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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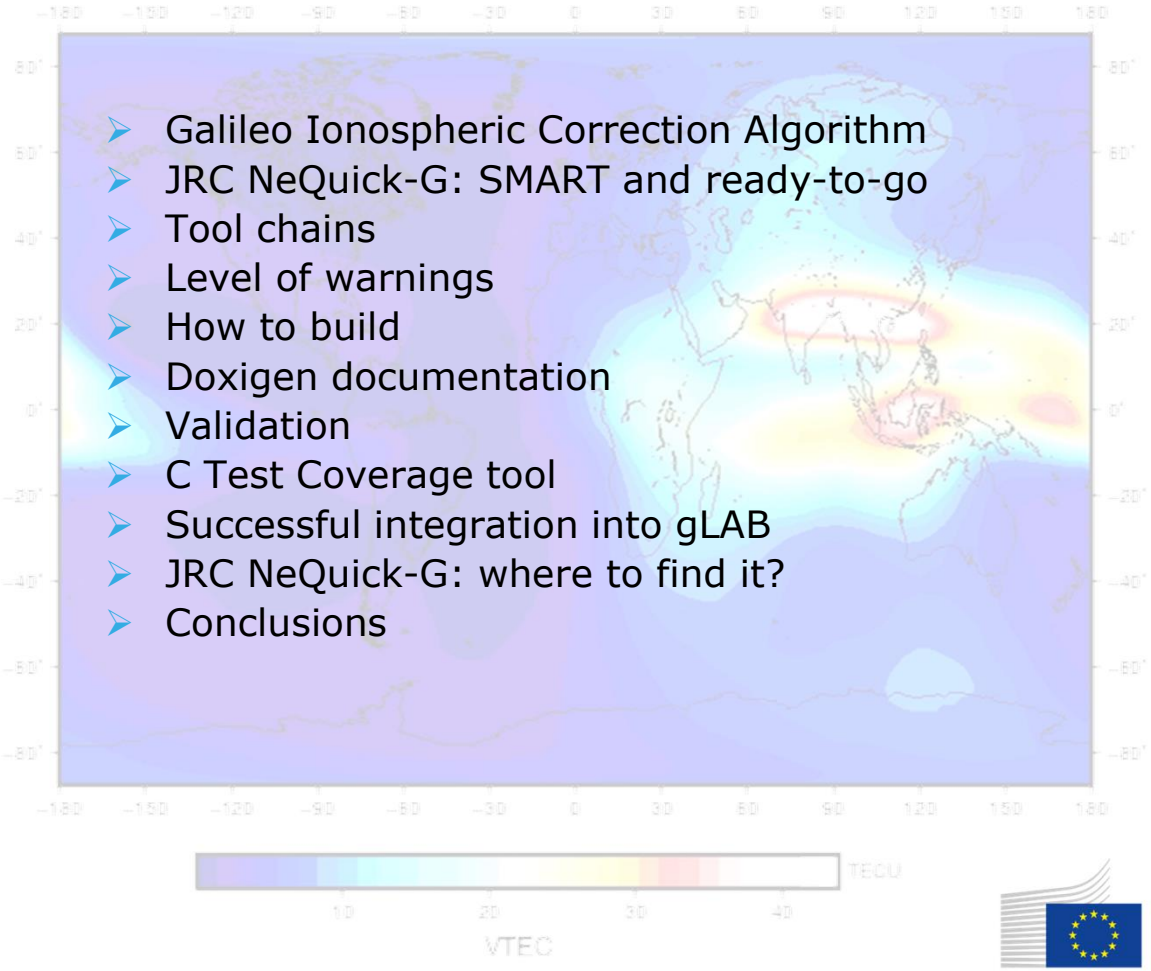
European Commission

Outline



- Galileo Ionospheric Correction Algorithm
- JRC NeQuick-G: SMART and ready-to-go
- Tool chains
- Level of warnings
- How to build
- Doxigen documentation
- Validation
- C Test Coverage tool
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- Conclusions

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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

