Keeping the universe connected.

Assessment of NeQuick G Performance and Usability
ICG-10, WG-B

Benjamin W. Ashman, National Aeronautics and Space Administration (NASA)

for NASA SCaN Program

Human Exploration and Operations Mission Directorate (HEOMD), NASA

ICG-10, Boulder, Colorado, USA, November 4, 2015

Background

- **Recommendations from ICG-9 Working Group B**
  - *To distribute to the Service Providers and Users the document providing the detailed description of the NeQuick algorithm implemented in Galileo for the correction of the ionospheric error in single frequency users;*
  - *For the Service Providers and interested users participating in the ICG, 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.*
- NASA is addressing the second part of this recommendation as input to wider US Government assessment
  - Performing evaluation of the NeQuick G model for single-frequency Global Positioning System (GPS) users, especially space-based users
  - Initial assessment considers class of models suited to supporting real-time navigation (NeQuick G and Klobuchar)
    - Other models of interest not compared at this time: NeQuick 1 and 2 (ICTP), IRI-2014 (COSPAR and URSI) and GAIM (JPL/USC)

NeQuick G Model Description

- NeQuick G is a semi-empirical profiler of the ionosphere that models electron density as a function of height, geographic latitude, geographic longitude, solar activity (specified by the Effective Ionization Level, Az), season (month) and time

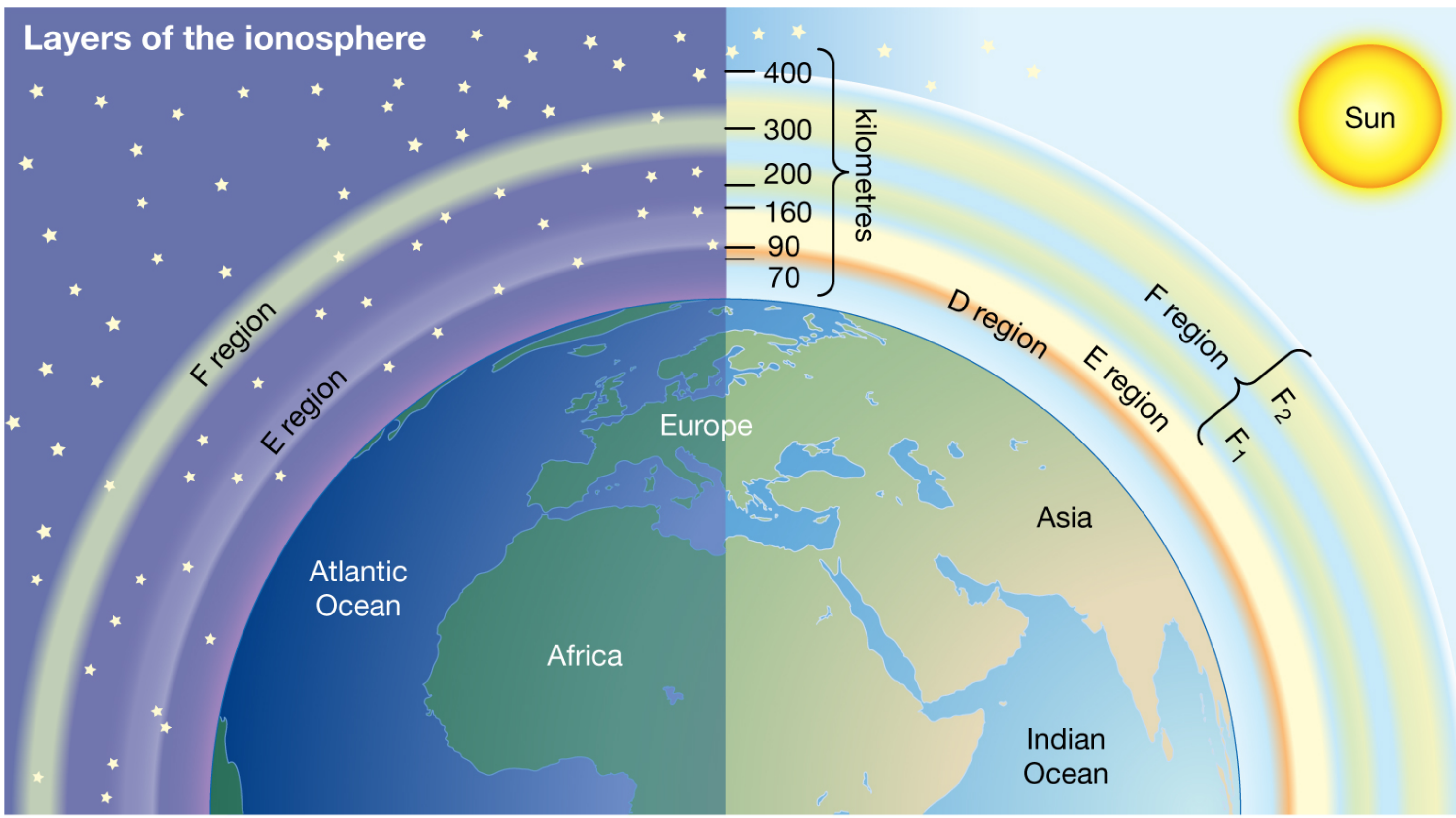


Image credit: Encyclopedia Britannica [1]

NeQuick G Model Description

- NeQuick is based on the Di Giovanni-Radicella (DGR) profile and is constructed around three anchor points: the E, F1 and F2 layer peaks.

