

# Release Notes for GFZ GRACE-FO Level-2 Products - version RL06

Last update: 18.08.2021

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## General Remarks:

- A GFZ GRACE-FO RL06 time series is being routinely processed and is currently available at the two GRACE archives GFZ/ISDC (Information System and Data Centre) and JPL/PO.DAAC (Physical Oceanography Distributed Active Archive Center) for the period from June 2018 through June 2021.
- GRACE-FO RL06 is the initial release of GRACE-FO Level-2 products indicating consistency and continuity with the current GRACE RL06 time series.
- Details on modifications w.r.t. GFZ GRACE RL06 [1] can be found in the GFZ GRACE-FO Level-2 Processing Standards Document for Level-2 Product Release 06 [2] which is also available at the GRACE archives.
- The GRACE-FO RL06 Level-2 filename convention is the same as for GRACE RL06, except for the “mission”-string which is changed from “GRAC” to “GRFO” (see GRACE-FO Level-2 Gravity Field Product User Handbook [3]).
- As for GRACE RL06, a linear mean pole is used during GRACE-FO RL06 Level-2 processing that negates the need for the correction of the  $C_{21}$  and  $S_{21}$  coefficients recommended by Wahr et al. (2015) [4], which was applicable for GRACE RL05 solutions.
- The following two versions of GFZ GRACE-FO RL06 monthly solutions are provided: (1) up to degree/order 60 and (2) up to degree/order 96 (in case of sufficient satellite ground track coverage).
- The uncertainties of the spherical harmonic coefficients provided with the GFZ GRACE-FO RL06 gravity field solutions have not been calibrated and represent the formal errors.

## User Recommendations & Requests:

- **Geocenter:** Consistent with GRACE, GRACE-FO is not sensitive to degree 1 harmonics (geocenter). GRACE/GRACE-FO Technical Note TN-13 [5] contains geocenter estimates using the methods of Swenson et al. (2008) [6] and Sun et al. (2016) [7], and is updated in synch with Level-2 monthly releases. These have been reprocessed for the entire GRACE and GRACE-FO time span to be consistent with the below-mentioned TN-14, so users need to replace the entire TN-13 time series. It is recommended to augment the GRACE and GRACE-FO geocenter with this product for surface mass change estimation.
- **$C_{20}$  coefficient:** Consistent with the GRACE SDS recommendations, GRACE-FO SDS recommends the replacement of the native GRACE-FO  $C_{20}$  coefficient with that from SLR. Note that GRACE Technical Note TN-11 will no longer be updated; it is replaced by GRACE/GRACE-FO Technical Note TN-14 [8] and contains both  $C_{20}$  and  $C_{30}$  estimates derived from SLR using

Level-2 RL06 standards. TN-14 is updated in synch with Level-2 monthly releases. It is recommended to replace the native GRACE and GRACE-FO  $C_{20}$  coefficients with this product for all months (April 2002 – current) [9].

- **$C_{30}$  coefficient:** The GRACE-FO SDS has determined that the  $C_{30}$  coefficient in GRACE-FO shows comparatively more variability relative to the long-term climatology derived from the GRACE  $C_{30}$  coefficient. Therefore, SDS recommends that users assess the impact on regional mass budgets of substituting the GRACE-FO  $C_{30}$  coefficient with one derived from SLR (similar to the  $C_{20}$  approach). It is recommended to replace the native GRACE and GRACE-FO  $C_{30}$  coefficients with the aforementioned Technical Note TN-14 [8] from August 2016 onwards (August 2016 – current) [10].
- **Feedback Request:** The GRACE-FO project SDS is looking for feedback from the Science Team and wider community on the impact of  $C_{20}$  and  $C_{30}$  replacements, either from these or other candidate SLR time series, on regional mass balances to support the project in further improving the handling of low-degree harmonics in GRACE and GRACE-FO data processing.

### Products:

There are usually 6 Level-2 product files available for each month where **YYYY** corresponds to a 4-digit year and **DDD** corresponds to a 3-digit day of year (for details regarding the product names see the GRACE-FO Level-2 Gravity Field Product User Handbook [3]):

#### **GSM-2\_YYYYDDD-YYYYDDD\_GRFO\_GFZOP\_BA01\_0600**

Unconstrained monthly gravity field solution estimated up to degree/order 60.

