



NeQuick-G: a SMART and ready-to-go implementation

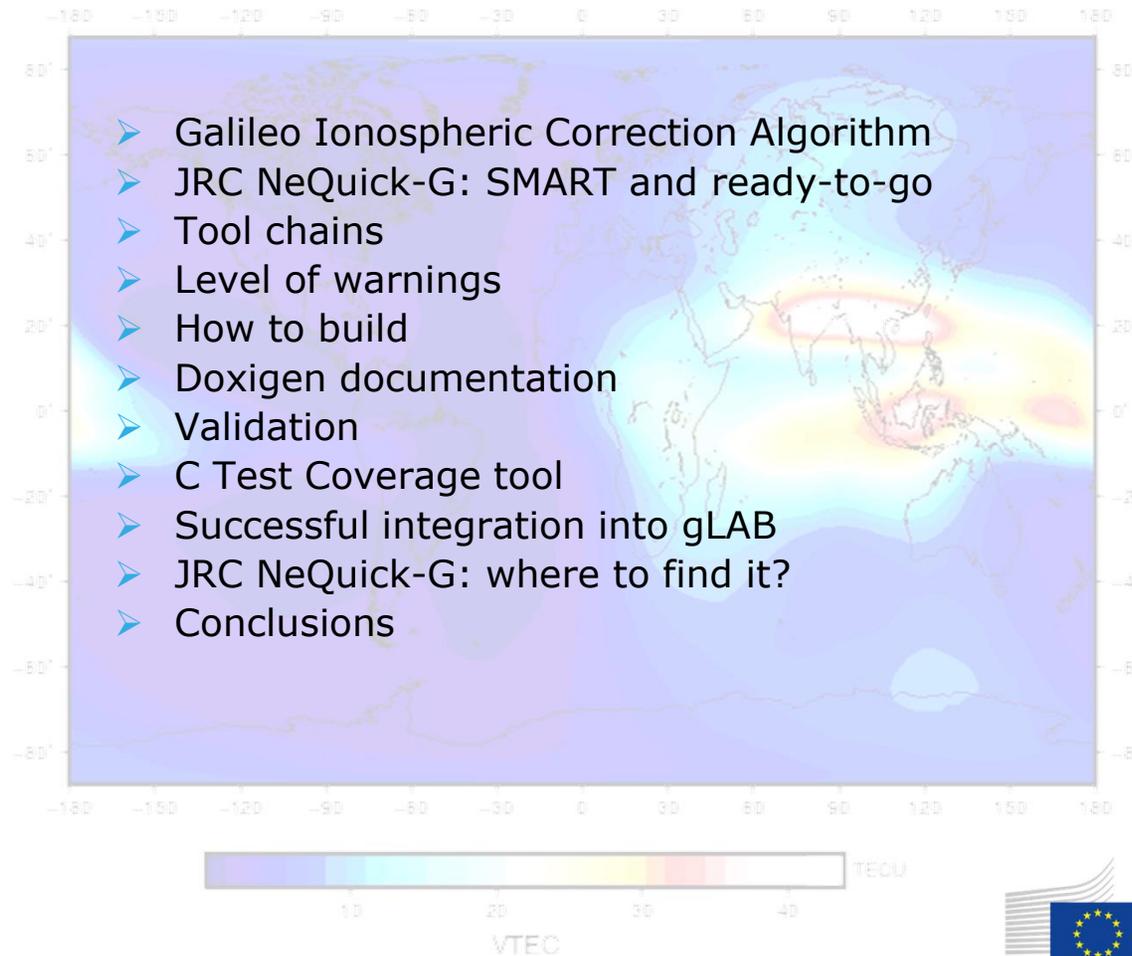
Angela Aragon-Angel (JRC)

