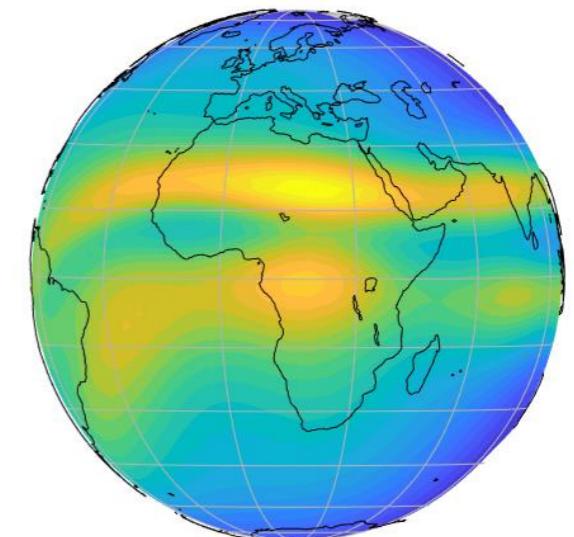


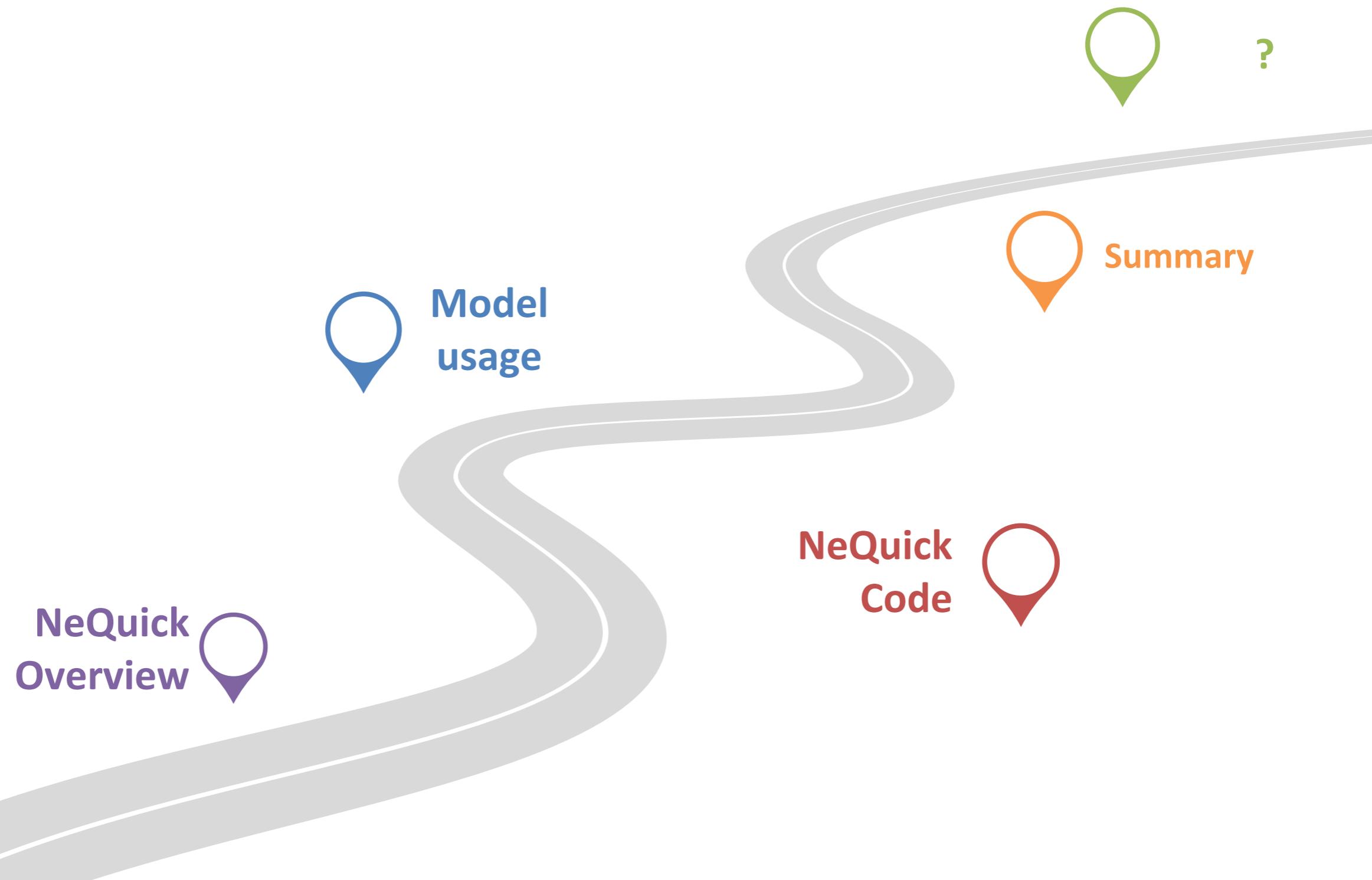
THE NEQUICK MODEL

Yenca Migoya-Orué
STI, ICTP

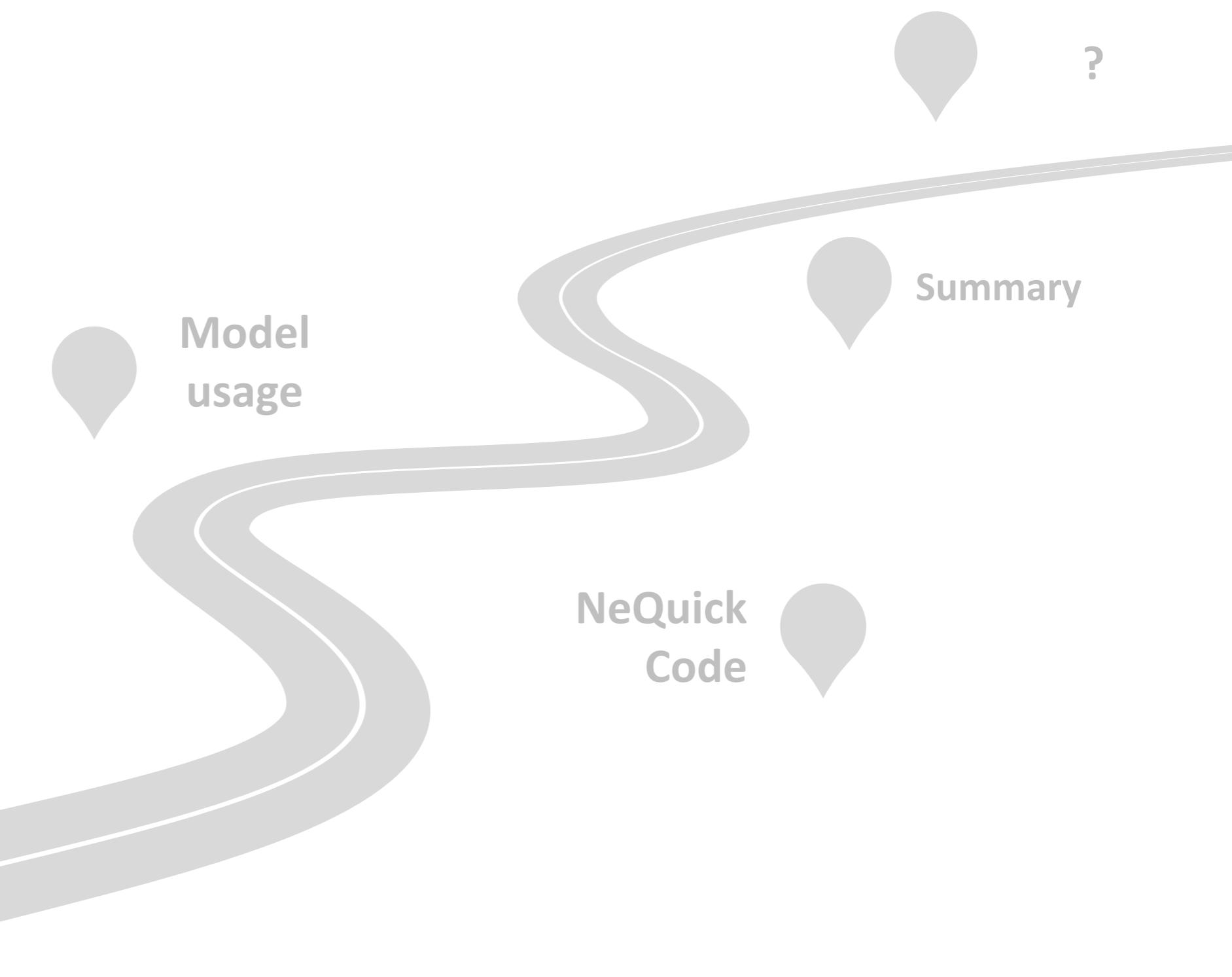


Eastern Africa Capacity Building Workshop on Space Weather and Low-latitude Ionosphere
Malindi, Kenya 3-12 October, 2023

