THE NEQUICK MODEL

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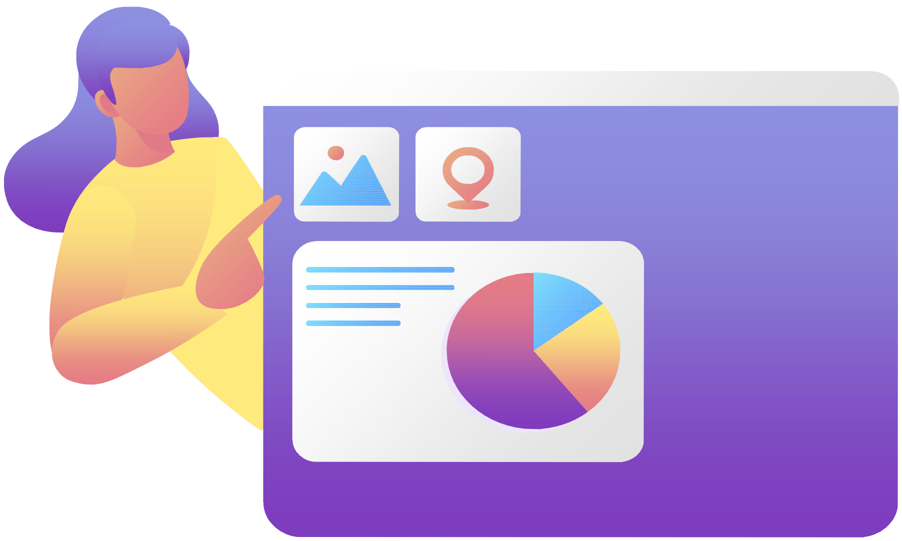
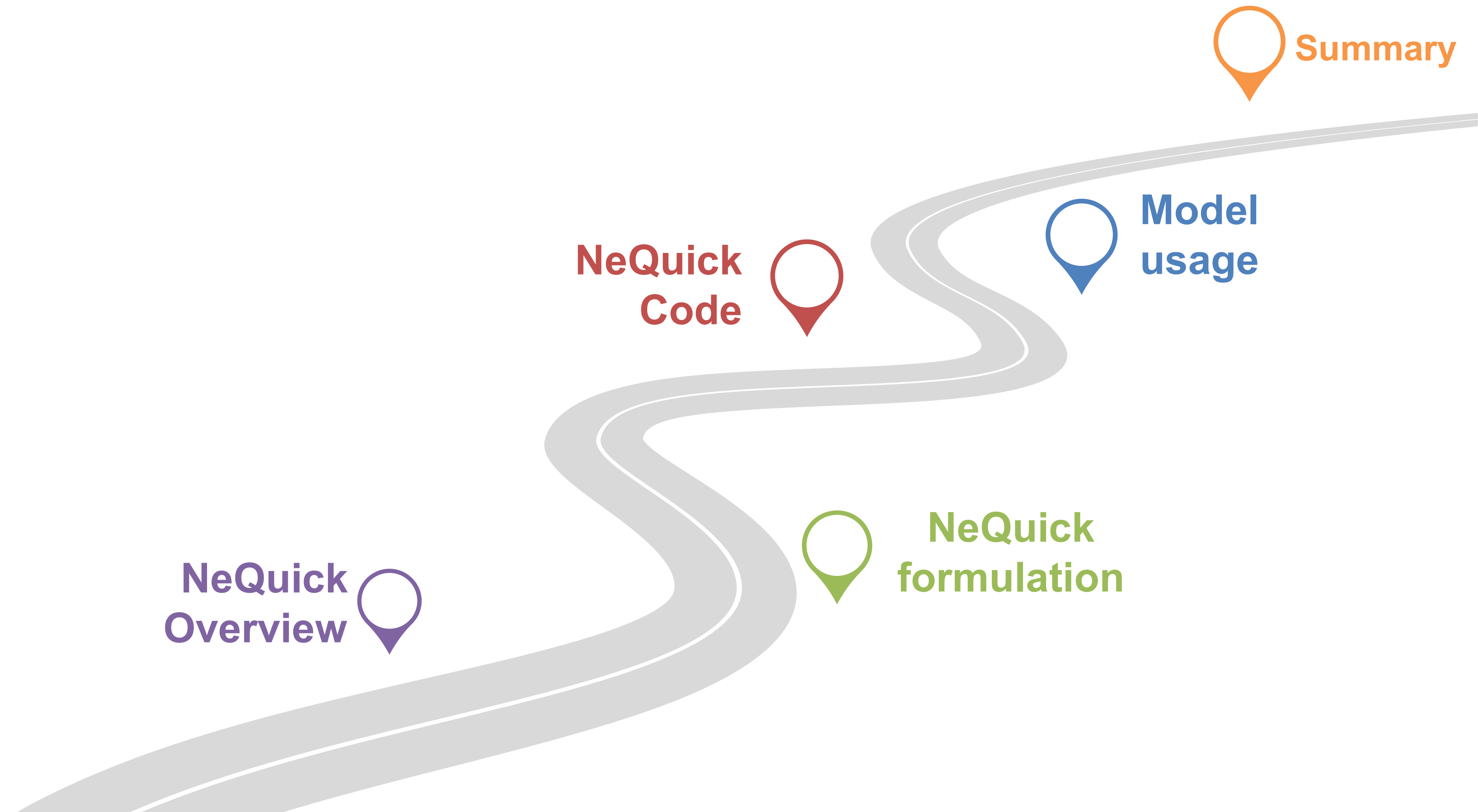
ICTP



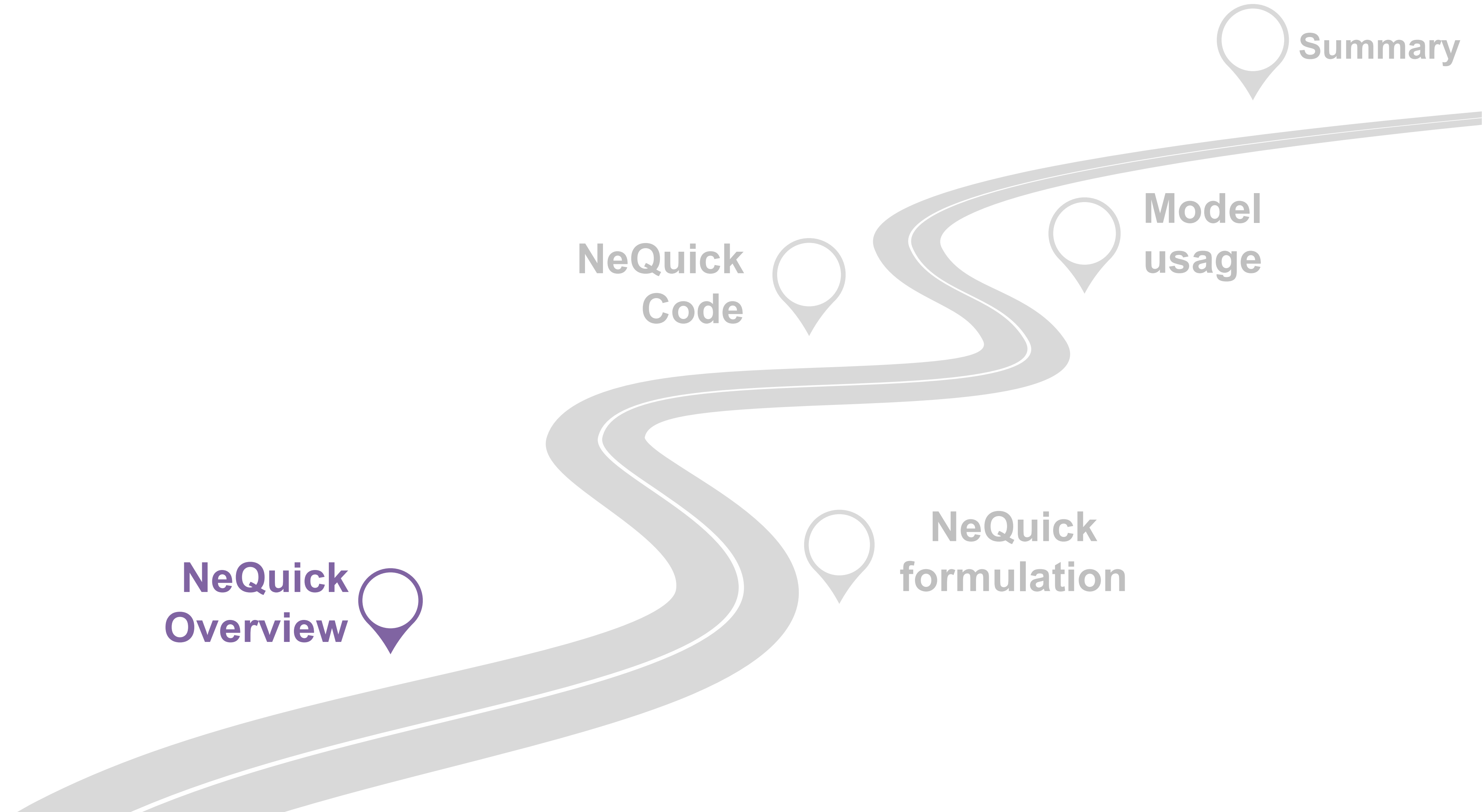
ICTP/African Capacity Building Workshop on Space Weather effects on GNSS
Trieste, 3-14 Oct, 2022