The European Commission's
science and knowledge service
Joint Research Centre

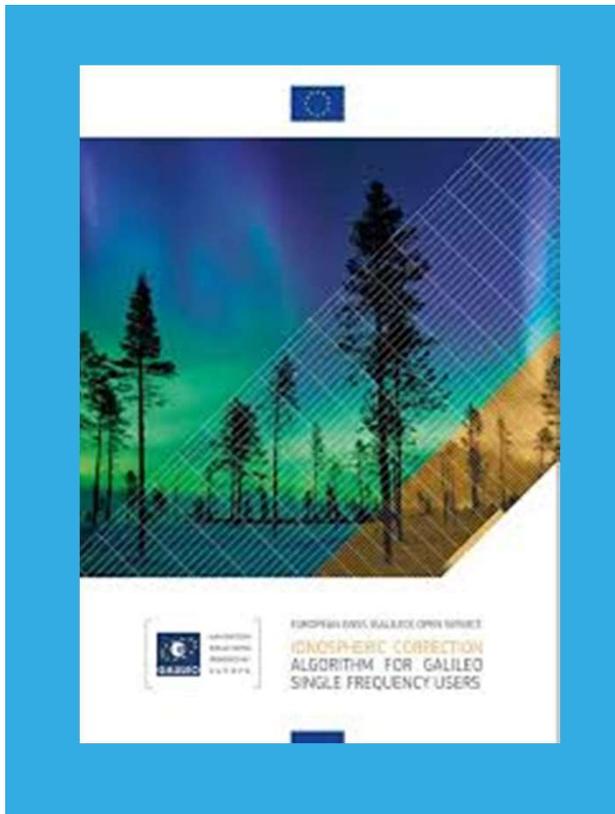
4th GNSS Raw Measurements Task Force Workshop
May 27 & 28, 2020



Outline



Galileo Ionospheric Correction Algorithm



- ✓ Issue 1.2, June 2016 available to public from GSA web site.
- ✓ Addresses mainly to Galileo OS receivers' manufacturers and OS SF users.
- ✓ Describes in detail the reference algorithm to be implemented at user receivers to compute the Galileo ionospheric corrections.
- ✓ Specific ICA for Galileo is **NeQuick-G**
- ✓ The driver for NeQuick-G is the effective ionization level, Az , where μ stands for the modified dip latitude or MODIP, which depends on the true magnetic dip I and the geographic latitude:

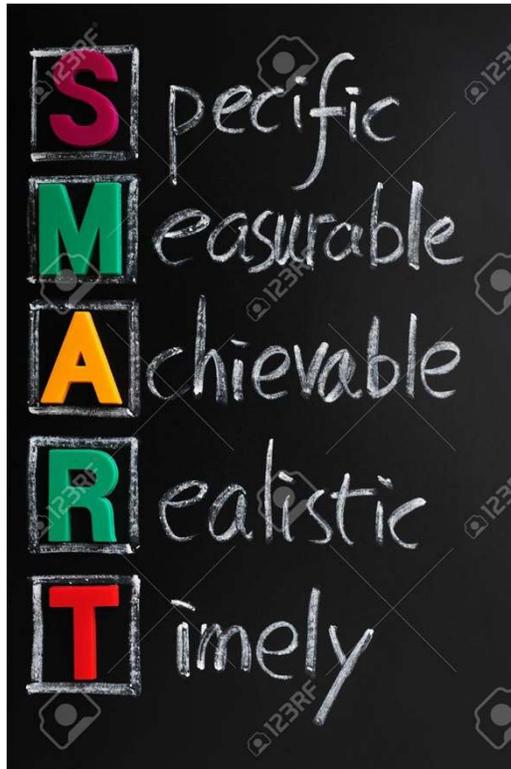
$$Az = a_0 + a_1\mu + a_2\mu^2$$

Broadcast coefficients by Galileo navigation message & obs

$$\tan \mu = \frac{I}{\sqrt{\cos \varphi}}$$

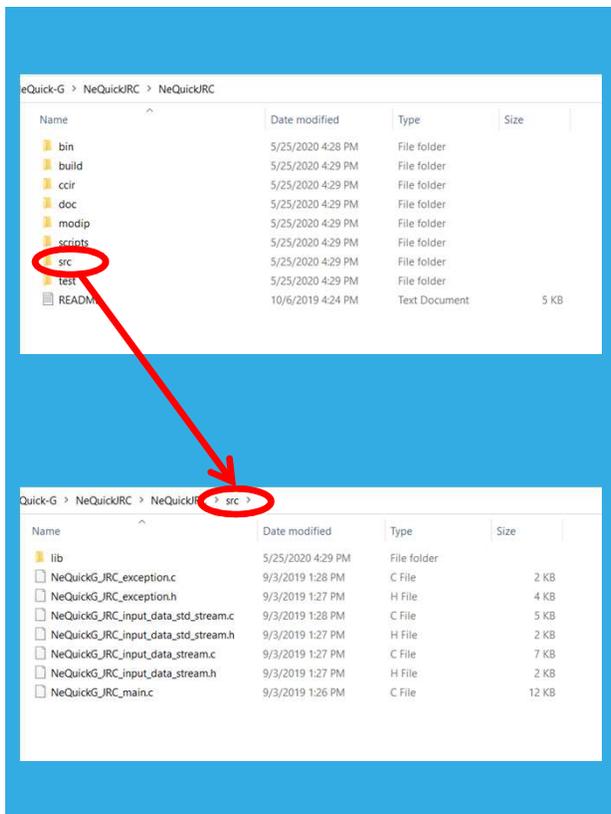


JRC NeQuick-G: SMART and ready-to-go



- ✓ The current source code has been designed in order to be modular; initially, it was considered the possibility to implement it in C++ but there were concerns about the final performance. Thus the final decision was to code in ISO/IEC 9899:2011 i.e. C11.
- ✓ The current source code is more legible for a potential programmer with little knowledge about ionosphere. Basically, reading the official reference document.
- ✓ Initially, an exceptions' mechanism was implemented (try and catch, inspired in C++ programming). Unfortunately, when testing the software distribution on a multi thread environment, it was proven not to be thread-safe.
- ✓ Other features, for instance, are regarding "define": they are not global; they are removed at the end of the file ("undefine"), when they are not needed any more.

JRC NeQuick-G: SMART and ready-to-go



- ✓ bin → Directory containing built in binary files
- ✓ build → makefiles to build are found here
- ✓ ccir → It contains 12 CCIR files required by NeQuick-G to launch calculations
- ✓ doc → Doxygen documentation
- ✓ modip → It contains the MODIP grid required by NeQuick-G to interpolate the MODIP value at the receiver location
- ✓ scripts → CCIR_to_c_source.pl
- ✓ src → Source codes (standard: ISO/IEC 9899:2011) i.e. *.c , *.h and driver
- ✓ test → To test the driver/library (Perl & Icov needed)
- ✓ UT → NeQuick-G unit tests (they have not been integrated into the public delivery)

It has been developed and tested to support the following OS:
Windows7, Cygwin 64 working on Windows 7 and Ubuntu 64



Tool chains

Along with the source code the following makefile are also provided (GNU make 4.2.1):

- ✓ A makefile for GNU gcc compiler version 8.3.0
- ✓ A makefile for clang compiler version 7.0.1-8
- ✓ A project for Microsoft Visual Studio 2015

Level of warnings

No warnings arising from compilation. The flags currently used are:

```
-m64 -std=c11 \  
-Wall -Wtrigraphs -Wcomment \  
-Wmissing-prototypes -Wunused-variable \  
-Wmissing-braces -Wfloat-equal -Wreturn-type \  
-Wshadow -Wpointer-arith -Wunused-parameter \  
-pedantic-errors -ffast-math \  

```



How to build

All the information you may need is self-contained in the makefile.

```
eriol@eriol-CELSIUS-H730: ~/Projects/Nequick/NeQuickJRC/build
File Edit View Search Terminal Help
(base) eriol@eriol-CELSIUS-H730:~/Projects/Nequick/NeQuickJRC/build$ ls -ltr
total 68
drwxrwxr-x 3 eriol eriol 4096 may 24 2019 msvc
-rw-rw-r-- 1 eriol eriol 143 may 29 2019 macros.mak
-rw-rw-r-- 1 eriol eriol 1095 jun 14 2019 help.mak
-rw-rw-r-- 1 eriol eriol 2762 jun 19 2019 check.mak
-rw-rw-r-- 1 eriol eriol 9218 sep 3 2019 makefile.mak
drwxrwxr-x 2 eriol eriol 4096 ene 8 16:08 clang
drwxrwxr-x 3 eriol eriol 4096 may 25 17:08 gcc
(base) eriol@eriol-CELSIUS-H730:~/Projects/Nequick/NeQuickJRC/build$
```

```
eriol@eriol-CELSIUS-H730: ~/Projects/Nequick/NeQuickJRC/build/gcc
File Edit View Search Terminal Help
(base) eriol@eriol-CELSIUS-H730:~/Projects/Nequick/NeQuickJRC/build$ cd gcc
(base) eriol@eriol-CELSIUS-H730:~/Projects/Nequick/NeQuickJRC/build/gcc$ make help
targets:
check
clean
clean_all
debug
doxygen
help
lint
release

configuration (make command line):
FTR_MODIP_CCIR_AS_CONSTANTS=1 CCIR coefficients/modip grip. No external files, added
as internal constants in the tool
(base) eriol@eriol-CELSIUS-H730:~/Projects/Nequick/NeQuickJRC/build/gcc$
```

Doxygen documentation

Automatic generation of documentation from the source code.