Talk roadmap

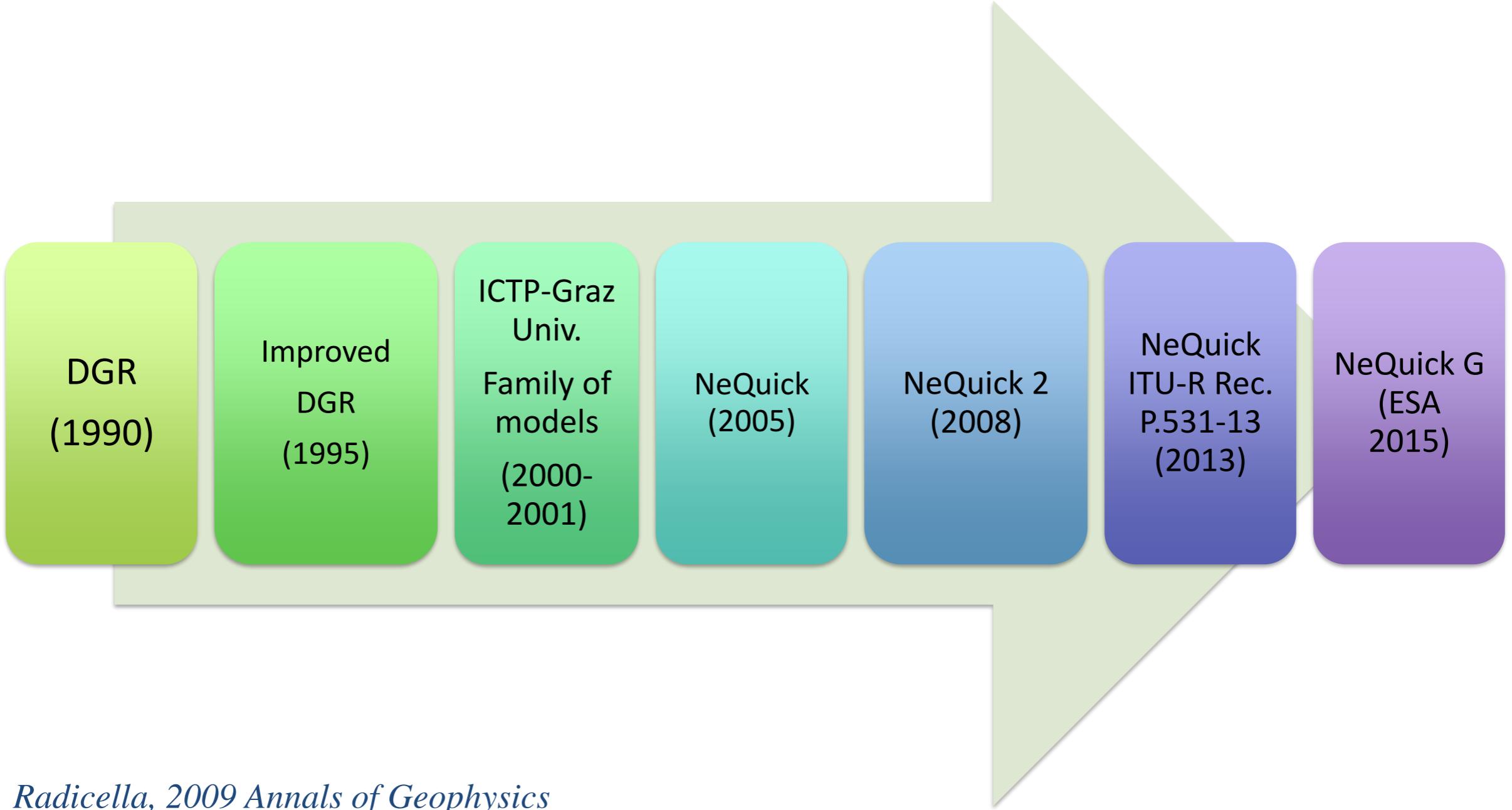


NeQuick
Overview



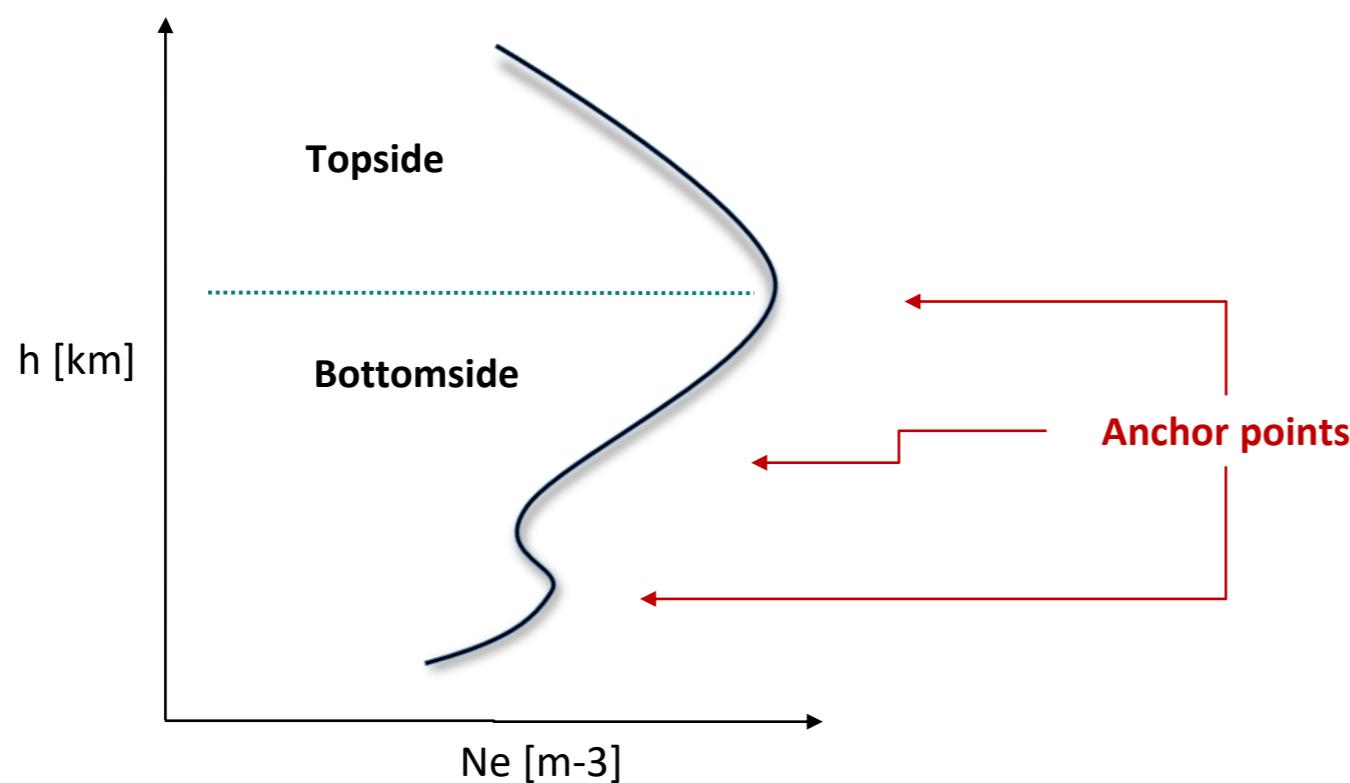
NeQuick Overview

A historical view

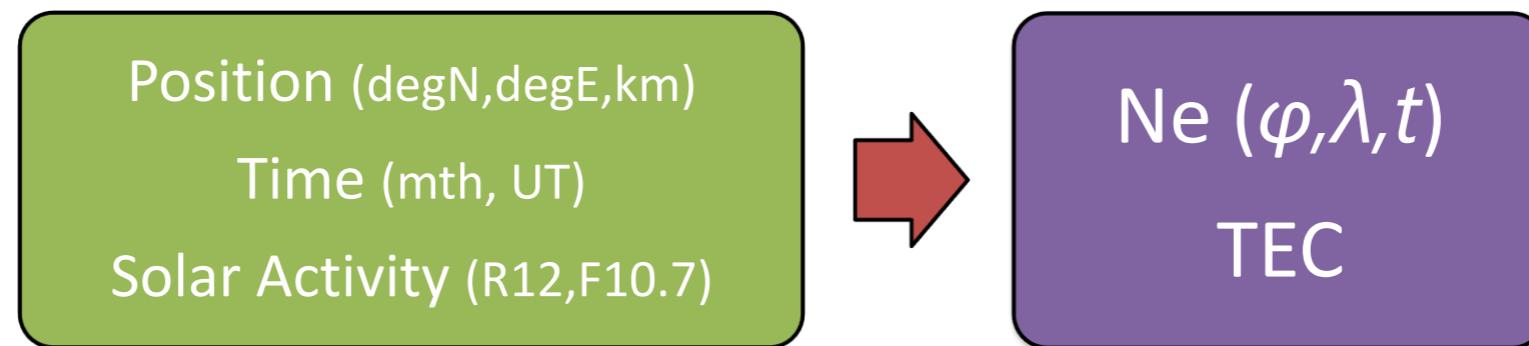


NeQuick Overview

NeQuick's profile includes 6 semi-Epstein layers and makes use of anchor points defined by foE, foF1, foF2 and M(3000)F2 values.