#### **GSM-2\_YYYYDDD-YYYYDDD\_GRFO\_GFZOP\_BB01\_0600**

Unconstrained monthly gravity field solution estimated up to degree/order 96.

*Note that for months with short-period repeat orbits, this solution might not always be published.*

#### **GAA-2\_YYYYDDD-YYYYDDD\_GRFO\_GFZOP\_BC01\_0600**

The average of the “atm” coefficients from the AOD1B RL06 product up to degree/order 180 over the same time span as the GSM products.

#### **GAB-2\_YYYYDDD-YYYYDDD\_GRFO\_GFZOP\_BC01\_0600**

The average of the “ocn” coefficients from the AOD1B RL06 product up to degree/order 180 over the same time span as the GSM products.

#### **GAC-2\_YYYYDDD-YYYYDDD\_GRFO\_GFZOP\_BC01\_0600**

The average of the “glo” coefficients from the AOD1B RL06 product up to degree/order 180 over the same time span as the GSM products; these harmonic coefficients are used as background model during Level-2 processing.

#### **GAD-2\_YYYYDDD-YYYYDDD\_GRFO\_GFZOP\_BC01\_0600**

The average of the “oba” coefficients from the AOD1B RL06 product up to degree/order 180 over the same time span as the GSM products.

*Note that the GAA/GAB/GAC/GAD products contain coefficients for degree 0 and 1; however, these coefficients are not used in the GFZ GRACE-FO Level-2 processing.*

*Also note that the averaging of the GAA/GAB/GAC/GAD products is computed over entire days, regardless of whether the full day (as opposed to a partial day) was included in Level-2 processing.*

*For further details about AOD1B see the Product Description Document for AOD1B Release 06 [11].*

Additional Level-2 product files (available only at ISDC):

**GSM-2\_YYYYDDD-YYYYDDD\_GRFO\_GFZOP\_BB01\_0600.snx**

Monthly normal equation of gravity field parameters up to degree/order 96 in SINEX format, available here: [ftp://iscdftp.gfz-potsdam.de/grace-fo/Level-2/GFZ/RL06\\_NEQs\\_SINEX/](ftp://iscdftp.gfz-potsdam.de/grace-fo/Level-2/GFZ/RL06_NEQs_SINEX/)

**Citation:**

Please use the following reference when using the time series of GFZ RL06 Level-2 products:

Dahle, Christoph; Murböck, Michael; Flechtner, Frank; Dobsław, Henryk; Michalak, Grzegorz; Neumayer, Karl H.; Abrykosov, Oleh; Reinhold, Anton; König, Rolf; Sulzbach, Roman; Förste, Christoph (2019). The GFZ GRACE RL06 Monthly Gravity Field Time Series: Processing Details and Quality Assessment. *Remote Sens.* 11(18):2116. <https://doi.org/10.3390/rs11182116>

The GFZ GRACE-FO RL06 Level-2 products are published as data publication via GFZ Data Services:

*GSM-Products:*

Dahle, Christoph; Flechtner, Frank; Murböck, Michael; Michalak, Grzegorz; Neumayer, Hans; Abrykosov, Oleh; Reinhold, Anton; König, Rolf (2019): GRACE-FO Geopotential GSM Coefficients GFZ RL06. V. 6.0. GFZ Data Services. [http://doi.org/10.5880/GFZ.GRACEFO\\_06\\_GSM](http://doi.org/10.5880/GFZ.GRACEFO_06_GSM)

*GAA-Products:*

Dobsław, Henryk; Dill, Robert; Dahle, Christoph (2019): GRACE-FO Geopotential GAA Coefficients GFZ RL06. V. 6.0. GFZ Data Services. [http://doi.org/10.5880/GFZ.GRACEFO\\_06\\_GAA](http://doi.org/10.5880/GFZ.GRACEFO_06_GAA)

*GAB-Products:*

Dobsław, Henryk; Dill, Robert; Dahle, Christoph (2019): GRACE-FO Geopotential GAB Coefficients GFZ RL06. V. 6.0. GFZ Data Services. [http://doi.org/10.5880/GFZ.GRACEFO\\_06\\_GAB](http://doi.org/10.5880/GFZ.GRACEFO_06_GAB)

