GREAT-UPD Users Guide

Xingxing Li, Xin Li, Guolong Feng, Xinjuan Han, Gege Liu, Jiaxin Huang, Bo Wang

Email: *xxli@sgg.whu.edu.cn*,
lixinsgg@whu.edu.cn,
glfeng@whu.edu.cn,
xjhansgg@whu.edu.cn

Contents

1 Overview

The GREAT (GNSS+ REsearch, Application and Teaching) software was designed and developed at the School of Geodesy and Geomatics of Wuhan University for precise orbit and clock determination, high-precision positioning and navigation applications. As one important module in GREAT software, GREAT-UPD was developed for multi-GNSS and multi-frequency uncalibrated phase delay (UPD) estimation. The open-source GREAT-UPD software is written in C++ 11 language following the Object-Oriented principle and can compile, run on several popular operating systems, such as Windows, Linux, and Macintosh. It consists of three portable program libraries named libUPD, libMat and libGnut. The libUPD library is mainly in charge of estimating UPD, including the encoding, decoding, and storage of auxiliary data involved in the UPD estimation, as well as the implementation of UPD algorithm. As for LibMat and libGnut, they are auxiliary libraries for the software. LibMat is an open-source C++ matrix library named newmat, which offers standard matrix operations. LibGnut library comes from the open-source GNSS software G-Nut, including the decoding and storage of GNSS data as well as basic parameter configuration module. The features of GREAT-UPD are:

(1) It supports multi-GNSS UPD estimation for: GPS (G), GLONASS (R), Galileo (E), BeiDou (C) satellites.

(2) It supports extra-wide-lane (EWL), wide-lane (WL) and narrow-lane (NL) UPD estimation. Note that the EWL UPD estimation for GLONASS satellites is not supported currently.

(3) All of the executable binary APs (application programs) for Windows/Linux/Macintosh are included in the package as well as the whole source programs of the libraries and AP.

(4) Adopting the open-source, cross-platform compilation tool CMake, which is convenient for users to customize their own executable APs.

(5) Providing cycle slip detection tool, efficient batch processing python scripts [Download GNSS Data, Cycle slip Detection, UPD Estimation] & plotting and analysis scripts of UPD.

2 Environmental Requirements and License

2.1 Environmental Requirements

The executable CUI AP for Windows in the package was built by VS (Microsoft Visual Studio) 2017 on Windows 10 (64bit). All of the necessary dynamic link libraries are involved in the folder. Moreover, the CUI AP and shared libraries for Linux were built and tested on CentOS Linux release 7.7.1908 and x64 CPU. As for Macintosh, the CUI AP and dynamic libraries were built by AppleClang 11.0.3.11030032 on MacOS 10.15.3, in which kernel version is Darwin 19.3.0.

Also, the users can use the open-source, cross-platform compilation tool CMake to build executable binary AP on their own operating systems (Windows, Linux or Macintosh).

2.2 License

GREAT-UPD is an open-source software, which is governed by the GNU General Public License (version 3) (https://www.gnu.org/licenses/gpl-3.0.html).

3 Installation

The software package can be accessed via the website (https://geodesy.noaa.gov/gps-toolbox). Extract the program package **GREAT-UPD_<ver>.zip** to appropriate directory **<install_dir>** (**<ver>** indicates the version number). The GREAT-UPD directory structure is as follows.

GREAT-UPD_<ver>	
./bin	The executable binary APs for Windows/Linux/Macintosh *
./src	Source programs of GREAT-UPD software *
./app	Main function of UPD estimation *
./LibUPD	Source programs of UPD estimation library *
./LibMat	Source programs of the newmat library *
./LibGnut	Source programs of the G-Nut library *
./sample data	Sample data for AP *
./UPD_2020001	Sample data for GREAT-UPD AP *
./util	Utilities *
./batch_process	Batch processing python scripts for UPD estimation *
./PreEdit	Cycle slip detection tool & Sample data *
./upd_analysis	Plotting and analysis scripts of UPD *
./doc	Document files *
./UPD_config	Sample XML files for GREAT-UPD *
GREAT-UPD_1.0.pdf	User manual

3.1 Windows

To conduct GNSS UPD estimation, you can either use the existing program under the folder **<install_dir>/GREAT-UPD_<ver>/bin/Windows**, or compile an executable program by yourself. The following instructions show how to build GREAT-UPD on Windows.

(1) Get CMake via the website (https://cmake.org/download/) and install it. Note that the minimum requirement of CMake version is 3.0.0.

(2) Execute the cmake-gui.

(3) Execute "Browse Source..." to select the folder **<install_dir>/GREAT-UPD_<ver>**, or you can drag CMakeList.txt in the directory **<install_dir>/GREAT-UPD_<ver>** to the interface of cmake-gui. Then modify attribute "Where to build the binaries" as **<install_dir>/GREAT-UPD_<ver>/build**.

(4) Execute "Configure" and choose the Integrated Development Environment (IDE) for the project (appears only the first time you click "Configure" button).

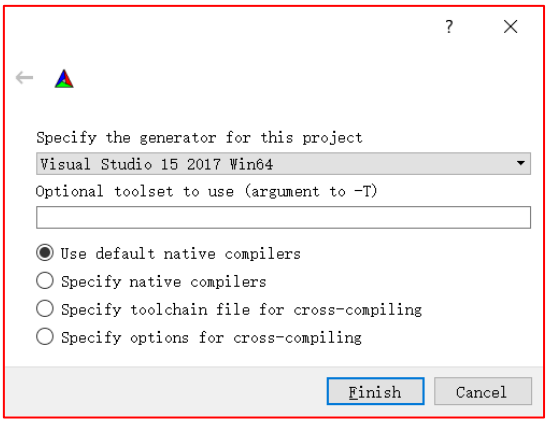

Figure 3.1-1 Example of IDE selection

(5) Execute "Generate" to write the build files to **<install_dir>/GREAT-UPD_<ver>/build** .

(6) Execute "Open Project" and then compile source code in corresponding IDE.