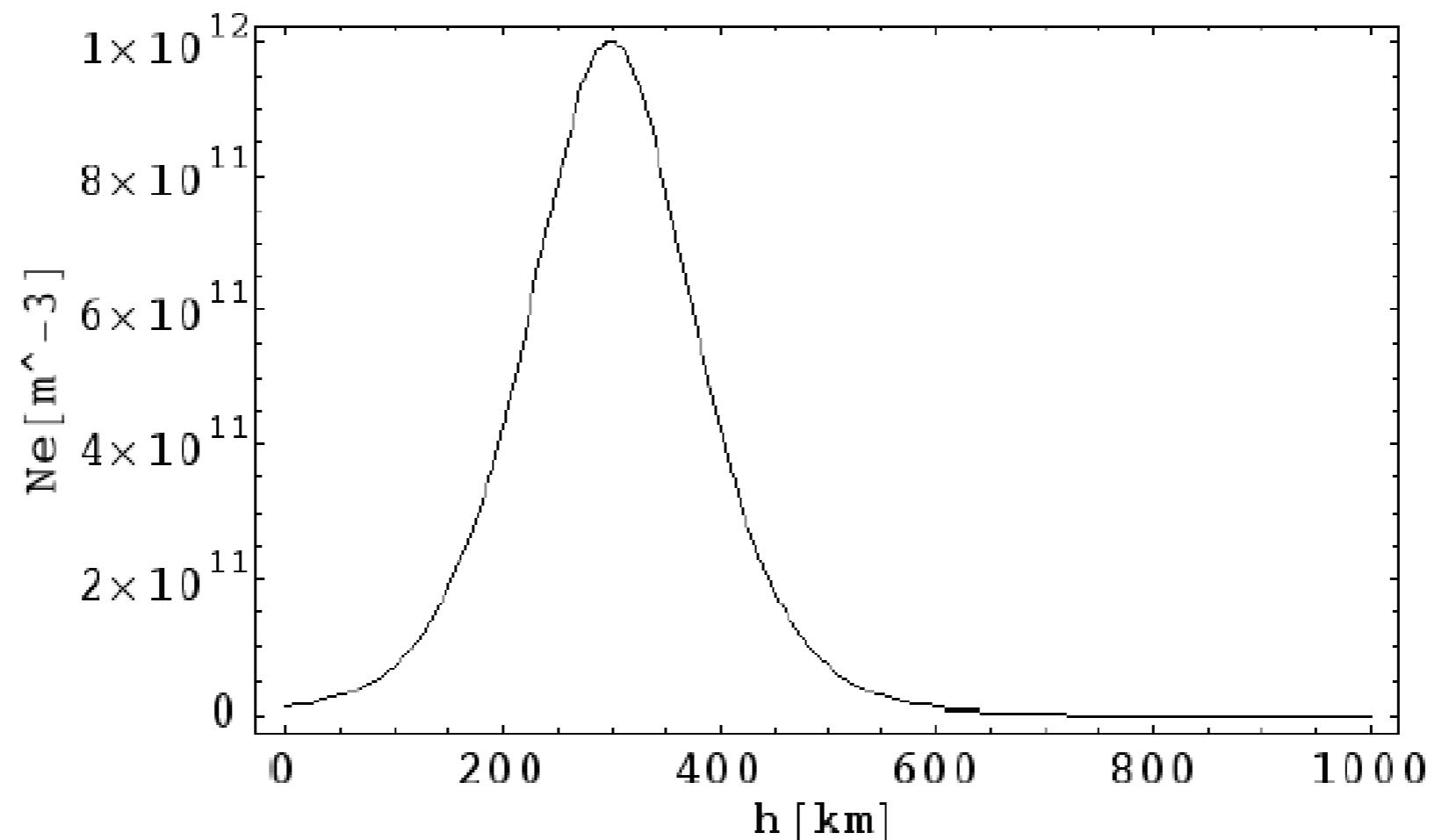


modelled (e.g. ITU-R coefficients for foF2, M(3000)F2) or experimentally derived



Epstein Layer

$$N(h, h_{max}, N_{max}, B) = \frac{4N_{max}}{(1 + \exp(h - h_{max}/B))^2} \frac{\exp(h - h_{max})}{B}$$

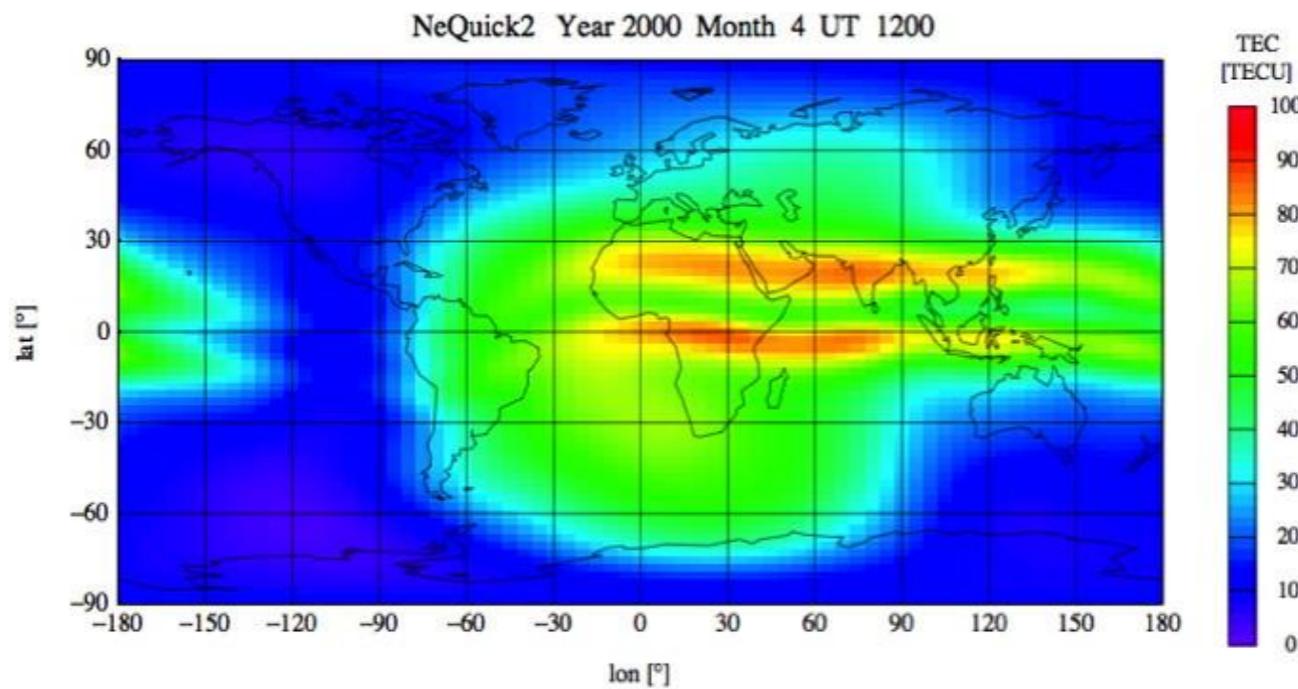


Epstein, (1930)

Rawer, K. (1982), Advances in Space Research

NeQuick 2 Overview

- Revision of the original DGR approach for the F1 and E regions formulation was done.
- Improvement of the topside.
- The computer code of the model was also improved.



COISSON, P. AND S.M. RADICELLA, R. LEITINGER AND B. NAVA (2006) Topside electron density in IRI and NeQuick: features and limitations parameters, *Adv. Space Res.*, 37, 937-942

LEITINGER, R., M.L. ZHANG and S. M. RADICELLA (2005), An improved bottomside for the ionospheric electron density model NeQuick, *Annals of Geophysics* 48(3) 525-534

NAVA. B., P. COISSON AND S.M. RADICELLA (2008), A new version of the NeQuick ionosphere electron density model; *J.of Atmos.and Solar-Terr. Physics.*

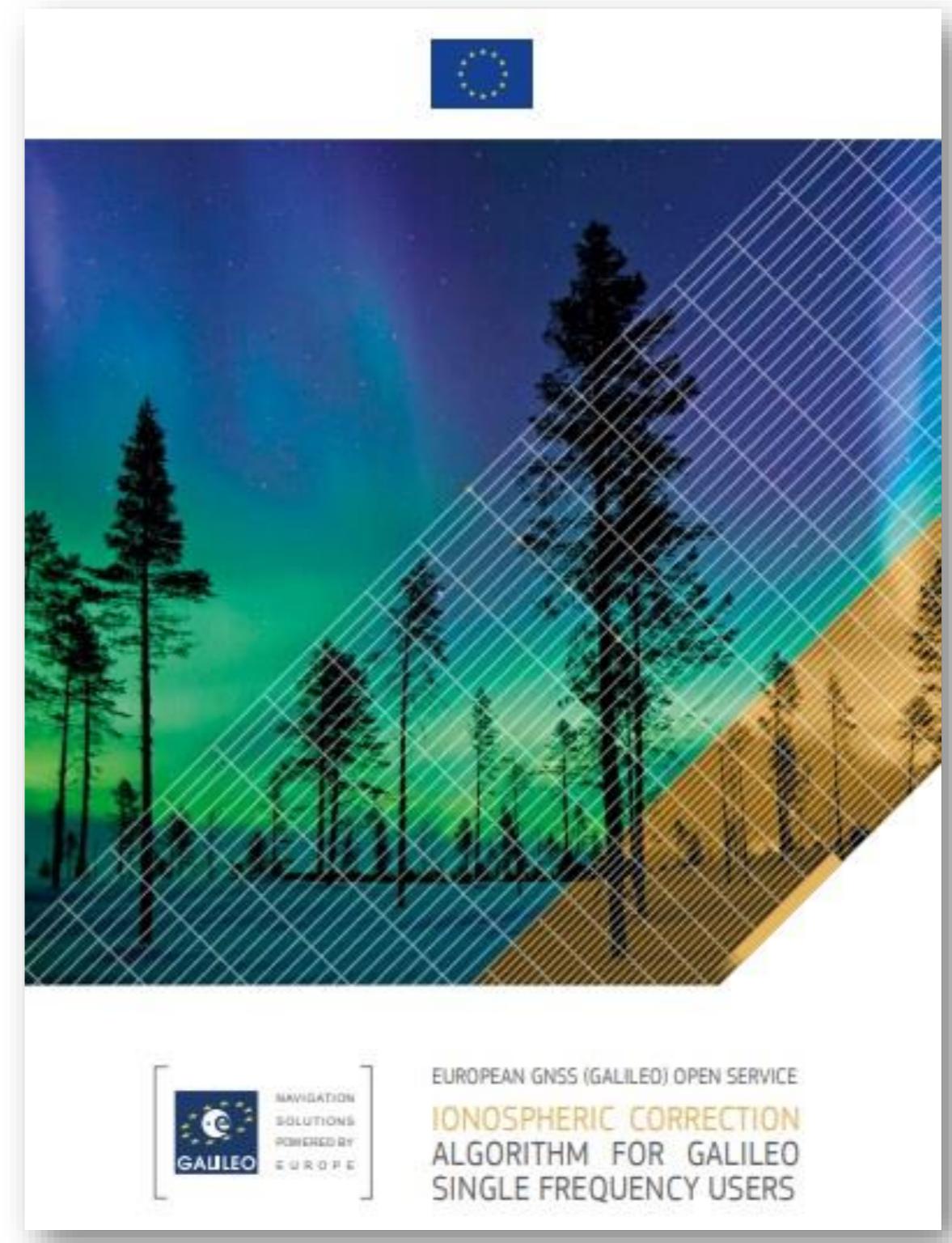
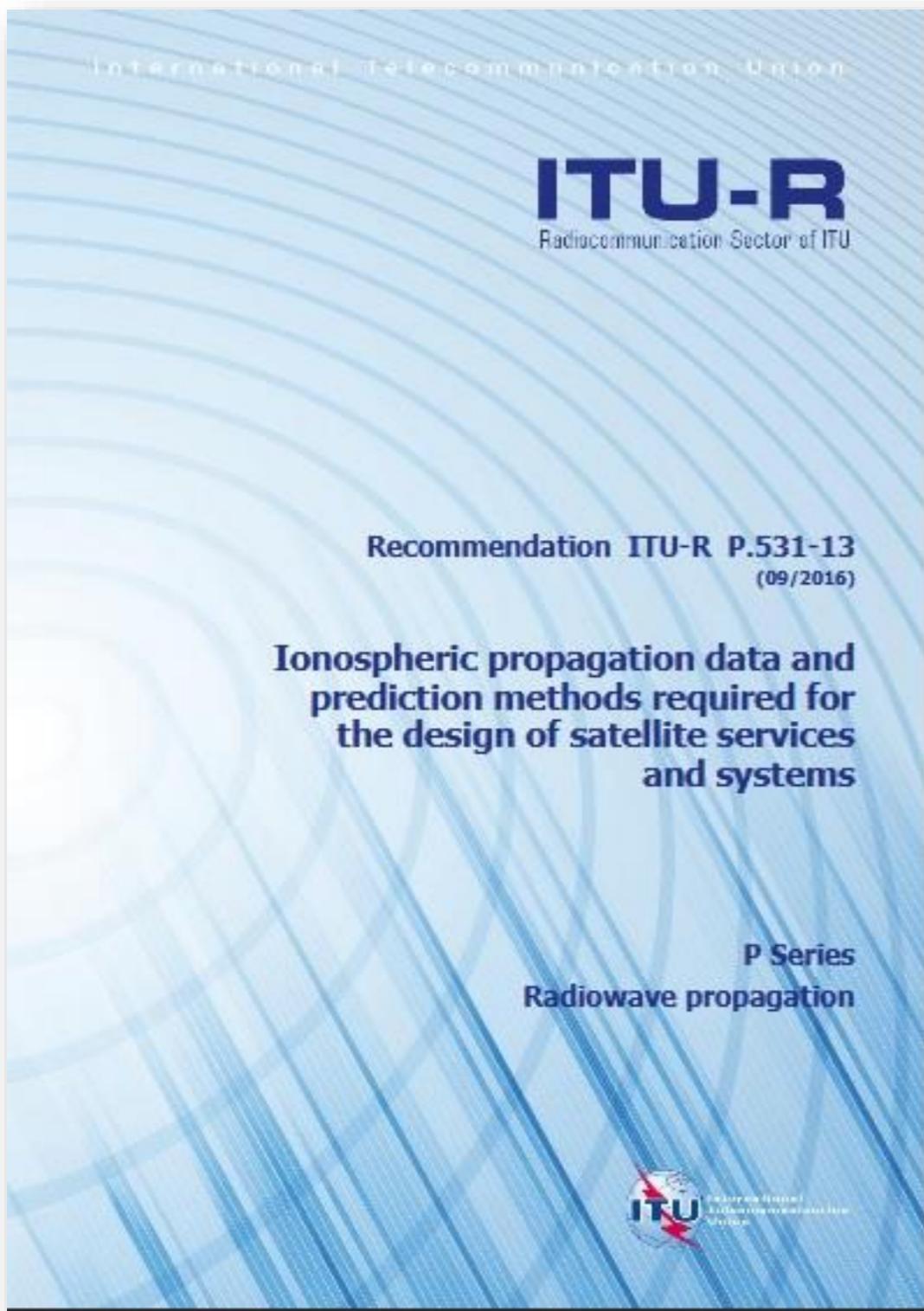
NeQuick Overview

