CENTER FOR ADVANCED AVIATION SYSTEM DEVELOPMENT (CAASD)

Ionospheric Corrections for GNSS

The Atmosphere and its Effect on GNSS Systems
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CAASD MITRE

Overview

- **Ionospheric delay corrections**
  - **Core constellations**
    - **GPS**
    - **GALILEO**
  - **SBAS**
  - **GBAS**
  - **Receiver**

Core Constellation Models

- **GPS and GALILEO use different models**
- **In both cases, these are simple models driven by a small number of coefficients broadcast by the satellites**
  - **Ground Control regularly updates the coefficients to account for the state of the ionosphere**
- **Such simple models are able to approximately reproduce the average historical behavior of the ionosphere**
- **But are unable to account for particular behaviors that may exist at any particular time and location**
  - **Ionospheric irregularities and storm effects, equatorial anomalies, depletions, etc.**

GPS Single-frequency Model

- **GPS broadcasts 8 coefficients allowing user receivers to compute ionospheric delay estimates based on a simple single-frequency global ionospheric model (Klobuchar)**
  - **The 8 coefficients are regularly updated to account for observed changes in the state of the ionosphere**
  - **The model can only account for predictable variations due to time of day and latitude**
  - **The model corrects statistically about 50% of iono delays**
    - **Corrections are better during quiet ionospheric conditions than during ionospheric storms**
  - **User receivers apply a standardized obliquity factor to convert between vertical and slant delays**

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GALILEO Single-Frequency Model

- **GALILEO uses a 3-D model called NeQuick**
- **The model is driven by an "effective ionization level," Az**
  - **GALILEO broadcasts 3 coefficients**
  - **The user uses them to compute Az given its geomagnetic coordinates**
- **The NeQuick model then uses Az to compute a range delay along the line-of-sight**

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The "Thin Shell" Model
1 of 2

- The "thin shell" approximation to the ionosphere (i.e., the propagation delays it causes) is used by GPS and SBAS
  - The model collapses the ionosphere to a thin shell at an altitude of 350 km
    - Ionospheric delays occur when the signals cross the shell (and nowhere else along the line line-of-sight)
    - The magnitude of the delay is a one-to-one function of the angle with which the line-of-sight crosses the thin shell
    - GPS and SBAS models provide estimates of vertical delays; from which the user derives slant delays
- GALILEO and GBAS do not rely on the thin shell model

The "Thin Shell" Model

2 of 2

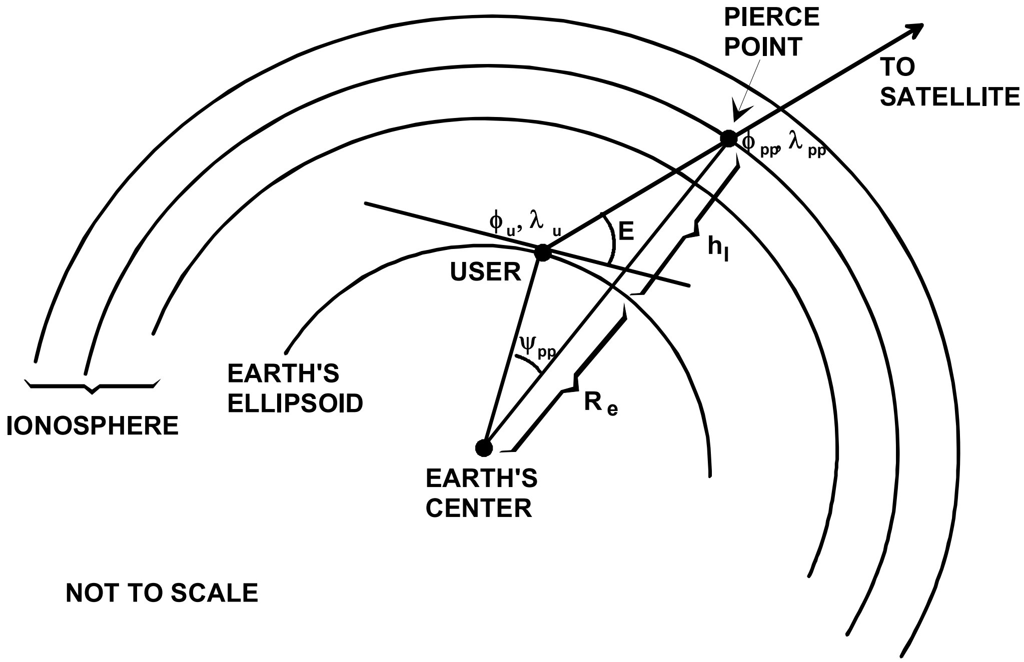

Figure from the SBAS MOPS, DO-229D

- **The ionosphere is treated as if it were a thin shell at 350 km above the Earth's Surface**
- **Slant Delay = Obliquity factor x Vertical delay**
- **GPS and SBAS broadcast vertical delay information**