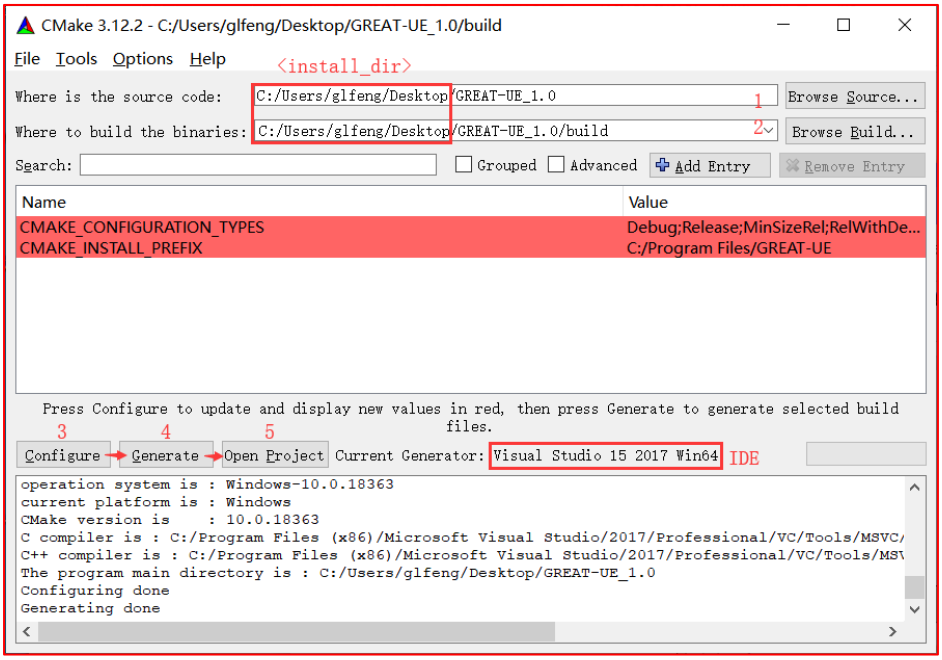

Figure 3.1-2 The compilation of GREAT-UPD in Windows

3.2 Linux/Macintosh

For Linux/Macintosh environment, you can use the existing program under the folder **<install_dir>/GREAT-UPD_<ver>/bin/<platform> (Linux/ Macintosh)** to estimate UPD. For Linux environment, before that, please enter

"**export LD_LIBRARY_PATH=<install_dir>/GREAT-UPD_<ver>/bin/Linux**"

to load the relevant shared libraries in the current terminal. You can also rebuild GREAT-UPD according to the following instructions.

(1) Get CMake via the website (https://cmake.org/download/) and install it. Note that the minimum requirement of CMake version is 3.0.0.

(2) Creat "build" directory in the directory **<install_dir>/GREAT-UPD_<ver>** and change the directory to "build".

>> **mkdir <install_dir>/GREAT-UPD_<ver>/build**

>> **cd <install_dir>/GREAT-UPD_<ver>/build**

(3) Execute "cmake ../" and then "make" to compile the source code. The executable GREAT-UPD can be found in **<install_dir>/GREAT-UPD_<ver>/build/Bin**.

>> **cmake ../**

>> **make**

```
[glfeng@swarm02 greatUE]$
[glfeng@swarm02 greatUE]$ mkdir build
[glfeng@swarm02 greatUE]$ cd build/
[glfeng@swarm02 build]$ cmake3 ../
-- The C compiler identification is GNU 4.8.5
-- The CXX compiler identification is GNU 4.8.5
-- Check for working C compiler: /usr/bin/cc
-- Check for working C compiler: /usr/bin/cc -- works
-- Detecting C compiler ABI info
-- Detecting C compiler ABI info - done
-- Detecting C compile features
-- Detecting C compile features - done
-- Check for working CXX compiler: /usr/bin/c++
-- Check for working CXX compiler: /usr/bin/c++ -- works
-- Detecting CXX compiler ABI info
-- Detecting CXX compiler ABI info - done
-- Detecting CXX compile features
-- Detecting CXX compile features - done
-- Performing Test COMPILER_SUPPORTS_CXX11
-- Performing Test COMPILER_SUPPORTS_CXX11 - Success
-- Performing Test COMPILER_SUPPORTS_CXX0X
-- Performing Test COMPILER_SUPPORTS_CXX0X - Success
-- operation system is : Linux-3.10.0-1062.9.1.el7.x86_64
-- current platform is : Linux
-- CMake version is    : 3.10.0-1062.9.1.el7.x86_64
-- C compiler is : /usr/bin/cc
-- C++ compiler is : /usr/bin/c++
-- The program main directory is : /workfs/glfeng/project/great/greatUE
-- Configuring done
-- Generating done
-- Build files have been written to: /workfs/glfeng/project/great/greatUE/build
[glfeng@swarm02 build]$ make
make: Warning: File `Makefile' has modification time 28 s in the future
make[1]: Warning: File `CMakeFiles/Makefile2' has modification time 28 s in the future
make[2]: Warning: File `libMat/CMakeFiles/libMat.dir/flags.make' has modification time 28 s in the future
Scanning dependencies of target libMat
make[2]: warning:  Clock skew detected.  Your build may be incomplete.
make[2]: Warning: File `libMat/CMakeFiles/libMat.dir/flags.make' has modification time 28 s in the future
[  1%] Building CXX object libMat/CMakeFiles/libMat.dir/newmat/bandmat.cpp.o
[  2%] Building CXX object libMat/CMakeFiles/libMat.dir/newmat/cholesky.cpp.o
[  3%] Building CXX object libMat/CMakeFiles/libMat.dir/newmat/evalue.cpp.o
```

Figure 3.2-1 The compilation of GREAT-UPD in Linux

4 Data Processing Instructions

By convention, we have the following definitions firstly:
YYYY: 4-digit year; YY: 2-digit year; MM: 2-digit month; DD: 2-digit day;
DOY: 3-digit DOY (Day of Year).
Note that the python scripts mentioned in this session require Python 3.* environment.

4.1 Data Preparation

To conduct EWL or WL UPD estimation, you would often need to download GNSS observation data from global or regional networks. Differential code bias (DCB) correction should also be considered in UPD estimation. It is noted that some observation files are lack of GLONASS frequency numbers and BDS broadcast ephemeris is also needed for BDS satellite-induced code bias correction. Therefore, broadcast ephemeris is used as the input file of UPD estimation for GLONASS and BDS. For GPS EWL UPD estimation, inter-frequency clock bias (IFCB) should be corrected for GPS Block IIF satellites. For the format of IFCB file, please refer A.6.

As for NL UPD estimation, the input files include ambupd file and WL UPD file. For the formats of ambupd and UPD files, please refer A.3 and A.5. With the obtained WL UPD products, the WL ambiguities can be fixed by round strategy. Then, NL UPD can be estimated with float ionosphere-free (IF) ambiguities and fixed WL ambiguities. The IF ambiguities can be estimated by precise point positioning (PPP) float solutions, while the WL ambiguities are derived from Melbourne-Wübbena (MW) combination.

GREAT-UPD offers python scripts to download GNSS observation and navigation files and DCB files, which are under the folder **<install_dir>/GREAT-UPD_<ver>/util/batch_process**:

download_obs.py	Download multi-GNSS observation files provided by CDDIS. -ftp://cddis.gsfc.nasa.gov/pub/gps/data/daily/YYYY/DOY
download_dcb.py	Download GPS and GLONASS DCB files provided by CODE. -http://ftp.aiub.unibe.ch/CODE/YYYY
download_nav.py	Download GPS, GLONASS and multi-GNSS broadcast ephemeris files. -ftp://cddis.gsfc.nasa.gov/pub/gps/data/daily/YYYY/brdc -ftp://cddis.gsfc.nasa.gov/pub/gps/data/campaign/mgex/daily/rinex3/YYYY/brdm

4.2 Data Preprocessing

With the data for GNSS UPD estimation downloaded, data preprocessing should be performed before EWL/ WL UPD estimation. GREAT-UPD offers a data preprocessing tool named "GREAT-PreEdit", which could determine geometry-free (GF) & Melbourne-Wubbena cycle slip, exclude observation outliers, eliminate short arcs and so on. The configure file is expressed in Extensible Markup Language (XML) format. Users can modify settings in configure file for different purposes. To learn more details about configuration, please refer A.2. The output of cycle slip detection tool is ambflag file, please refer A.4.