Radicella, 2009 Annals of Geophysics

- NeQuick 2 topside adopted in IRI (since 2007 version) as topside option.
- NeQuick used to produce 'ionospheric scenarios' for EGNOS.
- NeQuick 2 included in the ESA (SPENVIS) Space Environment Information System.
- NeQuick-based version adopted as the model for ionospheric corrections in the single frequency operation of GALILEO.



NeQuick 2 in ITU-R and NeQuick G





ICG Working Groups Recommendations

- NeQuick Ionospheric Model

To assess the performance and usability of a NeQuick ionospheric correction algorithm for the single frequency users similar to the one adopted by Galileo in view of its expected good performance compared with other models, i.e. at low latitudes:

http://www.gsc-europa.eu/system/files/galileo_documents/Galileo_Ionospheric_Model.pdf

NeQuick versions

- NeQuick 1: available in ITU-R

- NeQuick 2: ITU-R source code,

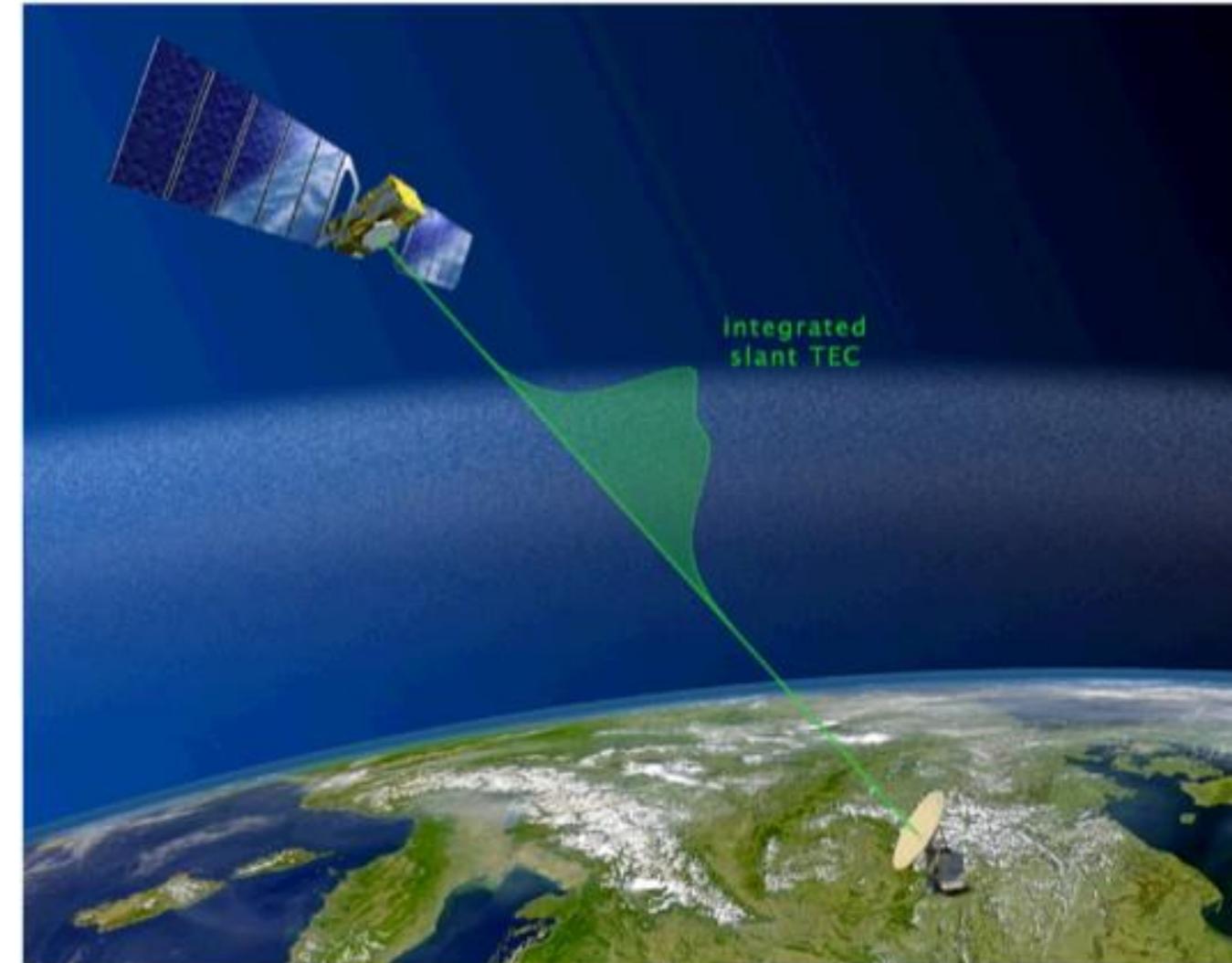
<https://www.itu.int/>

NeQuick 2 online: <http://t-ict4d.ictp.it/nequick2>

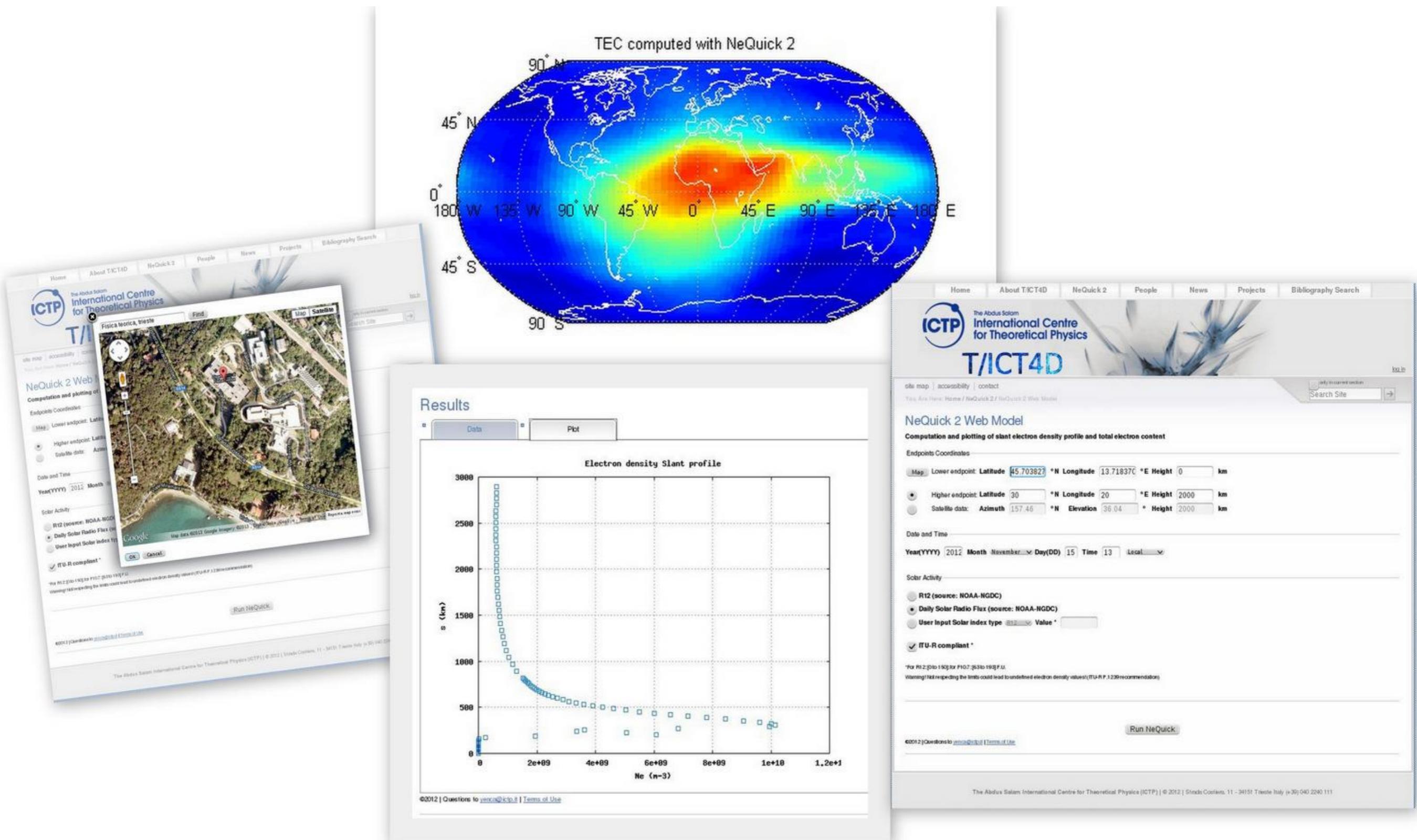
- NeQuick G (ESA)