  NeQuickG_JRC

European Commission

Main Page Related Pages Modules Data Structures Files

NeQuick-G (Galileo)

Ionospheric Correction Algorithm for Galileo Single Frequency Users.

Example implementation of the algorithm to compute ionospheric corrections based on the broadcast coefficients in the navigation message for Galileo single-frequency users. The term Galileo is used to refer to the Global Navigation Satellite System (GNSS) established under the European GNSS programme.

Spec(s):

- European GNSS (Galileo) Open Service. Ionospheric Correction Algorithm for Galileo Single Frequency Users, 1.2 September 2016

Hints for Usage:

- Initialize the library (`NeQuickG_library.init`) using the CCIR files and MODIP file provided with the library
- Set inputs:
 - solar activity coefficients (`NeQuickG_library.set_solar_activity_coefficients`)
 - time (`NeQuickG_library.set_time`)
 - receiver position (`NeQuickG_library.set_receiver_position`)
 - satellite position (`NeQuickG_library.set_satellite_position`)
- Get the Slant Total Electron Content in TECU (`NeQuickG_library.get_total_electron_content`)
- Free resources (`NeQuickG_library.close`)

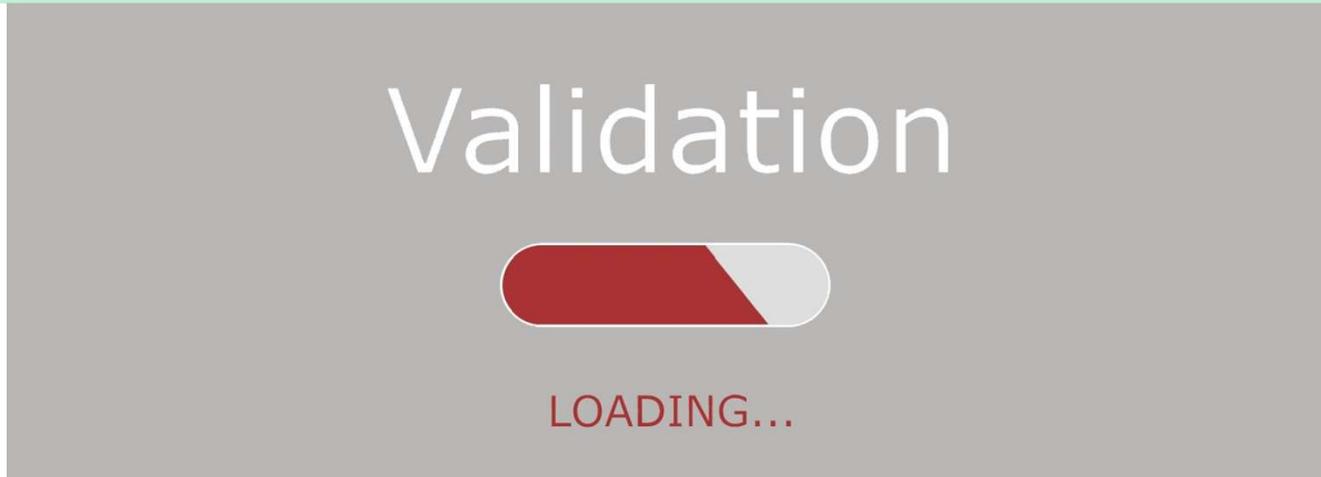
Author
Maria Angeles Aragon Angel (maria-angeles.aragon@ec.europa.eu)

Bug:
No known bugs.

Validation

Two validation stages:

- ✓ Official NeQuick-G document (108 test vectors)
- ✓ ESA NeQuick-G implementation (33396 test vectors)
- ✓ Initial validation using gLAB (175,214,364 test vectors)
- ✓ Massive validation using gLAB (2125 million test vectors)



Validation: Official NeQuick-G test vectors

All **108 examples** provided in the Galileo ICA official document correspond to the very same test case, which is **SLANT**.