Topside (above F2 layer peak): total electron density modeled as a modified Epstein layer, i.e., an Epstein layer scaled by an empirically determined, height-dependent parameter

Bottom side (100km – F2 layer peak): total electron density calculated as a sum of Epstein layers, one each for E, F1, and F2.

- Ionospheric group delay:

$$d_{Igr} = \frac{40.3}{f^2}\int_R^S N \cdot dl = \frac{40.3}{f^2} \cdot STEC$$

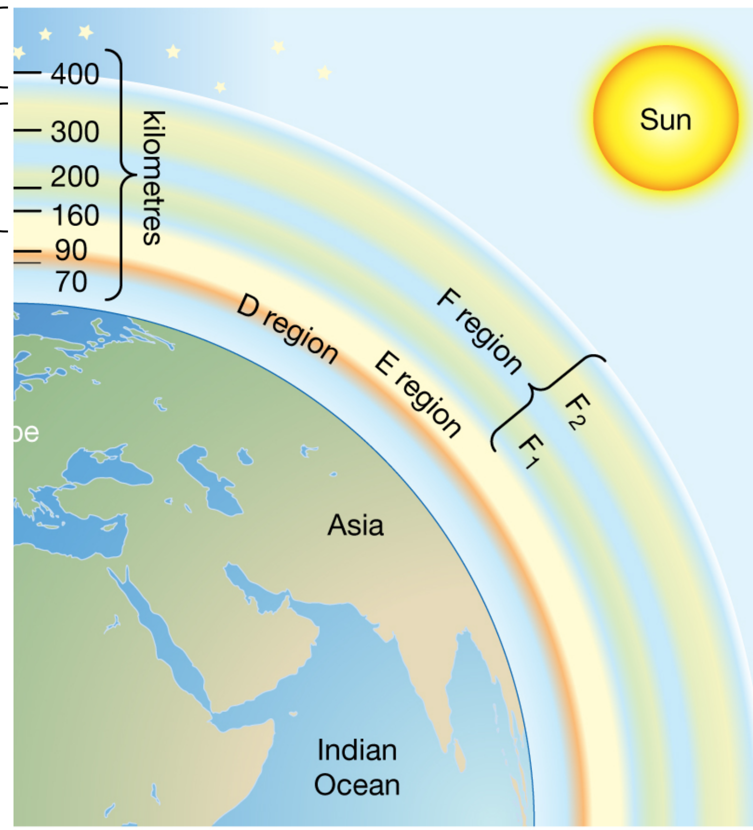
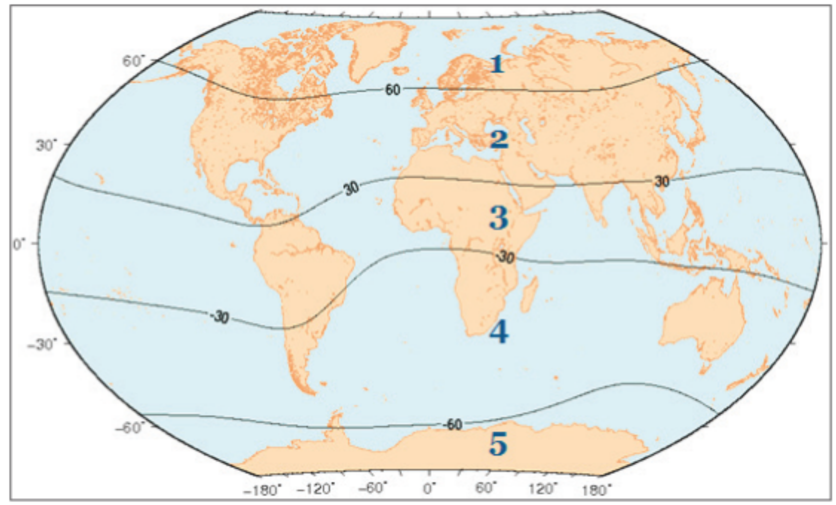


Image credit: Encyclopedia Britannica [1]

