The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

NeQuick model: Code and Uses

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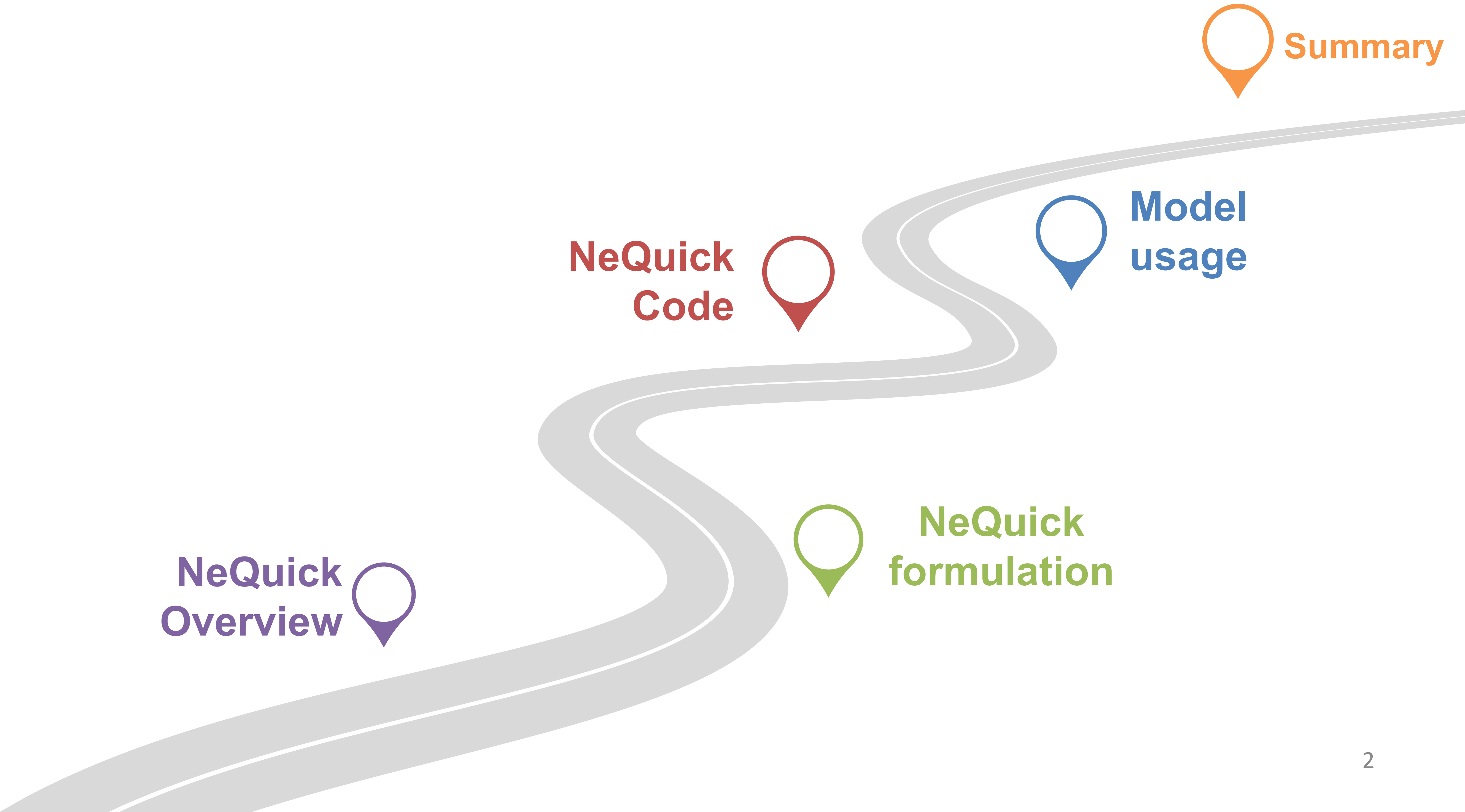
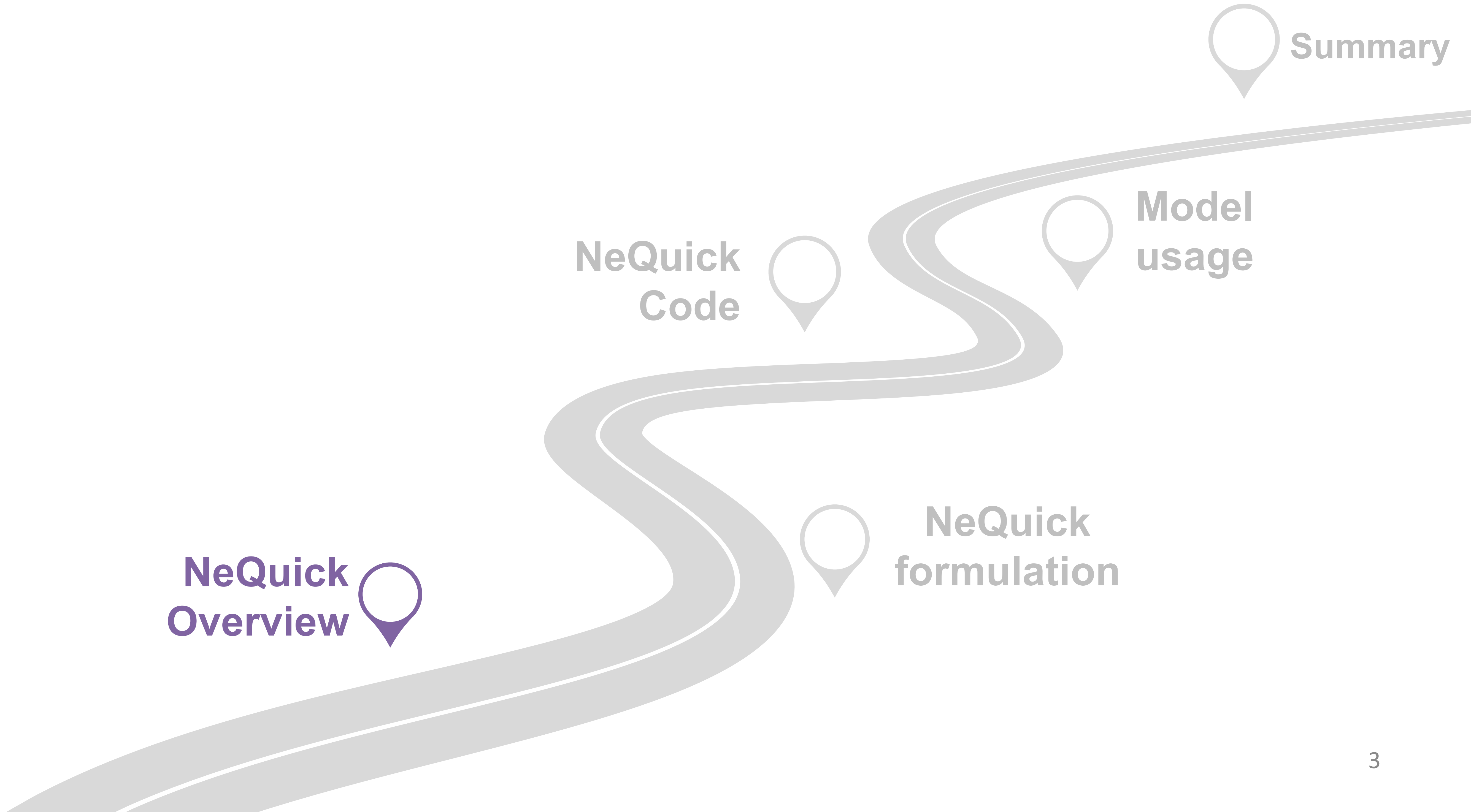
STI - ICTP