There are no test vectors for:

- The **VERTICAL** case
- Polar cap station (very unlikely, but it has to be tested)
- All broadcast parameters are set to 0
- Months of year (except April)

Validation: Official ESA test vectors

ESA has 11132 test cases with 3 different sets of coefficient: **33396 test vectors** falling to the very same test case, which is **SLANT**.

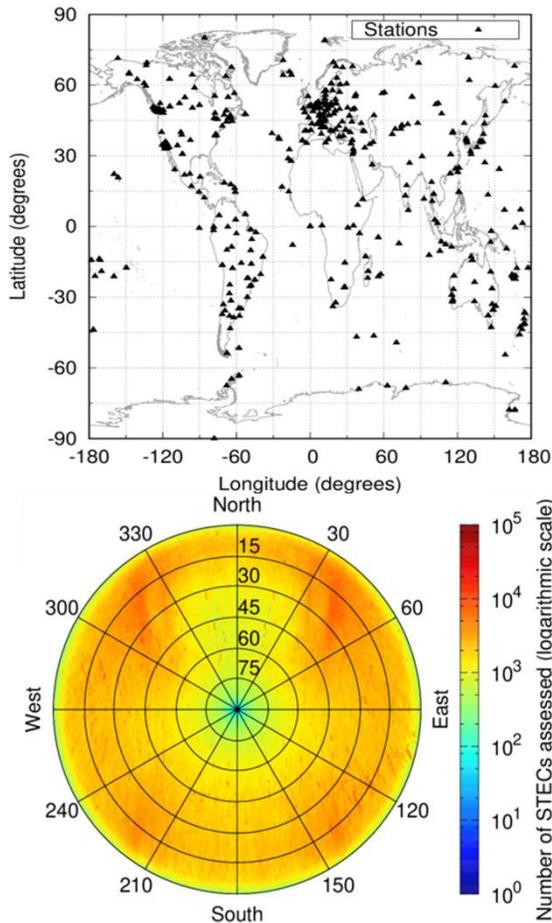
There are no test vectors for:

- The **VERTICAL** case
- Polar cap station (very unlikely, but it has to be tested)
- All broadcast parameters are set to 0

C Test Coverage tool

Filename ↕	Line Coverage	Functions ↕
NeQuickG JRC input data std stream.c	29.5 % 18 / 61	28.6 % 2 / 7
NeQuickG JRC TEC integration.c	38.2 % 34 / 89	50.0 % 5 / 10
NeQuickG JRC ray test.c	43.9 % 25 / 57	100.0 % 2 / 2
NeQuickG JRC UT.c	56.0 % 14 / 25	100.0 % 1 / 1
NeQuickG JRC main.c	59.4 % 82 / 138	62.5 % 5 / 8
NeQuickG JRC input data.c	66.7 % 12 / 18	75.0 % 3 / 4
NeQuickG JRC MODIP.c	70.6 % 12 / 17	100.0 % 3 / 3
NeQuickG JRC iono layer thickness test.c	72.2 % 26 / 36	100.0 % 2 / 2
NeQuickG JRC API test.c	73.5 % 50 / 68	100.0 % 7 / 7
NeQuickG JRC iono F1 layer test.c	77.8 % 7 / 9	100.0 % 2 / 2
NeQuickG JRC iono F2 layer fourier coefficients test.c	78.2 % 61 / 78	100.0 % 7 / 7
NeQuickG JRC Az test.c	80.0 % 8 / 10	100.0 % 2 / 2
NeQuickG JRC iono F2 layer test.c	80.7 % 46 / 57	100.0 % 4 / 4
NeQuickG JRC MODIP test.c	81.8 % 9 / 11	100.0 % 2 / 2
NeQuickG JRC exception.c	83.3 % 5 / 6	100.0 % 1 / 1
NeQuickG JRC iono E layer test.c	84.6 % 11 / 13	100.0 % 2 / 2
NeQuickG JRC solar test.c	84.6 % 11 / 13	100.0 % 2 / 2
NeQuickG JRC iono layer amplitudes test.c	85.0 % 34 / 40	100.0 % 2 / 2
NeQuickG JRC input data stream.c	86.4 % 57 / 66	100.0 % 8 / 8
NeQuickG JRC.c	86.9 % 86 / 99	92.3 % 12 / 13
NeQuickG JRC MODIP grid.c	87.8 % 65 / 74	100.0 % 9 / 9
NeQuickG JRC solar activity.c	90.0 % 36 / 40	100.0 % 7 / 7
NeQuickG JRC iono F2 layer fourier coefficients.c	93.4 % 142 / 152	100.0 % 16 / 16
NeQuickG JRC ray.c	94.7 % 125 / 132	100.0 % 14 / 14
NeQuickG JRC coordinates.c	94.7 % 36 / 38	87.5 % 7 / 8
NeQuickG JRC iono E layer.c	95.6 % 43 / 45	100.0 % 6 / 6
NeQuickG JRC interpolate.c	95.8 % 23 / 24	100.0 % 1 / 1
NeQuickG JRC Gauss Kronrod integration.c	96.9 % 31 / 32	100.0 % 3 / 3
ITU R P 371 8.c	100.0 % 5 / 5	100.0 % 1 / 1
NeQuickG JRC ray vertical.c	100.0 % 14 / 14	100.0 % 3 / 3
NeQuickG JRC iono F1 layer.c	100.0 % 25 / 25	100.0 % 3 / 3
NeQuickG JRC math utils.c	100.0 % 25 / 25	100.0 % 6 / 6
NeQuickG JRC geometry.c	100.0 % 26 / 26	100.0 % 5 / 5

