Assessing the Threat of Undersampled Ionospheric Irregularities for Wide Area Differential GPS Systems

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Outline

- WAAS requirements
- Nature of the ionospheric threat
- Methodology for assessing threat
- Case analysis
- Results of data deprivation studies
  - deprivation by annular regions
  - deprivation by rectangular boundaries
- Conclusion
WAAS Requirements

- Performance requirements
  - Positioning accuracy goals available over space and time
- Integrity requirements
  - Position error bounds are faithful
  - Analytical "proof" that system is safe
  - Analysis requires well-established assumptions
Nature of ionospheric threat

- Finite sampling of ionospheric medium
- During disturbed periods, delays can reach 40m vertical
- Highly structured
- Irregularity detector is part of the algorithm
Identifying Threatening Geometries

- Data deprivation studies reveal edge represents significant threat
- Real-time algorithm must identify areas where threat is potentially highest
- Threat model adjusts error bound in real-time to ensure integrity under all conditions
Vertical ionospheric delay is modeled using the thin shell approximation.
Distribution of measurements for one epoch

Color gives magnitude of delay at ionospheric pierce points (IPPs) in one epoch.
Algorithm for correlation analysis

- Define WAAS grid and rotation matrices \[(x, y, z) \rightarrow (e, n, u)\] at each IGP

- Select data from one epoch \((i.e.,\) one time-tag)

- Calculate obliquity factors

- Convert each IPP position to xyz coordinates

- Loop over WAAS IGPs
  
  - Sort epoch data by distance to IGP
  
  - Perform planar fit with 30 nearest points (within 2100 km)
  
  - Tabulate deviations from planarity inside threat domain:
    - as function of \(\chi^2\) (or \(\chi^2/\chi^2_{\text{threat}}\))
    - as function of metric (distance from IGP, fit radius, hole size)
dependence on irregularity detector

\( \chi^2 < 100 \)

The threat domain is here the entire WAAS grid.

More sample points are included same \( \chi^2 \) bins.
Storm time (7/15/00) decorrelation plots

$\chi^2$ range: [40, 100]

Dependence on $\chi^2$ is weak.
Quiet time (7/2/00) decorrelation plots
\( \chi^2 \) range: [40, 100]

Figures are similar to storm time for distances < 1000 km.
Comparing different threat domains

The threat domain is the entire WAAS grid.  

The threat domain is the fit radius.
Data deprivation studies

Exclude from fit the IPPs that reside within an annulus.
Excluding data from one annulus

\[ \frac{\chi^2}{\chi^2_{\text{threshold}}} : [0, 1.5] \quad 07/15/00 \]

IPPs are excluded that lie in the range 1400-1600 km.
Accumulating results for a series of data deprivation studies.

$\chi^2/\chi^2_{\text{threshold}}: [0, 1.5]$ 07/15/00

Data are excluded in a succession of annuli, each with 200 km width.
Deviations from Planarity
July 15, 2000, 23:50 UT

Undetected sharp gradients can exist next to undisturbed regions.
Deviations from planarity with the fit radius
July 15, 2000, 23:47 UT

An undetected gradient within the fit domain represents a potential major threat.
Data deprivation: an example

Data exclusion boundary
IGP
IPPs in fit

vertical delay (m)

Geographic Latitude (deg)
- 50 45 40 35 30 25 20
-140 -130 -120 -110 -100 -90 -80 -70 -60

10° x 10° threat domain

Fit radius (2100 km)

Geographic Longitude (deg)

GPS Receiver

JPL

LCS 01/24/01 18
Excluding from fit all data east and south of IGP

$\chi^2/\chi^2_{\text{threshold}}: [0, 1.5] \quad 07/15/00$
Excluding from fit the band 1000 - 1200 km and plotting vs. fit radius

Tabulating data within fit radius

Tabulating data within fit radius - 200 km
Tabulating points within threat radius (fit radius 200 km): expanding fit domain in 1° increments

+ 0° east and south of IGP

+ 1° east and south of IGP

+ 2° east and south of IGP

+ 3° east and south of IGP

+ 4° east and south of IGP

+ 5° east and south of IGP