Study of small scale plasma irregularities in the ionosphere

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Overview

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Global Navigation Satellite System

• Network of satellites with global coverage that continuously transmit encoded information enabling precise positioning on Earth

• Active GNSS systems:
  1) Global Positioning System (GPS)
  2) Globaln'naya Navigatsivannaya Sputnikovaya Sistema (GLONASS)

• In developing phase:
  1) Galileo (EU)
  2) COMPASS (China)
Global Navigation Satellite System

- The GNSS satellites transmit codes generated by atomic clocks, navigation messages and system-status information.
- Signals are modulated on two carrier frequencies L1 on 1.57542 GHz and L2 on 1.2276 GHz.
- The original GPS design contained two ranging codes:
  - Coarse/Acquisition or C/A code, available to the public.
  - Precision or P-code, usually reserved for military applications.
Global Navigation Satellite System

- Baseline constellation of about 24 to 30 satellites on orbital height of 19000 to 24000 km
- Orbit time period of about 12 hours to cover every area on Earth with at least 4 satellites
- New and modernized systems are developing, because GPS satellites do not sufficiently cover all regions
- Development of new signals for more accurate positioning, safety and commercial services (L5, L1C, E1, E5)
Global Navigation Satellite System

- How it works:

1. All satellites have clock set to exactly the same time
2. All satellites know their exact position from data sent to them from the system controllers
3. Each satellite transmits its position and a time signal
4. The signals travel to the receiver delayed by distance traveled
5. The differences in distance traveled make each satellite appear to have a different time
6. The receiver calculates the distance to each satellite and can then calculate its own position

http://www.aero.org/education/primers gps/howgpsworks.html
Augmentation systems - techniques used to improve the accuracy of positioning information.

- Rely on external information being integrated into the calculation process.

Augmentation systems:
- Wide Area Augmentation System (WAAS)
- Differential GPS (DGPS)
- Inertial Navigation Systems (INS)
- Assisted GPS (A-GPS)
2. Space weather
Space weather

- High coronal temperatures cause a continuous outflow of plasma from the corona – **solar wind**
- *Solar flares, prominences and coronal mass ejections* create storms of radiation, fluctuating magnetic fields, and swarms of energetic particles
- Solar plasma travels outward through the Solar System with the solar wind

Space weather

• Speed and pressure of solar wind changes all the time
• Space is filled with magnetic fields, which control the motions of charged particles
• The strengths and directions of the magnetic fields often shift
• Changes in radiation, the solar wind, magnetic fields, and other factors make up space weather
Space weather

- Solar plasma interacts with Earth's magnetic field, creating Earth's radiation belts and the auroras
- Earth is surrounded by a magnetic cavity called the "magnetosphere"

http://spaceplace.nasa.gov/spaceweather/
Space weather

- **Aurora** - collision of energetic charged particles with neutral Oxygen atoms and molecules in the high altitude atmosphere

- **Radiation belts** are made up of charged particles trapped by magnetic field

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http://en.wikipedia.org/wiki/Van_Allen_radiation_belt

http://www.nuitsacrees.fr/DP/Jokusarlon1_2000.jpg
3. Ionosphere and its effects
Ionosphere

- The ionosphere is a layer of the upper atmosphere ionized by radiation from the sun
  - From 50 km to about 1,200 to 1,600 km
  - Ionization mostly due to extreme UV, but also hard and soft X-rays, and other radiations
  - Several layers (D, E, F1, F2) depending on different chemical composition
- One of most important atmospheric layers for radio signal propagation:
  - Radio wave signal diffract from the ionosphere
  - GNSS (microwave) signals penetrate through the ionosphere
Ionosphere and its effects

- Density profiles of free electrons in the ionosphere

Ionosphere and its effects

- Chemical composition

Ionosphere and its effects

- Ionospheric effects on GNSS signals are:
  - Phase and group delay
  - Doppler shift
  - Faraday rotation
  - Ray-path bending
  - Scintillations
Ionosphere and its effects

- Scintillations – irregular fluctuations in signal phase and amplitude during propagation through ionosphere
- Caused by small-scale fluctuations in the refractive index of the ionospheric medium by inhomogeneties
- Ionospheric scintillation is primarily an equatorial and high-latitude ionospheric phenomenon - scintillation occur mainly in the F layer
Ionosphere and its effects

Ionosphere and its effects

- Scintillation indices:
  - for intensity:

\[ S_4 = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}} \]

\[ SI = \frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}} \]
Ionosphere and its effects

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Ionosphere and its effects

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    \[
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    \]
  - for phase
    \[
    \sigma_\phi^2 = \langle \phi^2 \rangle - \langle \phi \rangle^2
    \]
Ionosphere and its effects

- The total ionospheric profile is the superposition of different layers, with different chemical composition.
- Changes in GNSS signals during propagation and penetration through the ionosphere are being followed and measured every day by network of GNSS monitors.
- Various parameters are being used to describe fluctuations in GNSS signals.
- Total electron content (TEC) - total number of electrons present along a path between two points.
Ionosphere and its effects

\[ TEC = \int_{\text{raypath}} N_e(x, y, z) \cdot dz, \quad [10^{16} \text{ electrons/m}^2 = 1 \text{ TEC unit (TECU)}] \]
Ionosphere and its effects