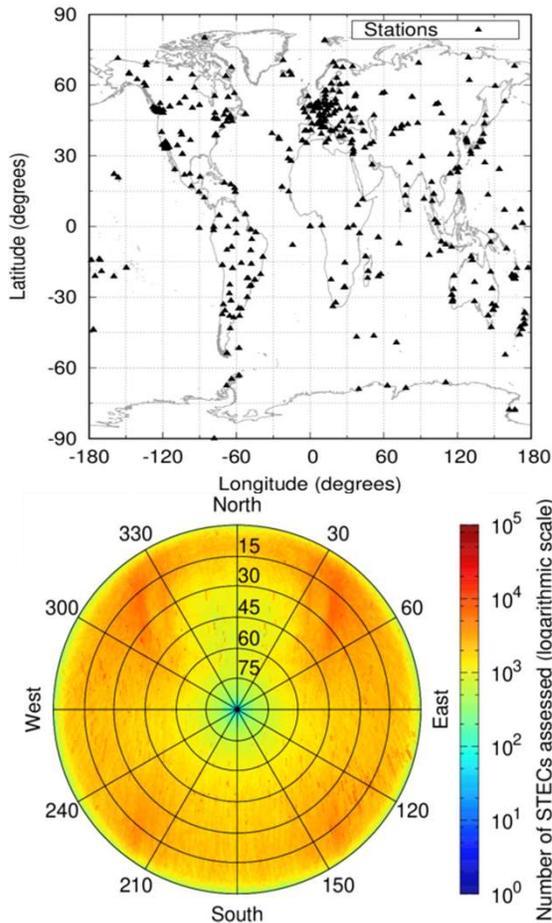
Successful integration into gLAB



- ✓ gLAB is a software tool suite developed by the research group of Astronomy and Geomatics (gAGE) from the Universitat Politècnica de Catalunya (UPC).
- ✓ gLAB performs precise modeling of GNSS observables (pseudorange and carrier phase) at the centimetre level, allowing standalone GPS positioning, PPP, SBAS and DGNSS.
- ✓ JRC NeQuick-G has been successfully integrated both:
 - ✓ As a library
 - ✓ Per request of the gLAB team, embedded in their code
- ✓ Both integrations of JRC NeQuick-G into gLAB have been massively tested.
- ✓ In order to generate benchmark values, the ESA NeQuick-G algorithm has been used.



Successful integration into gLAB



- ✓ 1st validation: 774 permanent stations from IGS. All satellites in view from GPS, Galileo, Glonass, Beidou, QZSS and IRNSS are modelled. In total, **175,214,364 STECs** that have been also compared against the implementation of NeQuick-G from the European Space Agency.
- ✓ 2nd validation: 1st day of every month for year 2019 have been selected. This constitutes a total number of **2125 million of STECs** inter-compared.
- ✓ After processing such large amount of data, only few discrepancies arise, which is a very positive outcome. Numerically, over 2125 million of STECs are equal, which account for the **99.998%** of the total.