Talk roadmap



Are you ready for…

NeQuiz?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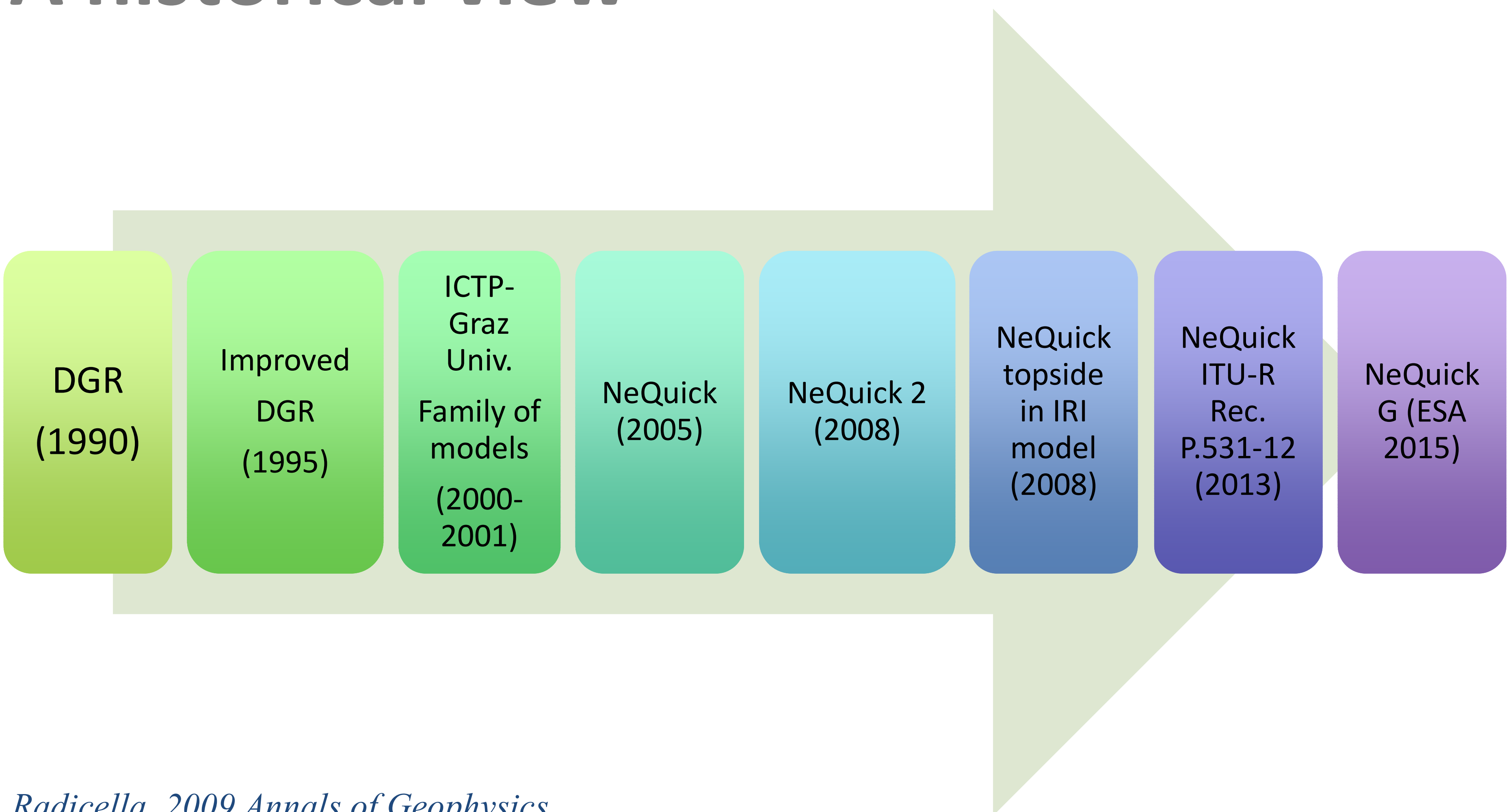
A historical view



Radicella, 2009 Annals of Geophysics

Trieste-Graz Family of models

Hochegger, G., B. Nava, S.M. Radicella, R. Leitinger (2000) Family of Ionospheric Models for Different Uses, Physics And Chemistry Of The Earth, Part C: Solar, Terrestrial & Planetary Science (25) 4, 307-310

Radicella, S.M., R. Leitinger, The Evolution of the DGR Approach to Model Electron Density Profiles, Adv. Space Res., Vol. 27, No. 1, 35-40, 2001

A family of Ne models, differing in complexity and with different but related application areas based on the DGR «profiler» concept has been developed in collaboration with the University of Graz, Austria.

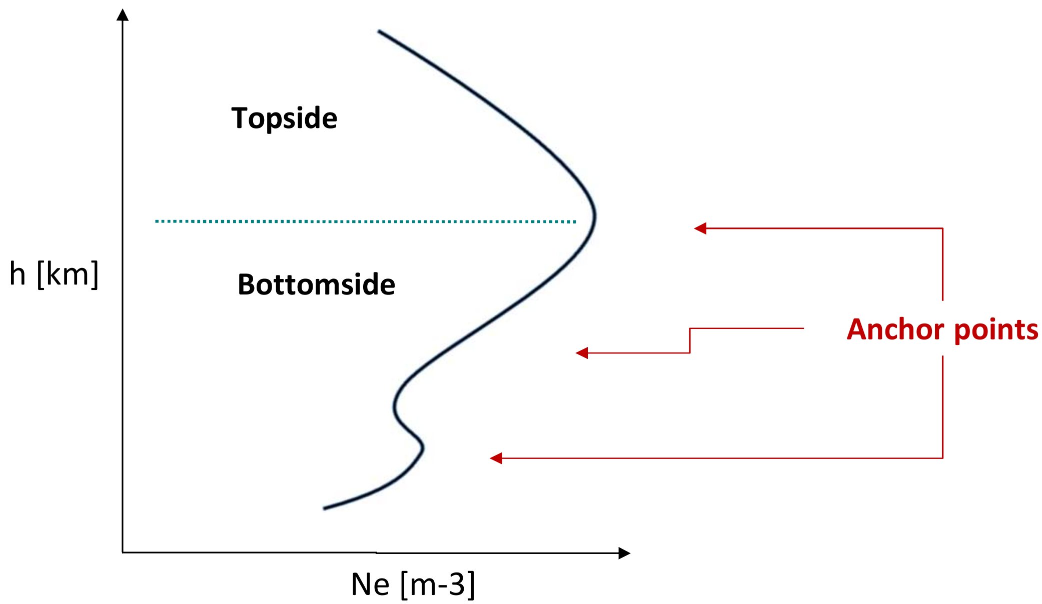
COSTprof: For ionospheric and plasmaspheric satellite to ground propagation with particular attention to the changes of gradients in the topside profile of electron density. This model was adopted by the COST 251 action of the European Commission as "profiler" for its final product.

NeUoG-plas: For assessment studies involving satellite to satellite propagation paths to take into account an accurate plasmaspheric electron density.

NeQuick: A quick-run model for transionospheric applications that allows to calculate both vertical or slant profile of electron density and TEC for any specified path.

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.



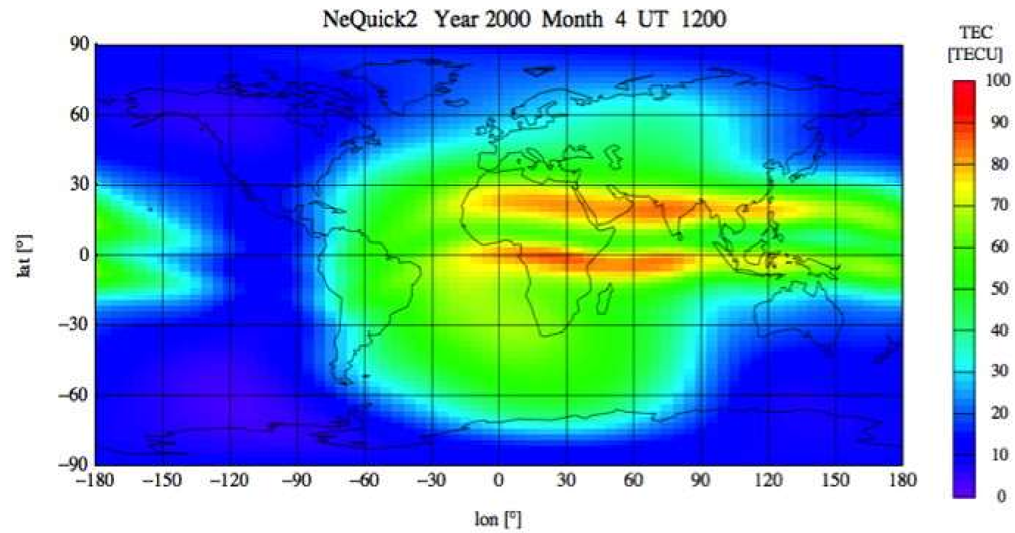
modelled (e.g. ITU-R coefficients for foF2, M(3000)F2) or experimentally derived

Position (degN,degE,km)
Time (mth, UT)
Solar Activity (R12,F10.7)

→

Ne (φ,λ,t)
TEC

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.