To run "GREAT-PreEdit" in a single project, the users only need to type command lines:

```
>> cd <project_dir>
>> <install_dir>\GREAT-UPD_<ver>\util\PreEdit\<platform>\GREAT-PreEdit
```

-x PreEdit_CONFIG.xml

Meanwhile, a python script named "**PreEdit.py**" is recommended if the users want to make a batch processing site-by-site and day-by-day. The python script is under the folder **<install_dir>/GREAT-UPD_<ver>/util/batch_process**. One can type "**PreEdit.py** -h" or "**PreEdit.py** --help" for help information, as shown in Fig 4.2-1.

```
Purpose: Cycle-slip detection
Usage: python  PreEdit.py  -c  <config_file>  --config=<config_file>
       -c|--config=        Reference ini file            (Required)
```

Figure 4.2-1 The help information of "**PreEdit.py**"

To run this script, the users need to prepare an Initialization File (.ini). The Fig. 4.2-2 shows the format of the Initialization File for "**PreEdit.py**". Moreover, the format of "sitelist" is shown in Fig. 4.2-3.

```
[project]
; Begin Time: Year-Mon-Day
ymd_beg = 2020-01-15
; End Time   : Year-Mon-Day
ymd_end = 2020-01-20
; Begin Time in Every Day: Hour:Min:Sec
hms_beg = 00:00:00
; End Time in Every Day   : Hour:Min:Sec
hms_end = 23:55:00
; System   : G or GC or GCE or GCRE
satsys = GCER
; SiteList: Site List
sitelist = /works/sitelist
; Interval: Sample Interval in Seconds
interval = 30
; Reference XML Path
ref_xml = ref_turboedit.xml
; Working Directory
work_dir = /works/turboedit
; Software Name
software = /works/GREAT-TURBOEDIT

[process]
; Minimum Cutoff Elevation in Degree
minimum_elev = 7

[data]
; File Directory
; -YYYY- can be replaced by 4-digit year
; -DDD- can be replaced by 3-digit DOY (Day of Year)
nav_dir = /works/nav/-YYYY-/-DDD-
obs_dir = /works/obs/-YYYY-/-DDD-
ambflag_dir = /works/ambflag/-YYYY--DDD-
```

Figure 4.2-2 The format of Initialization file for "**PreEdit.py**"

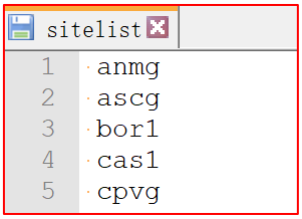

Fig. 4.2-3 The format of "sitelist"

4.3 UPD Estimation

Before performing UPD estimation, the users need to generate configure files. The details of UPD XML setting are explained in A.1.

To run "GREAT-UPD" in a single project, the users only need to type command lines:

```
>> cd <install_dir>/GREAT-UPD_<ver>/bin/<platform>
>> ./GREAT-UPD -x UPD_CONFIG.xml
```

Meanwhile, a python script named "**upd.py**" is recommended if the users want to make a batch processing for UPD estimation site-by-site and day-by-day. The python script is under the folder **<install_dir>/GREAT-UPD_<ver>/util/batch_process**. One can type "**upd.py** -h" or "**upd.py** --help" for help information as shown in Fig 4.3-1.

```
Purpose: UPD estimation script
Usage: python  upd.py  -c  <config_file>  --config=<config_file>
       -c|--config=        Reference ini file              (Required)
```

Figure 4.3-1 The help information of "upd.py"

To run this script, the users need to prepare an Initialization File (.ini). The Fig. 4.3-2 shows the format of the Initialization file for "**upd.py**".

```
[project]
; Begin Time: Year-Mon-Day
ymd_beg = 2020-01-15
; End Time  : Year-Mon-Day
ymd_end = 2020-01-20
; Begin Time in Every Day: Hour:Min:Sec
hms_beg = 00:00:00
; End Time in Every Day  : Hour:Min:Sec
hms_end = 23:55:00
; System  : G or C or E or R
satsys = G
; SiteList: Site List
sitelist = /works/sitelist
; Interval: Sample Interval in Seconds
interval = 30
; Reference XML Path
sat_rm = C01+C02
; Working Directory
work_dir = /works/upd
; Software Name
software = /works/GREAT-UPD

[process]
; UPD Mode : WL or NL or EWL or EWL_EPOCH or WL+NL[first WL, then NL]
upd_mode = WL

[data]
; File Directory
; -YYYY- can be replaced by 4-digit year
; -DDD- can be replaced by 3-digit DOY (Day of Year)
dcb_dir = /works/dcb
nav_dir = /works/nav/-YYYY-/-DDD-
obs_dir = /works/obs/-YYYY-/-DDD-
upd_dir = /works/-YYYY--DDD-
ifcb_dir = /works/-YYYY--DDD-
ambflag_dir = /works/-YYYY--DDD-
ambupd_dir = /works/-YYYY--DDD-
```

Figure 4.3-2 The format of Initialization File for "**upd.py**"

4.4 Results Plotting and Analysis

GREAT-UPD provides plotting and analysis scripts of UPD, which are written in MATLAB language and can work in Windows/Linux/Macintosh environment. Here, they have been tested under the version of MATLAB R2016a, R2017a. The description of each script is as follows:

<install_dir>/GREAT-UPD_<ver>/util/upd_analysis/NL&EWL_epoch

batch_epoch.m	Batch script to draw NL/EWL_epoch UPD
draw_epoch_upd.m	Draw time series and standard deviation (STD) of NL/EWL_epoch UPD
read_epoch_upd_file.m	Read NL/EWL_epoch UPD files

<install_dir>/GREAT-UPD_<ver>/util/upd_analysis/WL&EWL

batch_day.m	Batch script to draw EWL/WL UPD
draw_day_upd.m	Draw time series and STD of EWL/WL UPD
read_day_upd_files.m	Read EWL/WL UPD files

<install_dir>/GREAT-UPD_<ver>/util/upd_analysis/NL&EWL_epoch

batch_res.m	Batch script to draw EWL/WL/NL residual
draw_updres.m	Draw the distribution of the UPD residual, calculate averaged residual value as well as the percentages of UPD residual within ±0.15 cycles and ±0.25 cycles
read_updres_file.m	Read UPD residual files.

Take the Galileo satellites as an example.

The EWL, WL, NL UPDs for Galileo satellites are estimated and analyzed based on observations from DOY 091 to 120 of 2019. Here, E01 satellite is chosen as the reference satellite.

draw_day_upd (EWL): Fig. 4.4-1 shows the EWL UPD series of several Galileo satellites from DOY 091 to 120 of 2019.