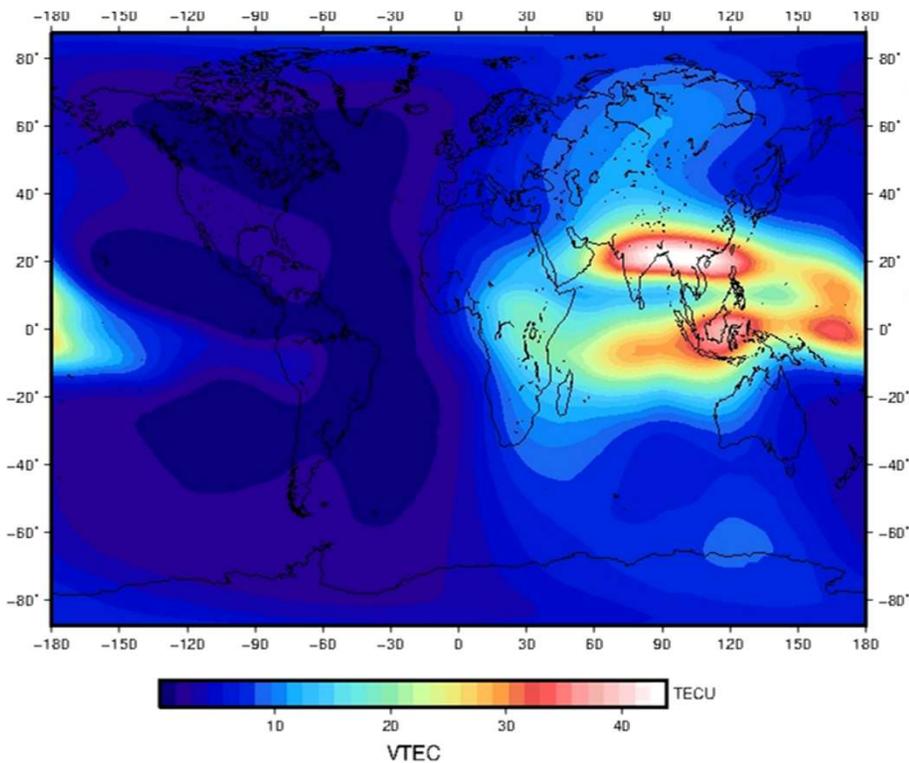
JRC NeQuick-G source code: where to find it?

The screenshot shows the website of the European GNSS Service Centre. The browser address bar displays the URL: <https://www.gsc-europa.eu/electronic-library/programme-reference-documents>. The page header includes the logo of the European Global Navigation Satellite Systems Agency and the title "European GNSS Service Centre". A navigation menu contains links for GALILEO, GNSS MARKET & APPLICATIONS, ELECTRONIC LIBRARY, SYSTEM & SERVICE STATUS, GSC PRODUCTS, and SUPPORT TO DEVELOPERS. A search bar is also present. The main content area is titled "Programme Reference Documents" and features a sidebar with categories: Programme Reference Documents, Service Notices, and Performance Reports. Under "Programme Reference Documents", there is a sub-menu for "Galileo" with options for "Open Service", "High Accuracy Service", and "Search and Rescue Service". A prominent button labeled "NEQUICK G SOURCE CODE" is visible in the right-hand navigation area. At the bottom of the page, there is a privacy notice and a "Decline" button. The browser's taskbar at the bottom shows the Windows logo, search bar, and various application icons, with the system clock indicating 5:45 PM on 5/22/2020.



This implementation has strictly followed the directions given in the official document

Conclusions



- ✓ JRC NeQuick-G is finally public after successful and rigorous testing with the gLAB tool.
- ✓ It has been designed to be highly modular, more legible for a potential programmer with no specific knowledge about signal propagation in the ionosphere.
- ✓ A library has been also developed to enable its quick integration into existing applications.
- ✓ It has been released as free and open source software under the terms of the European Union Public License (EURL), version 1.2.
- ✓ The open-source code is now ready to be implemented on single-frequency platforms and can be used on a global scale without limitation under the EURL. This freedom will contribute to a wider adoption of the NeQuick G model at user level.

Stay in touch



EU Science Hub: ec.europa.eu/jrc



Twitter: [@EU_ScienceHub](https://twitter.com/EU_ScienceHub)



Facebook: [EU Science Hub - Joint Research Centre](https://www.facebook.com/EU_Science_Hub_-_Joint_Research_Centre)



LinkedIn: [Joint Research Centre](https://www.linkedin.com/company/joint-research-centre)



YouTube: [EU Science Hub](https://www.youtube.com/EU_Science_Hub)