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

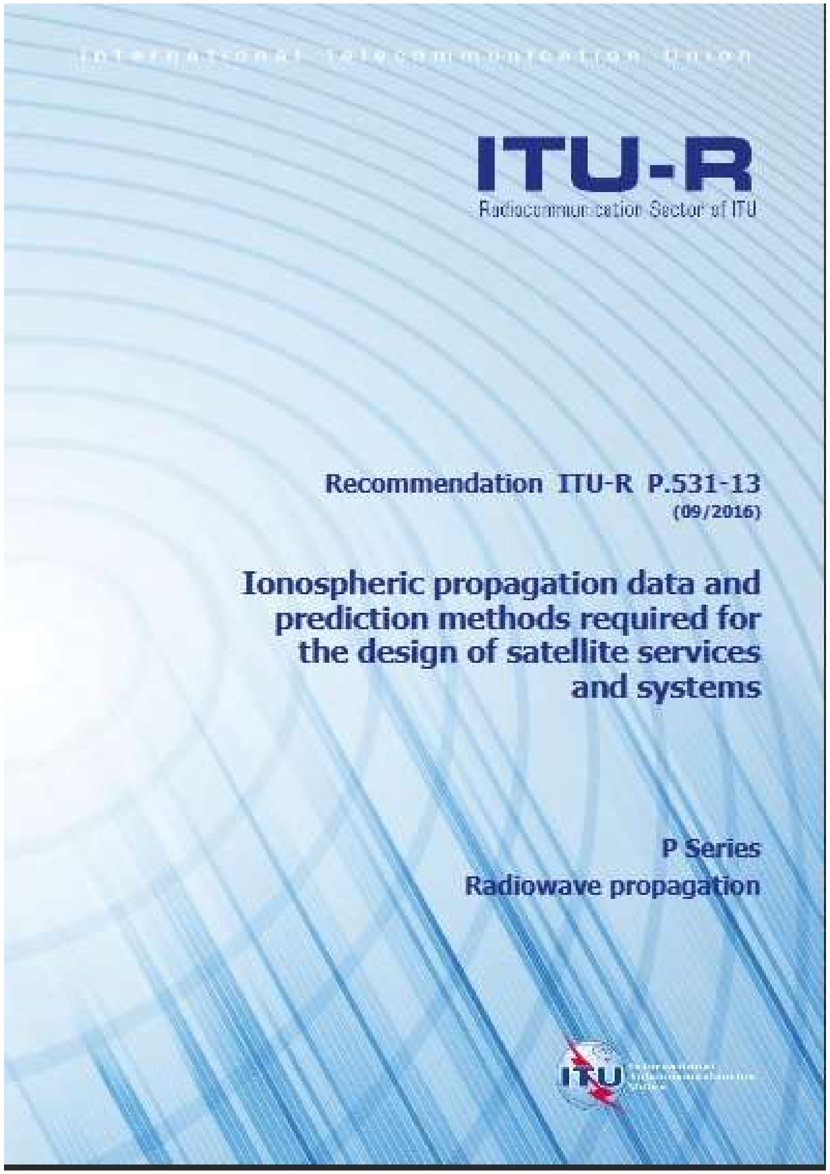
NAVA. B., P. COÏSSON AND S.M. RADICELLA (2008), A new version of the NeQuick ionosphere electron density model; J.of Atmos.and Solar-Terr. Physics.

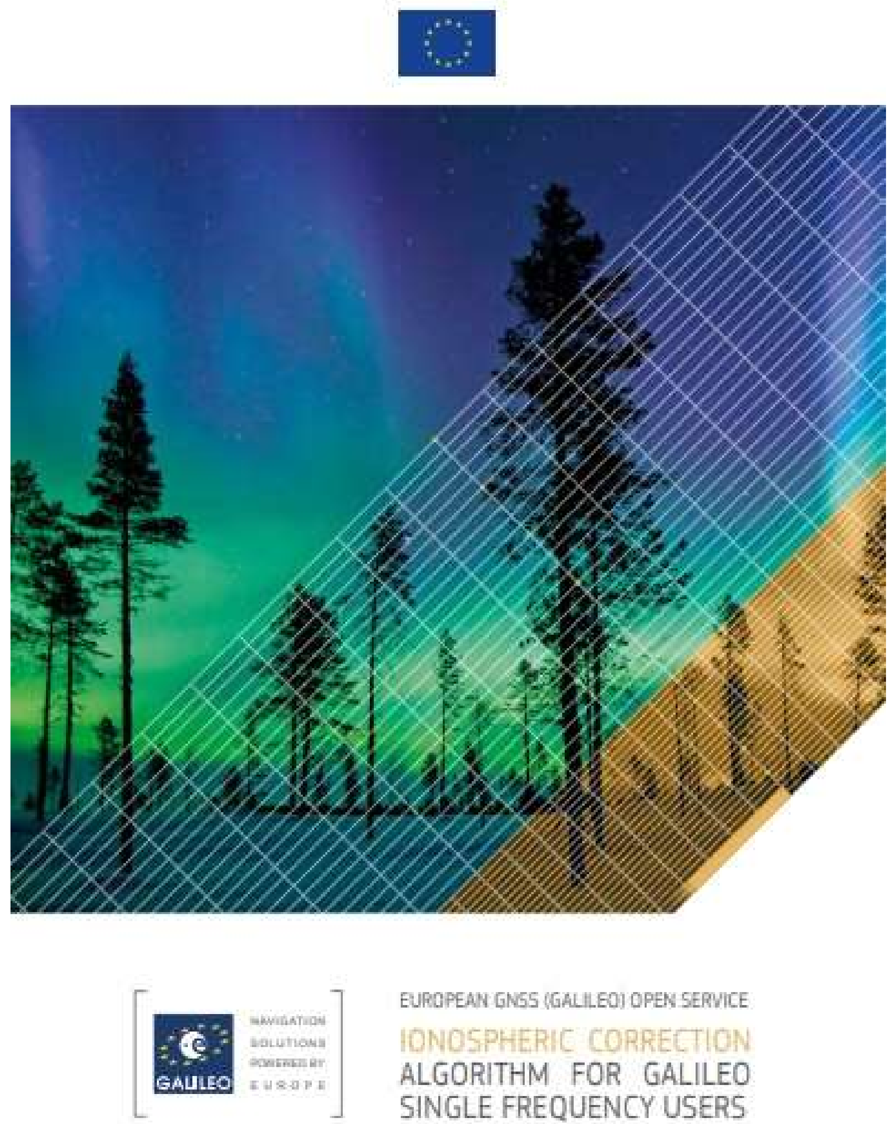
NeQuick Overview

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

NeQuick 2 in ITU-R and NeQuick G



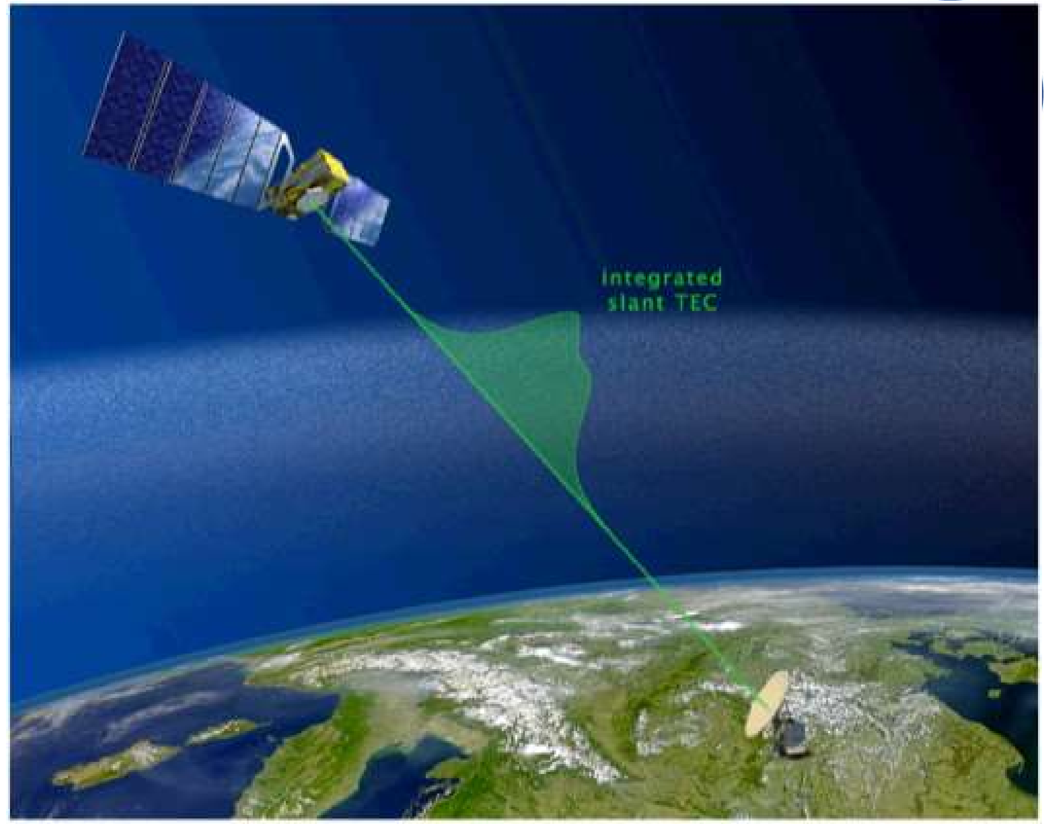


ICG Working Groups Recommendations

- 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,

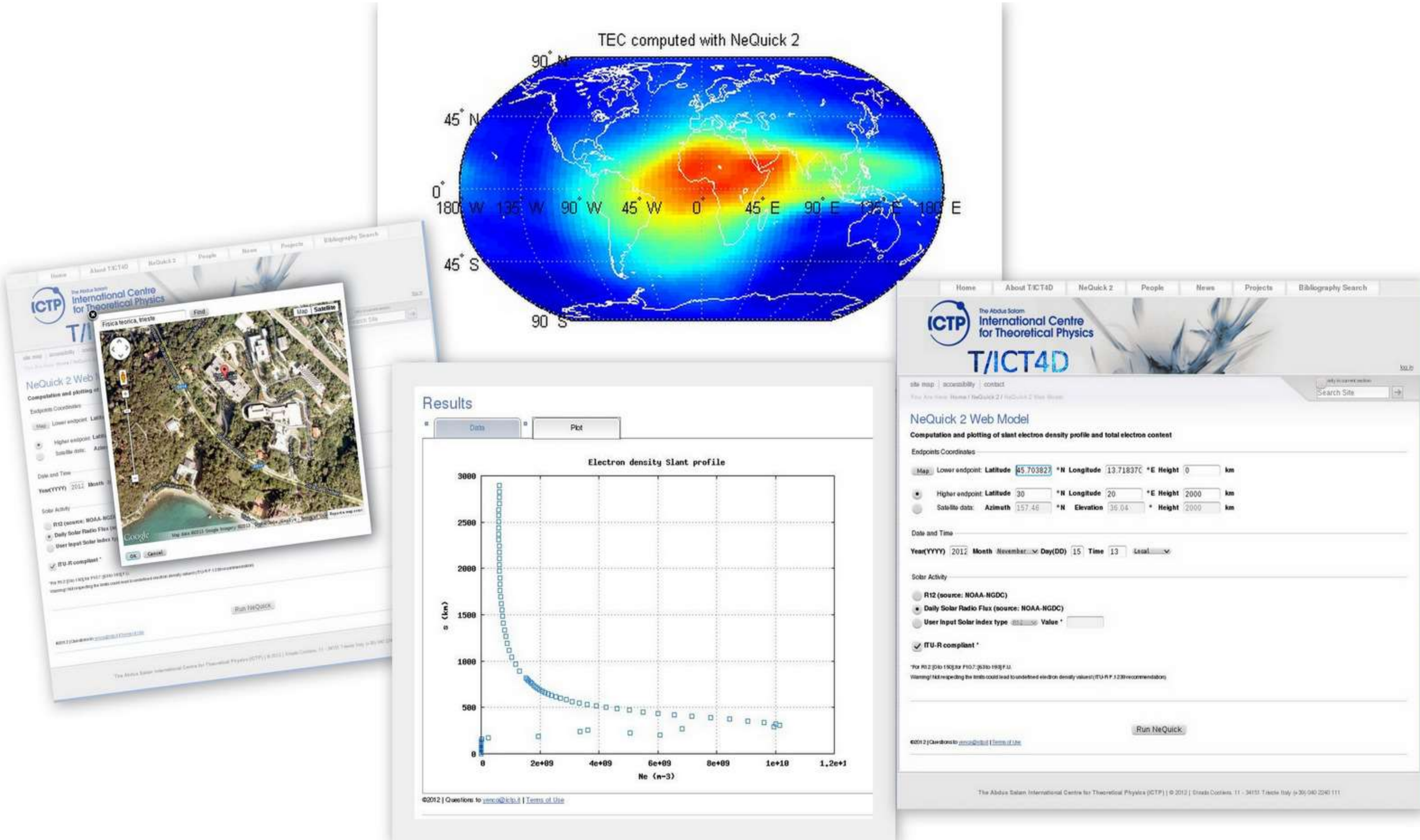
https://www.itu.int/rec/R-REC-P.531-14-201908-I/en