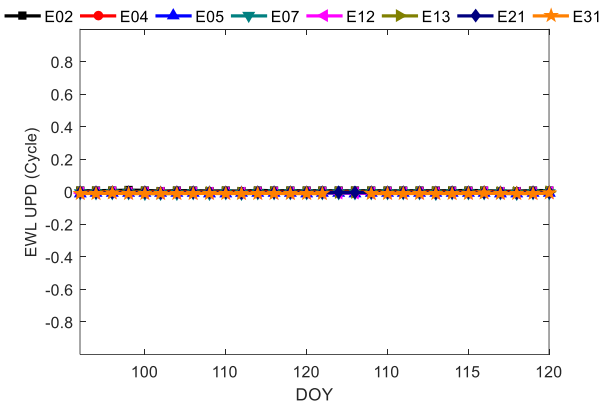

Figure 4.4-1 The EWL UPD of Galileo satellites from DOY 091 to 120 of 2019

draw_day_upd (WL): Fig. 4.4-2 shows the WL UPD series of several Galileo satellites from DOY 091 to 120 of 2019.

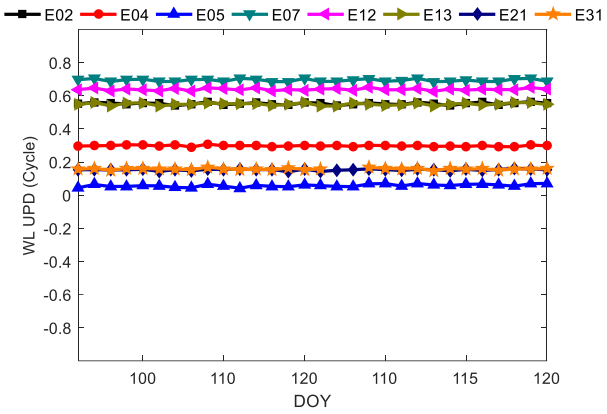

Figure 4.4-2 The WL UPD of Galileo satellites from DOY 091 to 120 of 2019

`draw_epoch_upd (NL):` Fig. 4.4-3 shows the NL UPD series of several Galileo satellites on DOY 094 of 2019.

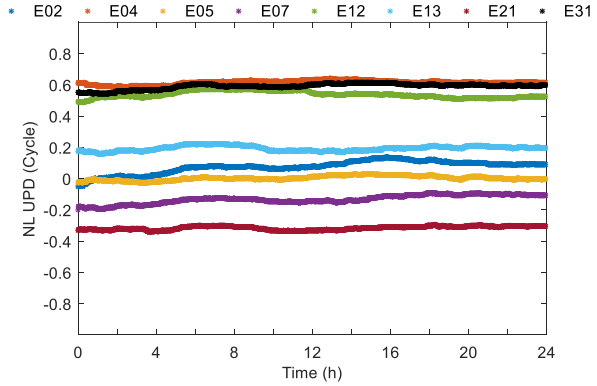

Figure 4.4-3 The NL UPD of Galileo satellites on DOY 094 of 2019.

`WL_STD/NL_STD:` Fig. 4.4-4 shows the STDs of WL and NL UPDs for each Galileo satellite. The average STDs of WL, NL UPDs are 0.0066 and 0.0233 cycles, respectively.

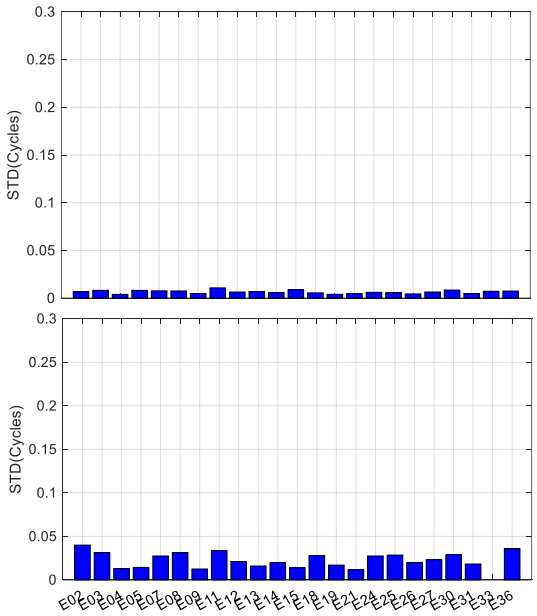

Figure 4.4-4 STDs of WL (top) and NL (bottom) UPDs of Galileo satellites

`draw_updres:` The residuals are defined as the fractional parts of the corresponding float ambiguities corrected by UPDs. Fig. 4.4-4 shows the distribution of the Galileo WL (*left*) and NL (*right*) residuals on DOY 094 of 2019, as well as the averaged residual values and the percentages of WL, NL residuals within ±0.15 cycles , ±0.25 cycles.

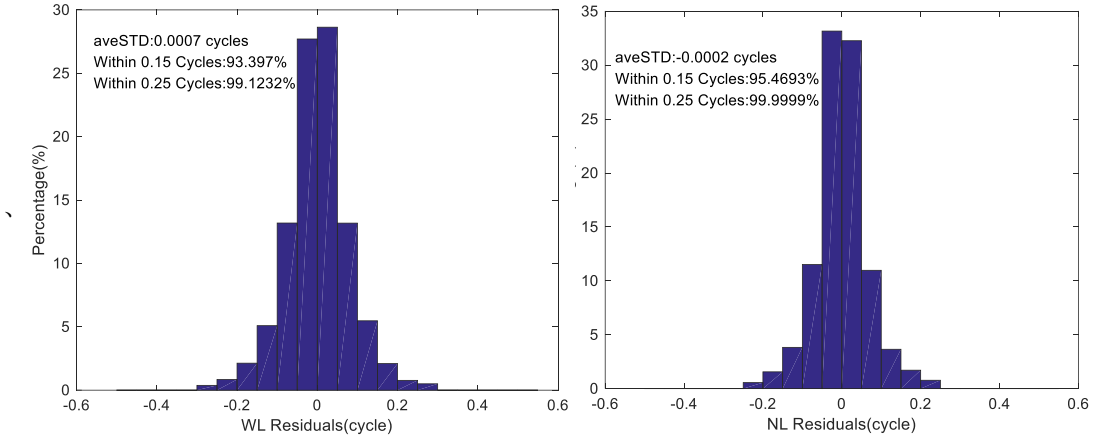

Figure 4.4-5 Distribution of the Galileo WL (*left*) and NL (*right*) residuals on DOY 094 of 2019

5 Support

Any suggestions, corrections, and comments about GREAT-UPD are sincerely welcomed and could be sent to:

Xingxing Li
Email: lxlq109121@gmail.com, xxli@sgg.whu.edu.cn
Address: Room 421, School of Geodesy and Geomatics, Wuhan University, 129 Luoyu Road, 430079, Wuhan, China

Xin Li
Email: lixinsgg@whu.edu.cn
Address: School of Geodesy and Geomatics, Wuhan University, 129 Luoyu Road, 430079, Wuhan, China

Guolong Feng
Email: glfeng@whu.edu.cn
Address: School of Geodesy and Geomatics, Wuhan University, 129 Luoyu Road, 430079, Wuhan, China

Xinjuan Han
Email: xjhansgg@whu.edu.cn
Address: School of Geodesy and Geomatics, Wuhan University, 129 Luoyu Road, 430079, Wuhan, China

It is recommended to acknowledge GREAT-UPD when you find it useful!