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

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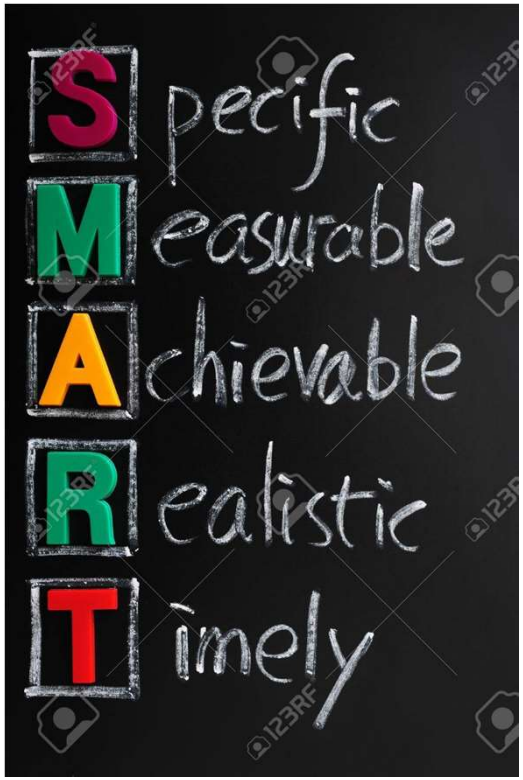
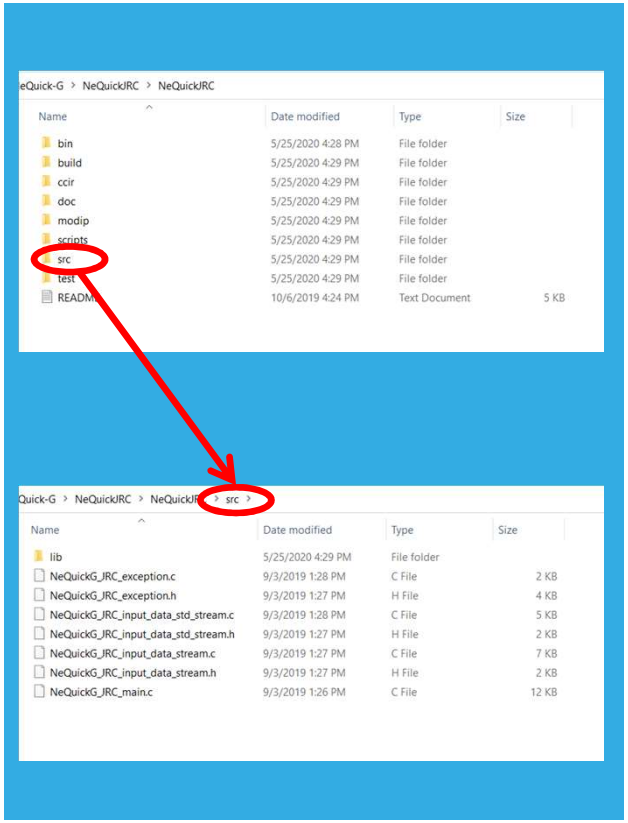
JRC NeQuick-G: SMART and ready-to-go



- ✓ 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 ➔ Doxigen 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**

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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

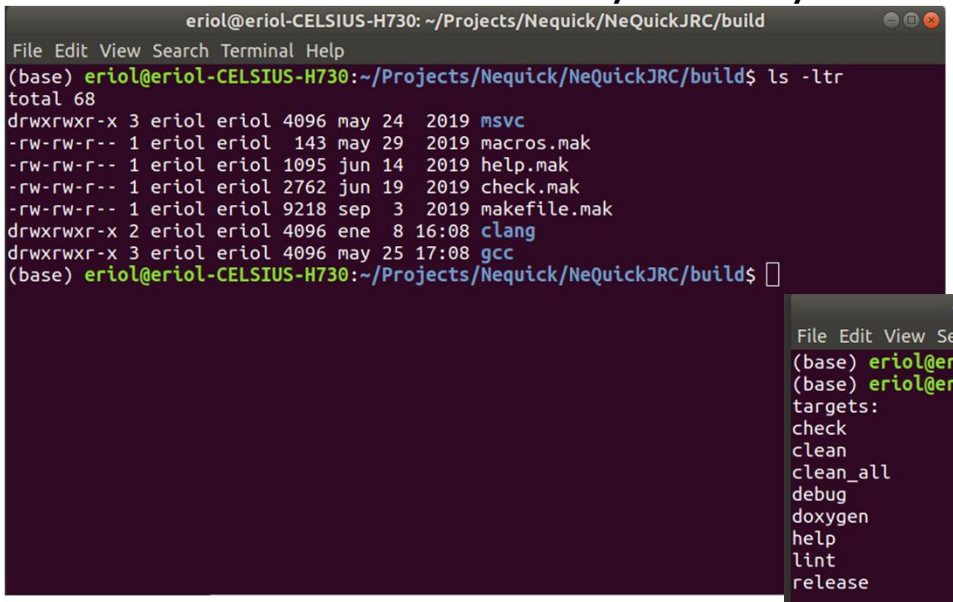
No warnings arising from compilation. The flags currently used are:

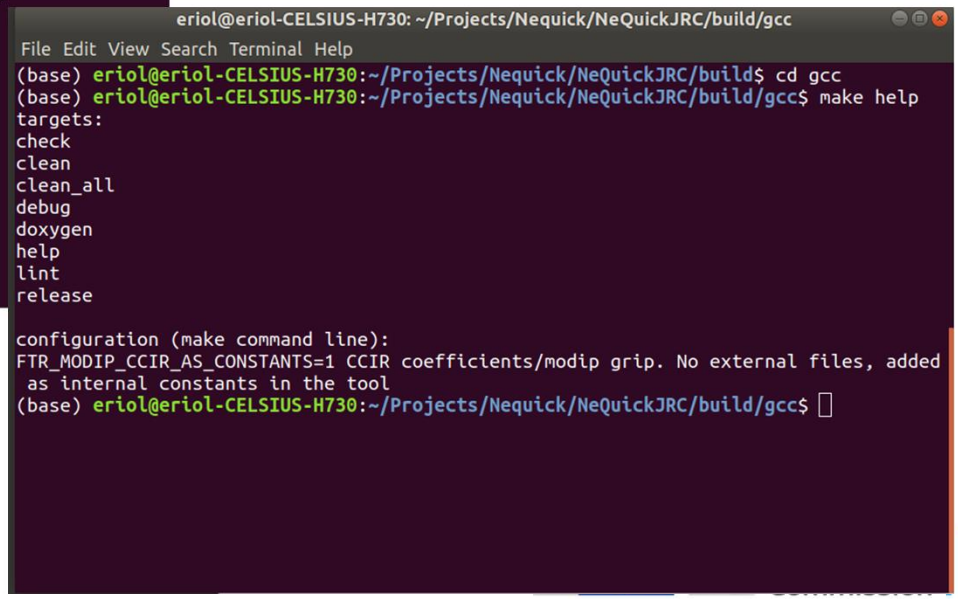
```
-m64 -std=c11 \
-Wall -Wtrigraphs -Wcomment \
-Wmissing-prototypes -Wunused-variable \
-Wmissing-braces -Wfloat-equal -Wreturn-type \
-Wshadow -Wpointer-arith -Wunused-parameter \
-pedantic-errors -ffast-math \
```

 Static analyzer (PC-lint for C/C++ (NT) Vers. 9.00L)

How to build

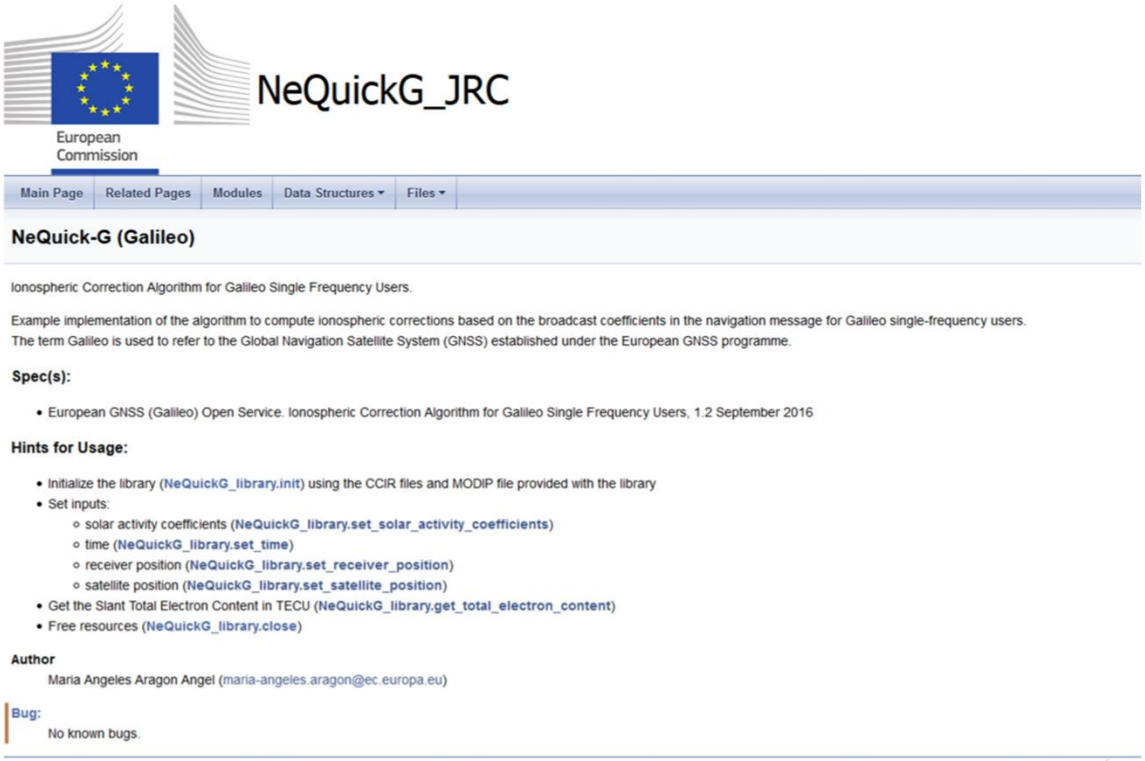
All the information you may need is self-contained in the makefile.