Implementation and Performance



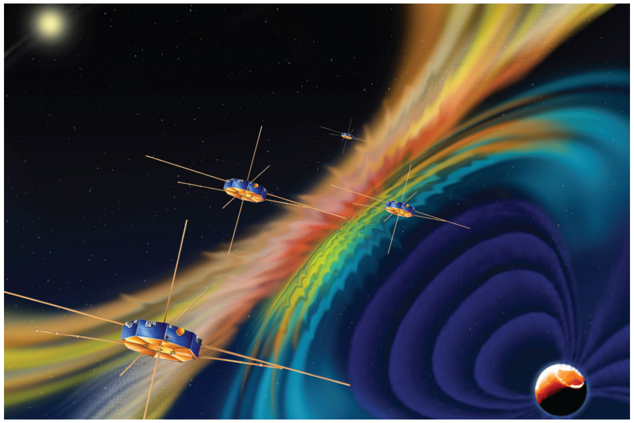
- Implementation
  - –User must obtain three broadcast parameters a_{i0}, a_{i1}, a_{i2}
  - –600 kB of publicly available files also required (CCIR maps for bottom side model and MODIP grid)
  - –Driving parameter of NeQuick G is the Effective Ionization Level, Az: $Az = a_{i0} + a_{i1} \times MODIP + a_{i2} \times (MODIP)^2$
- Performance
  - –Study performed during In Orbit Validation (April 2013 to March 2014) showed approximately 70% removal of ionosphere-induced ranging errors for ground stations (versus 50% using the GPS Klobuchar model) [2] [3]
  - –Earlier studies using simulated broadcast parameters showed performance NeQuick G and Klobuchar to be comparable [4] [5] [6]

Image credit: NeQuick G documentation [7]

Use Cases and User Segments

Space Users

- **High altitude users**, such as those in high earth orbit (HEO), geostationary orbit (GEO) or elsewhere in the space service volume (SSV):
    - Receive signals transmitted beyond the limb of the Earth; these users typically mask the atmosphere and would not benefit from an improved ionosphere model
- **Precision low earth orbit (LEO) users**, such as Earth science missions:
    - Utilize precise, dual-frequency receivers that remove the ionospheric group delay directly and would not benefit from a single frequency model



High altitude user: MMS

Precision LEO user: ICESat-2

Use Cases and User Segments

Space Users

- **Other LEO users**:
  - –GPS Klobuchar model is not applicable to LEO users without modification; thin shell approximation inadequate for users operating near the shell height
  - –Most users accept ionospheric errors, though extensions of the Klobuchar model have been developed that introduce height-dependent features [7] [8]
  - –NeQuick G would be useful to LEO users if it could be applied as-is and broadcast parameters could be obtained

Single frequency LEO user: GPM

Terrestrial Users

- **Potential mass-market receiver applications:**
  - –Majority of applications do not require an improvement but NeQuick G could offer redundancy and responsiveness to daily variations
- **High fidelity users**, such as those performing scientific remote sensing or geodesy:
  - –Employ dual-frequency receivers and would not benefit
- **Military users:**
  - –Would require broadcast parameters through approved US channels

Findings and Recommendations

Findings

1. Some studies have shown NeQuick G to perform 40% better than the Klobuchar model in removing ionosphere-induced ranging errors for terrestrial users, while other studies have shown NeQuick G and Klobuchar to have comparable performance
2. There is value in an improved ionospheric model, though the space users that would benefit directly appear to be limited to single frequency users in LEO with daily access to the NeQuick G broadcast parameters.

Recommendations

1. Implementation issues such as computational speed, memory usage, and other hardware requirements should be assessed once the NeQuick G code is published.
2. Analysis of NeQuick G's performance in space applications should be performed.

NASA has performed initial analysis of NeQuick G and is drafting a white paper to circulate with other US agencies for their perspectives in anticipation of a final document for ICG-11.

References

[1] "Layers of Earth's Ionosphere". Art. *Encyclopædia Britannica Online*. Web. 25 Oct. 2015. URL http://www.britannica.com/science/ionosphere-and-magnetosphere/images-videos/The-day-and-night-differences-in-the-layers-of-Earths/167048.

[2] European Space Agency. European GNSS (Galileo) Open Service - Ionospheric Correction Algorithm for Galileo Single Frequency Users. Technical report, European Union, 2015. URL www.gsc-europa.eu/system/files/galileo_documents/Galileo_ Ionospheric_Model.pdf.

[3] R. Prieto-Cerdeira, R. Orús-Pérez, R. Lucas-Rodriguez, and M. Falcone. Performance of the Galileo Single-Frequency Ionospheric Correction During In-Orbit Validation. GPS World, June 2014. URL http://gpsworld.com/innovation-the-european-way/.

[4] A. Angrisano, S. Gaglione, C. Gioia, M. Massaro, and S. Troisi. Benefit of the NeQuick Galileo Version in GNSS Single-Point Positioning. International Journal of Navigation and Observation, 2013:1–11, 2013. URL http://dx.doi.org/10.1155/2013/302947.

[5] A. Farah. Comparison of GPS/GALILEO single frequency ionospheric models with vertical TEC maps. Artificial satellites, 43(2):75–90, 2008.

[6] B. Bidaine. Ionosphere Modelling for Galileo Single Frequency Users. PhD thesis, University of Liè, 2012.

[7] National Aeronautics and Space Administration. GPS-Enhanced Onboard Navigation System (GEONS). http://itpo.gsfc.nasa.gov/downloads/featured_technologies/aerospace_ aeronautics/gsc_14687_1_geons.pdf, 2015.

[8] O. Montenbruck and E. Gill. Ionospheric correction for GPS tracking of LEO satellites. Journal of Navigation, 55(02):293–304, 2002.

Backups