Appendix A File Formats

By convention, we have the following definitions firstly:
YYYY: 4-digit year; YY: 2-digit year; MM: 2-digit month; DD: 2-digit day;
DOY: 3-digit DOY (Day of Year);
hh: 2-digit hour; mm: 2-digit minute; ss: 2-digit second
SITE: upper format of site name; site: lower format of site name

A.1 Configure XML for GREAT-UPD

A configuration file containing processing options, solution options and file options. It is expressed in XML format, which contains the "Keyword = Value" form records indicating the various options. The texts starting with "<!--" and ending with "-->" in a line are treated as comments. The following table shows the format of the XML file.

Item	Descriptions	Element in XML File
General Settings for UPD Estimation (First Level Element)		**<gen>**
Begin Time	Set begin time in form of GPS time. The format is, "YYYY-MM-DD hh:mm:ss".	<beg>
End Time	Set end time in form of GPS time. The format is, "YYYY-MM-DD hh:mm:ss".	<end>
Station List	Set station list for UPD estimation.	<rec>
Satellite System	Set satellite system for UPD estimation. Note that only one system is allowed here.	<sys>
Sampling Interval	Set sampling interval of UPD estimation.	<int>
Excluded Satellites	Set the excluded satellites for UPD estimation. Fill in the PRN numbers of the satellites separated by spaces.	<sat_rm>
Input Files Settings for UPD Estimation (First Level Element)		**<inputs>**
RINEX OBS File	RINEX observation file used for UPD estimation. Note that it supports RINEX 2.10, 2.11, 2.12, 3.00, 3.01, 3.02, 3.03, 3.04 OBS.	<rinexo>
RINEX NAV File	RINEX navigation file used for UPD estimation. Note that it supports RINEX 2.10, 2.11, 2.12, 3.00, 3.01, 3.02, 3.03, 3.04 NAV. Only GLONASS decoder is provided.	<rinexn>
DCB File	DCB file used for EWL/EWL_epoch/WL UPD estimation. It is in CODE format.	<biabern>
Ambupd File	Ambupd file used for NL UPD estimation. For the format, please refer A.3.	<ambupd>
Ambflag File	Ambflag file used for EWL/EWL_epoch/WL UPD estimation. For the format, please refer A.4.	<ambflag>
WL UPD File	WL UPD file used for NL UPD estimation. For the format, please refer A.5.	<upd>

Item	Descriptions	Element in XML File
IFCB File	IFCB file used for EWL/EWL_epoch UPD estimation. For the format, please refer A.6.	<ifcb>
Processing Settings for UPD Estimation (First Level Element)		**<process>**
UPD Mode	Set mode of UPD estimation, the corresponding attribute is "updmode". The value of "updmode" is optional: - EWL: EWL UPD estimation - EWL_epoch: epoch-wisely EWL UPD estimation - WL: WL UPD estimation - NL: NL UPD estimation	
bds_code_bias_corr	whether to correct BDS satellite-induced code bias. The value is optional: -true: correct -false: not correct	
Output Files Settings for UPD Estimation (First Level Element)		**<outputs>**
Append	Whether to rewrite the log in original log file, the corresponding attribute is "append". The value of "append" is optional: - true: append - false: not append	
Verb	Set log file output level, the corresponding attribute is "verb". The value of "verb" is optional: - 0/1/2/3/4/5 (5: highest > 0: lowest)	
Log File	Set output log file.	<log>
UPD File	Set output UPD file. For the format, please refer A.5.	<upd>

EXAMPLE

```
<config>
<!-- general descriptions -->
<gen>
    <beg> 2019-11-03 00:00:00 </beg> <!-- beg time -->
    <end> 2019-11-03 23:55:30 </end> <!-- end time -->
    <sys> GAL </sys>                 <!-- GNSS system: GPS/GLO/BDS/GAL -->
    <rec> ABMF </rec>                <!-- processing sites -->
    <int> 30 </int>                  <!-- sampling interval -->
    <sat_rm> </sat_rm>               <!-- exclude certain satellites during UPD estimation -->
</gen>

<!-- input descriptions -->
<inputs>
    <ambupd> ABMF_ambupd_2019307 </ambupd> <!-- ambupd decoder: provide float IF and widelane ambiguities -->
    <rinexn> brdm3070.19p </rinexn>        <!-- nav RINEX decoder -->
    <upd> upd_wl_2019307_E </upd>          <!-- upd decoder: provide widelane upd -->
</inputs>

<!-- mode of UPD estimation: WL(widelane)/EWL(extra-widelane)/NL(narrowlane)/EWL_epoch -->
<process updmode="NL" />

<gps>
    <band> 1 2 5 </band>
</gps>

<gal>
    <band> 1 5 7 </band>
</gal>

<bds>
    <band> 2 7 6 </band>
</bds>

<glo>
    <band> 1 2 </band>
</glo>

<!-- output descriptions -->
<outputs append="false" verb="2">
    <log> LOGRT.log </log>          <!-- log encoder -->
    <upd> upd_nl_2019307_E </upd>   <!-- upd encoder -->
</outputs>

</config>
```

Figure A.1-1 Example of XML for NL UPD estimation

```
<config>
<!-- general descriptions -->
<gen>
    <beg> 2017-01-01 01:00:00 </beg> <!-- beg time -->
    <end> 2017-01-01 23:55:00 </end> <!-- end time -->
    <sys> GLO </sys>                 <!-- GNSS system: GPS/GLO/BDS/GAL -->
    <rec> AUCK </rec>                <!-- processing sites -->
    <int> 30 </int>                  <!-- sampling interval -->
    <sat_rm> </sat_rm>               <!-- exclude certain satellites during UPD estimation -->
</gen>

<!-- input descriptions -->
<inputs>
    <rinexo> auck0010.17o </rinexo>          <!-- obs RINEX decoder -->
    <rinexn> brdm0010.17p </rinexn>          <!-- nav RINEX decoder -->
    <ambflag> auck0010.17o.ambflag </ambflag>  <!-- ambflag decoder: cycle slip [GPS:L1/L2,GAL:E1/E5a,BDS:B1/B2,GLO:G1/G2] -->
    <biabern> P1C11701.DCB P1P21701.DCB P2C21701_RINEX.DCB </biabern> <!-- code bias decoder -->
</inputs>

<!-- mode of UPD estimation: WL(widelane)/EWL(extra-widelae)/NL(narrowlane)/EWL_epoch -->
<!-- choose whether to correct BDS satellite-induced code bias -->
<process updmode="WL" bds_code_bias_corr="true"/>

<gps>
    <band> 1 2 5 </band>
</gps>

<gal>
    <band> 1 5 7 </band>
</gal>

<bds>
    <band> 2 7 6 </band>
</bds>

<glo>
    <band> 1 2 </band>
</glo>

<!-- output descriptions -->
<outputs append="false" verb="2">
    <log> LOGRT.log </log>          <!-- log encoder -->
    <upd> upd_wl_2017001_R </upd>   <!-- upd encoder -->
</outputs>

</config>
```