Doxigen documentation

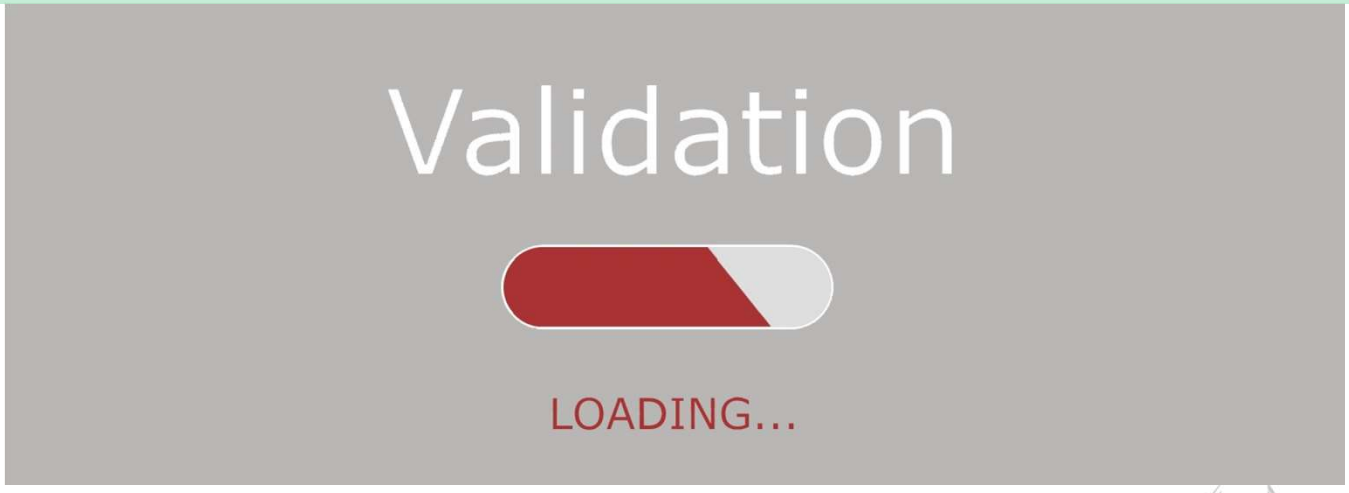
Automatic generation of documentation from the source code.



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)



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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

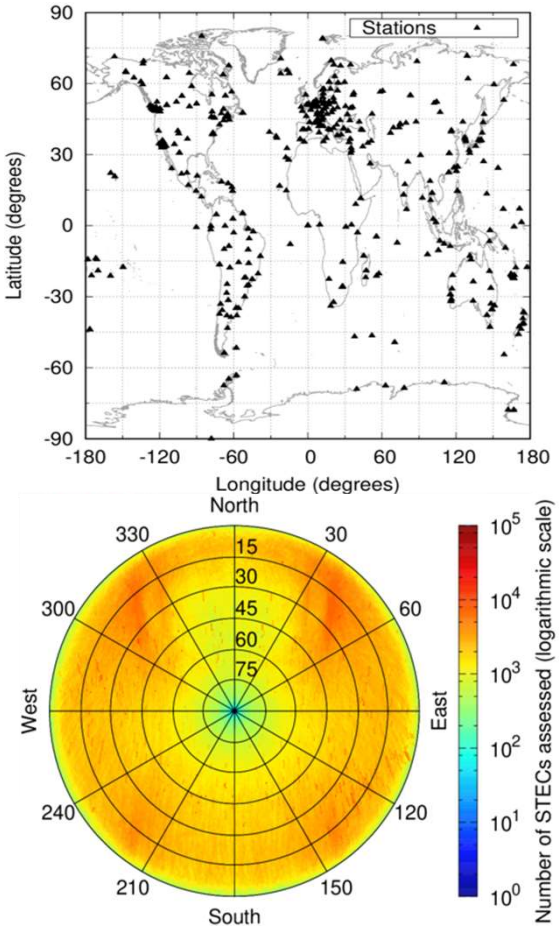
ESA has 11132 test cases with 3 different sets of coefficient: **33396 test vectors** falling to the very same test case, which is **SLANT**.
There are no test vectors for:

- 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 Politecnica 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.

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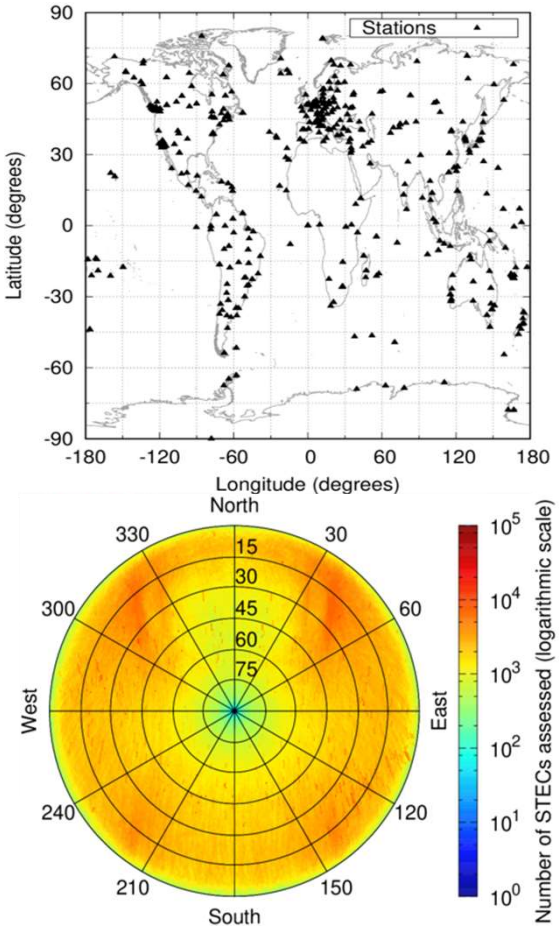
Successful integration into gLAB



- ✓ 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.

