Ingesting different kinds of data into NeQuick

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Outline

- Overview of the techniques implemented to adapt NeQuick model to experimental data:
  
  - vTec map ingestion
    - validation: using ionosonde-derived foF2 data
    - internal consistency: using GPS-derived sTec data
    - validation: using Occultation-derived sTec data
  
  - Ground-based TEC & ionosonde peak parameters ingestion
    - validation: using JRO data
  
  - Case study: LISN TEC data ingestion
    - validation: using JRO data / ionosonde-derived foF2 data
Introduction

- Empirical models like IRI and NeQuick have been developed as climatological models, able to reproduce the typical median condition of the ionosphere.

- In order to pass from “climate” to “weather”, there is a need to have models able to reproduce the current conditions of the ionosphere.

- Several assimilation schemes have been developed. They are of different complexity and rely on different kinds of data (GAIM, EDAM).

- In the case of NeQuick, the methods used to adapt the model to experimental data are intended to be simple and quick.

- Therefore they rely on the use of “effective” parameters, that are defined on the bases of model and the experimental data used (e.g. foF2 or TEC).
Basic concepts

Model(s) features relevant to implement adaptation techniques.

• The model can be considered as profiler.
  • The profile formulation is based on anchor points modeled in terms of ionosonde parameters (e.g. $f_{oE}$, $f_{oF1}$, $f_{oF2}$ and $M(3000)F2$).
  • For a given epoch & ray-path the model TEC is (essentially) a monotonic function of the solar activity index, that can be regarded as an “effective ionization level” parameter (e.g. effective$_{f10.7}$).
Adapting NeQuick model to vertical TEC maps
vTEC map USTEC

grid points:
lat. = 10°, 60° step 1°
lon. = -150°, -50° step 1°
Reconstructed foF2 map

grid points:
lat. = 10°, 60° step 1°
lon. = -150°, -50° step 1°
Reconstructed Ne map

Grid points:
lat. = 10°, 60° step 1°
lon. = -150°, -50° step 1°
vTEC map data ingestion

At a given epoch

One vTEC map

Minimize the mismodelings

\[ |vTEC_{\text{exp}, i} - vTEC_{\text{mod}(az), i}| \]

Az (effective F10.7) grid

Use NeQuick to reconstruct the 3D electron density of the ionosphere that reproduces the starting vTEC map

Reconstruct sTEC along any ray-path

Reconstruct foF2 maps
• vTec map ingestion scheme validation
  • using LaPlata global vTEC maps and manually scaled foF2 values
  • hourly data for Apr. 2000 (HSA) and Sep. 2006 (LSA) have been used
  • statistics on: \( \Delta \text{foF2} = \text{foF2}_{\text{NeQ2}} - \text{foF2}_{\text{exp}} \)

Notice: validation is on sTEC calibration + mapping function + spherical harmonics expansion + ITU-R coeff + model formulation + vTEC data ingestion technique.
Location of the Ionosondes used for the validation
Location of the Ionosondes used for the validation
Global statistics (effective F10.7)

Δ foF2 RecAz

- Apr. 2000
- Sep. 2006

The Abdus Salam International Centre for Theoretical Physics
Global statistics (R12)

Apr. 2000

Sep. 2006
The ingestion technique requires that the model vertical TEC has to “match” the experimental vertical TEC at any given location and time. Therefore when the retrieved foF2 are different from the ground-truth values it can be said that NeQuick is not able to perfectly reproduce the experimental slab thickness.

Weakness in the NeQuick slab thickness formulation
• vTec map ingestion scheme “internal” consistency check
  • using ground-based GPS-derived sTec from ~ 200 GPS receivers
  • hourly data for Sep. 21\textsuperscript{st}, 2006
  • statistics on: $\Delta \text{sTec}= \text{sTec}_{\text{NeQ2}} - \text{sTec}_{\text{exp}}$

$s\text{Tec}_{\text{exp}}$ are the same data used to produce the vTec maps
• vTec map ingestion scheme validation
  • using space-based GPS-derived sTec from ~ 500 occultation (COSMIC)
  • hourly data for Sep. 21st, 2006
  • statistics on: $\Delta sTec = sTec_{NeQ2} - sTec_{exp}$