Figure A.1-2 Example of XML for WL UPD estimation

```
<config>
 <!-- general descriptions -->
 <gen>
   <beg> 2017-01-01 01:00:00 </beg> <!-- beg time -->
   <end> 2017-01-01 23:55:00 </end> <!-- end time -->
   <sys> GPS </sys>                 <!-- GNSS system: GPS/GLO/BDS/GAL -->
   <rec> AUCK </rec>                <!-- processing sites -->
   <int> 30 </int>                  <!-- sampling interval -->
   <sat_rm>  </sat_rm>              <!-- exclude certain satellites during UPD estimation -->
 </gen>

 <!-- input descriptions -->
 <inputs>
   <rinexo> auck0010.17o </rinexo>              <!-- obs RINEX decoder -->
   <rinexn> brdm0010.17p </rinexn>              <!-- nav RINEX decoder -->
   <ambflag> auck0010.17o.ambflag </ambflag>    <!-- ambflag decoder: cycle slip [GPS:L2/L5,GAL:E5a/E5b,BDS:B2/B3 -->
   <biabern> P1C11701.DCB P1P21701.DCB P2C21701_RINEX.DCB </biabern> <!-- code bias decoder -->
   <ifcb> ifcb_2017001 </ifcb>                  <!-- optional: ifcb decoder -->
 </inputs>

 <!-- mode of UPD estimation: WL(widelane)/EWL(extra-widelae)/NL(narrowlane)/EWL_epoch -->
 <!-- choose whether to correct BDS satellite-induced code bias -->
 <process updmode="EWL" bds_code_bias_corr="true"/>  <!-- "EWL" for EWL UPD estimation, "EWL_epoch" for epoch-wisely EWL UPD estimation -->

 <gps>
   <band> 1 2 5 </band>
 </gps>

 <gal>
   <band> 1 5 7 </band>
 </gal>

 <bds>
   <band> 2 7 6 </band>
 </bds>

 <glo>
   <band> 1 2 </band>
 </glo>

 <!-- output descriptions -->
 <outputs append="false" verb="2">
   <log> LOGRT.log </log>           <!-- log encoder -->
   <upd> upd_ewl_2017001_G </upd>   <!-- upd encoder -->
 </outputs>

</config>
```

Figure A.1-3 Example of XML for EWL/EWL_epoch UPD estimation

A.2 Configure XML for GREAT-PreEdit

A configuration file containing processing options, solution options and file options. It is expressed in XML format, which contains the "Keyword = Value" form records indicating the various options. The texts starting with "<!--" and ending with "-->" in a line are treated as comments. The following table shows the format of the XML file.

Item	Descriptions	Element in XML File
General Settings for PreEdit (First Level Element)		**<gen>**
Begin Time	Set begin time in form of GPS time. The format is, "YYYY-MM-DD hh:mm:ss".	<beg>
End Time	Set end time in form of GPS time. The format is, "YYYY-MM-DD hh:mm:ss".	<end>
Station List	Set station list for cycle slip detection.	<rec>
Satellite Systems	Set satellite systems for cycle slip detection.	<sys>
Sampling Interval	Set sampling interval of cycle slip detection.	<int>
Input Files Settings for PreEdit (First Level Element)		**<inputs>**
RINEX OBS File	RINEX observation file used for cycle slip detection. Note that it supports RINEX 2.10, 2.11, 2.12, 3.00, 3.01, 3.02, 3.03, 3.04 OBS.	<rinexo>

Item	Descriptions	Element in XML File
RINEX NAV File	RINEX navigation file used for cycle slip detection. Note that it supports RINEX 2.10, 2.11, 2.12, 3.00, 3.01, 3.02, 3.03, 3.04 NAV.	<rinexn>
Satellite Settings for PreEdit (First Level Element)		**<gps>/<bds> /<gal>/<glo>**
Satellite PRN List	Set the satellites for cycle slip detection. Fill in the PRN numbers of the satellites separated by spaces.	<sat>
Band	Set observation band of specified satellite system. - GPS: 1->L1, 2->L2, 5->L5 - GAL: 1->E1, 5->E5a, 7->E5b - BDS: 2->B1, 7->B2, 6->B3 - GLO: 1->G1, 2->G2	<band>
Processing Settings for PreEdit (First Level Element)		**<process>**
Elevation Mask	Set elevation mask angle in degree, the corresponding attribute is "minimum_elev".	
PreEdit Settings for PreEdit (First Level Element)		**<PreEdit>**
Use Ephemeris	Check whether use broadcast ephemeris, the corresponding attribute is "valid". The value of "valid" is optional: - true: use broadcast ephemeris - false: not use broadcast ephemeris	<ephemeris>
Check PC Combination	Whether check the difference between PC combination and geometric distance. Optional "attribute-value" pairs are showed as follows, - "pc_limit": threshold of residuals in meter, its value can be any positive number - "valid": "true" or "false", which means check or not	<check_pc>
Check LWLG	whether check MW+GF combination of the two specified bands. Optional "attribute-value" pairs are showed as follows, - "lw_limit": threshold of residuals in cycle (MW), its value can be any positive number - "lg_limit": threshold of residuals in cycle (GF), its value can be any positive number - "lg_rms_limit": threshold of standard deviation of residuals in cycle (GF), its value can be any positive number - "valid": "true" or "false", which means check or not	<check_lwlg>
Large Gap	Ambiguity is inserted if data missing is longer than this setting, the corresponding attribute is "gap_limit". The value of "gap_limit" can be any positive number, unit: second.	<length_gap>

Item	Descriptions	Element in XML File
Short Arc	Data piece shorter than this setting is considered as short piece, the corresponding attribute is "short_limit". The value of "short_limit" can be any positive number, unit: second.	<length_short>
Check Statistics	Whether check statistics. Optional "attribute-value" pairs are showed as follows, - "min_percent": the percentage of epochs (> 4 satellites) in all epochs - "min_mean_nprn": minimum mean satellite number (total observation number divided by epoch number) - "max_mean_namb": maximum mean ambiguity number (total ambiguity number divided by satellite number) - "valid": "true" or "false", which means check or not	<statistical_threshold>
Output Files Settings for PreEdit (First Level Element)		**<outputs>**
Append	Whether to rewrite the log in original log file, the corresponding attribute is "append". The value of "append" is optional: - true: append - false: not append	
Verb	Set log file output level, the corresponding attribute is "verb". The value of "verb" is optional: - 0/1/2/3/4/5 (5: highest > 0: lowest)	
Log File	Set output log file.	<log>
Ambflag File	Set output Ambflag file. For the format, please refer A.4.	<ambflag>

