



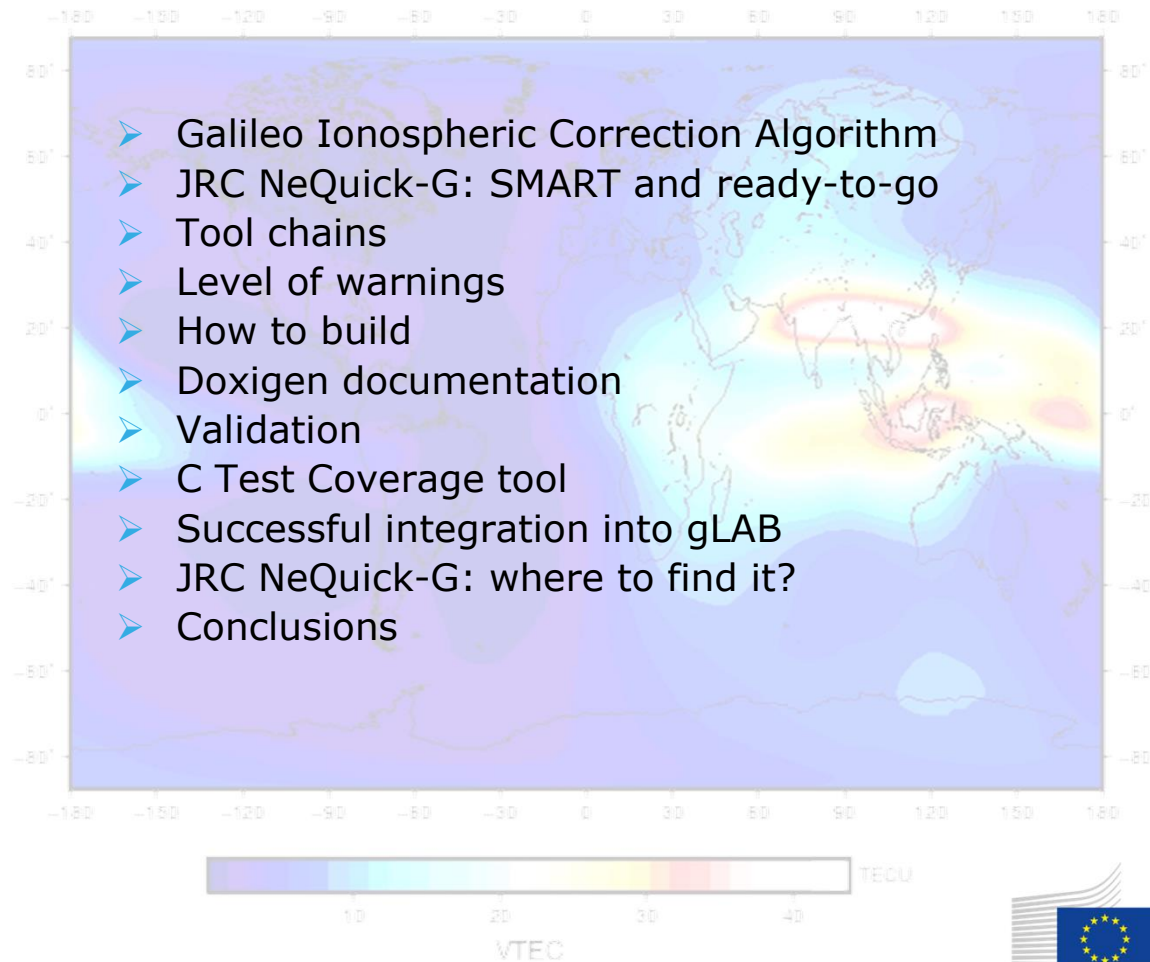
NeQuick-G: a SMART and ready-to-go implementation