*GAC-Products:*

Dobsław, Henryk; Dill, Robert; Dahle, Christoph (2019): GRACE-FO Geopotential GAC Coefficients GFZ RL06. V. 6.0. GFZ Data Services. [http://doi.org/10.5880/GFZ.GRACEFO\\_06\\_GAC](http://doi.org/10.5880/GFZ.GRACEFO_06_GAC)

*GAD-Products:*

Dobsław, Henryk; Dill, Robert; Dahle, Christoph (2019): GRACE-FO Geopotential GAD Coefficients GFZ RL06. V. 6.0. GFZ Data Services. [http://doi.org/10.5880/GFZ.GRACEFO\\_06\\_GAD](http://doi.org/10.5880/GFZ.GRACEFO_06_GAD)

**Overview of available solutions:**

The following table shows the currently available monthly Level-2 GFZ GRACE-FO RL06 products, where

- **Release Date** is chronologically starting from first provision of GFZ RL06 data till today.
- **Product Name** is in agreement with the Level-2 Gravity Field Product User Handbook [3].
- **Month** is the calendar month the Level-2 products are assigned to (usually one complete month of data is used, exact start and end epochs are provided in the Level-2 product headers).
- **Reference epoch** is the proper mean epoch of the Level-2 products taking into account complete or partial days between start and end epoch which were not used during the generation of the Level-2 products; the reference epoch is given in civilian date and UTC time (rounded to minutes).
- **Arcs & Days** are the number of orbital arcs used for the generation of the Level-2 products and the accumulated number of actual days over these orbital arcs (i.e. the amount of days where GRACE data has been incorporated in the Level-2 processing).
- **Max. d/o** is the maximum degree and order for the corresponding Level-2 product.
- **GAX** is yes, if the corresponding GAA, GAB, GAC and GAD products are available, too (nominal case).
- **Comments**, which are explained in detail further below.

Release Date	Product Name	Month	Reference epoch	Arcs & Days	Max. d/o	GAX	Comments
18.08.2021	GSM-2_2021152-2021181_GRFO_GFZOP_BA01_0600 GSM-2_2021152-2021181_GRFO_GFZOP_BB01_0600	2021-06	21-06-16 T00:34	35 29.69	60x60 96x96	Yes	3)