EXAMPLE

```
<config>
 <gen>                                  <!-- general descriptions -->
   <beg> 2017-07-29 00:00:00 </beg>     <!-- beg time -->
   <end> 2017-07-29 23:59:59 </end>     <!-- end time -->
   <sys> GPS GAL BDS GLO </sys>         <!-- GNSS system: GPS/GLO/BDS/GAL -->
   <rec> GOP7 </rec>                    <!-- processing sites -->
   <int> 30 </int>                      <!-- sampling interval -->
 </gen>

 <inputs>                              <!-- input descriptions -->
   <rinexo> gop72100.17o </rinexo>     <!-- obs RINEX decoder -->
   <rinexn> brdm2100.17p </rinexn>     <!-- nav RINEX decoder -->
 </inputs>

<gps>                  <!-- list of GPS satellites and observation bands -->
   <sat> G01  G02  G03  G04  G05  G06  G07  G08  G09  G10 </sat>
   <band> 1 2 </band>   <!-- 1->L1,2->L2,5->L5 -->
</gps>

<gal>                  <!-- list of Galileo satellites and observation bands -->
   <sat> E01  E02  E03  E04  E05  E06  E07  E08  E09  E10 </sat>
   <band> 1 5 </band>   <!-- 1->E1,5->E5a,7->E5b -->
</gal>

<bds>                  <!-- list of BDS satellites and observation bands -->
   <sat> C01  C02  C03  C04  C05  C06  C07  C08  C09  C10 </sat>
   <band> 2 7 </band>   <!-- 2->B1,7->B2,6->B3 -->
</bds>

<glo>                  <!-- list of GLONASS satellites and observation bands -->
   <sat> R01  R02  R03  R04  R05  R06  R07  R08  R09  R10 </sat>
   <band> 1 2 </band>   <!-- 1->G1,2->G2 -->
</glo>

 <process  minimum_elev="7"  />  <!-- minimum elevation -->

<turboedit>                                          <!-- turboedit settings -->
  <ephemeris    valid="true"   />                    <!-- whether use ephemeris, For PC check and elev check should set true -->
  <check_pc     pc_limit="250"  valid="true" />      <!-- whether check range residuals, unit: m -->
  <check_lwlg   lw_limit="4"  lg_limit="1"  lg_rms_limit="2" valid="true" /> <!-- whether check MW+GF combination, unit: cycle -->
  <length_gap   gap_limit="600"   />                 <!-- ambiguity is inserted if data missing longer, unit:s, default 600s -->
  <length_short short_limit="300" />                 <!-- data piece shorter considered as short piece, unit:s, default 1800s -->
  <statistical_threshold  min_percent="60"  min_mean_nprn="4"  max_mean_namb="3"  valid="true" />  <!-- statistical threshold -->
</turboedit>

 <outputs append="false" verb="1">                     <!-- output descriptions  -->
   <log> LOGRT.xml.log </log>                          <!-- log encoder -->
   <ambflag> ambflag/$(rec)-DOY-0.-YY-o.ambflag </ambflag>  <!-- ambflag encoder -->
 </outputs>
</config>
```

Figure A.2-1 Example of XML for PreEdit

A.3 Ambupd File

DESCRIPTION

Ambupd file is the input file of NL UPD estimation, and it is a text file in which a line contains ambiguity messages. It contains WL ambiguities and IF ambiguities. The IF ambiguities can be estimated by PPP float solutions. The following table shows the format of the ambupd file. (Note: In order to adapt to the batch python scripts, please name an ambupd file as "**SITE_ambupd_YYYYDOY**" format)

No	Data Record/Field	Data Section Description	Format
1	Ambiguity Messages	A line contains WL ambiguities and IF ambiguities, which consists of the following fields.	
(1)	Modified Julian Day	Modified Julian Day.	I8
(2)	Time of day	Time of a day in seconds.	F10.1
(3)	Station name	Name of the station.	A5
(4)	PRN number	PRN number of GNSS satellite.	A4
(5)	IF ambiguity	IF ambiguity derived from PPP float solution, unit: meter.	F19.3
(6)	WL ambiguity	WL ambiguity, unit: cycle.	F19.3
(7)	Standard deviation	Standard deviation of WL ambiguity.	F10.3

EXAMPLE

```
   58663      0.0 BOR1 R04          5.316          -15.345      0.194
   58663      0.0 BOR1 R05          2.415          -19.817      0.022
   58663      0.0 BOR1 R14        -16.138          -58.796      0.074
   58663      0.0 BOR1 R15          5.544           -8.829      0.011
   58663      0.0 BOR1 R16          6.014           -2.262      0.007
   58663      0.0 BOR1 R22          1.487          -17.798      0.049
   58663      0.0 BOR1 R23        -34.871         -100.910      0.028
   58663     30.0 BOR1 R04          5.316          -15.345      0.194
   58663     30.0 BOR1 R05          2.415          -19.817      0.022
   58663     30.0 BOR1 R14        -16.138          -58.796      0.074
```

Figure A.3-1 Example of ambupd file format

A.4 Ambflag File

DESCRIPTION

Ambflag file is the output of GREAT-PreEdit, and it is a text file which contains cycle slip information of a station. It is also one of the input files for WL/EWL/EWL_epoch UPD estimation. The file is separated to records or lines by CR/LF. Each record consists of several fields. The following table shows the format of the ambflag file. (Note: In order to adapt to the batch python scripts, please name an ambflag file as "**siteDOY0.YYo.ambflag**")

No	Header Label (Columns 61-80)	Header Section Description	Formats
1	SOFTWARE / DATE	- Name of program creating current file - Date and time of file creation	A20,20X, A16,4X
2	STATION	- Name of station	A4,56X
3	SYS / FREQ1 / FREQ2	- Different satellite systems (GPS/GAL/GLO/BDS) - The first band used to cycle slip (MW+GF check) - The second band used to cycle slip (MW+GF check) Frequency: GPS=>L1, L2, L5 GAL=>E1, E5a, E5b BDS=>B1, B2, B3 GLO=>G1, G2	A3,3X, A3,3X, A3,45X
4	BEGIN TIME	- Begin Time of the cycle slip information (4-digit-year, month, day, hour, min, sec) - Time system (fixed as GPST)	I6,4I4,F7.2 11X,A4,16X
5	END TIME	- End Time of the cycle slip information (4-digit-year, month, day, hour, min, sec) - Time system (fixed as GPST)	I6,4I4,F7.2 11X,A4,16X
6	INTERVAL	- Interval in seconds	F10.2,50X
7	END OF HEADER	- Last record in the header section	60X

No	Data Record/Field	Data Section Description	Formats
1	Cycle slip Messages	A line contains cycle slip and some additional	

No	Data Record/Field	Data Section Description	Formats
		information.	
(1)	Ambiguity flag	The flag which indicates the availability of GNSS observations. AMB: Available observation arcs, which means you need to insert or update ambiguities. BAD: Not re-initialize ambiguities, only exclude bad observations. DEL: Unavailable observation arcs due to long-term data interruption or poor data quality.	A3, 3X
(2)	PRN number	PRN number of GNSS satellite.	A3
(3)	Begin epoch	Begin epoch (from the start time, at certain intervals).	I8
(4)	End epoch	End epoch (from the start time, at certain intervals).	I8
(5)	Reason descriptions	The description of ambiguity flag.	4X,A16

EXAMPLE

```
     GREAT-PreEdit                           05-May-2020     SOFTWARE / DATE
AREG                                                         STATION
GPS    L1    L2                                              SYS / FREQ1 / FREQ2
GAL    E1   E5a                                              SYS / FREQ1 / FREQ2
GLO    G1    G2                                              SYS / FREQ1 / FREQ2
BDS    B1    B2                                              SYS / FREQ1 / FREQ2
  2020   01   01   00   00   00.00          GPST             BEGIN TIME
  2020   01   01   23   55   00.00          GPST             END TIME
    30.00                                                    INTERVAL
                                                             END OF HEADER
AMB   E04      1      314    RN_biggap
AMB   E12      1      314    RN_biggap
AMB   E14      1      107    RN_biggap
AMB   E19      1      314    RN_biggap
AMB   E21      1      314    RN_biggap
AMB   E26      1      182    RN_biggap
AMB   E33      1      314    RN_biggap
AMB   G01      1      314    RN_biggap
AMB   G03      1      314    RN_biggap
DEL   G04      1     2798    RN_mixed
AMB   G08      1      121    RN_biggap
```

Figure A.4-1 Example of ambflag file format

A.5 UPD File

DESCRIPTION

UPD file is just a text file containing EWL/WL/NL UPD records. A line indicates a UPD record of specified satellite. The following table shows the format of the UPD file.