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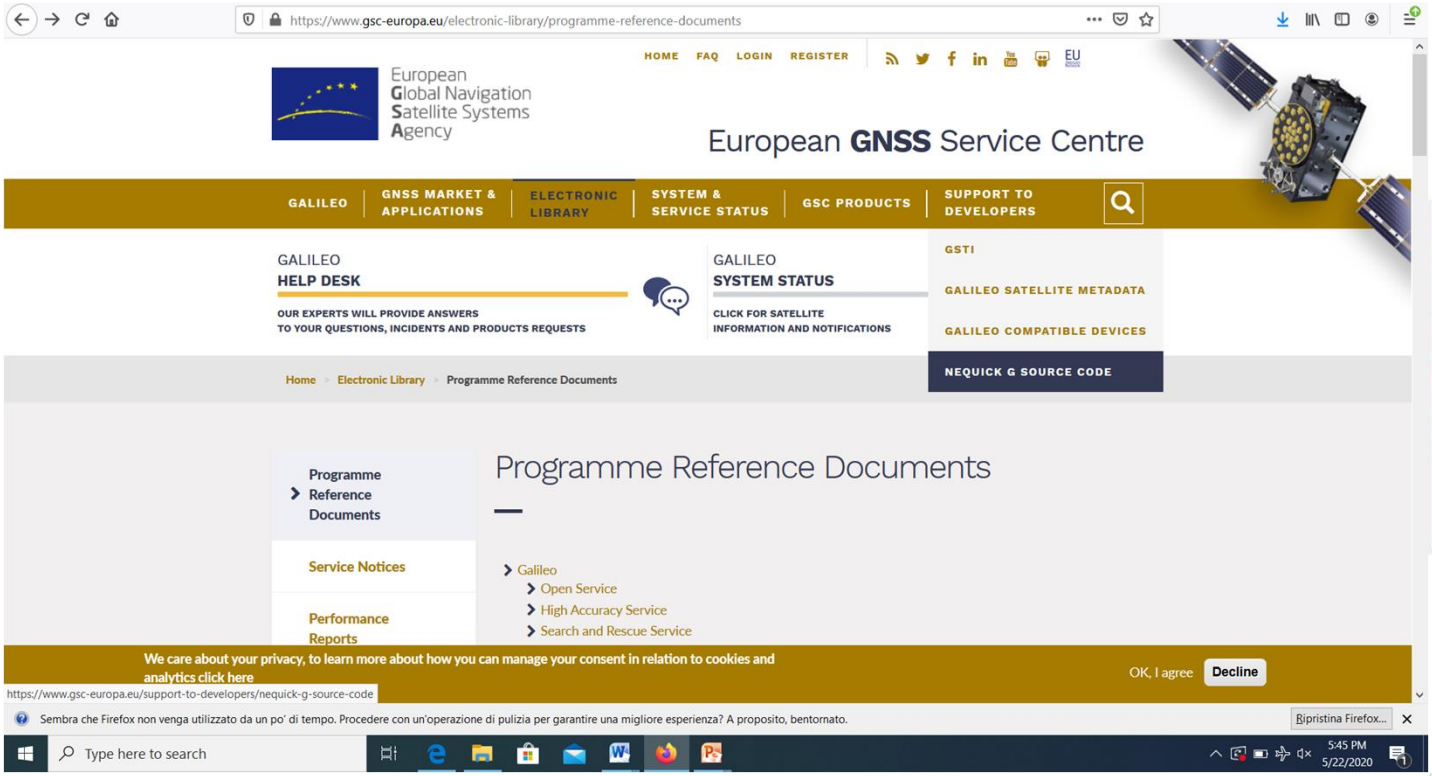
JRC NeQuick-G source code: where to find it?



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

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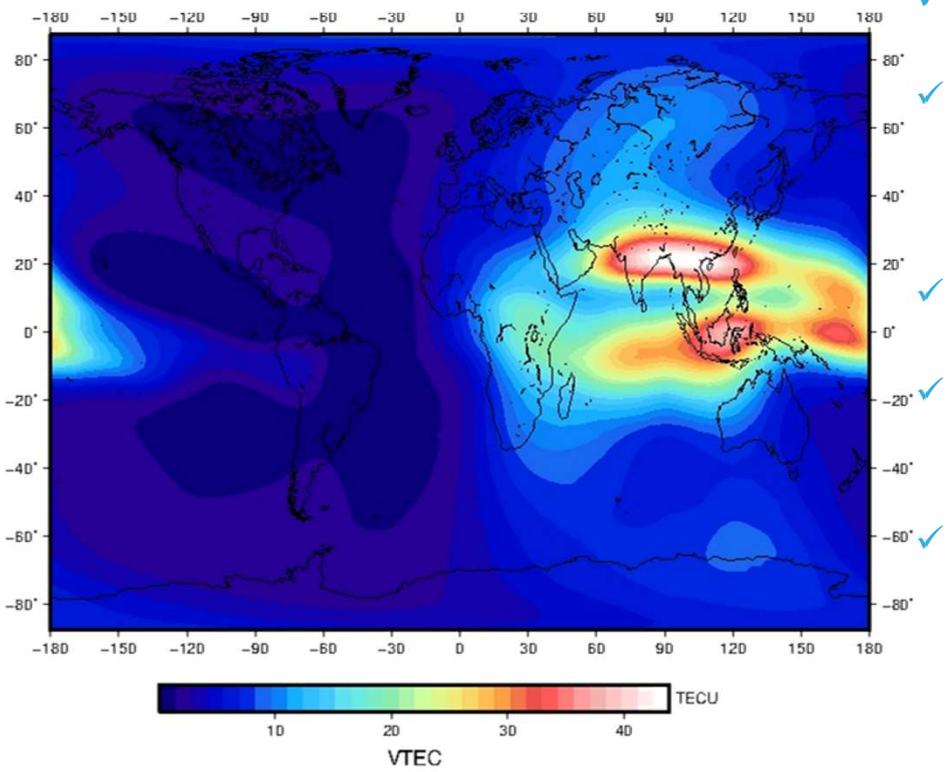
Conclusions



- ✓ 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 (EUPL), 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 EUPL. This freedom will contribute to a wider adoption of the NeQuick G model at user level.

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