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

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Outline



Galileo Ionospheric Correction Algorithm



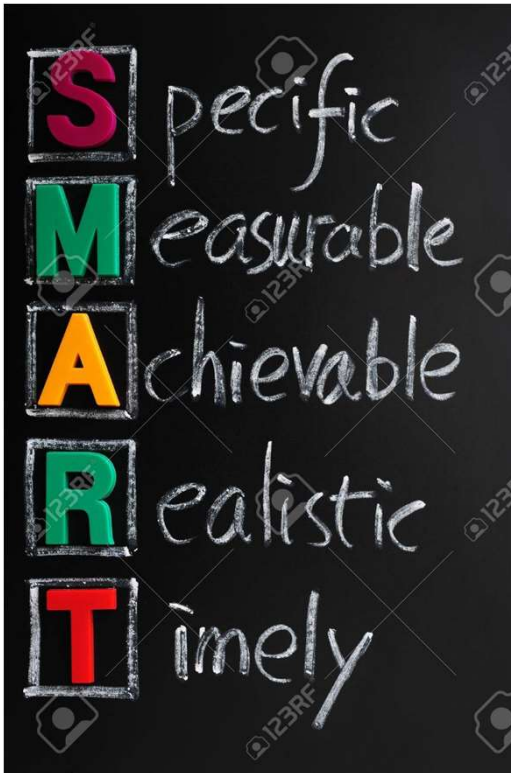
- ✓ Issue 1.2, June 2016 available to public from GSA web site.
- ✓ Addresses mainly to Galileo OS receivers' manufacturers and OS SF users.
- ✓ Describes in detail the reference algorithm to be implemented at user receivers to compute the Galileo ionospheric corrections.
- ✓ Specific ICA for Galileo 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

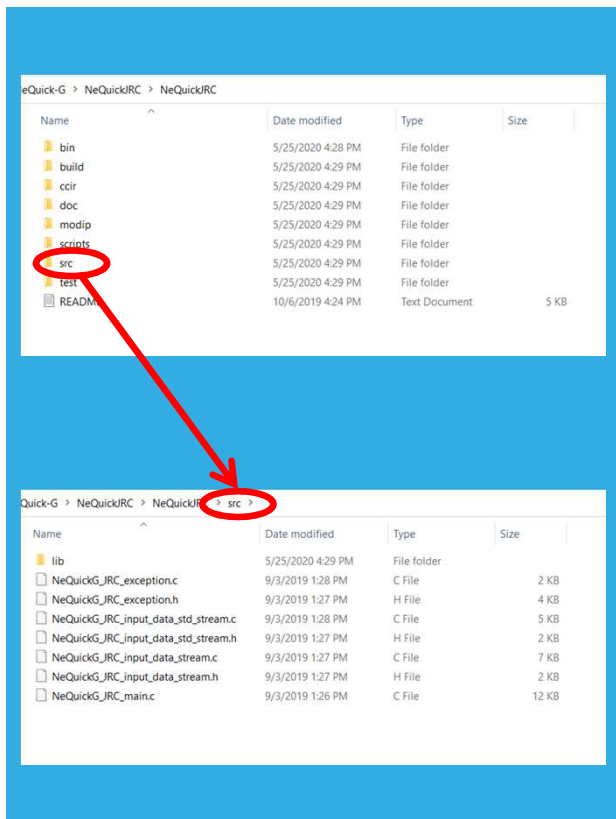
$$\tan \mu = \frac{I}{\sqrt{\cos \varphi}}$$

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.

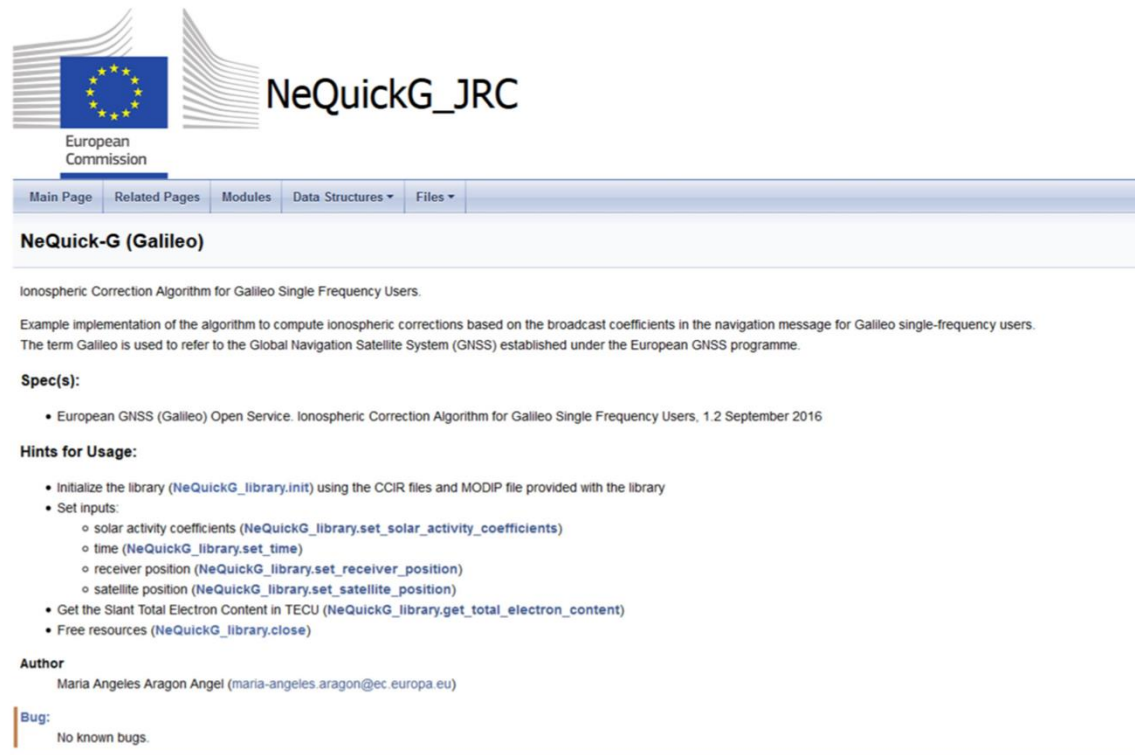
```
eriol@eriol-CELSIUS-H730: ~/Projects/Nequick/NeQuickJRC/build
File Edit View Search Terminal Help
(base) eriol@eriol-CELSIUS-H730:~/Projects/Nequick/NeQuickJRC/build$ ls -ltr
total 68
drwxrwxr-x 3 eriol eriol 4096 may 24 2019 msvc
-rw-rw-r-- 1 eriol eriol 143 may 29 2019 macros.mak
-rw-rw-r-- 1 eriol 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$
```