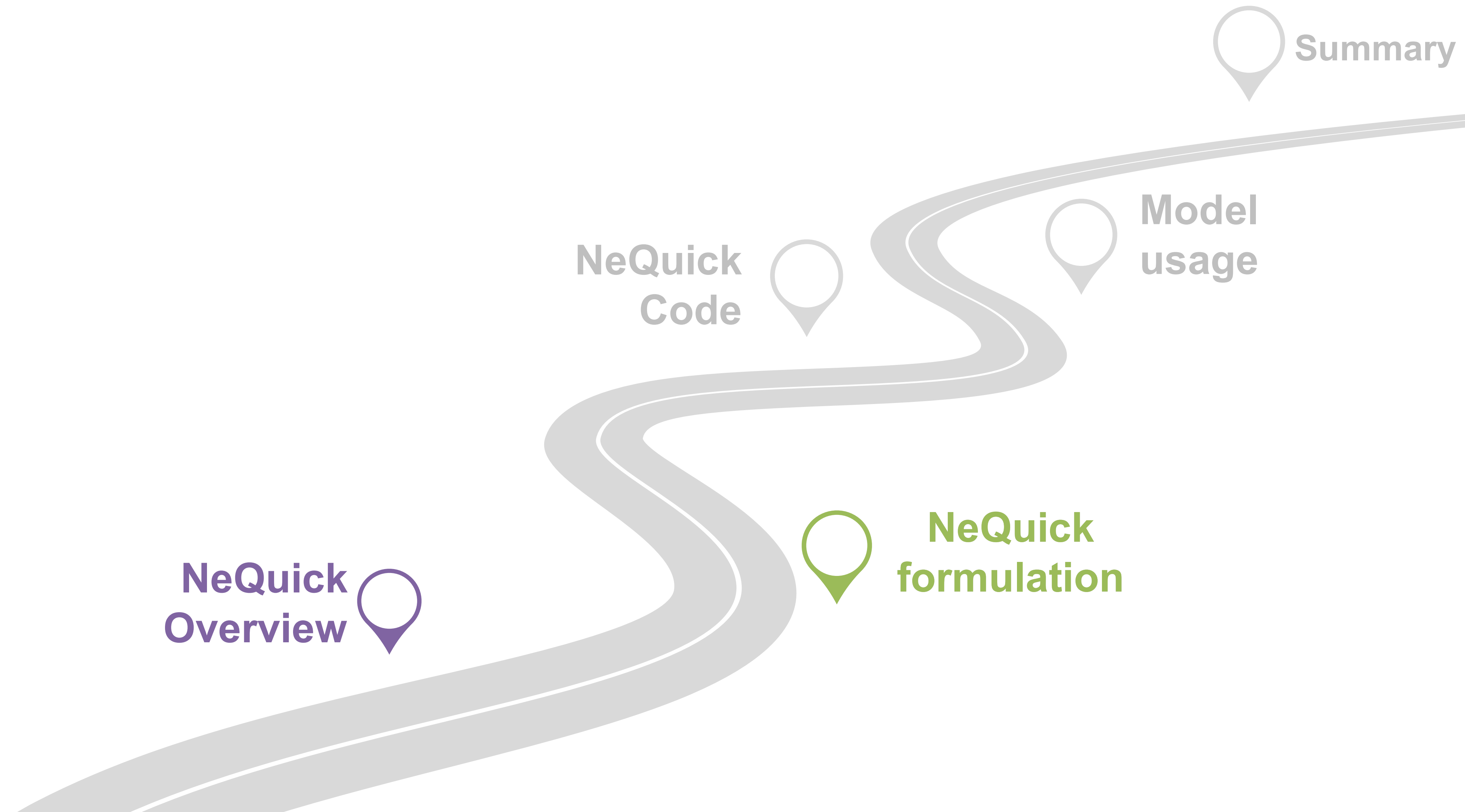
NeQuick 2 online: http://t-ict4d.ictp.it/nequick2

- NeQuick G (ESA) $$Az = a_0 + a_1\mu + a_2\mu^2$$

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

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

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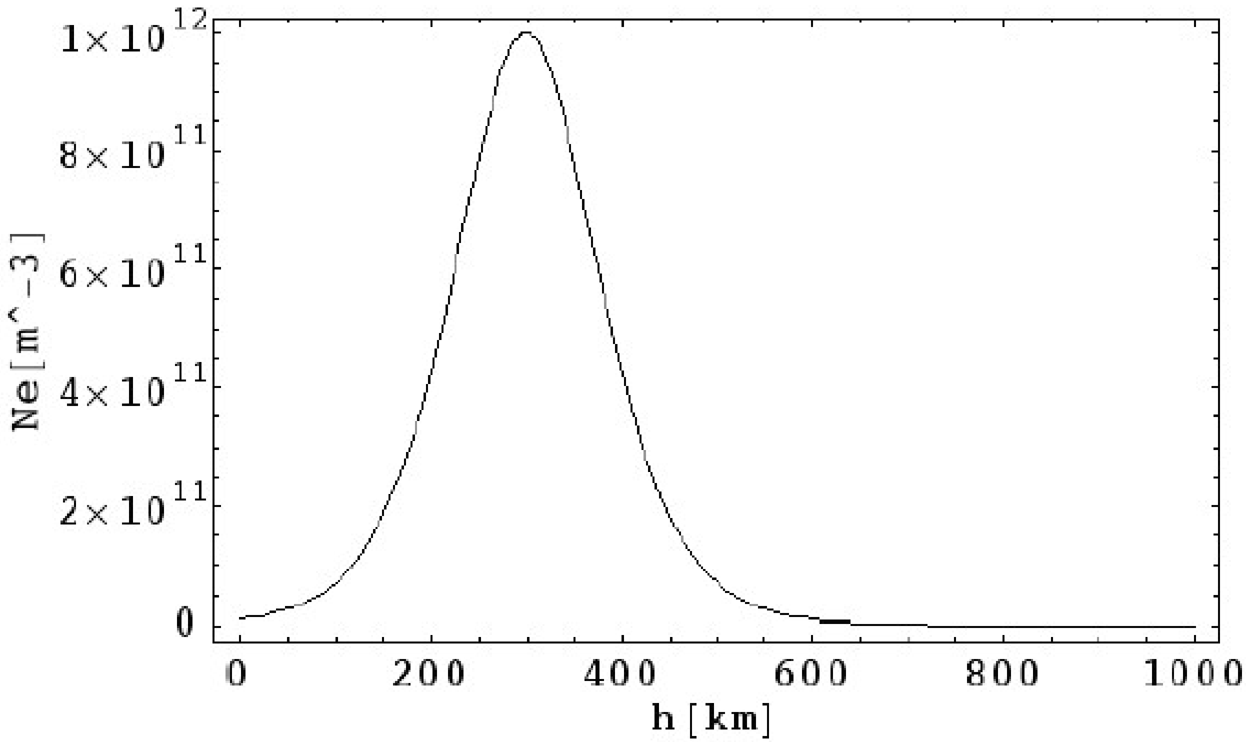
Epstein Layer