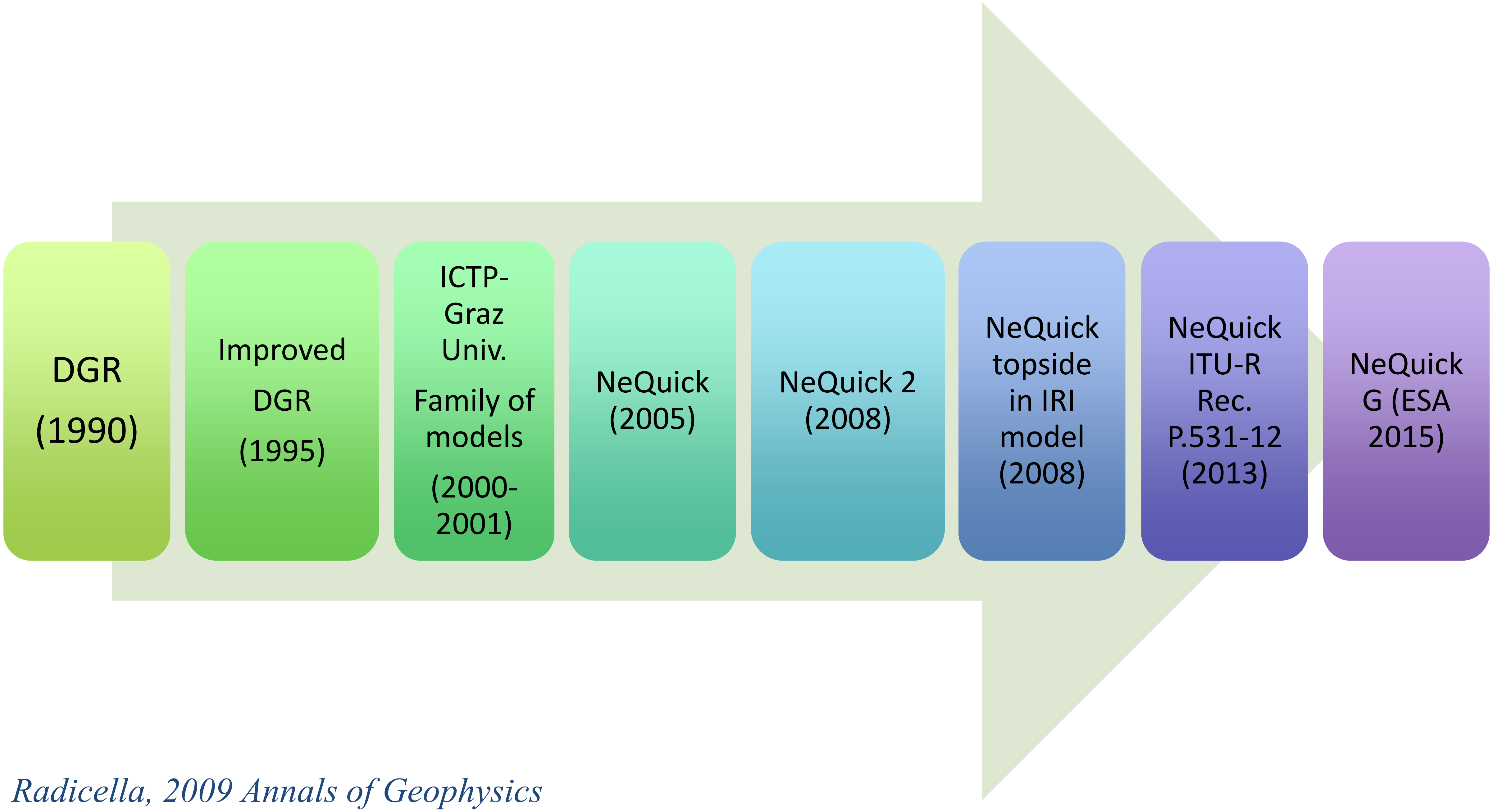
Regional Workshop on GNSS and Space Weather
Rabat, Morocco 9-13 May, 2022

Talk roadmap




NeQuick Overview
NeQuick formulation
NeQuick Code
Model usage
Summary

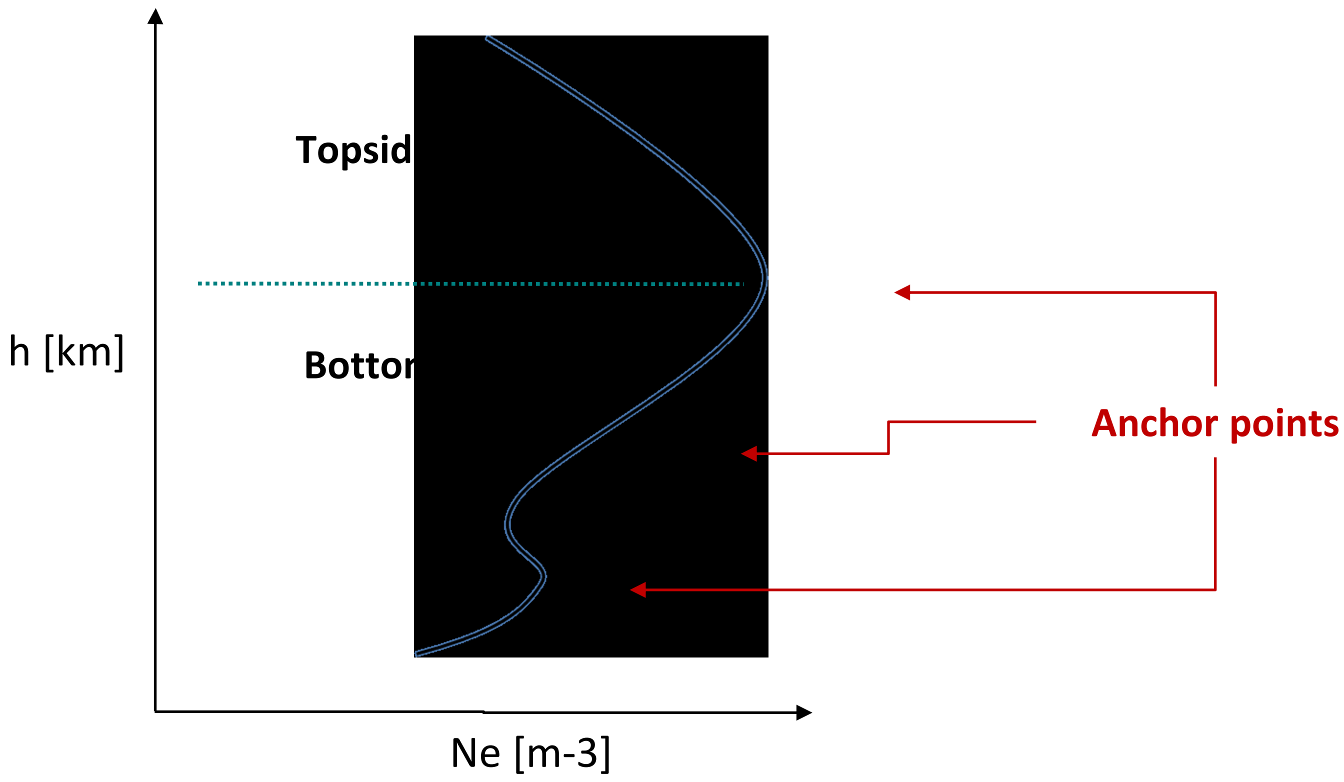
A historical view



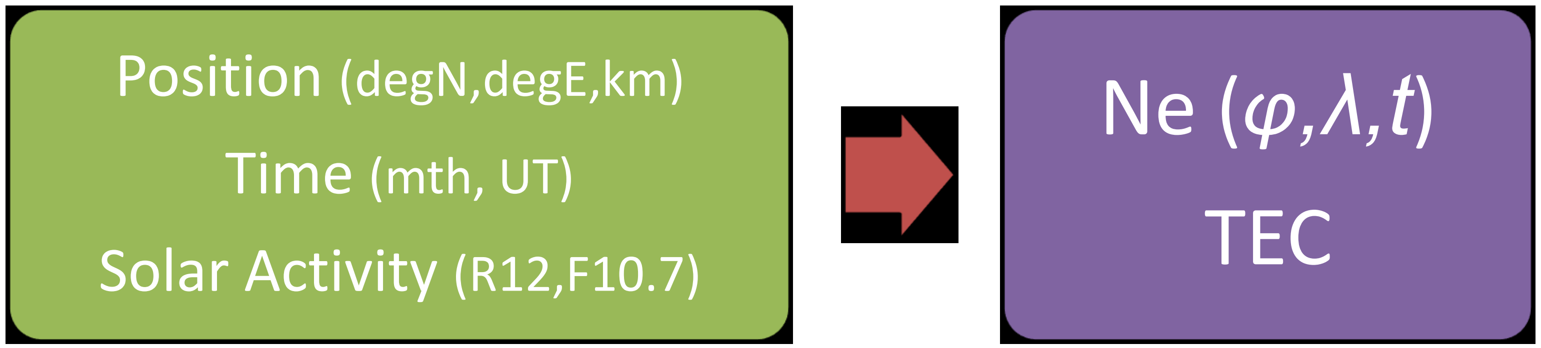
Radicella, 2009 Annals of Geophysics

NeQuick Overview

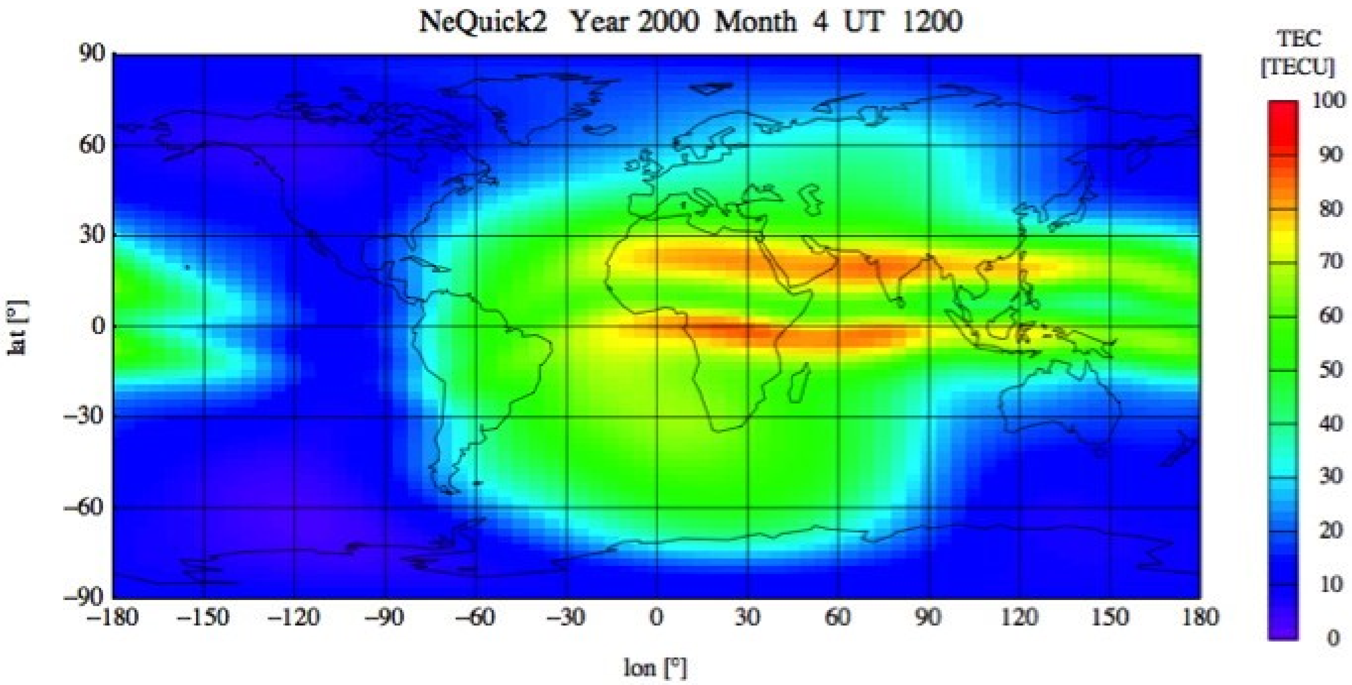
NeQuick's profile includes 6 semi-Epstein layers and makes use of anchor points defined by foE, foF1, foF2 and M(3000)F2 values.