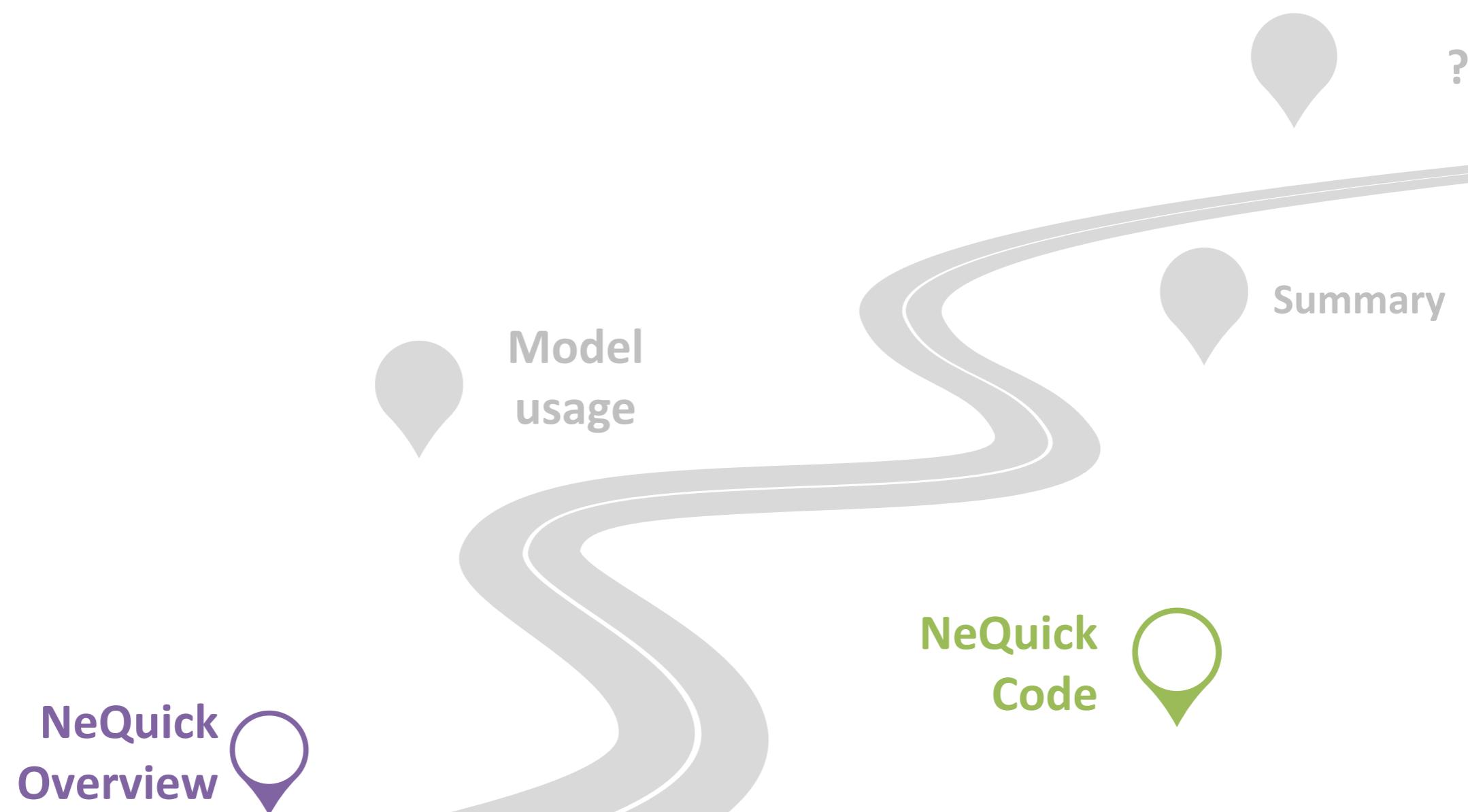
$$Az = a_0 + a_1\mu + a_2\mu^2$$

<https://www.gsc-europa.eu/support-to-developers/ionospheric-correction-algorithms/nequick-g-source-code>

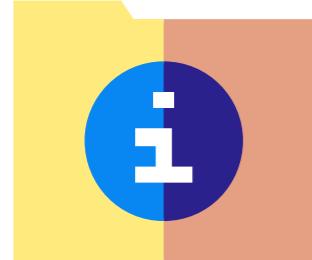


NeQuick 2 online: <http://t-ict4d.ictp.it/nequick2>





The NeQuick model



Content of NeQuick 2 package

- `NeQuick_2_0_2.for`
 - `slQu_2_0_2.for`
 - `ccir11.asc...ccir22.asc`
 - `modip.asc`
 - `R12.dat`
 - `/Test cases`
 - `README.txt`
- }
- FORTRAN 77 source code
- ITU-R coefficients
- Grid of modip values
- R12 values from 1931 to 2015



ITU-R (CCIR) files

NeQuick 2 uses the **ITU-R coefficients** to compute $foF2$ and $M(3000)F2$ characteristics. These coefficients are stored in the ccirXX.asc files and include the spherical harmonic coefficients representing the development of monthly median $foF2$ and $M(3000)F2$ all over the world.

The coefficients correspond to **low (SSN=0)** and **high (SSN=100)** solar activity conditions and are interpolated (or extrapolated) to obtain the values for the solar activity required.

Note: Since NeQuick 2 is compliant with ITU-R Recommendation P.1239 does not accept (**by default**) F10.7 input values below 63 F.U. (R12=0) and saturates the F10.7 at 193 F.U (R12=150) if solar flux input exceeds 193 F.U (R12=150).



Modip file

NeQuick 2 uses a grid of modip, (μ) contained in the file **modip.asc**. The values of modip (in degrees) are organized from 90 S to 90N of latitude in steps of 5 degrees and from 180W to 180E of longitude in steps of 10 degrees.

$$\tan \mu = \frac{I}{\sqrt{\cos \phi}} \quad \text{Rawer [1963]}$$

Note: The modip map included in the package of NeQuick 2 ITU-R version corresponds to the geomagnetic field for the year 1970.

In the case you want to update or use a different geomagnetic field model you can replace the **modip.asc** file taking into account the grid spacing.

NeQuick Code



Main functions and subroutines

NeQuick2_0_2.for

- All the necessary functions and subroutines to compute Ne.
- Model parameters functions.
- Auxiliary parameters computation.

slQu2_0_2.for

- Main program
- Calculate TEC for arbitrarily chosen rays which do not cut the surface of the Earth between the given endpoints.
- Auxiliary subroutines and functions

Slqu.dat

NeQuick Code

NeQuick_2_0_2.for

```
function NeQuick(h,alat,along,mth,flx,UT) → Ne [m-3]
subroutine prepNeQ(alat,along,mth,UT,flx) → hm,Nm,thickness parameters
```

Ne Computation:

```
function NeNeQ(h,hm,aep,bb) → Ne [m-3]
function NeMdGR(aep,hm,bb,h) → Ne [m-3], h<=hmF2
function topq(h,No,hmax,Ho) → Ne [m-3], h>hmF2
subroutine prepmdgr(mth,R12,foF2,efoF1,efoE,M3000)→ hm,Nm,thickness param.
```

NeQuick_2_0_2.for

Cont.d

```
subroutine ef1(alat,mth,flx,chi,foF2) → efoE[MHz],efoF1[MHz]
subroutine cciri(xMODIP,mth,UT,R12,alat,along) → foF2[MHz],M3000
function gamma1(xMODIP,alat,along,hour,iharm,nq,k1,m,mm,m3,sfe)
function peakh(foE,foF2,M3000) → hmF2[km]
subroutine modin(pmodip)
function amodip(pmodip,alat,along) -> modip
```

slQu_2_0_2.for

TEC Calculation

ray conventions:

- spherical Earth ($RE=6371,2\text{km}$)
- straight line "rays"
- coordinate s [km] along the ray, origin in ray perigee, point of ray closest to the centre of the Earth.

function **gint** → numerical integration along a slant ray

function **gintv** → numerical integration along a vertical ray
(if $r_p < 0.1\text{km}$)

NeQuick Code

For compliancy reasons, the NeQuick 2 code does not allow a F10.7 input below 63 F.U. (R12=0) and saturates the F10.7 at 193 F.U (R12=150).