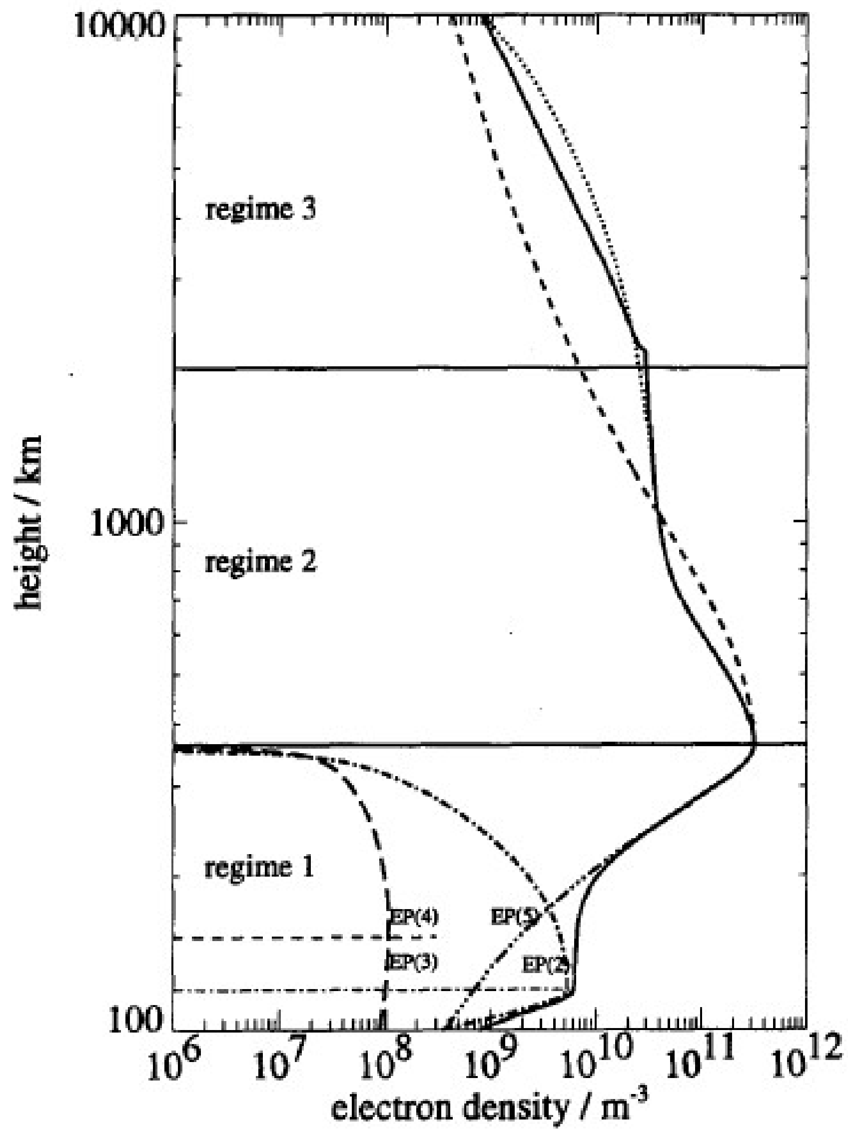
$$N(h,hmax,Nmax,B) = \frac{4Nmax}{(1+\exp(h-hmax/B))^2} \exp\left(\frac{h-hmax}{B}\right)$$



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

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

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

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

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

Thickness Parameters

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

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

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

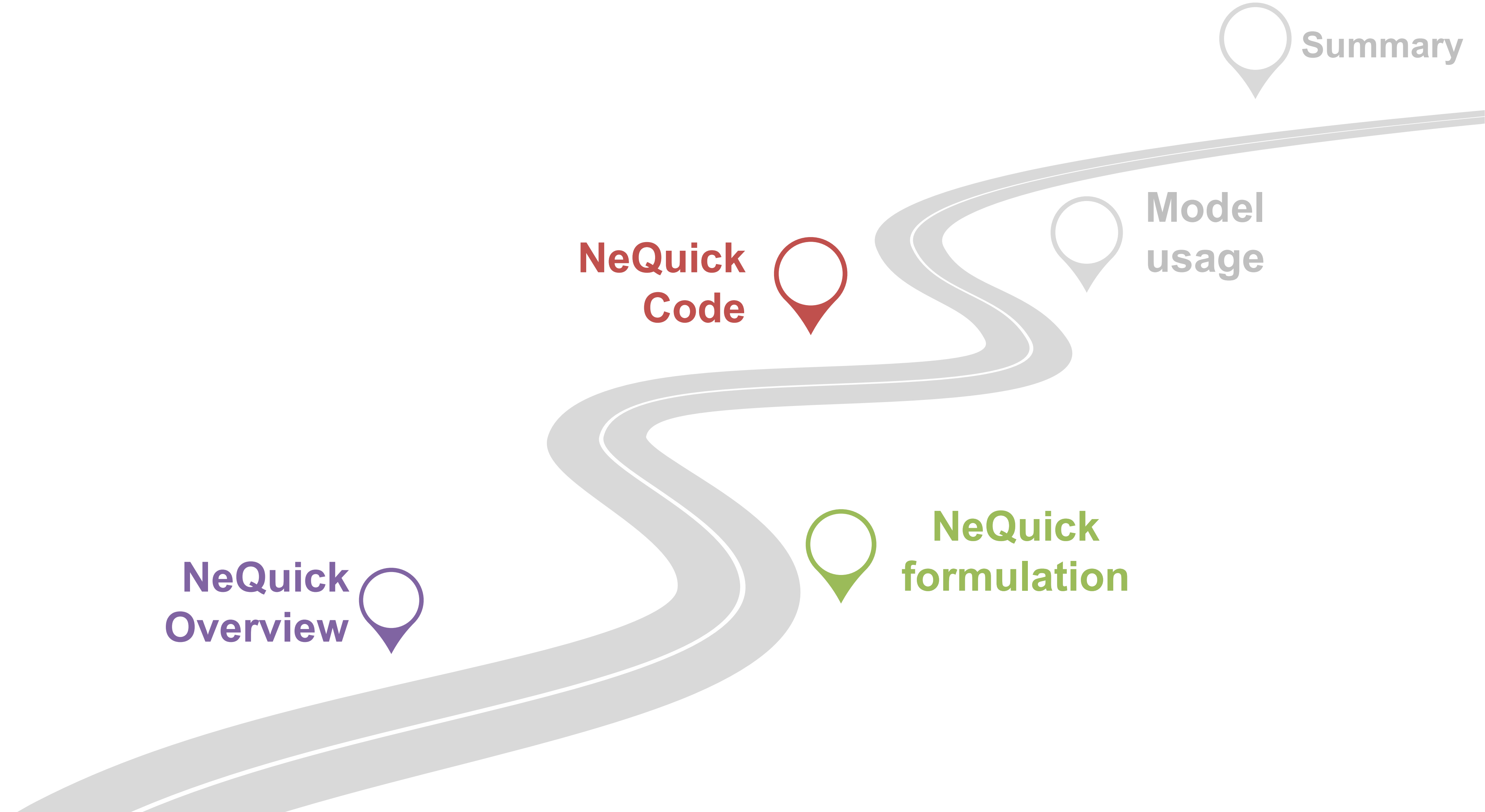
Titheridge, (1996)

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

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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Summary

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

NeQuick_2_0_2.for and 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

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.

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

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
```

<u>Ne Computation:</u>

```
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

slQu_2_0_2.for *Cont.d*

```
subroutine rays →  set and check ray endpoints,
                   calculates geometric parameters for ray

subroutine dat_t_sa →  set date and solar activity

subroutine gcirc → calculates great circle path properties

subroutine naut → calculates position of ray perigee, zenith angle of
ray at lower endpoint, and slant to vertical projection factor cos(chi)

subroutine geogra → calculates h, lat and long along the ray from the
perigee of the ray, s

function eld →  gives Ne as a function of the coordinate s
```

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).

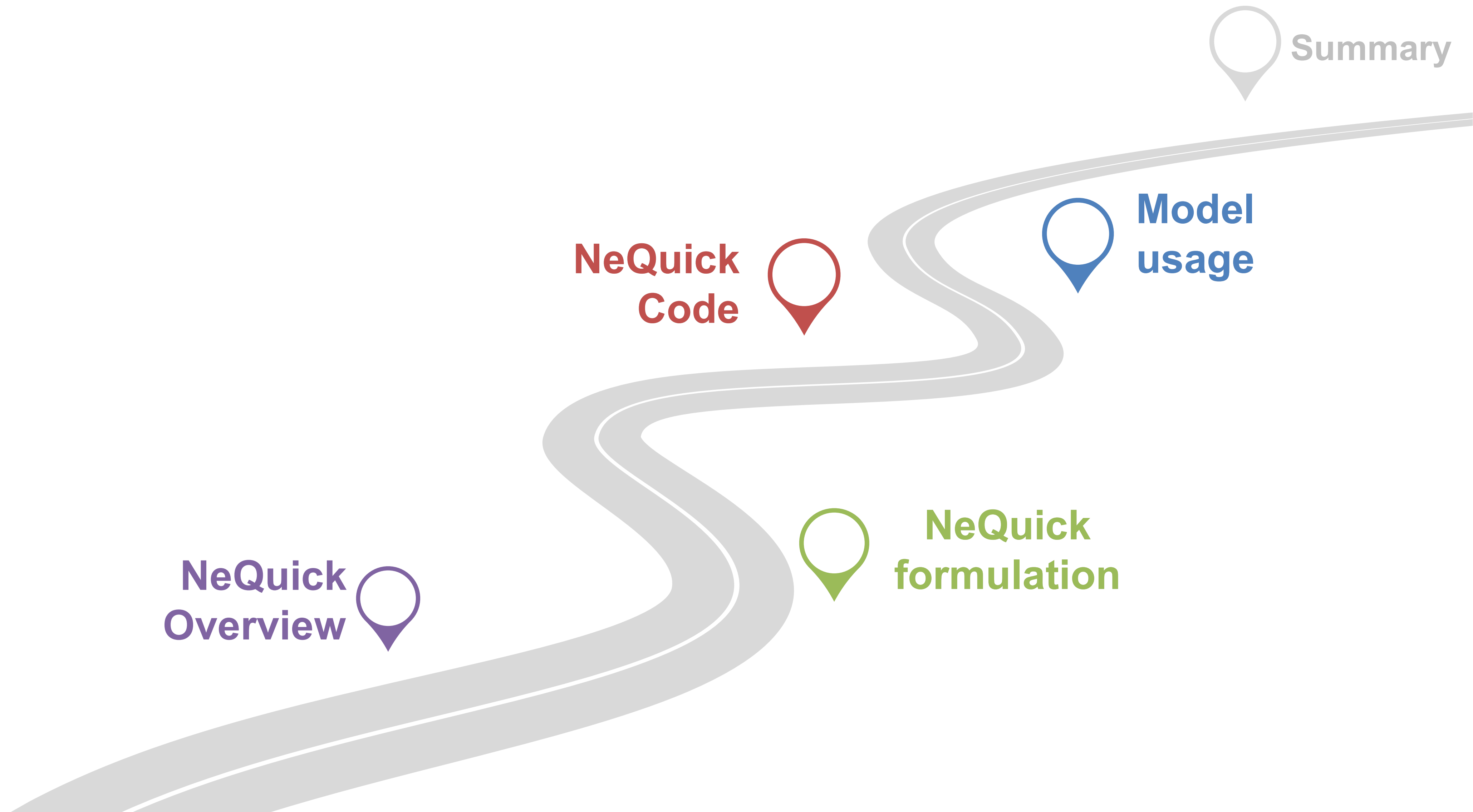
If a value below 63 F.U (R12=0) is input, the subroutine will stop the program. The limits on F10.7 (or R12) input can be removed at the user's own risk by commenting the lines 197 to 208 in the source file NeQuick_2_1.for (prepNeq subroutine) as follows:

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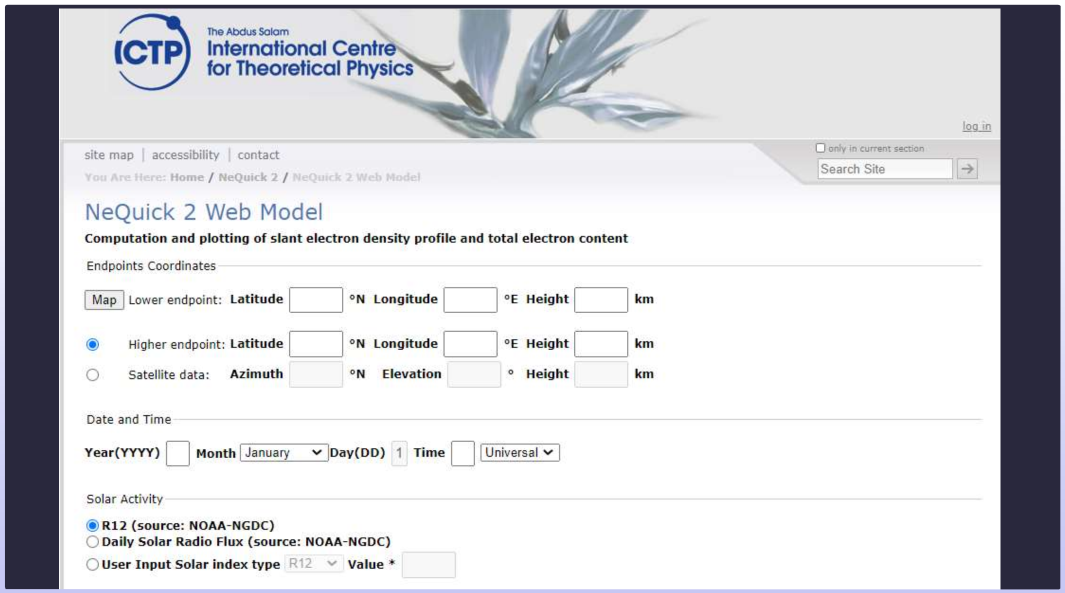
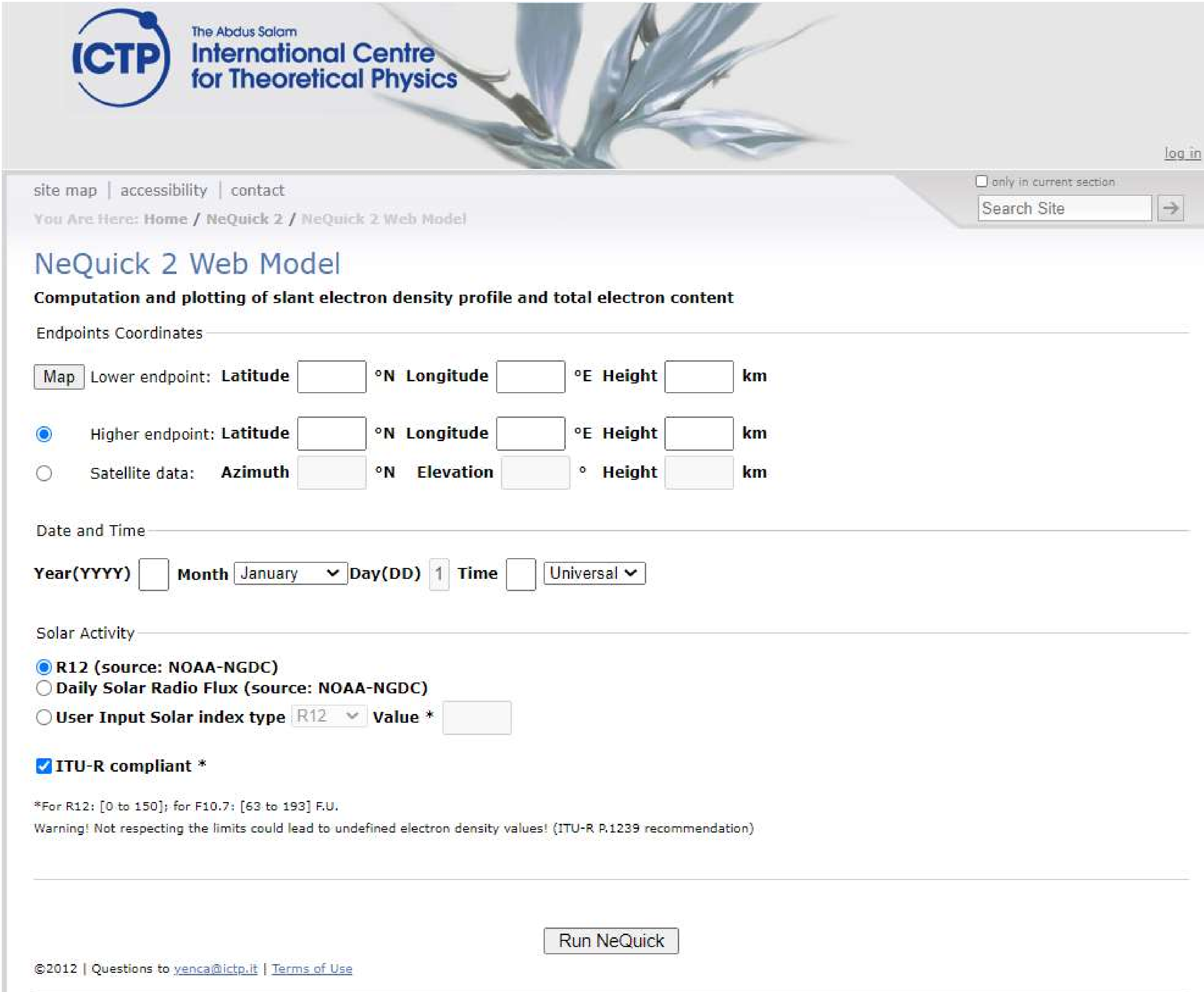
http://t-ict4d.ictp.it/nequick2





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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** 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

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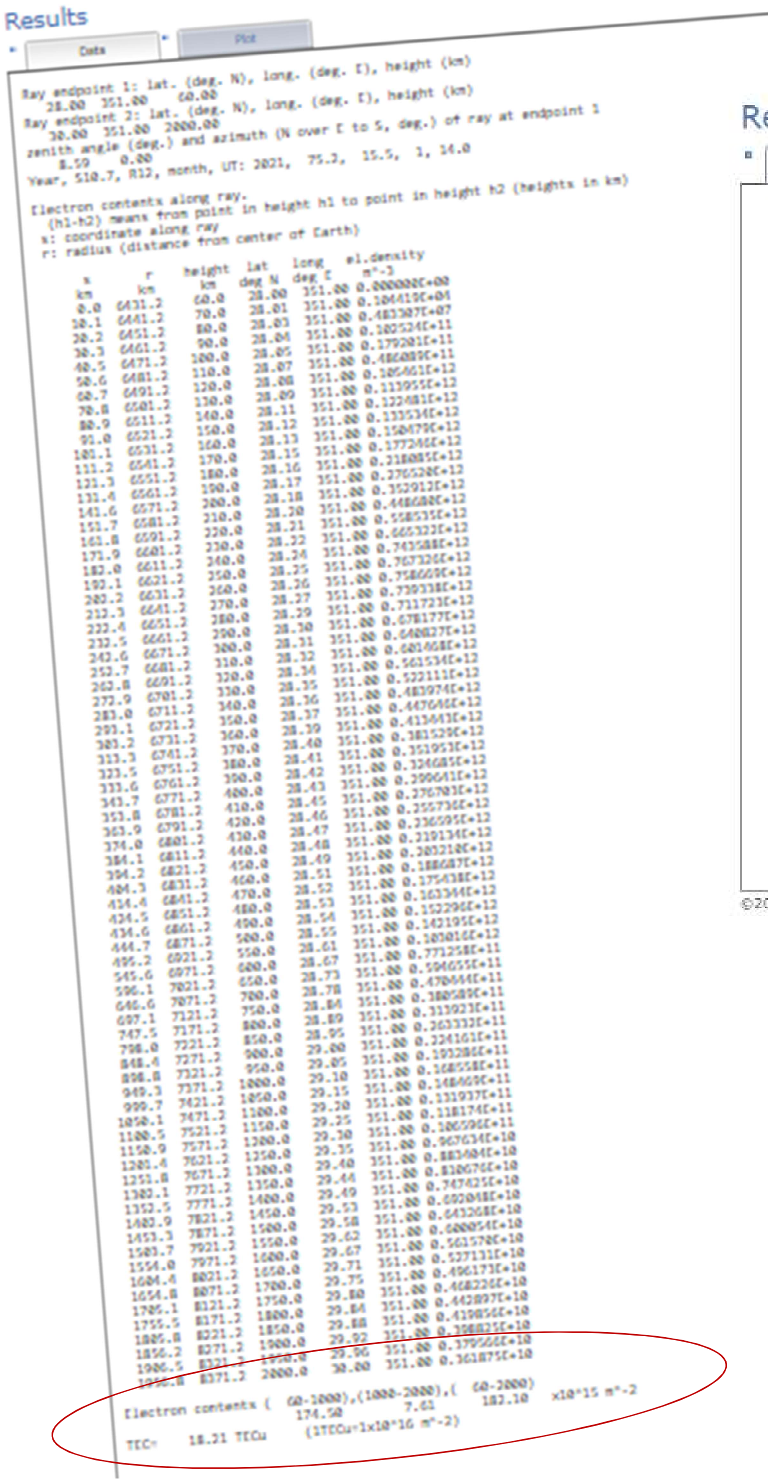
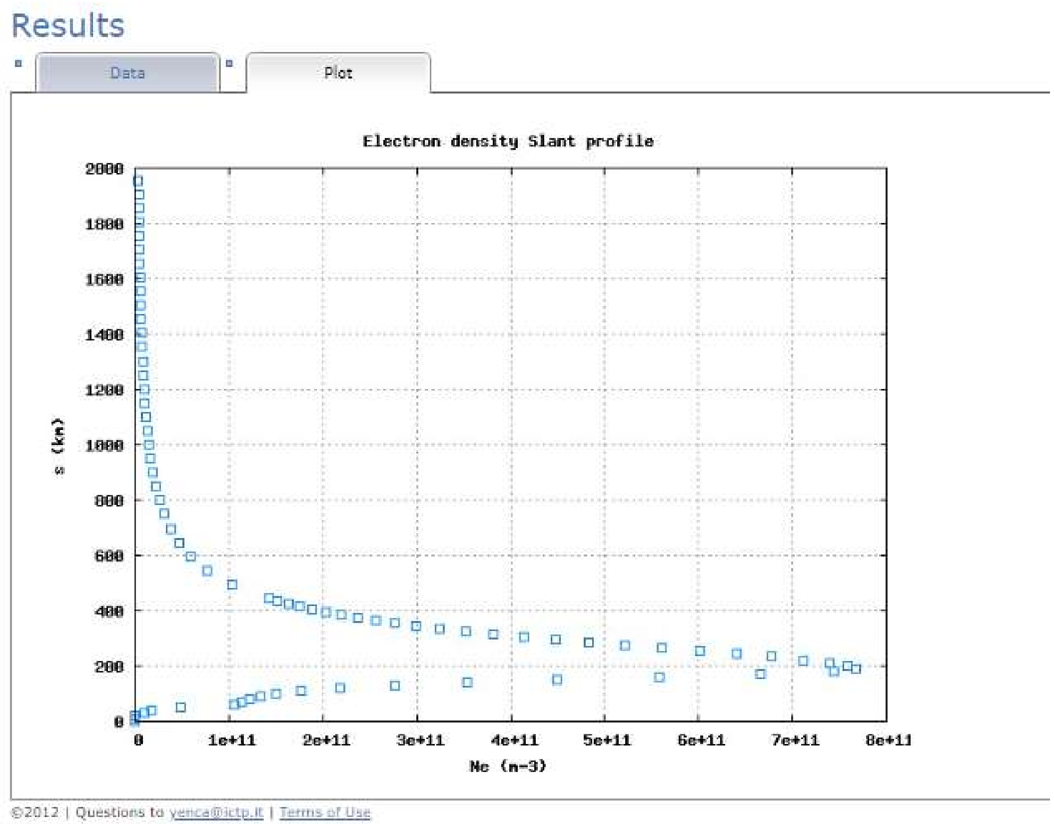
http://t-ict4d.ictp.it/nequick2