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



NeQuick 2 Overview



• Revision of the original DGR approach for the F1 and E regions formulation was done.

• Improvement of the NeQuick topside.

•The computer code of the model was also improved.

Coïsson, 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

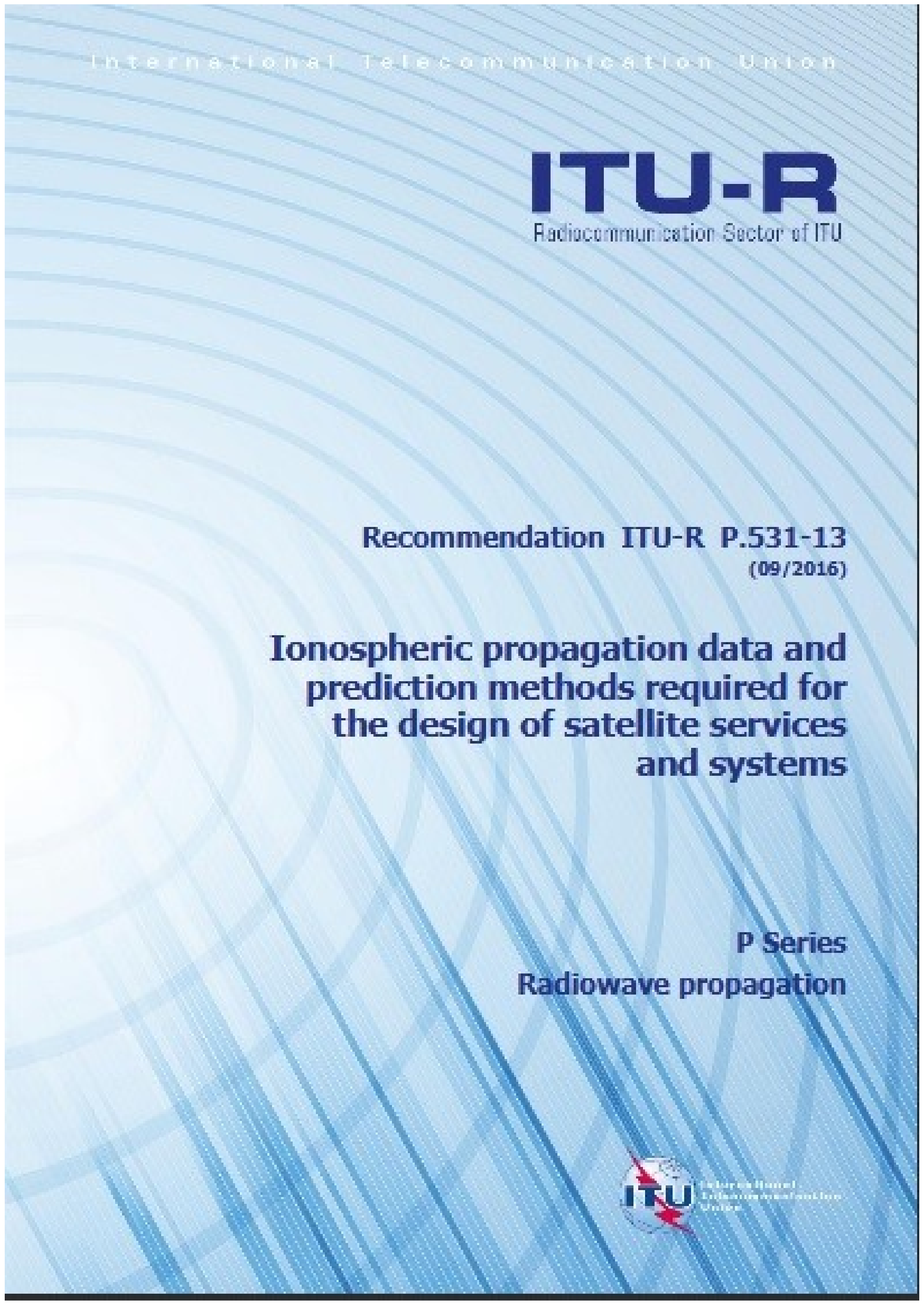
Nava. B., P. Coïsson and S.M. Radicella (2008), A new version of the NeQuick ionosphere electron density model; J.of Atmos.and Solar-Terr. Physics.

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 adopted as the model for ionospheric corrections in the single frequency operation of GALILEO.