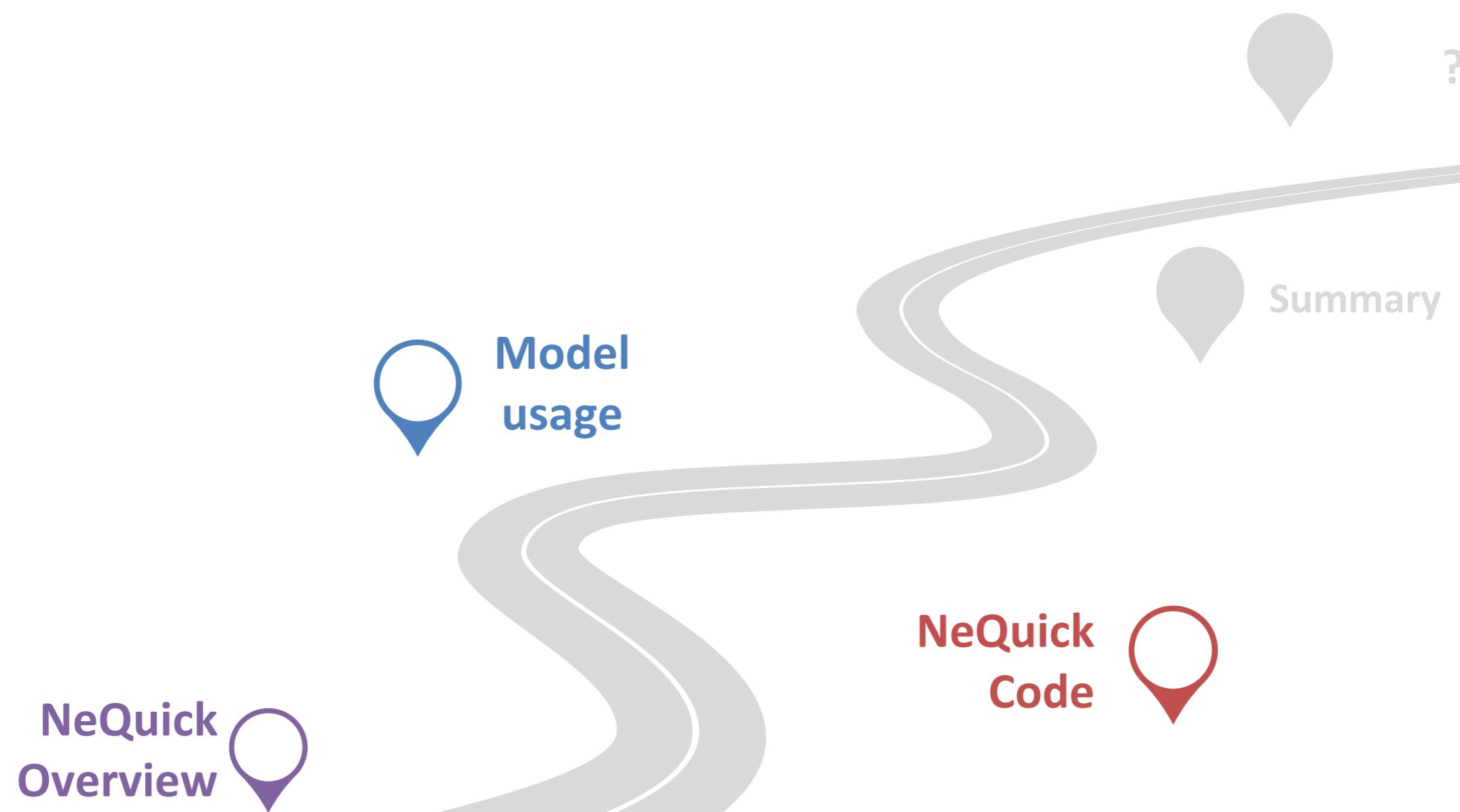
If a value below 63 F.U (R12=0) is input, the subroutine will stop the program. The limits on F10.7 (or R12) input can be removed at the user's own risk by commenting the lines 197 to 208 in the source file `NeQuick_2_1.for` (prepNeq subroutine) as follows:

NeQuick Code

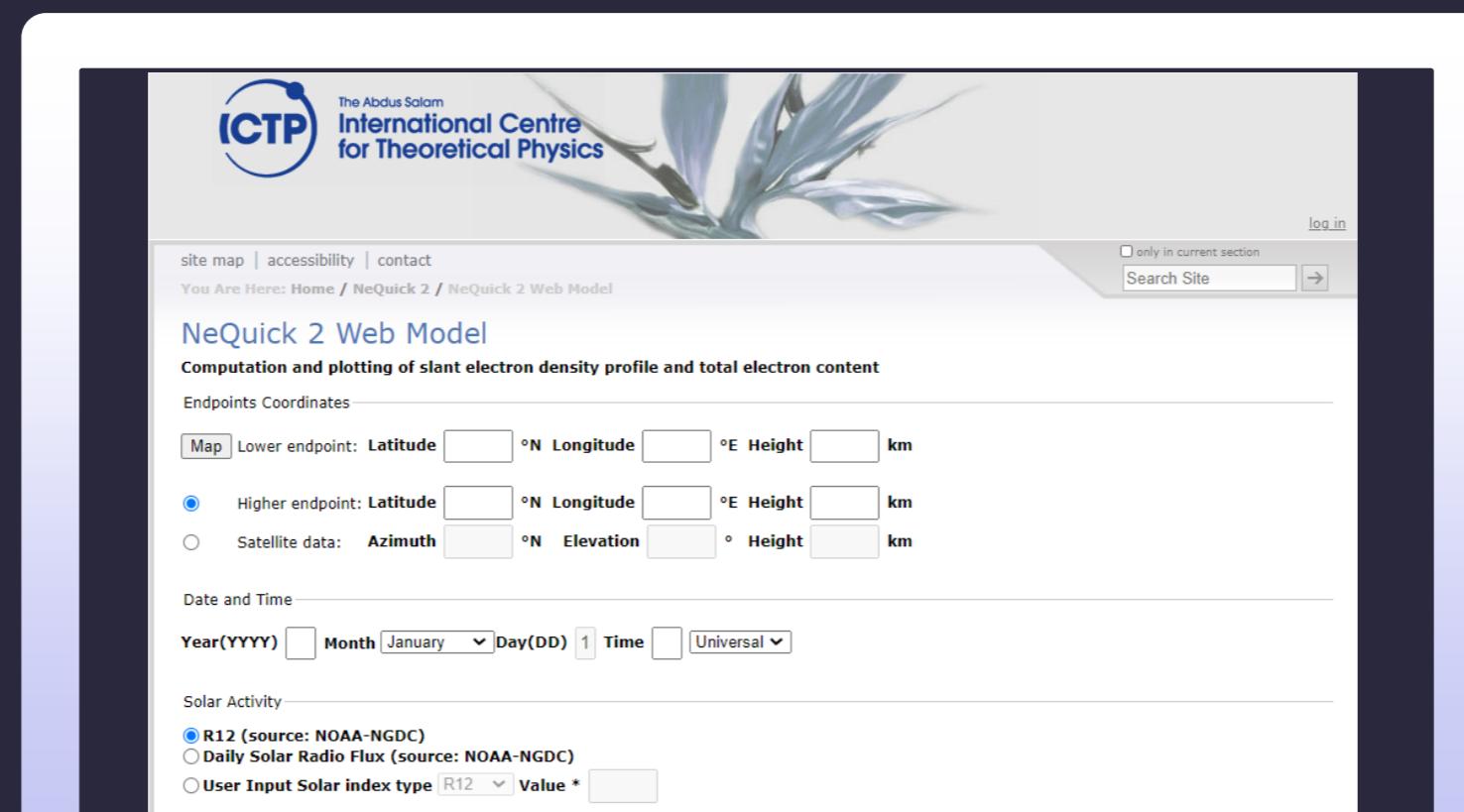
```
195C *** flux saturation above 193 FU and blocked below 63 FU to avoid
196C unrealistic or undefined electron density values! ***
197C if (flx1 .gt. 193.0D0) then
198C   flx1=193.0D0
199C   write(*,'(2A/A/A)')'***WARNING! Solar flux limit F=193 (R12=150) ',
200C   &           ' exceeded.',
201C   &           ' NeQuick saturates F to 193 units',
202C   &           ' (ITU-R P.1239 reccomendation).'
203C   endif
204C   if (flx1 .lt. 63.0D0) then
205C     write(*,'(2A/A)')'***WARNING! Solar flux below 63 FU (R12 <0) ',
206C     &           'program stopped!'
207C   stop
208C   endif
```

WARNING!

After removing the limits on F10.7 (or R12), if values outside the range [63,193] for F10.7 (or [0,150] for R12) are used, unrealistic or undefined electron densities values can be obtained



<http://t-ict4d.ictp.it/nequick2>



The screenshot shows the NeQuick 2 Web Model interface. At the top, there's a header with the ICTP logo and a search bar. Below the header, the main content area has a title "NeQuick 2 Web Model" and a subtitle "Computation and plotting of slant electron density profile and total electron content". There are three main input sections: "Endpoints Coordinates", "Date and Time", and "Solar Activity". In the "Endpoints Coordinates" section, there are three options: "Map" (selected), "Higher endpoint", and "Satellite data". Each option has fields for Latitude, Longitude, Height, and Azimuth/Elevation. In the "Date and Time" section, there are fields for Year (YYYY), Month (January to December), Day (DD), Time (Universal), and a dropdown for Timezone. In the "Solar Activity" section, there are three options: "R12 (source: NOAA-NGDC)" (selected), "Daily Solar Radio Flux (source: NOAA-NGDC)", and "User Input Solar index type" with a dropdown for R12, F10.7, or F10.7_Smooth.