05.08.2021	GSM-2_2021121-2021151_GRFO_GFZOP_BA01_0600 GSM-2_2021121-2021151_GRFO_GFZOP_BB01_0600	2021-05	21-05-16 T09:41	36 30.62	60x60 96x96	Yes	2)
09.06.2021	GSM-2_2021091-2021120_GRFO_GFZOP_BA01_0600 GSM-2_2021091-2021120_GRFO_GFZOP_BB01_0600	2021-04	21-04-16 T01:39	34 29.25	60x60 96x96	Yes	2)
06.05.2021	GSM-2_2021060-2021090_GRFO_GFZOP_BA01_0600 GSM-2_2021060-2021090_GRFO_GFZOP_BB01_0600	2021-03	21-03-16 T06:38	36 29.92	60x60 96x96	Yes	2)
12.04.2021	GSM-2_2021032-2021059_GRFO_GFZOP_BA01_0600 GSM-2_2021032-2021059_GRFO_GFZOP_BB01_0600	2021-02	21-02-14 T21:38	33 27.65	60x60 96x96	Yes	2)
12.03.2021	GSM-2_2021001-2021031_GRFO_GFZOP_BA01_0600 GSM-2_2021001-2021031_GRFO_GFZOP_BB01_0600	2021-01	21-01-16 T11:37	35 30.90	60x60 96x96	Yes	2)
17.02.2021	GSM-2_2020336-2020366_GRFO_GFZOP_BA01_0600 GSM-2_2020336-2020366_GRFO_GFZOP_BB01_0600	2020-12	20-12-16 T10:55	43 30.46	60x60 96x96	Yes	2)
20.01.2021	GSM-2_2020306-2020335_GRFO_GFZOP_BA01_0600 GSM-2_2020306-2020335_GRFO_GFZOP_BB01_0600	2020-11	20-11-15 T13:11	46 26.20	60x60 96x96	Yes	1)
21.12.2020	GSM-2_2020275-2020305_GRFO_GFZOP_BA01_0600 GSM-2_2020275-2020305_GRFO_GFZOP_BB01_0600	2020-10	20-10-16 T08:14	39 29.49	60x60 96x96	Yes	2)
16.11.2020	GSM-2_2020245-2020274_GRFO_GFZOP_BA01_0600 GSM-2_2020245-2020274_GRFO_GFZOP_BB01_0600	2020-09	20-09-15 T18:20	35 28.69	60x60 96x96	Yes	2)
08.10.2020	GSM-2_2020214-2020244_GRFO_GFZOP_BA01_0600 GSM-2_2020214-2020244_GRFO_GFZOP_BB01_0600	2020-08	20-08-16 T11:24	41 30.52	60x60 96x96	Yes	2)
09.09.2020	GSM-2_2020183-2020213_GRFO_GFZOP_BA01_0600 GSM-2_2020183-2020213_GRFO_GFZOP_BB01_0600	2020-07	20-07-16 T11:26	35 30.58	60x60 96x96	Yes	2)
30.07.2020	GSM-2_2020153-2020182_GRFO_GFZOP_BA01_0600 GSM-2_2020153-2020182_GRFO_GFZOP_BB01_0600	2020-06	20-06-16 T00:18	36 29.77	60x60 96x96	Yes	2)
07.07.2020	GSM-2_2020122-2020152_GRFO_GFZOP_BA01_0600 GSM-2_2020122-2020152_GRFO_GFZOP_BB01_0600	2020-05	20-05-16 T15:23	38 29.75	60x60 96x96	Yes	2)
10.06.2020	GSM-2_2020092-2020121_GRFO_GFZOP_BA01_0600 GSM-2_2020092-2020121_GRFO_GFZOP_BB01_0600	2020-04	20-04-16 T00:54	34 29.80	60x60 96x96	Yes	2)