NeQuick 2 in ITU-R and NeQuick G

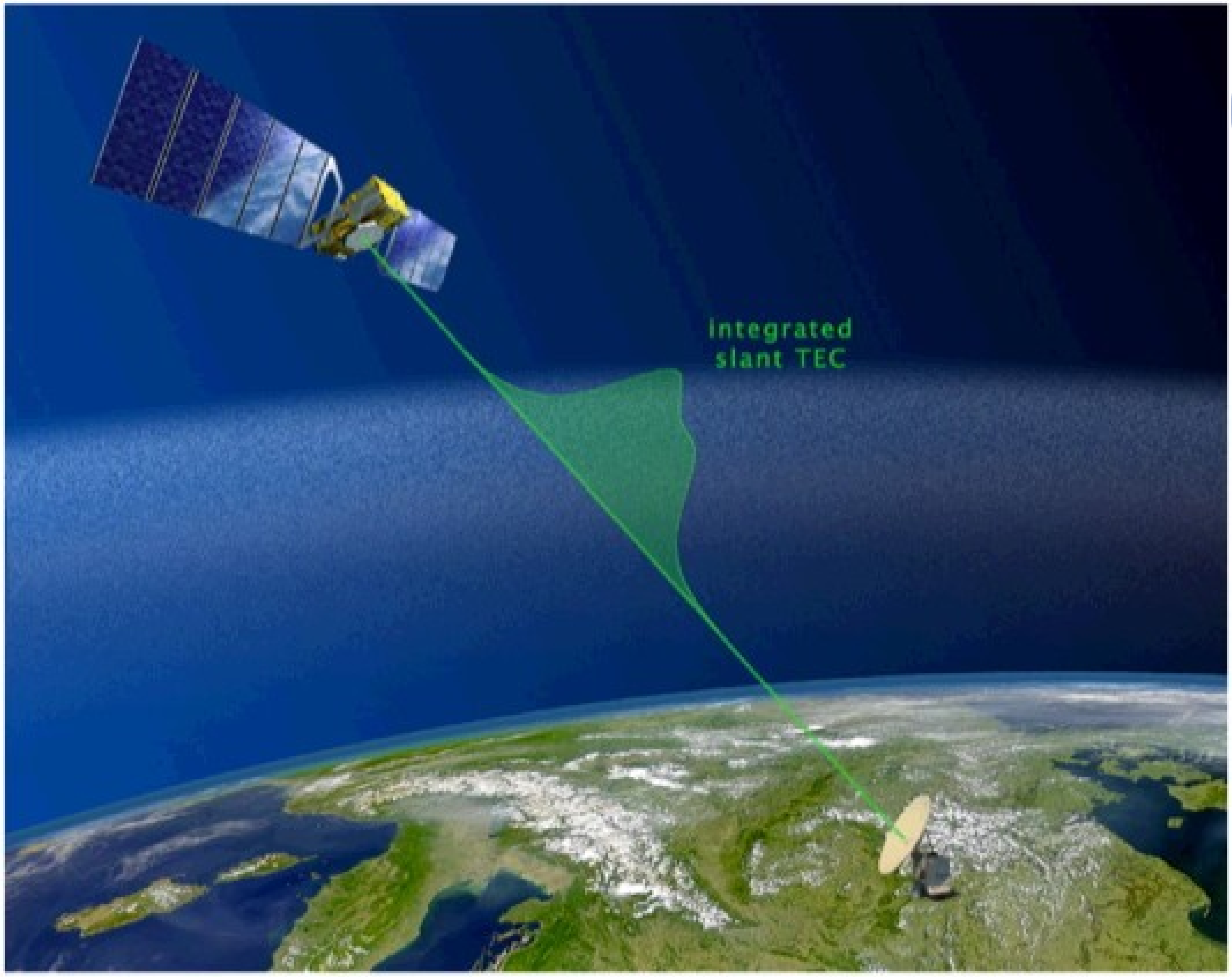


ICG Working Groups Recommendations

- 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,

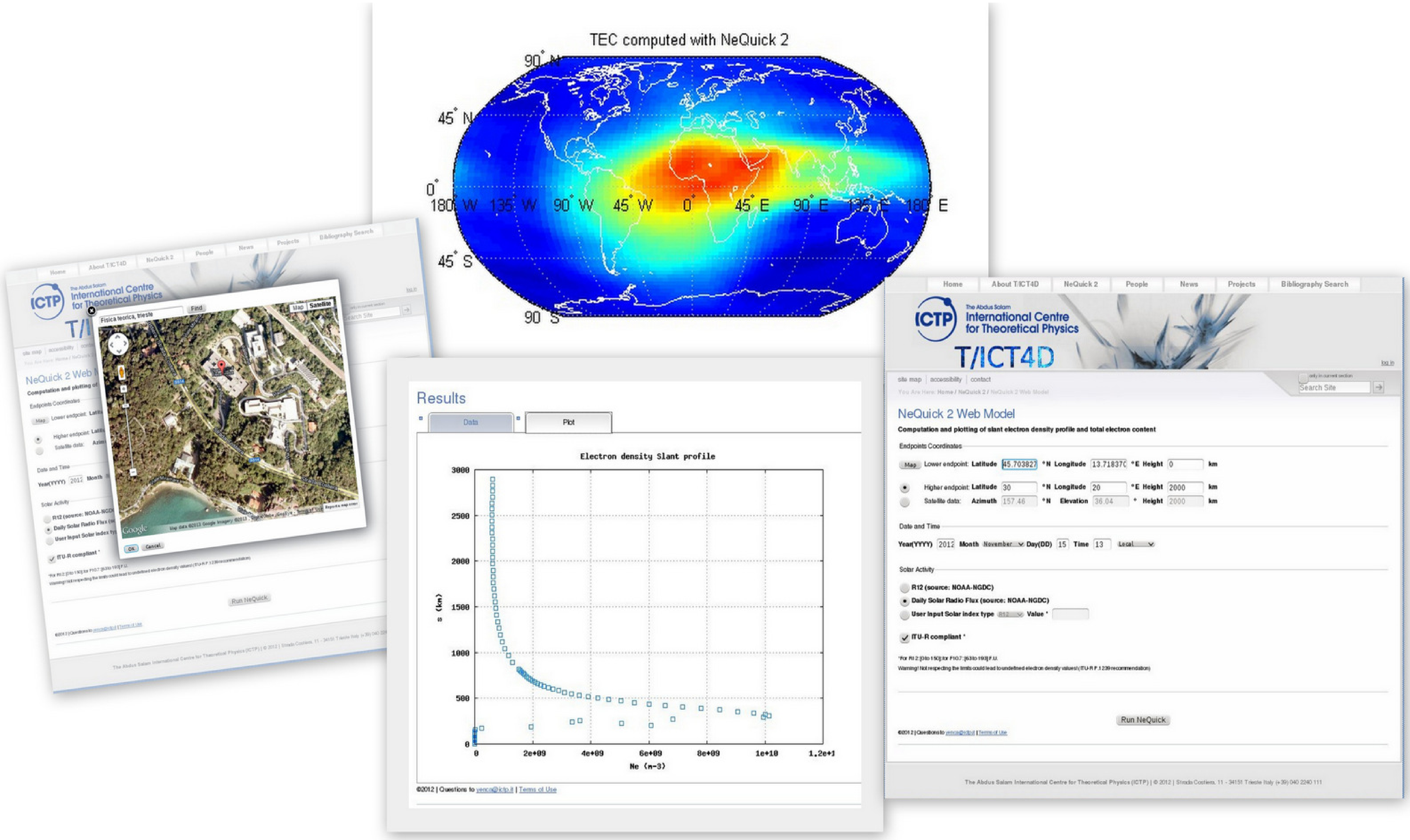
https://www.itu.int/rec/R-REC-P.531-14-201908-I/en

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

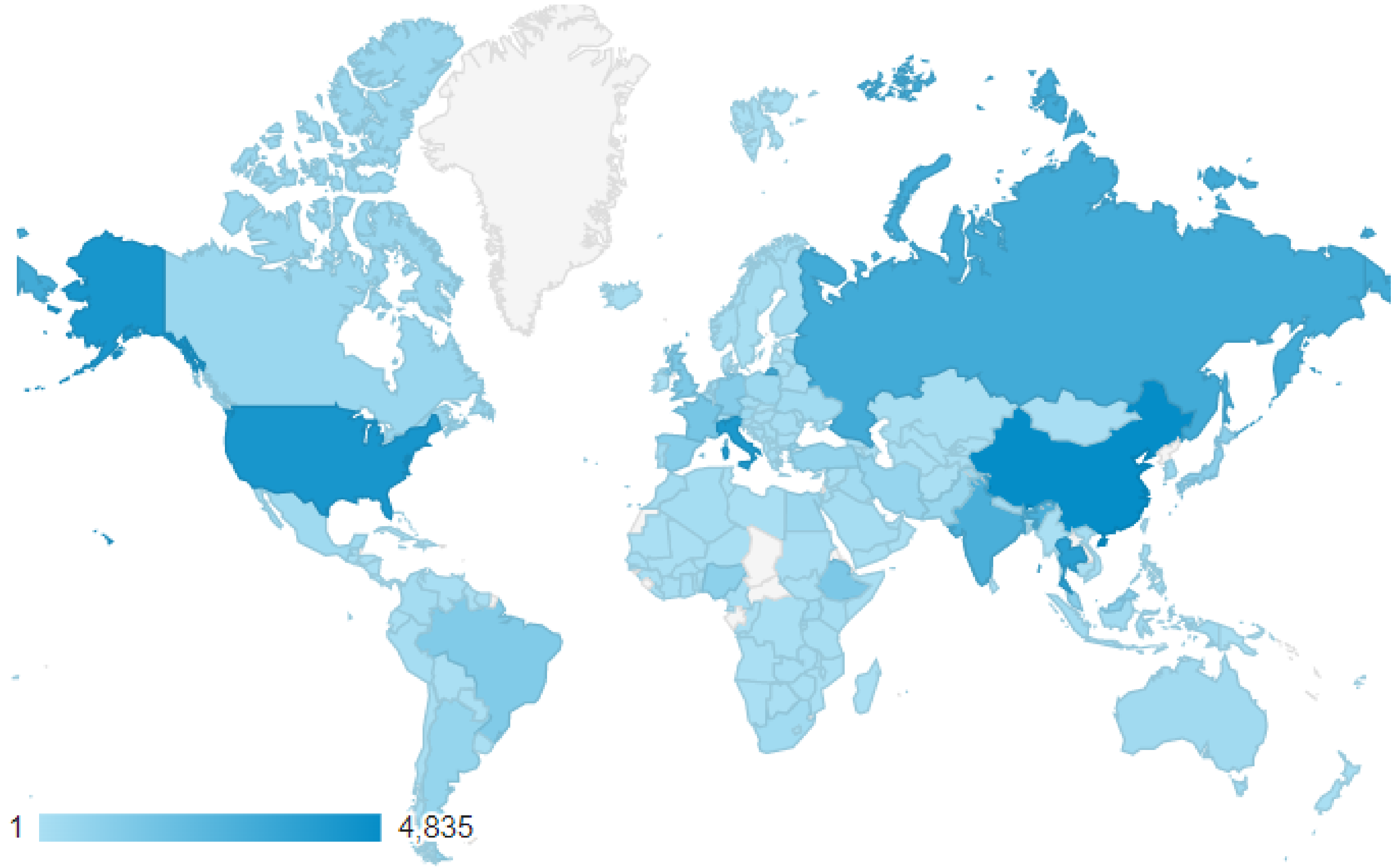
- NeQuick G (ESA)

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

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



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



Statistics

Web services usage
#sessions

1.	China	4,835	(10.51%)
2.	Spain	1,029	(2.24%)
3.	India	2,823	(6.14%)
4.	Italy	4,149	(9.02%)
5.	Russia	3,043	(6.62%)
6.	United States	4,282	(9.31%)
7.	Andorra	1	(0.00%)
8.	United Arab Emirates	103	(0.22%)
9.	Afghanistan	6	(0.01%)
10.	Antigua & Barbuda	1	(0.00%)