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NeQuick 2 Web Model

Computation and plotting of slant electron density profile and total electron content

Endpoints Coordinates

Map Lower endpoint: Latitude °N Longitude °E Height km

Higher endpoint: Latitude °N Longitude °E Height km

Satellite data: Azimuth °N Elevation ° Height km

Date and Time

Year(YYYY) Month Day(DD) 1 Time Universal

Solar Activity

R12 (source: NOAA-NGDC)

Daily Solar Radio Flux (source: NOAA-NGDC)

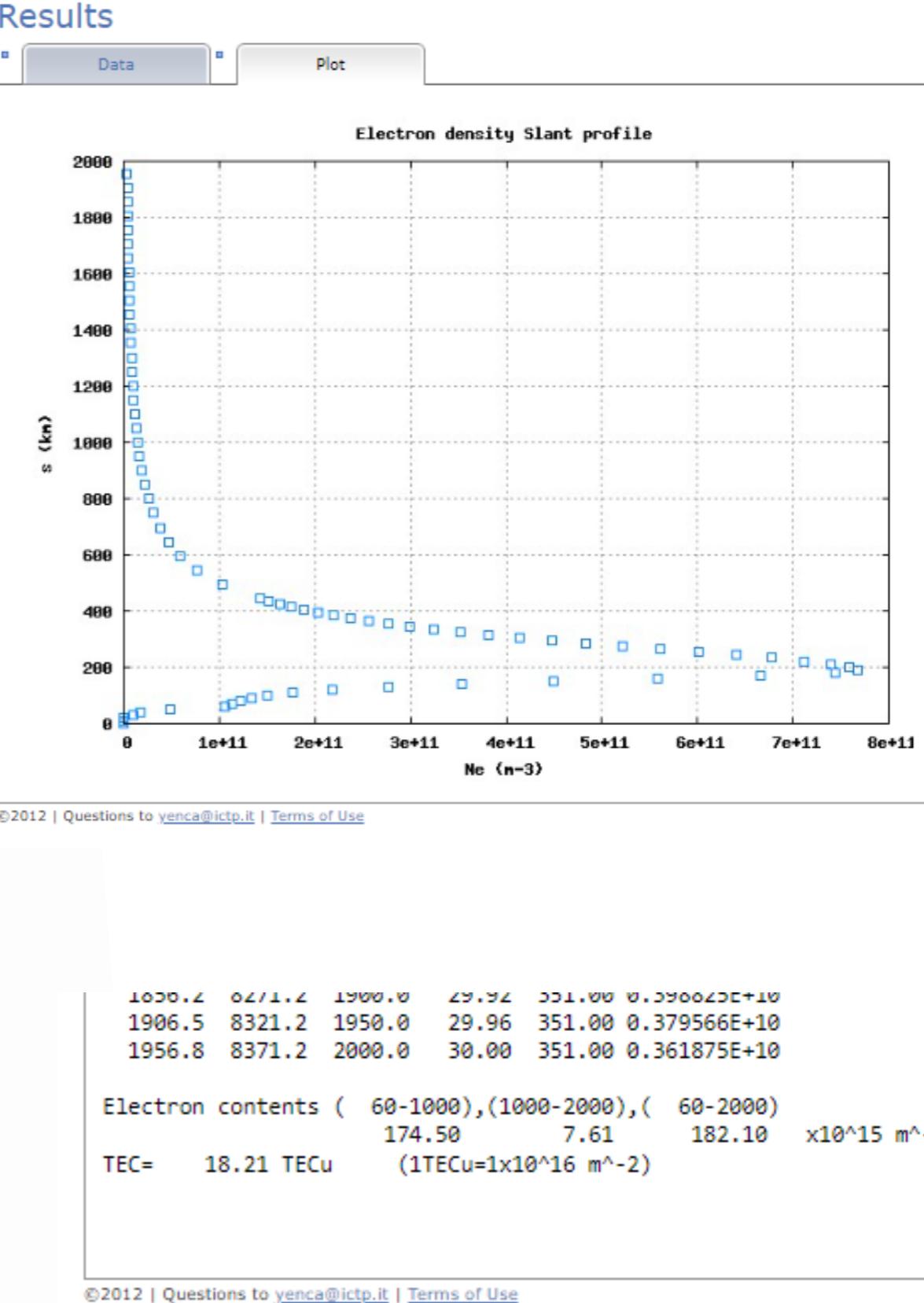
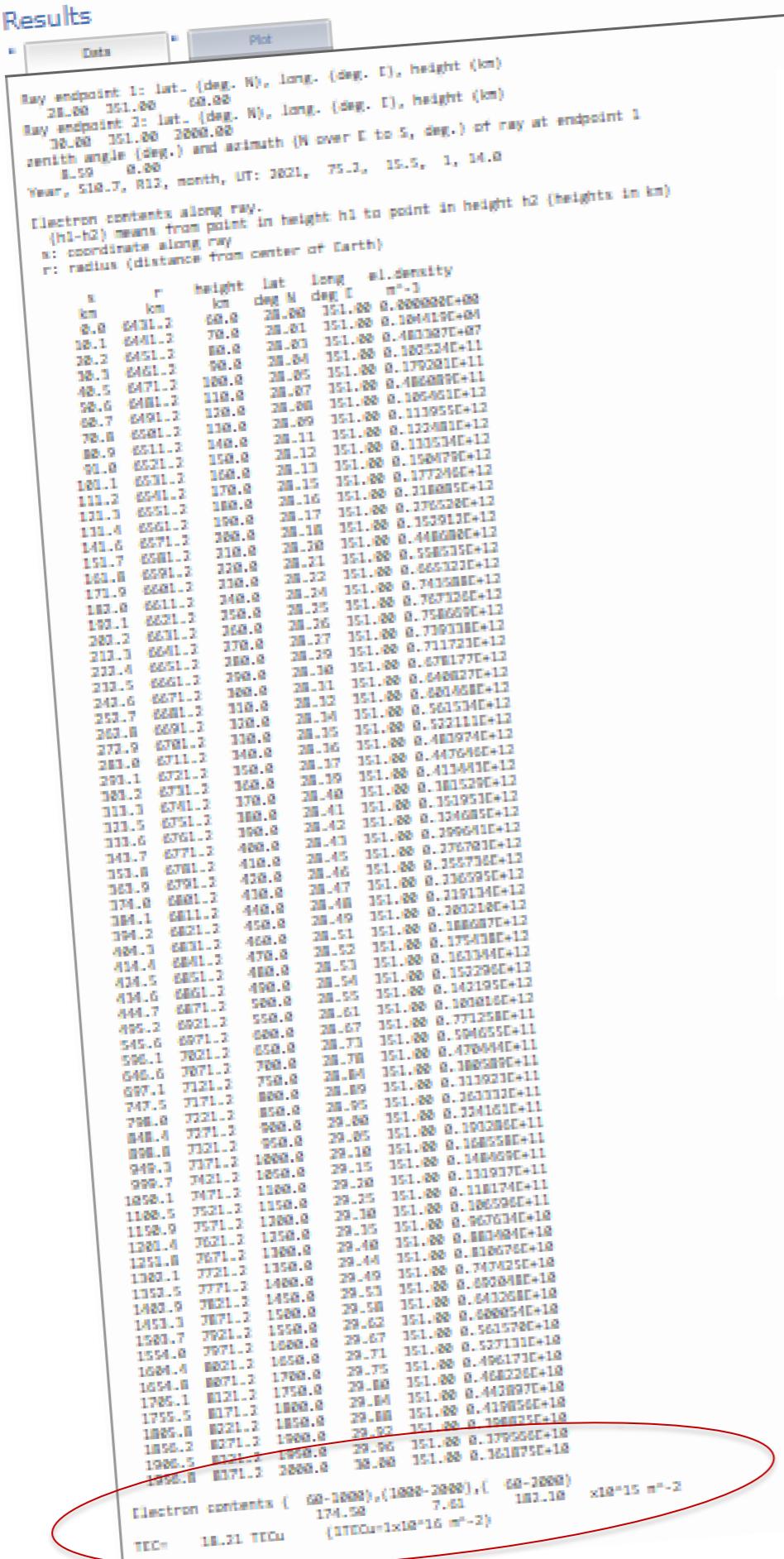
User Input Solar index type Value *

ITU-R compliant *

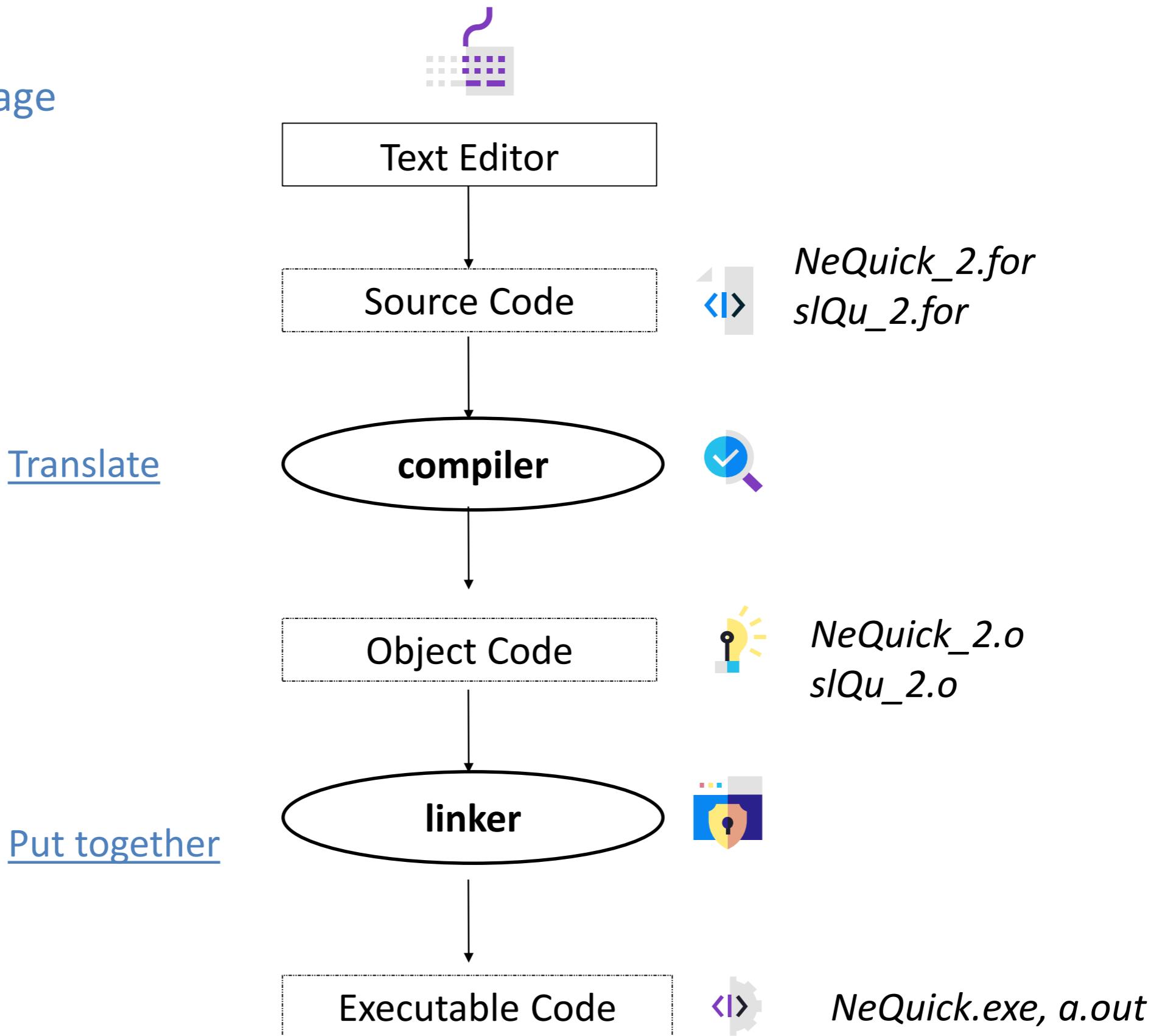
*For R12: [0 to 150]; for F10.7: [63 to 193] F.U.