$sTec_{exp}$ and $sTec_{NeQ2}$ correspond to the part of the LEO -> GPS link below the LEO orbit
Location of the GPS receivers used for the consistency check
Ground-based TEC data

ΔTEC

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<td>AVER.</td>
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$\Delta \text{TEC} = s\text{TeC}_{\text{NeQ2}} - s\text{TeC}_{\text{exp}}$
TEC & ΔTEC Statistics: 2006 09 21

Space-based (RO)TEC data

ΔTec = sTec_{NeQ2} - sTec_{exp}
Space-based (RO) $\Delta$TEC/TEC

Ground-based $\Delta$TEC/TEC

(TEC < 1TECU removed)
Comparing ground-based and space-based TEC statistics it is possible recognize that:

\[
\text{TEC/}\Delta\text{TEC} \text{ is remarkably bigger for RO than for ground-based TEC}
\]

\[
\text{Possible NeQuick slab thickness weak formulation and/or incorrectly retrieved } \text{hmF2}
\]
Adapting NeQuick model to experimental slant TEC and foF2 data at a given location

(Use of slab thickness to constrain the NeQuick profile shape parameter)
At a given epoch:

- One GPS receiver
  - n experimental slant TEC (n satellites)

- One ionosonde
  - One experimental foF2
    - Using ITU-R coeff., minimize foF2 mismodeling as a function of (formally) F10.7
      - Az\_foF2
        - (effective parameter related to foF2)
  - One experimental hmF2
    - Using Dudeney formula & ITU-R coeff., minimize hmF2 mismodeling as a function of (formally) F10.7
      - Az\_hmF2
        - (effective parameter related to hmF2)

Using NeQuick with Az\_foF2 and Az\_hmF2 (to locally constrain model peak values), minimize RMS of TEC mismodelings as a function of the model thickness parameter B2bot

Obtain the correction factor for B2bot for the area of interest, at the given epoch

Use NeQuick to retrieve (locally) the 3D electron density of the ionosphere
Adaptation method validation

Use JRO profiles to simulate the process of adapting NeQuick to GPS derived TEC and ionosonde peak parameters data.

TEC and peak parameters are known from the profile.

After model adaptation it is possible to compare profiles in order to evaluate the adaptation technique effectiveness.
Adaptation method validation

Jicamarca Radio Observatory (JRO) location
Validation example 1
Validation example 2
Validation example 3
A case study

Adapt NeQuick model to LISN TEC data (days 11-12-13 Mar 2011)

Reconstruct foF2 values

Validate the results (where possible) with:

- JRO data and
- manually scaled foF2 data from Tucumán ionosonde
Validation example 2

JICA 2011 03 12
JRO foF2  F107 foF2  NeQ foF2 (LISR TEC ingested)
Validation example 3
Validation example 4
Validation example 5

The abdus salam international centre for theoretical physics
Validation example 5

The abdus salam international centre for theoretical physics
Validation example 5 (RO geom.)

- projections of the LEO -> GPS links below the LEO orbit
- tangent points of the LEO -> GPS links
Validation example 5 (RO profile)

TEC = 60 TECU
Tau = 170 km
Adapting NeQuick model to RO-derived* slab thickness and to LISN vertical TEC at Tucumán

Retrieve foF2

*spherical symmetry for the ionosphere electron density is assumed when electron density profiles are computed from RO TEC data using the Onion Peeling algorithm
NeQuick profile has been computed exactly over Tucumán
• The NeQuick can be adapted to ionosphere experimental data using the concept of “effective parameters”.

• The ingestion methods based on the use of effective parameters improve the performance of the model in terms of ionospheric “weather” description. (There is the need to improve the NeQuick formulation in terms of slab thickness).

• The studies carried out with JRO profiles have indicated that the contemporary availability of TEC and foF2 (plus hmF2) data can be considered as a “minimum requirement” for the implementation of an effective electron density retrieval technique based on NeQuick adaptation to experimental data.
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Thank you for your attention