• Alternative way for calculating TEC:

\[ TEC = \frac{1}{40.3} \left( \frac{f_1 f_2}{f_1 - f_2} \right) (P_2 - P_1) \]

\( f_1, f_2 \) - L1 and L2 band frequencies
\( P_1, P_2 \) - L1 and L2 band pseudoranges

• Simplified pseudorange equation:

\[ P_r^s = c \left( t_r - t^s \right) \]
Ionosphere and its effects

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\[ P_r^s = c \left( t_r - t_s \right) \]

Ionosphere and its effects

• The state of the ionosphere varies:
  ◦ with degree of exposure to the solar radiation
    - Daily
    - Seasonally
  ◦ on solar activity
    - Solar maximum versus solar minimum (≈11 year cycle)
    - Geomagnetic conditions: quiet versus storm
      • Sudden bursts of solar energy can cause magnetic storms and other irregularities
  ◦ on the magnetic latitude
Ionosphere and its effects

- Infrequent bursts of energy at the surface of the sun (e.g., solar flares) can cause magnetic storms
  - Material and radiations ejected by the sun at very high speeds cause changes in the magnetic field of the Earth
  - Changes in the magnetic field are quantified by various “indices” measured and published daily (Kp, Dst, Ap)
- Magnetic storms can cause variations in TEC which translate into disruption for GNSS users
  - Intensity of these effects vary depending on the location and time of the observations
Ionosphere and its effects

• K index
  ◦ Local measure of fluctuations in the horizontal component of earth's magnetic field at mid-latitude
  ◦ Measured every 3 hours from data collected over 3-hour intervals
  ◦ Range: 0-9 with 1/3 quantization

• Kp index
  ◦ Small letter “p” stands for planetary
  ◦ Computed from K indices reported by a number of observatories worldwide
Ionosphere and its effects

Estimated Planetary K index (3 hour data)

Begin: 2012 Mar 08 0000 UTC

Updated 2012 Mar 11 02:55:05 UTC

NOAA/SWPC Boulder, CO USA

http://www.swpc.noaa.gov/ftpmenu/plots.html
Ionosphere and its effects

- Dst (disturbance storm time) index
  - Measure of fluctuations in the horizontal component of earth's magnetic field in the mid-latitude and equatorial region
  - A negative value indicates a storm is in progress

- Ap index
  - Measure of the general level of geomagnetic activity over the globe for a given UT day
  - Derived from measurements of the variation of the \( ap \) indices during a geomagnetic storm event
Study of small scale plasma irregularities in the ionosphere

http://wdc.kugi.kyoto-u.ac.jp/dst_realtime/201202/index.html

http://rwc.lund.irf.se/rwc/dst/
Ionosphere and its effects

ISES Solar Cycle Ap Progression
Observed data through Feb 2012

Updated 2012 Mar 6

http://www.swpc.noaa.gov/SolarCycle
4. Case study
Instruments

- Instruments for remote sensing of the irregularities in the ionosphere:
  - Magnetometer – provide information about electrodynamics that governs ionospheric motion
  - Ionosonde – provides geophysical parameters (critical frequencies, electron density profiles, ionospheric drift in some cases)
  - Incoherent scatter radar (ISR) – allows measurement of electron density, ion and electron temperature and velocity and plasma drifts
Ionospheric plasma irregularities

- Plasma irregularities:
  - Equatorial spread F layer and plasma bubbles
  - Sporadic E layer
  - Tides and gravity waves
  - Ionospheric storms
  - Traveling Ionospheric Disturbances (TIDs)
  - Polar arcs
  - Polar patches
EISCAT measurements

- EISCAT incoherent scatter radar:
  - Emit powerful multi-mega-watt signals and receives picowatt signals
  - A radar beam scattering off electrons in the ionospheric plasma creates an incoherent scatter echo
  - Transmitters are located in Tromsø and Svalbard, and receivers in Kiruna and Sodankyla
EISCAT measurements

Ionosphere

EISCAT radar
EISCAT measurements

- Radar equation:

$$P_r = P_t \sigma_{radar} c \Delta T \frac{A_r}{(8 \pi R^2)}$$

- $P_t$ - transmitter power
- $\sigma_{radar}$ - radar scattering cross section
- $\Delta T$ - transmitted pulse length
- $A_r$ - effective receiving antenna area
- $R$ - distance from transmitter/receiver to scattered point

- Power spectrum of received signal and dependence of the ion line shape on plasma parameters

http://spaceweb.oulu.fi/education/NorFA97/EISCAT/expdesc.html
EISCAT measurements

- Experiments for calculating plasma lines from raw data
- Scan patterns, which can be used in measurements:


http://www.eiscat.se/about/experiments2/scans
EISCAT measurements


EISCAT measurements


5. Conclusion
Conclusion

- Small scale irregularities are not explored enough
- Discovering new methods for measuring and describing this type of irregularities
- The aim is prediction of all scales of irregularities and solving errors which can occur
- Improvement of physical and theoretical models of ionosphere and small scale irregularities
- Interaction with the project for the final prototype
Conclusion

• In addition to this scientific goals there is an idea to:
  ◦ Enable server for collecting GPS monitors data from University of Nova Gorica and Ajdovščina and analyzing it in daily, weekly and monthly period
  ◦ Web page for visualising analysed data from GPS monitors

• Attending courses, workshops and summer schools and interaction with experts in this field
Thank you for attention