Doxigen 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`)

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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



LOADING...

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)










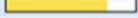























Validation: Official ESA test vectors

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

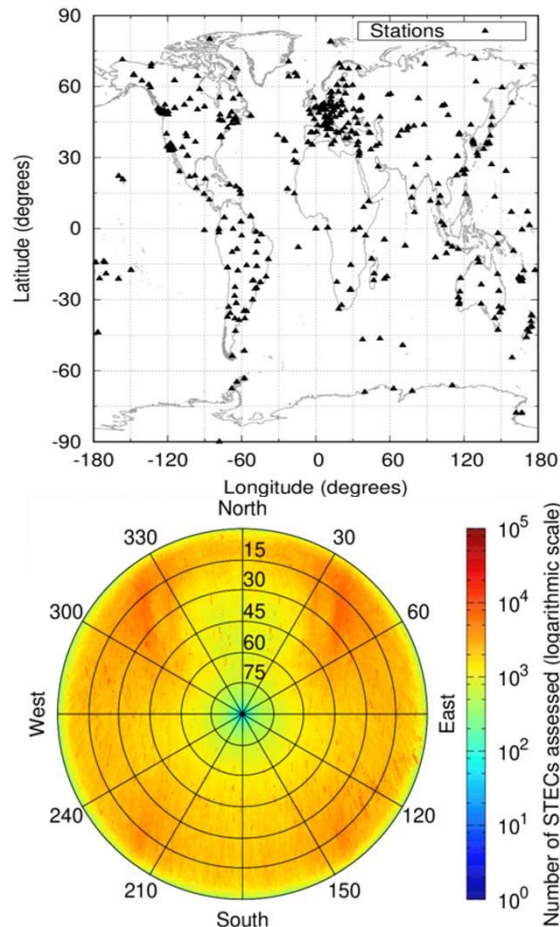
There are no test vectors for:

- 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

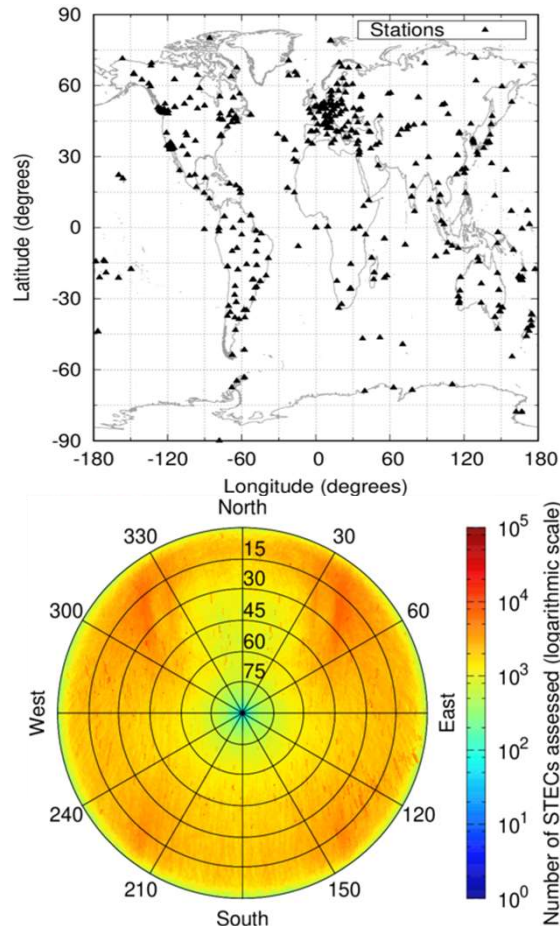
Filename ↕	Line Coverage			Functions ↕	
NeQuickG JRC input data std stream.c		29.5 %	18 / 61	28.6 %	2 / 7
NeQuickG JRC TEC integration.c		38.2 %	34 / 89	50.0 %	5 / 10
NeQuickG JRC ray test.c		43.9 %	25 / 57	100.0 %	2 / 2
NeQuickG JRC UT.c		56.0 %	14 / 25	100.0 %	1 / 1
NeQuickG JRC main.c		59.4 %	82 / 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.