Release Date	Product Name	Month	Reference epoch	Arcs & Days	Max. d/o	GAX	Comments
29.04.2020	GSM-2_2020061-2020091_GRFO_GFZOP_BA01_0600 GSM-2_2020061-2020091_GRFO_GFZOP_BB01_0600	2020-03	20-03-16 T17:52	34 30.20	60x60 96x96	Yes	2)
02.04.2020	GSM-2_2020032-2020060_GRFO_GFZOP_BA01_0600 GSM-2_2020032-2020060_GRFO_GFZOP_BB01_0600	2020-02	20-02-17 T07:19	31 21.55	60x60 96x96	Yes	2)
10.03.2020	GSM-2_2020001-2020031_GRFO_GFZOP_BA01_0600 GSM-2_2020001-2020031_GRFO_GFZOP_BB01_0600	2020-01	20-01-15 T10:17	29 24.03	60x60 96x96	Yes	2)
31.01.2020	GSM-2_2019335-2019365_GRFO_GFZOP_BA01_0600 GSM-2_2019335-2019365_GRFO_GFZOP_BB01_0600	2019-12	19-12-16 T11:51	34 30.89	60x60 96x96	Yes	2)
03.01.2020	GSM-2_2019305-2019334_GRFO_GFZOP_BA01_0600 GSM-2_2019305-2019334_GRFO_GFZOP_BB01_0600	2019-11	19-11-15 T23:43	36 29.27	60x60 96x96	Yes	2)
05.12.2019	GSM-2_2019274-2019304_GRFO_GFZOP_BA01_0600 GSM-2_2019274-2019304_GRFO_GFZOP_BB01_0600	2019-10	19-10-16 T10:50	35 29.99	60x60 96x96	Yes	2)
30.10.2019	GSM-2_2019244-2019273_GRFO_GFZOP_BA01_0600 GSM-2_2019244-2019273_GRFO_GFZOP_BB01_0600	2019-09	19-09-15 T18:17	30 27.77	60x60 96x96	Yes	2)
02.10.2019	GSM-2_2019213-2019243_GRFO_GFZOP_BA01_0600 GSM-2_2019213-2019243_GRFO_GFZOP_BB01_0600	2019-08	19-08-16 T00:25	35 29.14	60x60 96x96	Yes	2)
12.09.2019	GSM-2_2019182-2019212_GRFO_GFZOP_BA01_0600 GSM-2_2019182-2019212_GRFO_GFZOP_BB01_0600	2019-07	19-07-16 T05:58	36 29.93	60x60 96x96	Yes	2)
01.08.2019	GSM-2_2019152-2019181_GRFO_GFZOP_BA01_0600 GSM-2_2019152-2019181_GRFO_GFZOP_BB01_0600	2019-06	19-06-15 T19:56	33 29.22	60x60 96x96	Yes	2)
02.07.2019	GSM-2_2019121-2019151_GRFO_GFZOP_BA01_0600 GSM-2_2019121-2019151_GRFO_GFZOP_BB01_0600	2019-05	19-05-16 T07:25	35 30.03	60x60 96x96	Yes	2)
12.06.2019	GSM-2_2019091-2019120_GRFO_GFZOP_BA01_0600 GSM-2_2019091-2019120_GRFO_GFZOP_BB01_0600	2019-04	19-04-15 T22:53	32 29.82	60x60 96x96	Yes	2)
12.06.2019	GSM-2_2019060-2019090_GRFO_GFZOP_BA01_0600 GSM-2_2019060-2019090_GRFO_GFZOP_BB01_0600	2019-03	19-03-16 T06:44	35 30.26	60x60 96x96	Yes	1)
12.06.2019	GSM-2_2019026-2019063_GRFO_GFZOP_BA01_0600 GSM-2_2019026-2019063_GRFO_GFZOP_BB01_0600	2019-02	19-02-14 T01:13	28 22.83	60x60 96x96	Yes	2)
12.06.2019	GSM-2_2019001-2019031_GRFO_GFZOP_BA01_0600 GSM-2_2019001-2019031_GRFO_GFZOP_BB01_0600	2019-01	19-01-16 T11:36	33 29.97	60x60 96x96	Yes	2)
12.06.2019	GSM-2_2018335-2018365_GRFO_GFZOP_BA01_0600 GSM-2_2018335-2018365_GRFO_GFZOP_BB01_0600	2018-12	18-12-16 T14:29	35 30.33	60x60 96x96	Yes	2)
12.06.2019	GSM-2_2018305-2018334_GRFO_GFZOP_BA01_0600 GSM-2_2018305-2018334_GRFO_GFZOP_BB01_0600	2018-11	18-11-16 T04:37	33 29.26	60x60 96x96	Yes	2)
12.06.2019	GSM-2_2018295-2018313_GRFO_GFZOP_BA01_0600 GSM-2_2018295-2018313_GRFO_GFZOP_BB01_0600	2018-10	18-10-31 T01:20	20 16.68	60x60 96x96	Yes	2)
12.06.2019	GSM-2_2018182-2018199_GRFO_GFZOP_BA01_0600 GSM-2_2018182-2018199_GRFO_GFZOP_BB01_0600	2018-07	18-07-09 T18:53	20 17.36	60x60 96x96	Yes	2)
12.06.2019	GSM-2_2018152-2018181_GRFO_GFZOP_BA01_0600 GSM-2_2018152-2018181_GRFO_GFZOP_BB01_0600	2018-06	18-06-16 T01:52	32 27.84	60x60 96x96	Yes	1)