Model usage

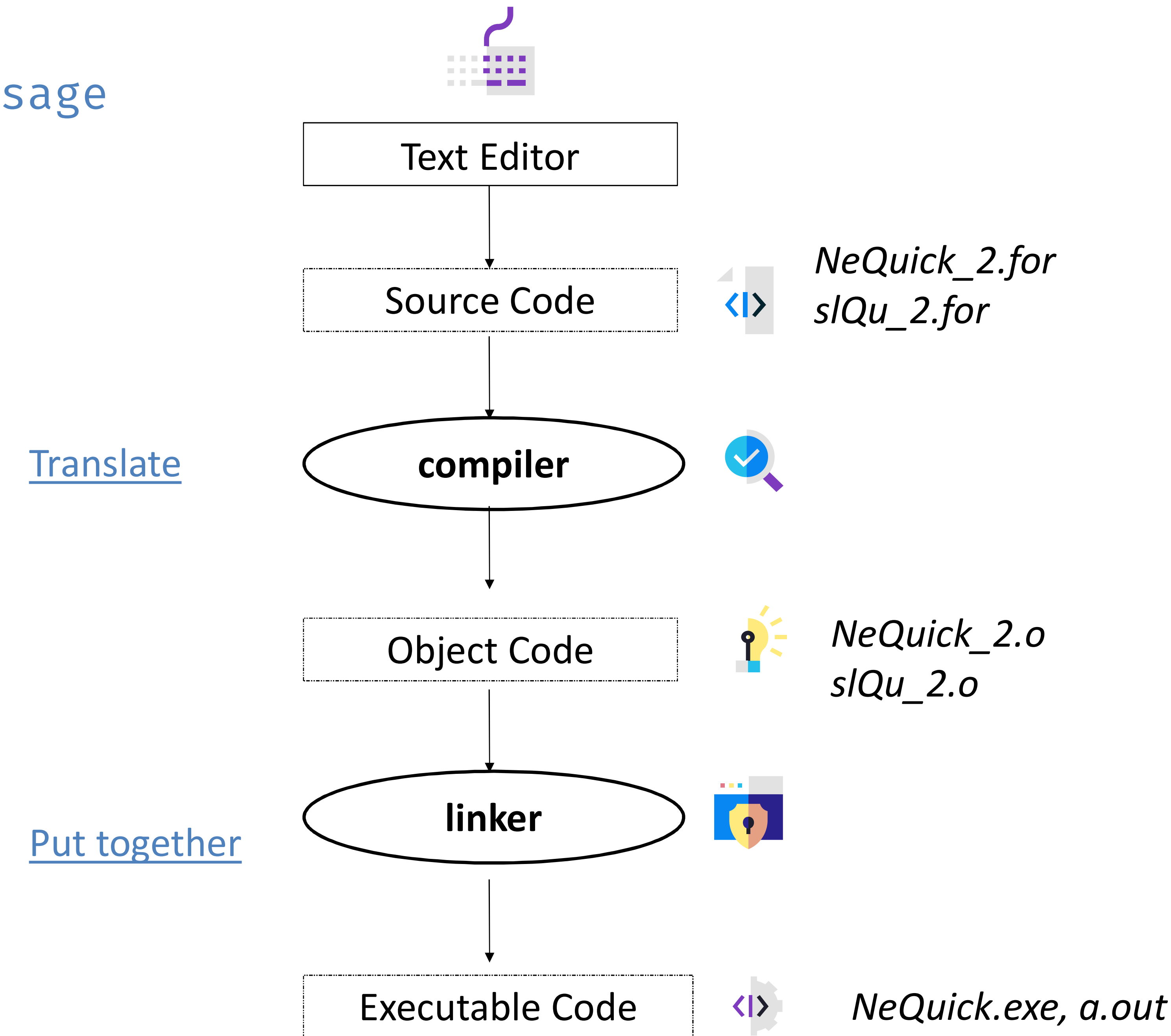




1856.2	8271.2	1900.0	29.92	351.00	0.398625E+10
1906.5	8321.2	1950.0	29.96	351.00	0.379566E+10
1956.8	8371.2	2000.0	30.00	351.00	0.361875E+10

```
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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slQu_2.for
Translate
compiler
Object Code
NeQuick_2.o
slQu_2.o
Put together
linker
Executable Code
NeQuick.exe, a.out

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

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
```

