>validity_flag</td> <td>CDF_INT1</td> <td>1</td> <td>-</td> <td>0 = nominal data 1 = anomalous data</td> </tr> <tr> <td>validity_flag_orbitmean</td> <td>CDF_INT1</td> <td>1</td> <td>-</td> <td>0 = nominal data 1 = anomalous data</td> </tr> </tbody> </table>					Field name	Type	Dimension	Unit	Contents	time	CDF_EPOCH	1	ms	Observation time (UTC)	altitude	CDF_REAL8	1	m	Observation altitude (GRS80)	latitude	CDF_REAL8	1	deg	Observation geodetic latitude	longitude	CDF_REAL8	1	deg	Observation longitude	local_solar_time	CDF_REAL8	1	h	Local solar time	density	CDF_REAL8	1	kg/m ³	Mass density	density_orbitmean	CDF_REAL8	1	kg/m ³	Orbit average of mass density (implemented as moving average)	validity_flag	CDF_INT1	1	-	0 = nominal data 1 = anomalous data	validity_flag_orbitmean	CDF_INT1	1	-	0 = nominal data 1 = anomalous data
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Notes	The latency for Level 1A and Level 1B GRACE-FO data is 3-4 weeks, which includes a precise orbit needed for the calibration of the accelerometer measurements.																																																						

4.2.2 Crosswind data product

Product identifier	WNDxACC_2
Definition	Thermosphere crosswind at the satellite location
Input Data	Calibrated accelerometer measurements, satellite aerodynamic and radiation pressure models, thermosphere models (temperature and composition, in-track wind), radiation flux data, satellite position and velocity, Earth orientation parameters, satellite mass, satellite inertial attitude
Input Time Span	1 day

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Product identifier	WNDxACC_2																																																	
Spatial representation	Time-series along satellite orbit																																																	
Time representation	UTC time																																																	
Units	See output data																																																	
Resolution	10–30 s time step (depending on the mission), equivalent to 76–228 km along the orbit																																																	
Uncertainty	N/A (the signal-to-noise ratio is so variable that a simple uncertainty quantification is not appropriate)																																																	
Quality indicator	Quality flag (see output data)																																																	
Data volume	Few MB per day per satellite																																																	
Data format	CDF																																																	
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validity_flag	CDF_INT1	1	-	0 = nominal data 1 = anomalous data																																														

Product identifier	WNDxACC_2
Output time span	1 day
Update rate	3 months
Latency	2 months, see notes
Notes	<ol style="list-style-type: none"> 1. The latency for Level 1A and Level 1B GRACE-FO data is 3-4 weeks, which includes a precise orbit needed for the calibration of the accelerometer measurements. 2. The availability of crosswind observations depends on the magnitude of the aerodynamic acceleration signal, which may not always be sufficiently large.

4.2.3 Conjunction data product

Product identifier	CON_EPH_2															
Definition	Conjunction information															
Input Data	Satellite ephemeris (satellite position over time), Earth orientation parameters															
Input Time Span	One month															
Spatial representation	Location and time of crossovers, time of orbital plane alignments															
Time representation	UTC time															
Units	See output data															
Resolution	N/A															
Uncertainty	N/A															
Quality indicator	N/A															
Data volume	Few MB (full mission, all satellites)															
Data format	CDF															
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<i>Field name</i>	<i>Type</i>	<i>Dimension</i>	<i>Unit</i>	<i>Contents</i>												
crossover_times	CDF_EPOCH	2	ms	Crossover times of the satellites (UTC)												
crossover_time_difference	CDF_REAL8	1	s	Time between the first and second satellite passing over the same location												

Product identifier	CON_EPH_2				
	crossover_satellites	CDF_UINT4	2	-	IDs of the satellites, see note 2
	crossover_altitudes	CDF_REAL8	2	m	Altitudes of the satellites at crossover (GRS80)
	crossover_latitude	CDF_REAL8	1	deg	Geodetic latitude of crossover
	crossover_longitude	CDF_REAL8	1	deg	Longitude of crossover
	crossover_magnetic_latitude	CDF_REAL8	1	deg	Magnetic latitude of crossover
	crossover_magnetic_longitude	CDF_REAL8	1	deg	Magnetic longitude of crossover
	crossover_local_solar_times	CDF_REAL8	2	h	Local solar times of the satellites at crossover
	plane_alignment_time	CDF_EPOCH	1	ms	Time of orbital plane alignment (UTC)
	plane_alignment_satellites	CDF_UINT4	2	-	IDs of the satellites, see note 2
	plane_alignment_ltan	CDF_REAL8	2	h	LTAN of the satellites
	plane_alignment_altitudes	CDF_REAL8	2	m	Altitudes of the satellites (GRS80)
	plane_alignment_ltan_rates	CDF_REAL8	2	h/d	LTAN drift rates of the satellites
Output time span	One month				
Update rate	3 months				
Latency	2 months, see note 3				
Notes	1. The product reports only crossovers, for which two satellites pass over the same location (defined by geodetic latitude and longitude) within a short time, which is reported in the global attribute "MAX_CROSSOVER_TIME_DIFFERENCE" in				

Product identifier	CON_EPH_2										
	<p>seconds. At the time of writing, we consider 6 hours, but this may change in the future depending on user feedback.</p> <p>2. Satellite IDs identify the satellites as follows:</p> <table border="1" data-bbox="571 573 1386 822"> <tbody> <tr> <td data-bbox="571 573 874 622">1, 2, 3</td> <td data-bbox="874 573 1386 622">Swarm A, B, and C</td> </tr> <tr> <td data-bbox="571 622 874 672">4</td> <td data-bbox="874 622 1386 672">CHAMP</td> </tr> <tr> <td data-bbox="571 672 874 721">5</td> <td data-bbox="874 672 1386 721">GOCE</td> </tr> <tr> <td data-bbox="571 721 874 770">6, 7</td> <td data-bbox="874 721 1386 770">GRACE 1 and 2</td> </tr> <tr> <td data-bbox="571 770 874 822">8, 9</td> <td data-bbox="874 770 1386 822">GRACE-FO 1 and 2</td> </tr> </tbody> </table> <p>3. The latency for Level 1A and Level 1B GRACE-FO data is 3-4 weeks, which includes a precise orbit needed for finding conjunctions. The latency of the medium-accuracy orbit for the Swarm mission is 3 days.</p> <p>4. The orbital plane alignments of GR1/GR2 and GF1/GF2 are not reported because the satellites fly in the same orbit, separated by about 200 km.</p> <p>5. Orbital plane alignments occur when the LTAN of the satellite' orbits are identical (co-rotation) or offset by 12 hours (counter-rotation).</p>	1, 2, 3	Swarm A, B, and C	4	CHAMP	5	GOCE	6, 7	GRACE 1 and 2	8, 9	GRACE-FO 1 and 2
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