**Comments:**

- 1) During gravity field estimation for this month, the fully-populated accelerometer scale factor matrix has been estimated once per orbital arc.
- 2) During gravity field estimation for this month, the fully-populated accelerometer scale factor matrix has been estimated globally once per month.
- 3) During gravity field estimation for this month, a fully-populated accelerometer scale factor matrix has been estimated once per orbital arc for days when the satellites were in nadir pointing mode, whereas from all other days when the satellites were in relative pointing mode one global fully-populated accelerometer scale factor matrix has been estimated.

## References:

- [1] Dahle, C.; Murböck, M.; Flechtner, F.; Dobsław, H.; Michalak, G.; Neumayer, K. H.; Abrykosov, O.; Reinhold, A.; König, R.; Sulzbach, R.; Förste, C. (2019). The GFZ GRACE RL06 Monthly Gravity Field Time Series: Processing Details and Quality Assessment. *Remote Sens.* 11(18):2116. <https://doi.org/10.3390/rs11182116>
- [2] Dahle, C.; Flechtner, F.; Murböck, M.; Michalak, G.; Neumayer, H.; Abrykosov, O.; Reinhold, A.; König, R. (2019): *GRACE-FO D-103919 (Gravity Recovery and Climate Experiment Follow-On), GFZ Level-2 Processing Standards Document for Level-2 Product Release 06 (Rev. 1.0, June 3, 2019), (Scientific Technical Report STR - Data; 19/09)*, Potsdam: GFZ German Research Centre for Geosciences. DOI: <http://doi.org/10.2312/GFZ.b103-19098>
- [3] Yuan, D.N. (2019): *GRACE-FO Level-2 Gravity Field Product User Handbook (Rev. 1.0, May 22, 2019)*, JPL Publication D-103922, [ftp://isdctftp.gfz-potsdam.de/grace-fo/DOCUMENTS/Level-2/GRACE-FO\\_L2\\_Gravity\\_Field\\_Product\\_User\\_Handbook\\_v1.0.pdf](ftp://isdctftp.gfz-potsdam.de/grace-fo/DOCUMENTS/Level-2/GRACE-FO_L2_Gravity_Field_Product_User_Handbook_v1.0.pdf)
- [4] Wahr, J.; Nerem, R. S.; Bettadpur, S. V. (2015): *The pole tide and its effect on GRACE time-variable gravity measurements: Implications for estimates of surface mass variations*. *Journal of Geophysical Research: Solid Earth*, 120, 6, 4597-4615. DOI: <http://doi.org/10.1002/2015JB011986>
- [5] GRACE Technical Note 13: *Monthly estimates of degree-1 (geocenter) gravity coefficients, generated from GRACE (04-2002 - 06/2017) and GRACE-FO (06/2018 onward) RL06 solutions*, [ftp://isdctftp.gfz-potsdam.de/grace-fo/DOCUMENTS/TECHNICAL\\_NOTES/TN-13\\_GEOC\\_GFZ\\_RL06.txt](ftp://isdctftp.gfz-potsdam.de/grace-fo/DOCUMENTS/TECHNICAL_NOTES/TN-13_GEOC_GFZ_RL06.txt)
- [6] Swenson, S.; Chambers, D.; Wahr, J. (2008): *Estimating geocenter variations from a combination of grace and ocean model output*. *Journal of Geophysical Research: Solid Earth*, 113(B8). DOI: <https://doi.org/10.1029/2007JB005338>
- [7] Sun, Y.; Riva, R.; Ditmar, P. (2016): *Optimizing estimates of annual variations and trends in geocenter motion and J2 from a combination of GRACE data and geophysical models*. *Journal of Geophysical Research: Solid Earth*, 121(11). DOI: <https://doi.org/10.1002/2016JB013073>
- [8] GRACE Technical Note 14: *NASA GSFC SLR C20 and C30 solutions*, [ftp://isdctftp.gfz-potsdam.de/grace-fo/DOCUMENTS/TECHNICAL\\_NOTES/TN-14\\_C30\\_C20\\_SLR\\_GSFC.txt](ftp://isdctftp.gfz-potsdam.de/grace-fo/DOCUMENTS/TECHNICAL_NOTES/TN-14_C30_C20_SLR_GSFC.txt)
- [9] Loomis, B. D.; Rachlin, K. E.; Luthcke, S. B. (2019): *Improved Earth oblateness rate reveals increased ice sheet losses and mass-driven sea level rise*. *Geophysical Research Letters*, 46. DOI: <https://doi.org/10.1029/2019GL082929>
- [10] Loomis, B. D.; Rachlin, K. E.; Wiese, D. W.; Landerer, F. W.; Luthcke, S. B. (2020): *Replacing GRACE/GRACE-FO C30 with satellite laser ranging: Impacts on antarctic ice sheet mass change*. *Geophysical Research Letters*. <https://doi.org/10.1029/2019GL085488>
- [11] Dobsław, H.; Bergmann-Wolf, I.; Dill, R.; Poropat, L.; Flechtner, F. (2017): *GRACE 327-750 (Gravity Recovery and Climate Experiment), Product Description Document for AOD1B*

*Release 06 (Rev. 6.1, October 19, 2017), [ftp://isdctftp.gfz-potsdam.de/grace-fo/DOCUMENTS/Level-1/GRACE\\_AOD1B\\_Product\\_Description\\_Document\\_for\\_RL06.pdf](ftp://isdctftp.gfz-potsdam.de/grace-fo/DOCUMENTS/Level-1/GRACE_AOD1B_Product_Description_Document_for_RL06.pdf)*