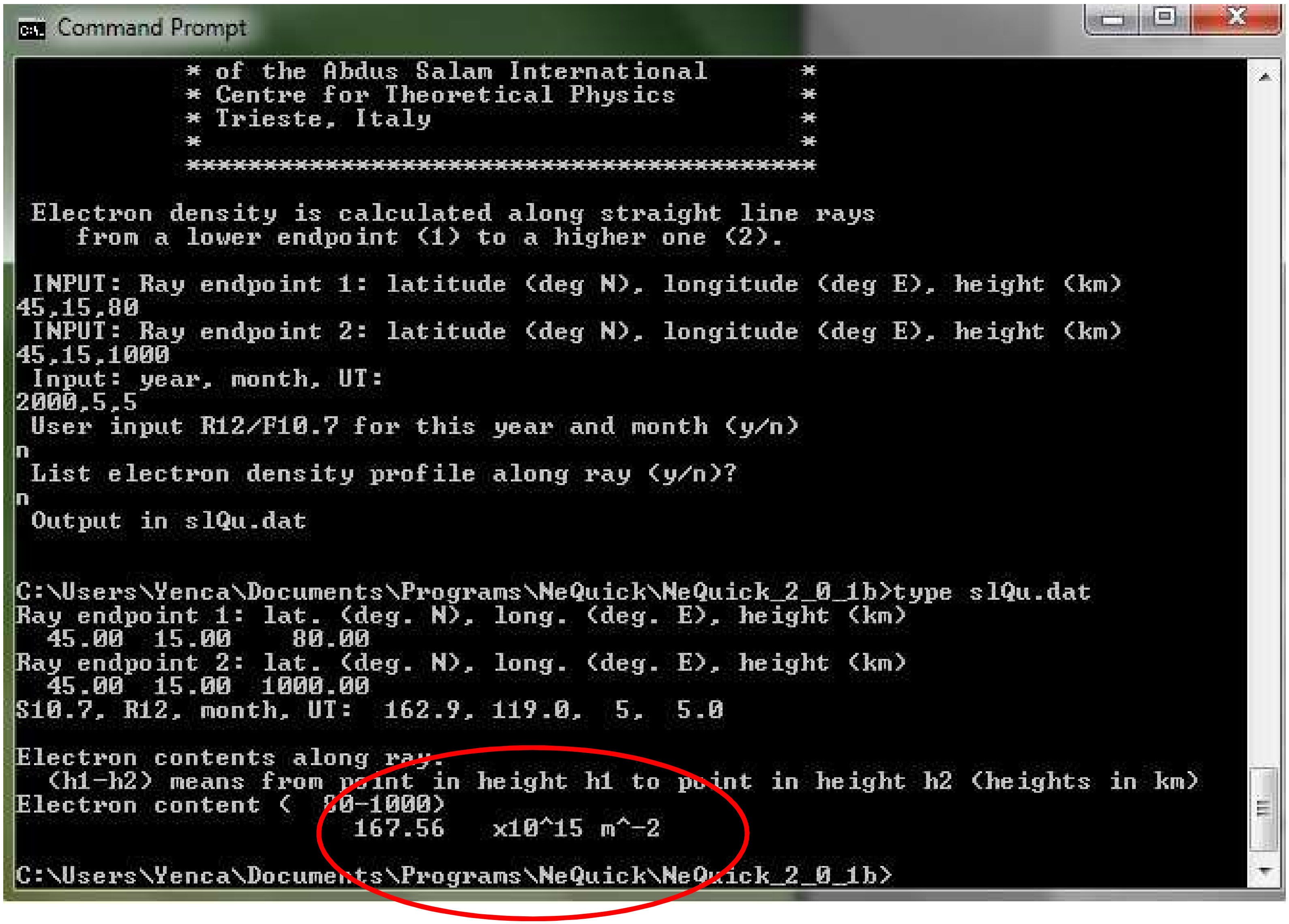
To run:

```
./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…



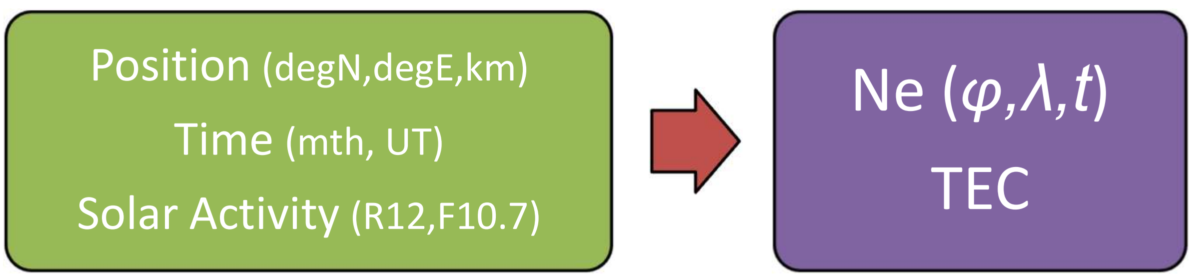
Not TECU!

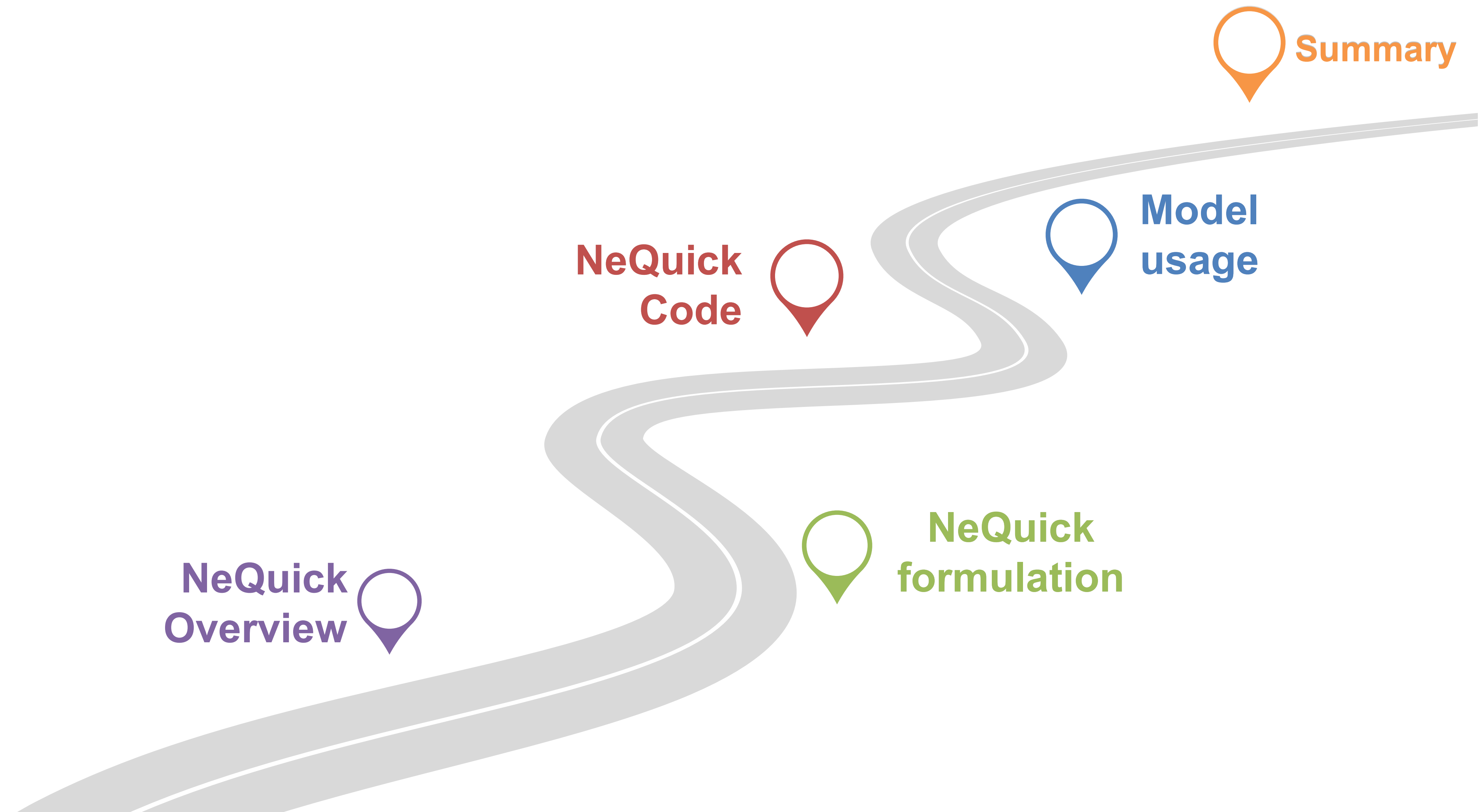
Running…

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





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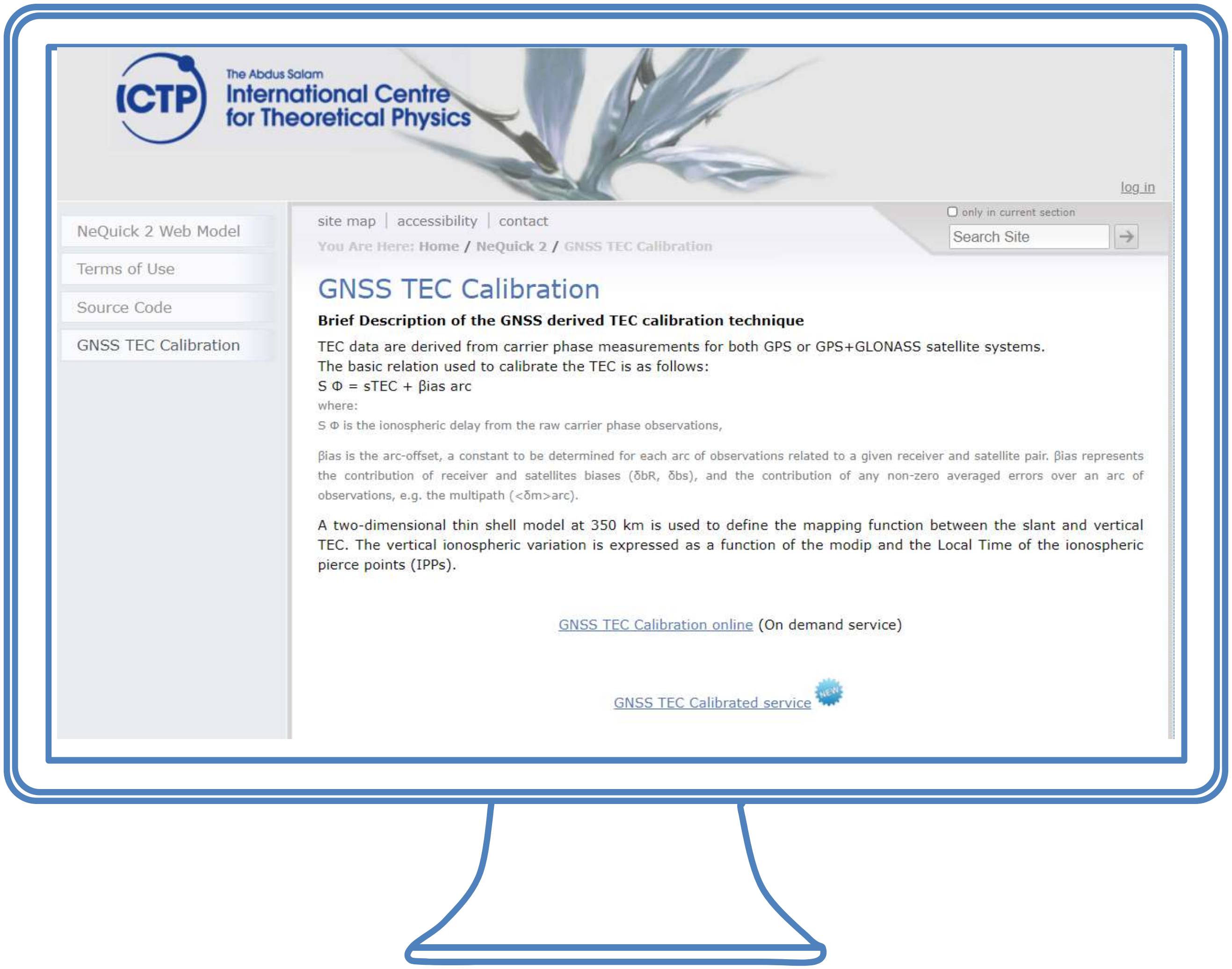
Summary

- NeQuick is a three-dimensional and time dependent empirical ionospheric electron density model to represent the climatology of the ionosphere.
- 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 ☺).

GNSS TEC data

https://t-ict4d.ictp.it/nequick2/gnss-tec-calibration



Thank you!

yenca@ictp.it