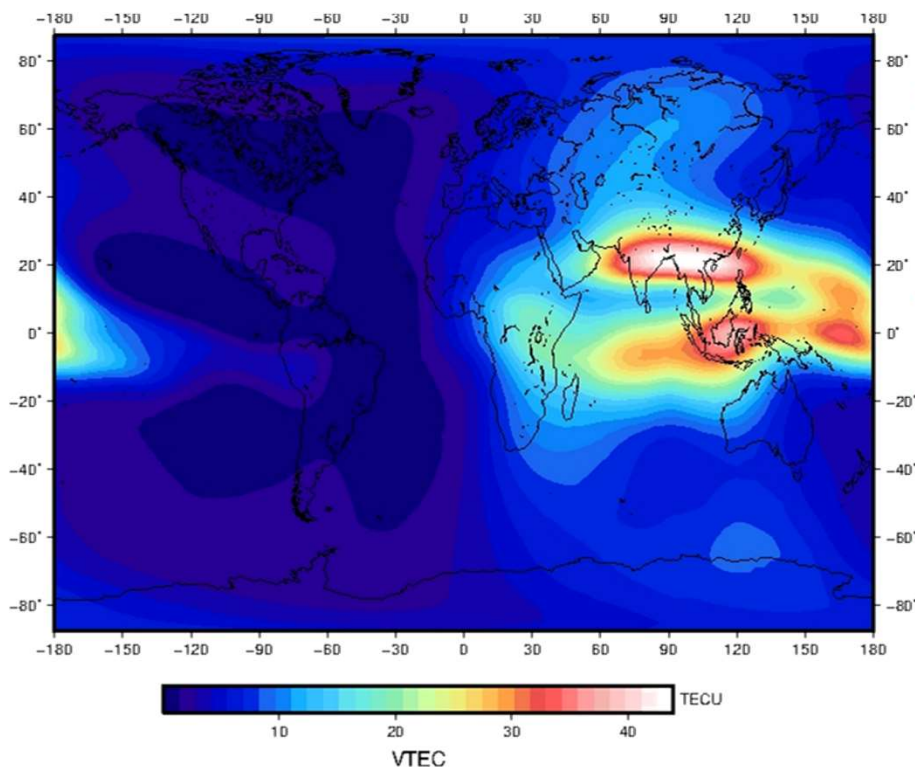
JRC NeQuick-G source code: where to find it?

The screenshot shows the website of the European GNSS Service Centre (GSC-Europa). The browser address bar displays the URL: <https://www.gsc-europa.eu/electronic-library/programme-reference-documents>. The website header includes the European GNSS Service Centre logo and navigation links: HOME, FAQ, LOGIN, REGISTER, and social media icons. A main navigation bar contains links for GALILEO, GNSS MARKET & APPLICATIONS, ELECTRONIC LIBRARY, SYSTEM & SERVICE STATUS, GSC PRODUCTS, and SUPPORT TO DEVELOPERS. The ELECTRONIC LIBRARY section is active, showing a sidebar with 'Programme Reference Documents' selected. The main content area is titled 'Programme Reference Documents' and lists categories: Galileo, Open Service, High Accuracy Service, and Search and Rescue Service. A sidebar on the right lists 'GALILEO SYSTEM STATUS', 'GSTI', 'GALILEO SATELLITE METADATA', 'GALILEO COMPATIBLE DEVICES', and 'NEQUICK G SOURCE CODE'. A footer banner at the bottom states: 'We care about your privacy, to learn more about how you can manage your consent in relation to cookies and analytics click here'. The browser's address bar shows the full path to the source code: <https://www.gsc-europa.eu/support-to-developers/nequick-g-source-code>. The Windows taskbar at the bottom shows the time as 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.

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