NeQuick **70k/year**

NeQuick Overview

NeQuick formulation

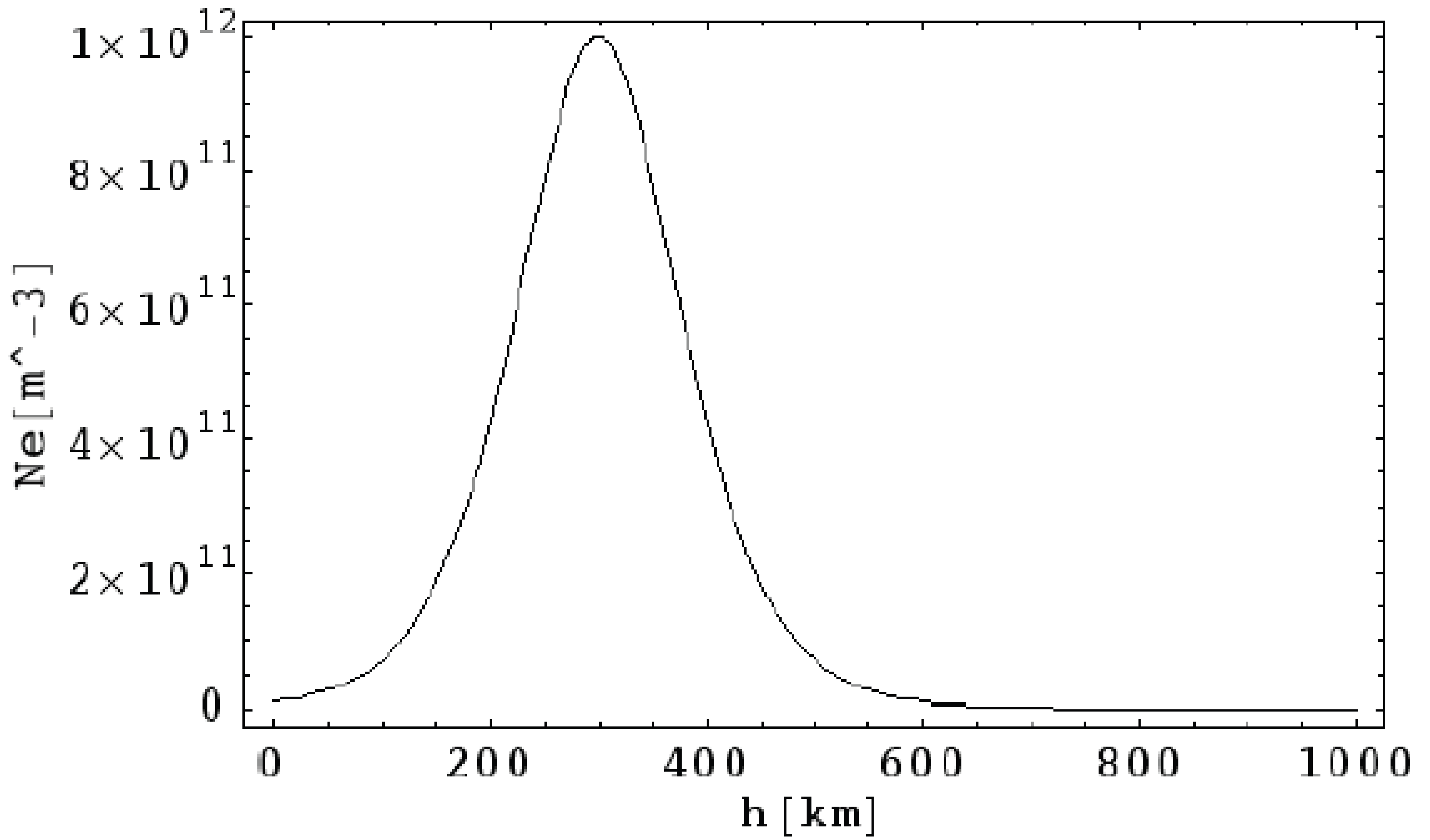
NeQuick Code

Model usage

Summary

Epstein Layer

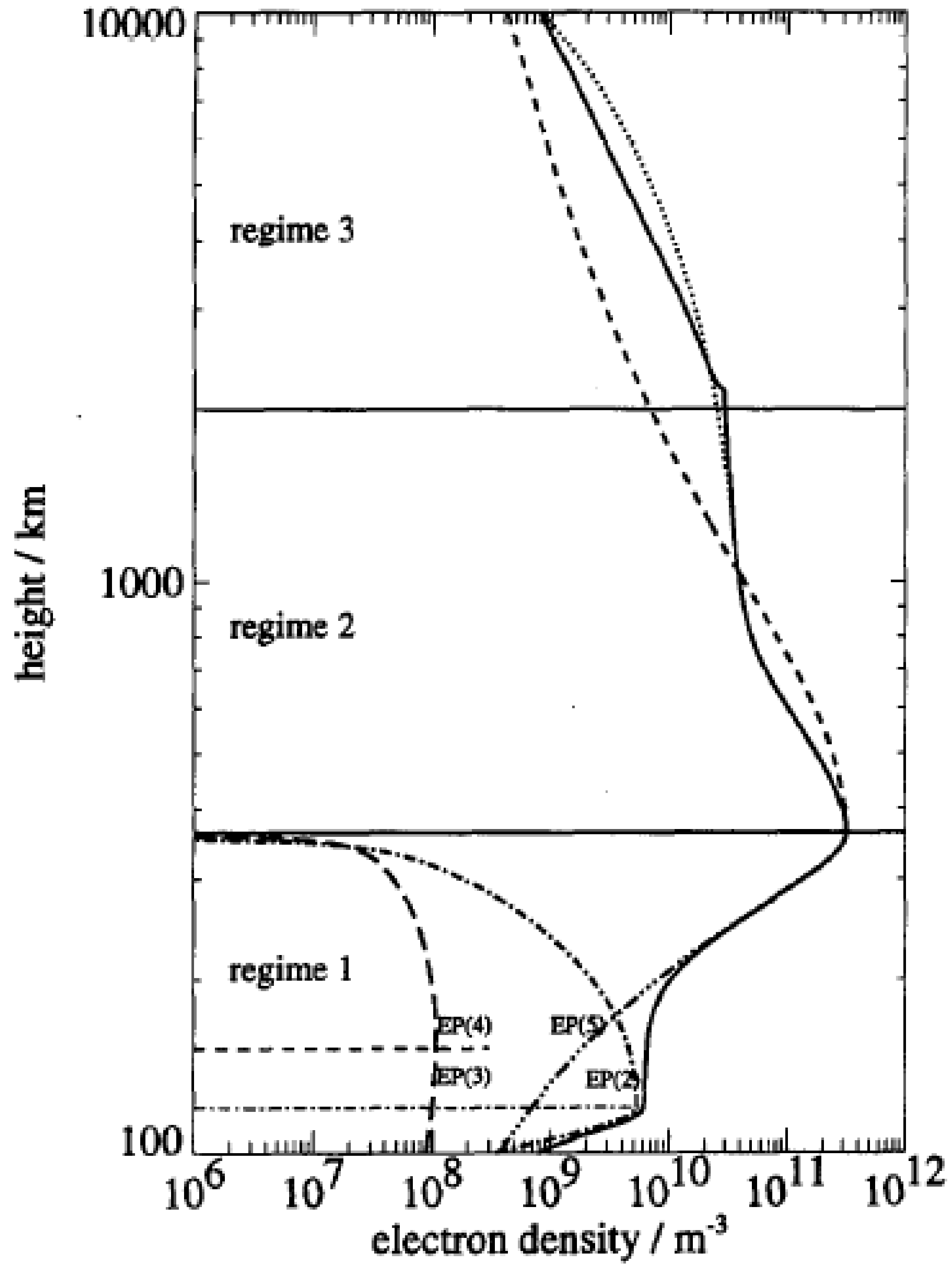
$$N(h,hmax,Nmax,B) = \frac{4Nmax}{(1+\exp(h-hmax/B))^2} \exp\left(\frac{h-hmax}{B}\right)$$



Epstein, (1930) *Rawer, K. (1982),Advances in Space Research*

NeQuick formulation

Hochegger et al, 2000, Phys. Chem. Earth



Bottomside

Nava et al, 2008, Journal of Atmospheric and Solar-Terrestrial Physics

$$N_{bot}(h) = N_E(h) + N_{F1}(h) + N_{F2}(h)$$

$$N_E(h) = \frac{4Nm^*E}{\left(1+\exp\left(\frac{h-hmE}{BE}\xi(h)\right)\right)^2}\exp\left(\frac{h-hmE}{BE}\xi(h)\right)$$

$$N_{F1}(h) = \frac{4Nm^*F1}{\left(1+\exp\left(\frac{h-hmF1}{B1}\xi(h)\right)\right)^2}\exp\left(\frac{h-hmF1}{B1}\xi(h)\right)$$

$$N_{F2}(h) = \frac{4NmF2}{\left(1+\exp\left(\frac{h-hmF2}{B2}\right)\right)^2}\exp\left(\frac{h-hmF2}{B2}\right)$$

$$\xi(h) = \exp\left(\frac{10}{1+1|h-hmF2|}\right)$$

to avoid secondary maxima

Topside

$$N(h) = \frac{4NmF2}{(1+\exp(z))^2}\exp(z)$$

$$z = \frac{h - hmF2}{H}$$

$$H = H_0\left[1 + \frac{rg(h - hmF2)}{rH_0 + g(h - hmF2)}\right]$$

Thickness Parameters

$$BE_{bot} = 5$$

$$BE_{top} = \max\left(0.5\left(hmF1 - hmE\right), 7\right)$$

Leitinger et al,2005

$$B1_{bot} = 0.5\left(hmF1 - hmE\right)$$

$$B1_{top} = 0.3\left(hmF2 - hmF1\right)$$

$$B2_{bot} = \frac{0.385 NmF2}{\left(dN/dh\right)_{max}}$$

$$H = kB2_{bot}\left[1 + \frac{rg\left(h - hmF2\right)}{rkB2_{bot} + g\left(h - hmF2\right)}\right]$$

NeQuick formulation

Thickness Parameters

$$\ln\left(\left(\frac{dN}{dh}\right)_{max}\right) = -3.467 + 1.714\ln\left(foF2\right) + 2.02\ln\left(M(3000)F2\right)$$