Warning! Not respecting the limits could lead to undefined electron density values! ([ITU-R P.1239 recommendation](#))

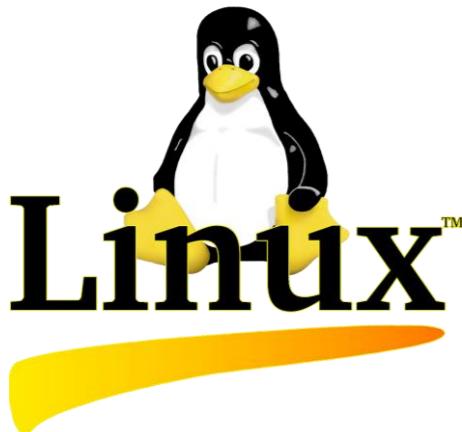
Model usage



Model usage



Fortran 77 compilers



F77, G77

Intel Fortran Compiler for Linux

Gfortran – the GNU Fortran Compiler

Salford FTN95 Compiler



For Windows Users:

MinGW 's (Gfortran, G77)

Cygwin

Force Project



MinGW64



Cygwin



Model usage

NeQuick Compilation

Compile and **Link** **NeQuick_2.for** and **sIQu_2.for** with a FORTRAN 77 compiler

Command format:

```
compiler [-o outputfile] NeQuick_2.for sIQu_2.for
```

For example:

```
f77 -o neq2 NeQuick_2.for sIQu_2.for
```

To run:

```
./neq2  
./a.out  
a.exe
```

Running...

```
C:\WINDOWS\system32\cmd.exe - neqtest
C:\Documents and Settings\yenca>0:
0:\progs\NeQuick2\NeQuick_2>neqtest

*****
*           NeQuick 2           *
*   slant profile and electron content  *
*   *
* This software is meant for scientific  *
* use only.                                *
*   *
* Please acknowledge                      *
* the Aeronomy and Radiopropagation    *
* Laboratory                            *
* of the Abdus Salam International     *
* Centre for Theoretical Physics       *
* Trieste, Italy                         *
*   *
*****


Electron density is calculated along straight line rays
from a lower endpoint <1> to a higher one <2>.

INPUT: Ray endpoint 1: latitude <deg N>, longitude <deg E>, height <km>
```

Running...

```
Command Prompt
* of the Abdus Salam International *
* Centre for Theoretical Physics *
* Trieste, Italy *
*
*****
Electron density is calculated along straight line rays
from a lower endpoint (1) to a higher one (2).

INPUT: Ray endpoint 1: latitude <deg N>, longitude <deg E>, height <km>
45,15,80
INPUT: Ray endpoint 2: latitude <deg N>, longitude <deg E>, height <km>
45,15,1000
Input: year, month, UT:
2000,5,5
User input R12/F10.7 for this year and month <y/n>
n
List electron density profile along ray <y/n>?
n
Output in s1Qu.dat

C:\Users\Yenca\Documents\Programs\NeQuick\NeQuick_2_0_1b>type s1Qu.dat
Ray endpoint 1: lat. <deg. N>, long. <deg. E>, height <km>
  45.00 15.00  80.00
Ray endpoint 2: lat. <deg. N>, long. <deg. E>, height <km>
  45.00 15.00 1000.00
S10.7, R12, month, UT: 162.9, 119.0, 5, 5.0

Electron contents along ray.
<h1-h2> means from point in height h1 to point in height h2 (heights in km)
Electron content (< 80-1000>
                  167.56  x10^15 m^-2

C:\Users\Yenca\Documents\Programs\NeQuick\NeQuick_2_0_1b>
```

Not TECU!

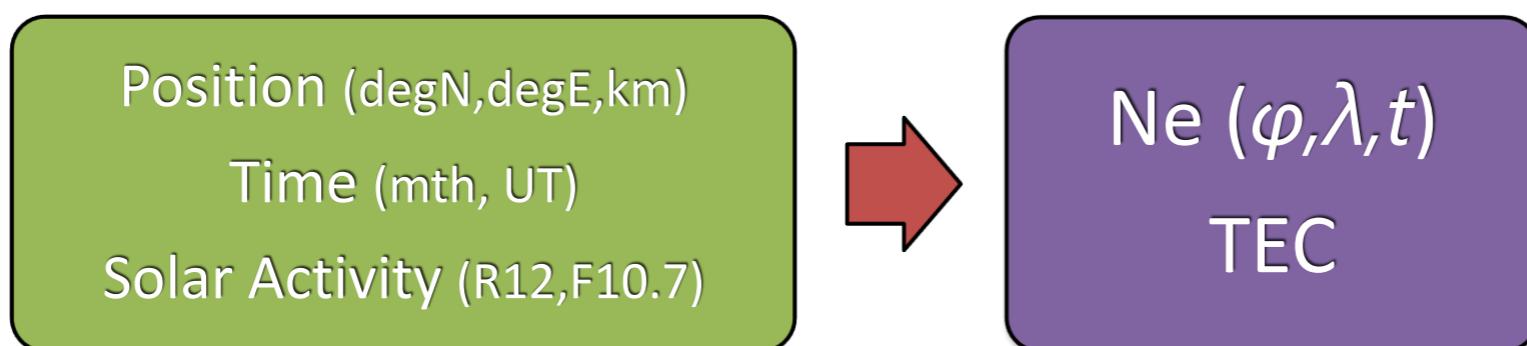
Running...

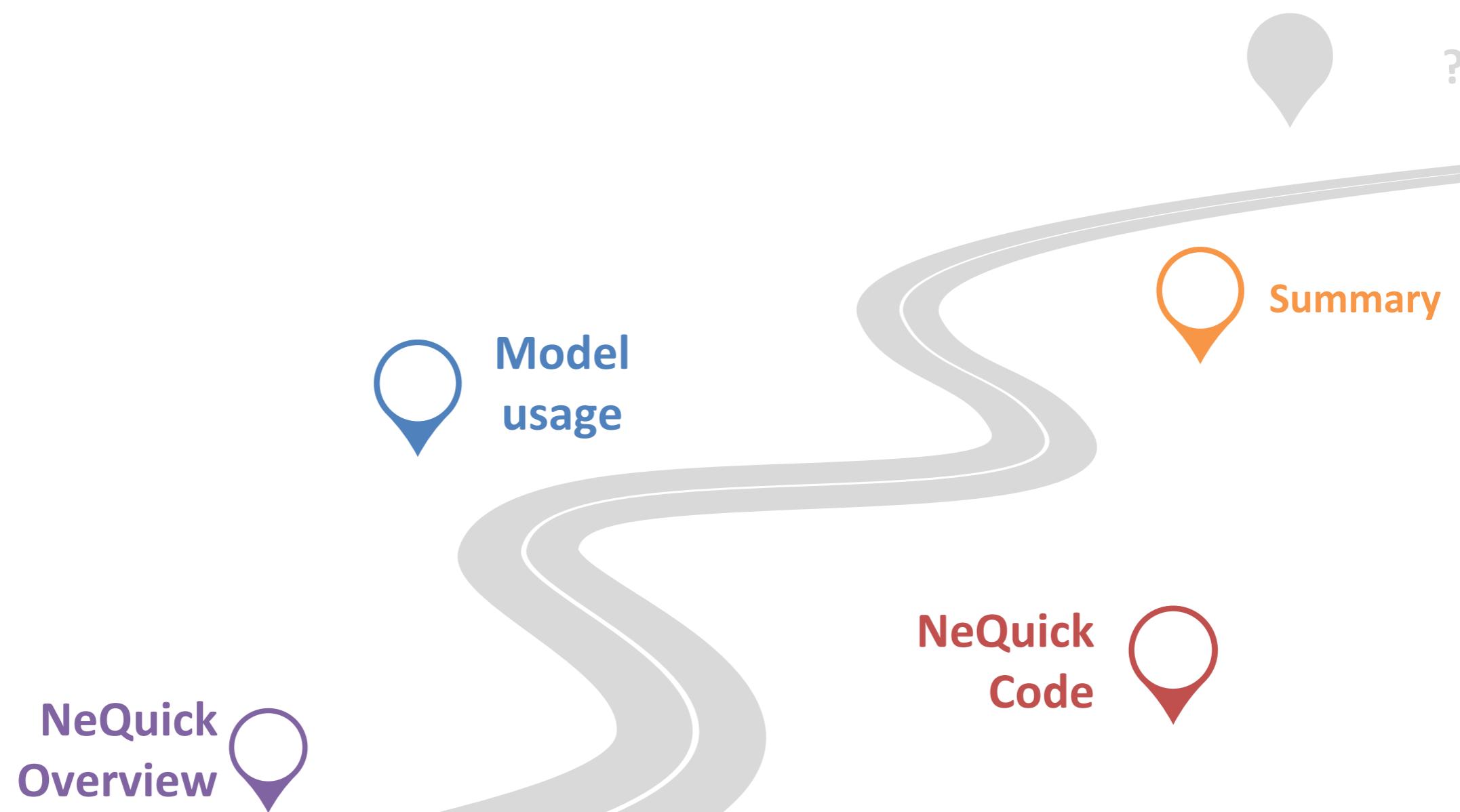


Model usage

May I use NeQuick 2 to assess its performance during geomagnetic storms?

NeQuick is an empirical climatological model that represents monthly median states of the ionosphere





Summary

- NeQuick is a three-dimensional and time dependent empirical ionospheric electron density model to represent the climatology of the ionosphere.
- Predecessors, versions and usage of the model have been presented, together with the main functions and subroutines.
- We have briefly demonstrated how to run and use the model (and how you should not 😊).

Are you ready for...

NeQuiz?

Thank you!



yenca@ictp.it