No	Record/Field	Description	Formats
1	File header	The line starting with "%" is header line, which indicates UPD type.	
2	Solution body	Solution body consists of the following fields. The field contents are varied according to the UPD options.	

No	Record/Field	Description	Formats
(1)	Epoch time	It is an optional output which indicates the valid time of UPD.	
		It is necessary for epoch-wisely estimated NL/EWL_epoch UPD.	
		The format is showed as follows.	
		- " EPOCH-TIME"	1X,A
		- Modified Julian Day	2X,I6
		- Time of a day in seconds	2X,F8.1
(2)	UPD messages	A line contains value and standard deviation of UPD for specified satellite.	
		- Availability indicator (" " => available, "x" => unavailable)	A1
		- PRN number	A3
		- UPD value, unit: cycle	8X,F10.3
		- standard deviation of UPD	F10.3
		- Number of stations used for specified satellite UPD estimation	I5
(3)	End indicator	The flag which indicates the end of file.	
		- " EOF"	A

EXAMPLE

```
% UPD generated using upd_WL
 G01           0.000      0.030   27
 G02           0.207      0.000   29
 G03          -0.173      0.030   27
 G04          -0.089      0.039   12
 G05          -0.008      0.031   25
 G06           0.094      0.030   27
 G07          -0.454      0.034   19
 G08          -0.491      0.030   28
 G09          -0.151      0.030   29
EOF
```

Figure A.5-1 Example of WL UPD file format

```
% UPD generated using upd_EWL
 G01           0.000      0.020   29
xG02          -0.082  10000.000    0
 G03          -0.181      0.020   29
xG04          -0.082  10000.000    0
xG05          -0.082  10000.000    0
 G06           0.679      0.000   30
xG07          -0.082  10000.000    0
 G08           0.276      0.020   30
 G09          -0.073      0.020   28
 G10           0.168      0.020   29
EOF
```

Figure A.5-2 Example of EWL UPD file format

```
% UPD generated using upd_NL
 EPOCH-TIME    58689    82770.0
 G01              0.443      0.036    21
 G02              0.421      0.038    18
 G03              0.365      0.035    23
 G04              0.285      0.054     7
 G05             -0.062      0.038    18
 G06              0.551      0.036    21
 G07              0.587      0.035    23
 G08              0.450      0.036    22
 G09              0.818      0.000    27
 G10             -0.627      0.038    18
 EPOCH-TIME    58689    82800.0
 G01              0.443      0.037    21
 G02              0.421      0.038    18
 G03              0.366      0.035    23
 G04              0.285      0.054     7
 G05             -0.062      0.038    18
 G06              0.551      0.036    21
 G07              0.587      0.035    23
 G08              0.450      0.036    22
 G09              0.818      0.000    27
EOF
```

Figure A.5-3 Example of NL UPD file format

```
% UPD generated using upd_EWL_epoch
 EPOCH-TIME    58849    86340.0
 G01              1.188      0.038    16
xG02              0.000      0.000     0
 G03              0.476      0.000    17
xG05              0.000      0.000     0
 G06              0.978      0.039    15
xG07              0.000      0.000     0
 G08              2.277      0.042    12
 G09              0.209      0.042    12
 G10              0.910      0.038    16
 EPOCH-TIME    58849    86370.0
 G01              1.188      0.039    16
xG02              0.000      0.000     0
 G03              0.476      0.000    17
xG05              0.000      0.000     0
 G06              0.976      0.039    15
xG07              0.000      0.000     0
 G08              2.278      0.042    12
 G09              0.208      0.042    12
 G10              0.910      0.039    16
EOF
```

Figure A.5-4 Example of EWL_epoch UPD file format

A.6 IFCB File

DESCRIPTION

IFCB file is just a text file containing IFCB records. A line indicates an IFCB record of specified satellite. The following table shows the format of the IFCB file.

No	Record/Field	Description	Formats
1	IFCB messages	A line contains IFCB information, which consists of the following fields.	
(1)	Epoch time	It indicates the valid time of IFCB. The format is showed as follows.	
		- " EPOCH-TIME"	1X,A
		- Modified Julian Day	2X,I6
		- Time of a day in seconds	2X,F8.1
(2)	IFCB messages	A line contains value and standard deviation of IFCB for specified satellite.	
		- Availability indicator (" " => available, "x" => unavailable)	A1
		- PRN number	A3
		- IFCB value, unit: cycle	8X,F10.3
		- standard deviation of IFCB	F10.3
		- Number of stations used for specified satellite IFCB estimation	I5

EXAMPLE

```
 EPOCH-TIME   58689    86040.0
 G01           -0.011      0.005   54
xG02            0.000  10000.000    0
 G03           -0.019      0.007   43
xG04            0.000  10000.000    0
xG05            0.000  10000.000    0
 G06            0.012      0.032   28
xG07            0.000  10000.000    0
 G08            0.017      0.008   72
 G09            0.001      0.009   59
 G10           -0.011      0.007   30
 EPOCH-TIME   58689    86070.0
 G01           -0.013      0.006   54
xG02            0.000  10000.000    0
 G03           -0.020      0.008   42
xG04            0.000  10000.000    0
xG05            0.000  10000.000    0
 G06            0.011      0.005   28
xG07            0.000  10000.000    0
 G08            0.016      0.008   72
 G09            0.001      0.006   59
 G10
```

Figure A.6-1 Example of IFCB file format

Appendix B Default Priorities of Multiple Signals

If input observation data contains multiple signals in a frequency, GREAT-UPD will selects a signal for processing by the following default priorities.

System	Frequency.	Signal Priority (1: highest > 10: lowest) *							
		1	2	3	4	5	6	7	8
GPS	L1	1M	1Y	1W	1P	1X	1L	1S	1C
	L2	2M	2Y	2W	2P	2X	2L	2S	2C
	L5	5X	5Q	5I					
GLONASS	G1(range)	1P	1C						
	G1(phase)	1C	1P						
	G2	2P	2C						
Galileo	E1	1Z	1X	1C	1B	1A			
	E5a	5X	5Q	5I					
	E5b	7X	7Q	7I					
BeiDou	B1	2X	2Q	2I					
	B2	7X	7Q	7I					
	B3	6X	6Q	6I					