Mosert de Gonzalez and Radicella,1990

$$k = 3.22 - 0.0538 foF2 - 0.00664 hmF2 + 0.113\frac{hmF2}{B2_{bot}} + 0.00257 R12$$

k>=1

Coisson et al., 2006

Peak Heights

$$hmE = 120$$

$$hmF1 = \frac{hmE + hmF2}{2}$$

Leitinger et al,(2005)

$$hmF2 = \frac{1490MF}{M + \Delta M} - 176$$

Radicella and Zhang,(1995)
Dudeney, (1978, 1983)

$$\Delta M = \begin{cases} 0.253/(foF2/foE \\ \quad -1.215) - 0.012, \\ -0.012 & \text{if } foE = 0, \end{cases}$$

$$MF = M\sqrt{\frac{0.0196M^2 + 1}{1.2967M^2 - 1}} \qquad M = M(3000)F2.$$

Critical Frequencies

$$(foE)^2 = \left(a_e\sqrt{F107}\right)^2 (\cos\chi_{eff})^{0.6} + 0.49$$

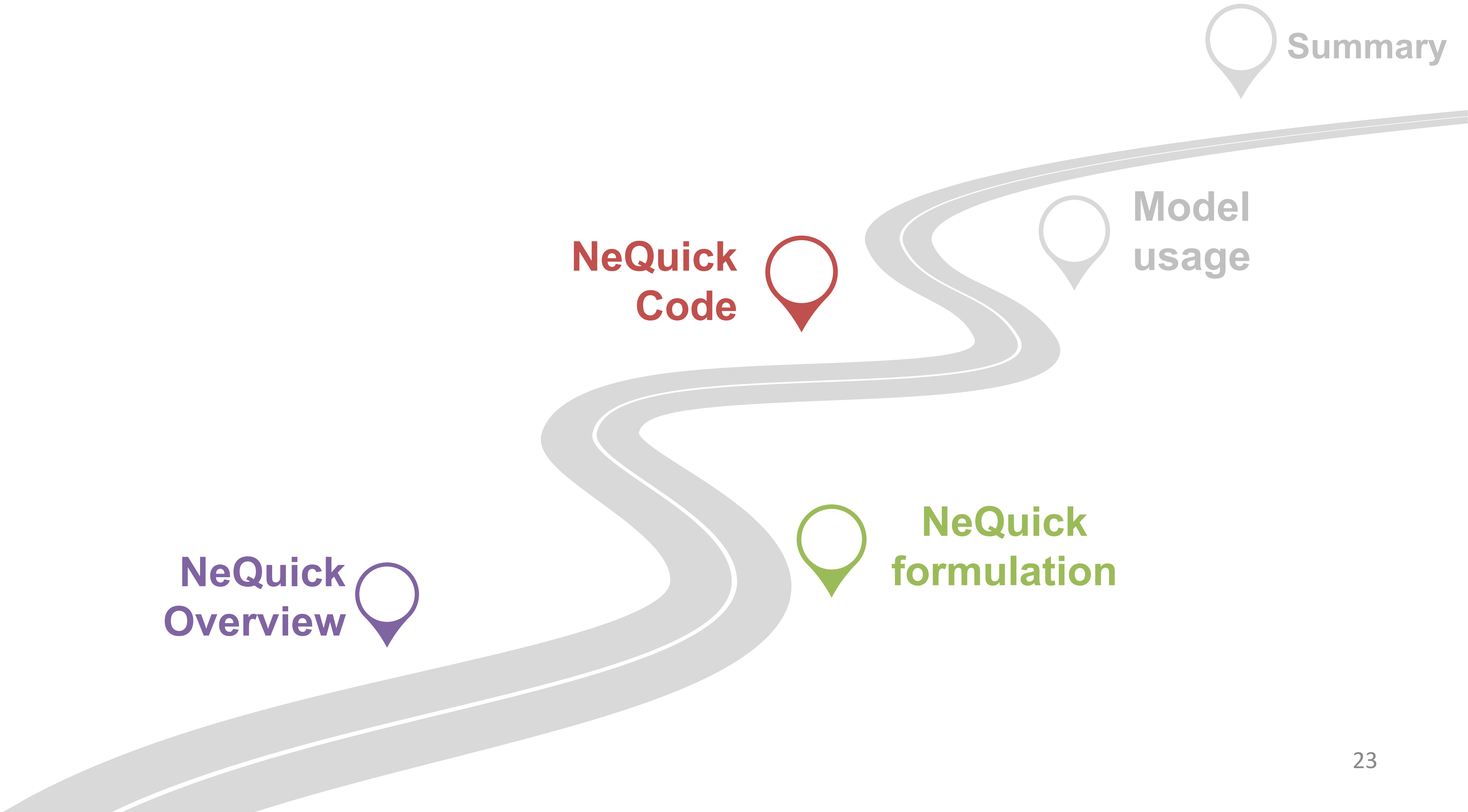
Titheridge, (1996)

$$foF1 = \begin{cases} 1.4\ foE & \text{if} \quad foE \geq 2 \\ 0 & \text{if} \quad foE < 2 \\ 0.85\ 1.4\ foE & \text{if } 1.4\ foE > 0.85\ foF2 \end{cases}$$

Leitinger et al.(2005)

$foF2$ modeled in terms of ITU – R coefficients

$M = M(3000)F2.$ modeled in terms of ITU – R coefficients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NeQuick Code

Content of NeQuick 2 package

- NeQuick_2_0_2.for
- slQu_2_0_2.for

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

NeQuick Code

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 must be 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.

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

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 Code

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 (R_E=6371,2km)
- 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<0.1km)

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).

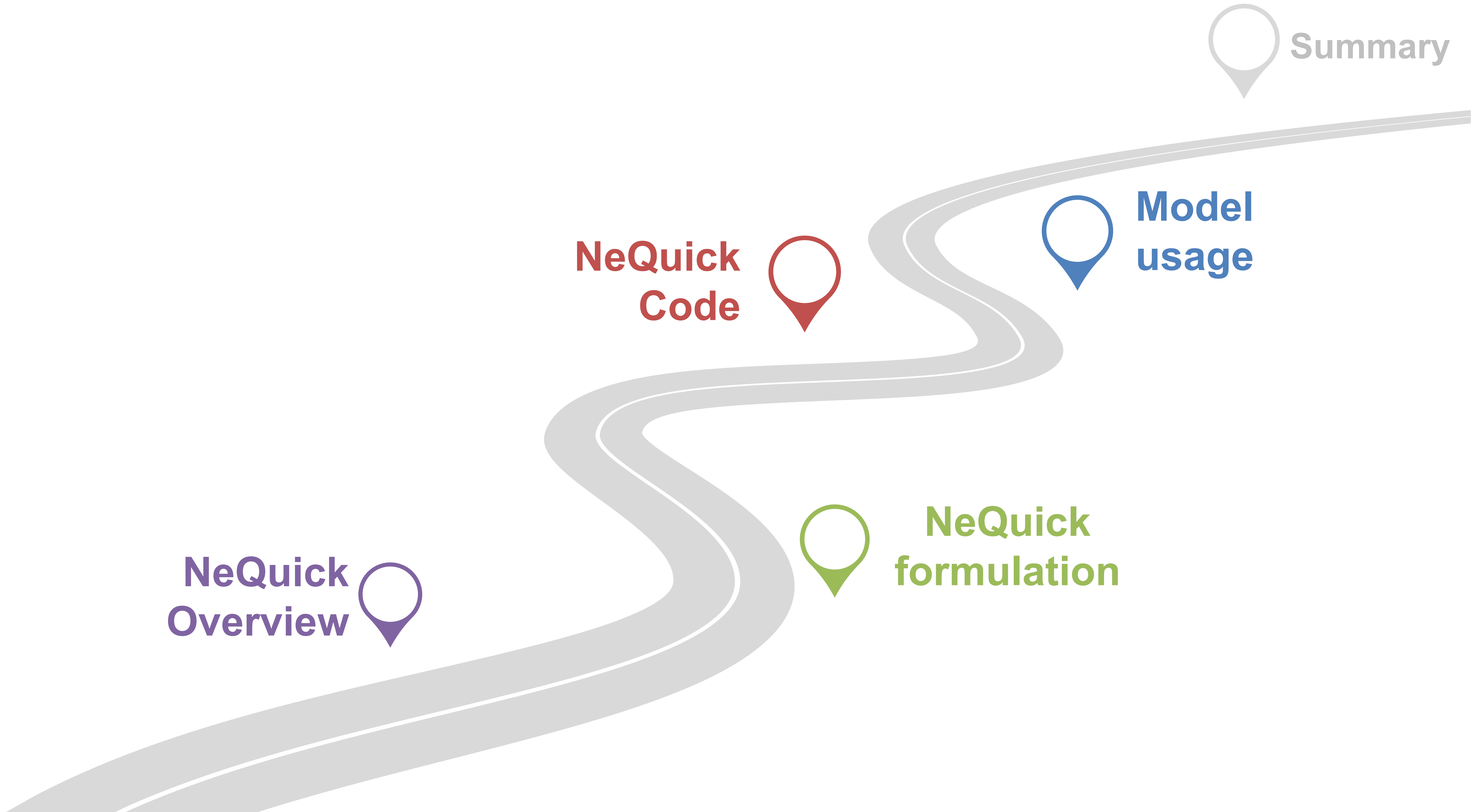
If a value below 63 F.U (R12=0) is input, the subroutine will stop the program. The limits on F10.7 (or R12) input can be removed at the user's own risk by commenting the lines 197 to 208 in the source file NeQuick_2_1.for (prepNeq subroutine) as follows:

NeQuick Code

```
C     *** flux saturation above 193 FU and blocked below 63 FU to avoid
C     unrealistic or undefined electron density values! ***
C     if (flx1 .gt. 193.0D0) then
C     flx1=193.0D0
C     write(*,'(2A/A/A)')'***WARNING! Solar flux limit F=193 (R12=150)',
C    &                        ' exceeded.',
C    &                        ' NeQuick saturates F to 193 units',
C    &                        ' (ITU-R P.1239 reccomendation).'
C     endif
C     if (flx1 .lt. 63.0D0) then
C     write(*,'(2A/A)')'***WARNING! Solar flux below 63 FU (R12 <0)',
C    &                       'program stopped!'
C     stop
C     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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The Abdus Salam International Centre for Theoretical Physics

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

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** January **Day(DD)** 1 **Time** Universal

Solar Activity

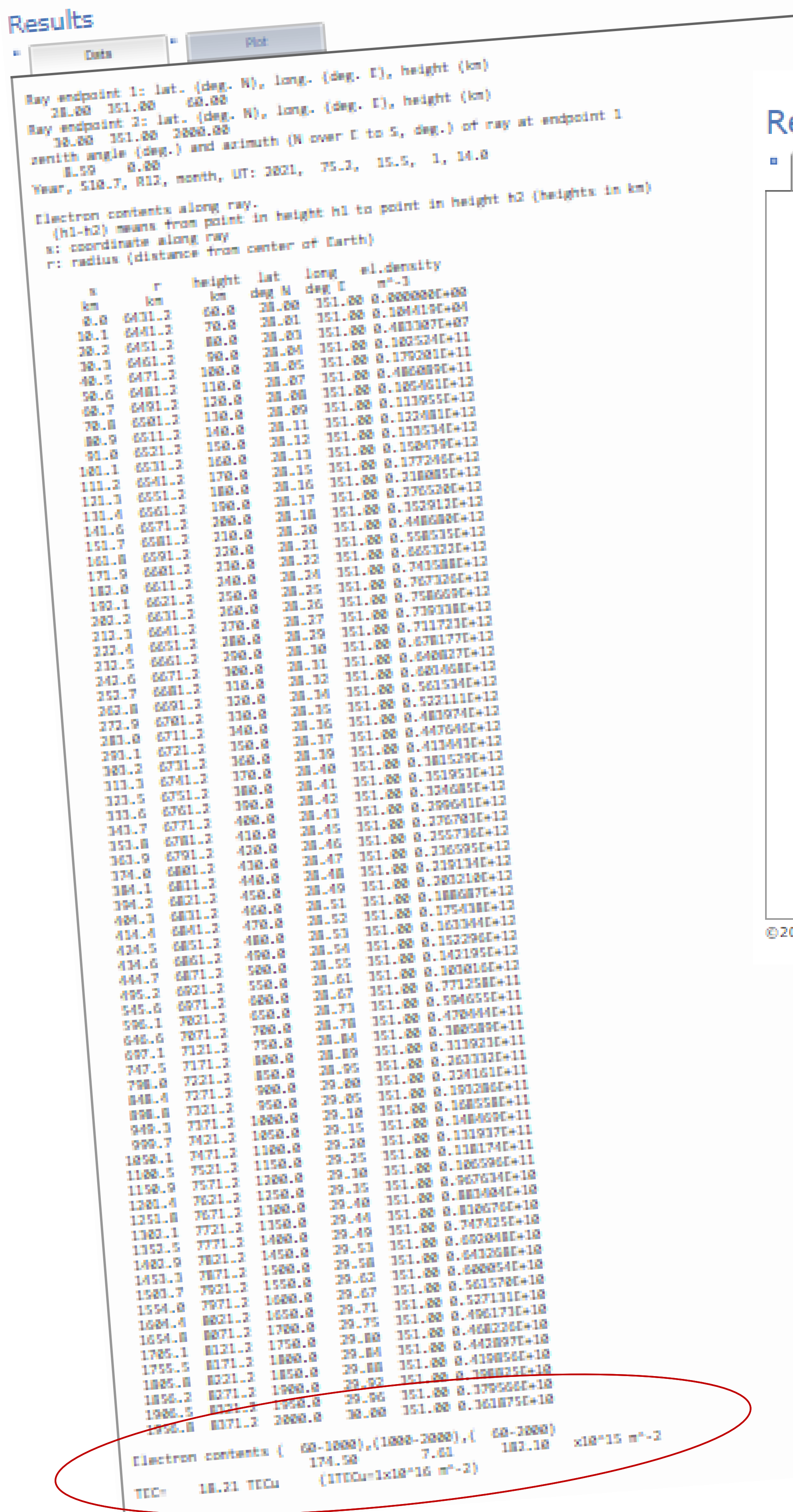
R12 (source: NOAA-NGDC)
Daily Solar Radio Flux (source: NOAA-NGDC)
User Input Solar index type R12 **Value ***

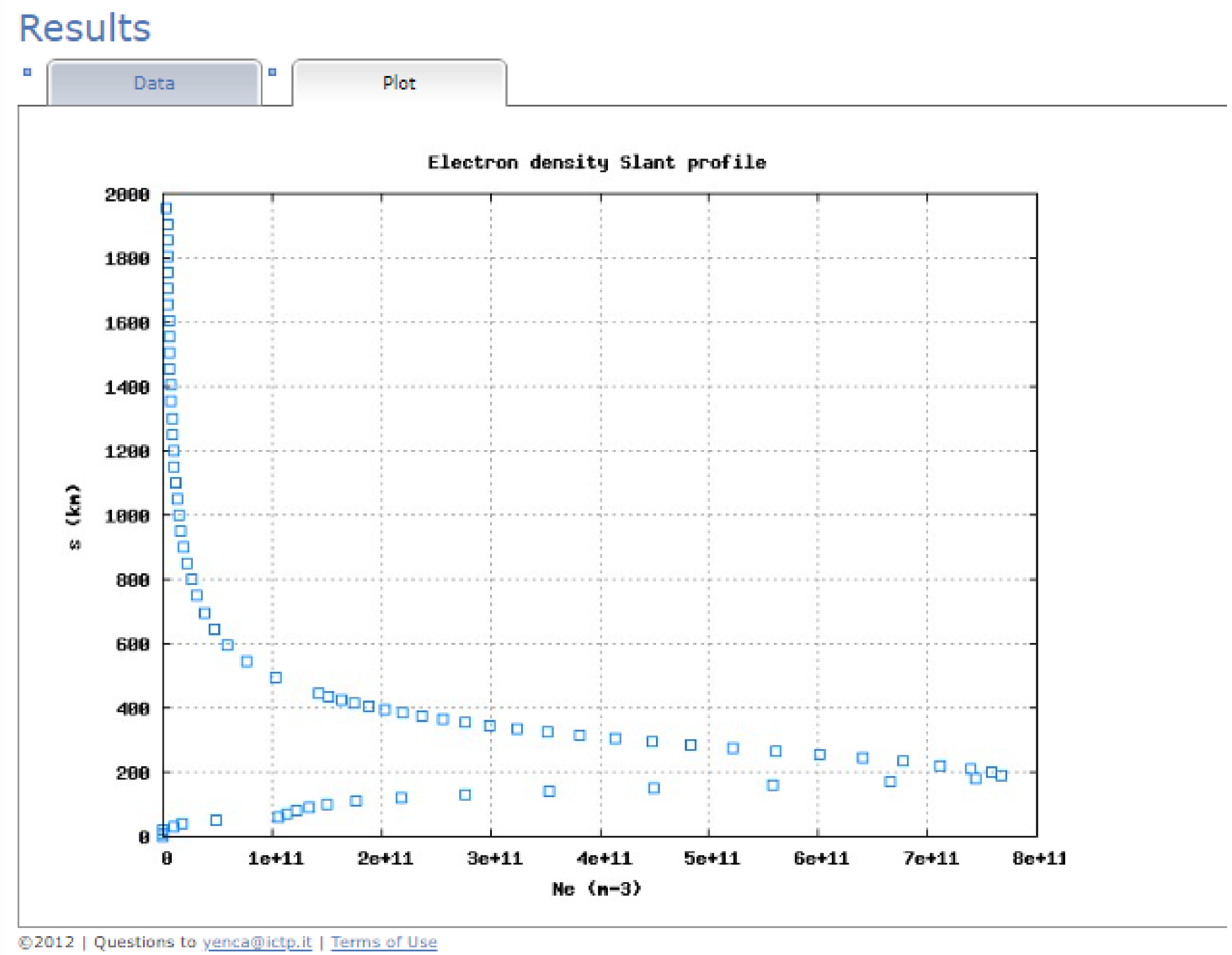
ITU-R compliant *

*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)

Run NeQuick

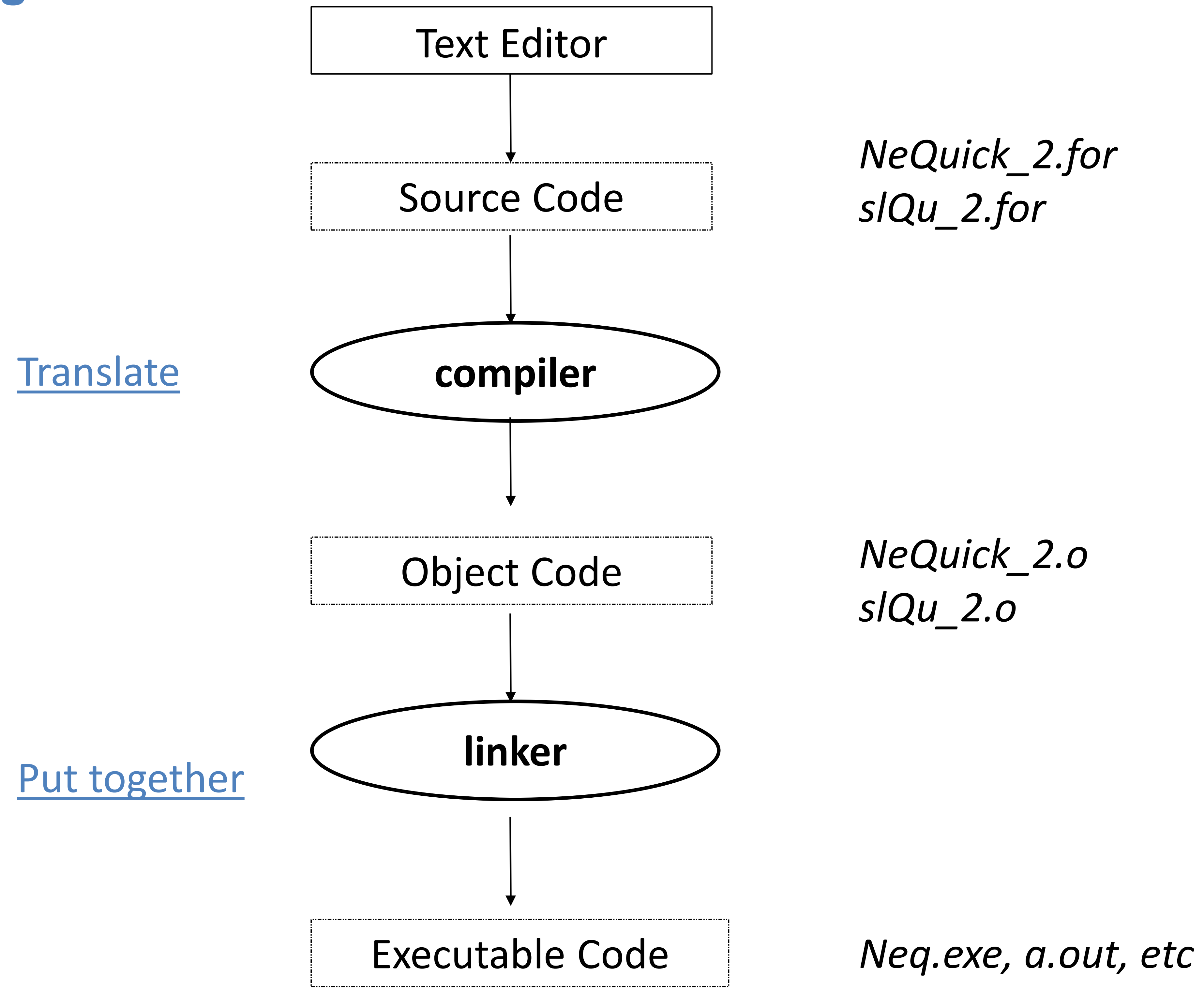
Model usage






```
  1906.5   8321.2   1950.0    29.96   351.00 0.379566E+10
  1956.8   8371.2   2000.0    30.00   351.00 0.361875E+10

 Electron contents (  60-1000),(1000-2000),(  60-2000)
                        174.50        7.61      182.10    x10^15 m^-2
 TEC=     18.21 TECu     (1TECu=1x10^16 m^-2)
```

Model usage



Text Editor
Source Code
NeQuick_2.for
slQu_2.for
Translate
compiler
Object Code
NeQuick_2.o
slQu_2.o
Put together
linker
Executable Code
Neq.exe, a.out, etc

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

MinGWW64

Cygwin

Model usage

NeQuick Compilation

Compile and Link NeQuick_2.for and **slQu_2.for** with a FORTRAN 77 compiler

Command format:

```
compiler [-o outputfile] NeQuick_2.for slQu_2.for
```

For example:

```
f77 -o neq2 NeQuick_2.for slQu_2.for
```

To run:

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

Running…

C:\WINDOWS\system32\cmd.exe - neqtest

```
C:\Documents and Settings\yenca>O:

O:\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…

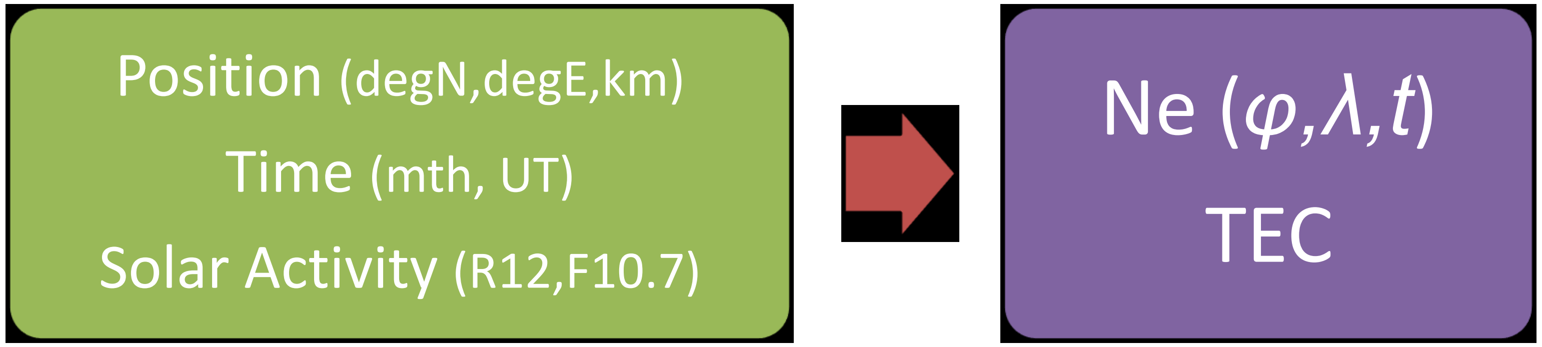
```
          * of the Abdus Salam International      *
          * Centre for Theoretical Physics        *
          * Trieste, Italy                        *
          *                                       *
          *****************************************

 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 slQu.dat


C:\Users\Yenca\Documents\Programs\NeQuick\NeQuick_2_0_1b>type slQu.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>
```

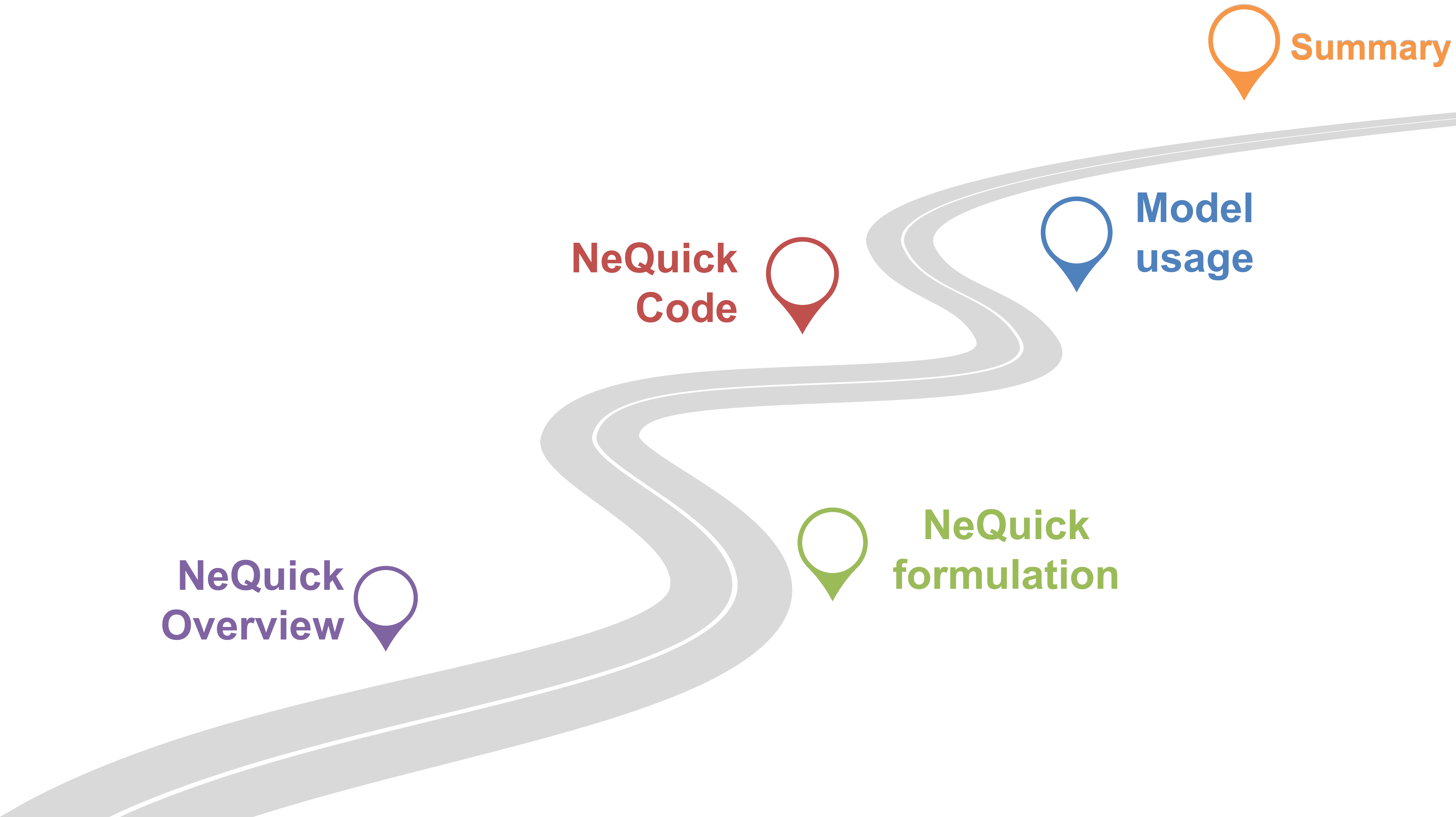
Not TECU!

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

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Summary

- NeQuick is a three-dimensional and time dependent ionospheric electron density model based on an empirical climatological representation of the ionosphere.

- The predecessors, versions and formulation 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 😉).

Thank you!

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