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SBAS Ionospheric Corrections

1 of 2

- **SBAS broadcasts vertical iono corrections (IGDs) and error "bounds" (GIVEs) at ionospheric grid points (IGPs)**
- **User receivers interpolate between IGPs and apply an obliquity factor to convert between vertical and slant delays and error bounds**
- **GIVEs provide users with "overbounding sigmas" (i.e., conservative estimates of the standard deviation) for the residual errors**
  - **These are high integrity estimates (probability of misleading information < 1×10^{-7})**
  - **Ensuring this level of integrity is one of the main challenges of developing SBAS iono algorithms**

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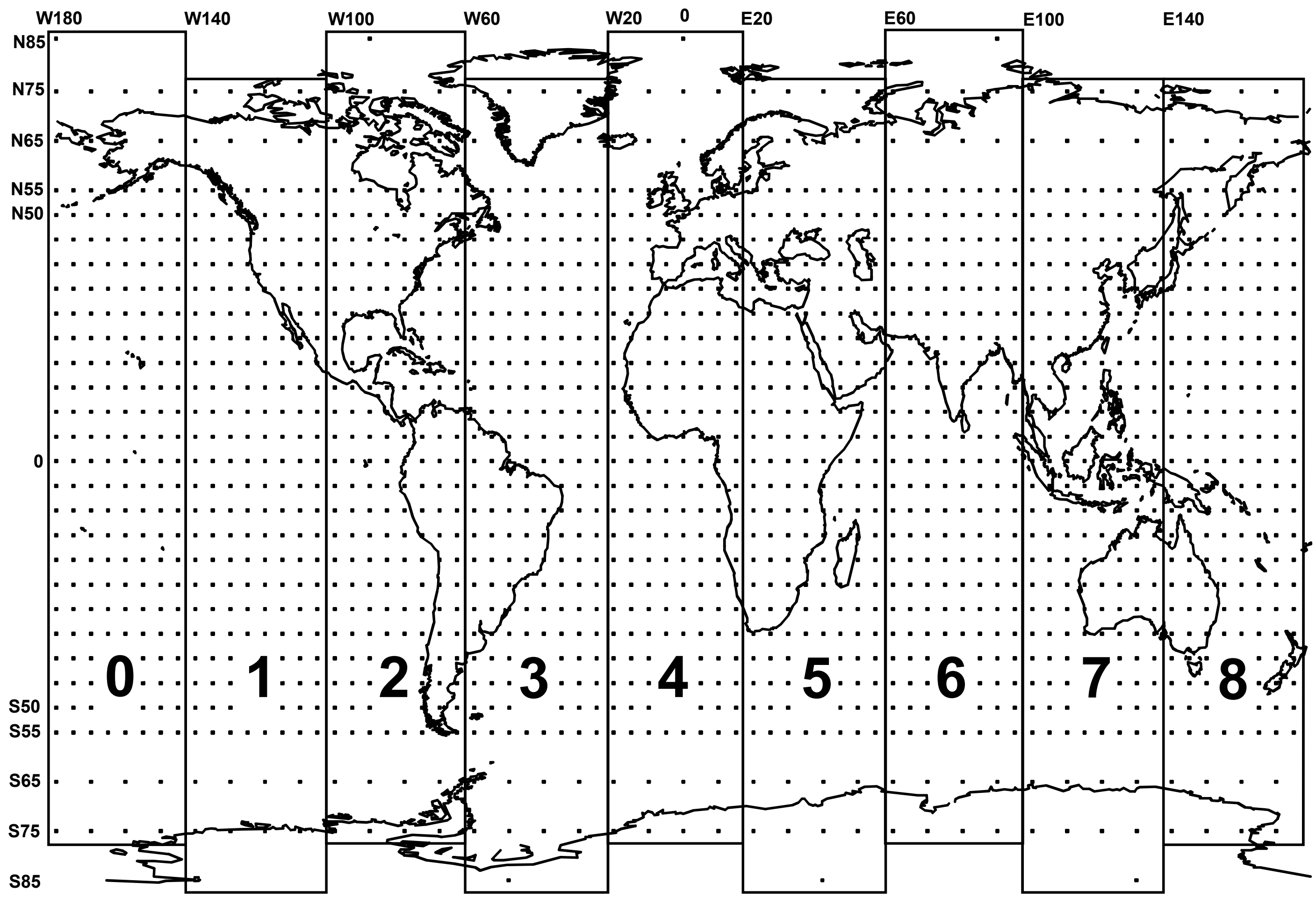
SBAS Ionospheric Corrections
2 of 2

- **SBAS calculates vertical iono corrections (IGDs) and error “bounds” (GIVEs) from dual-frequency measurements**
  - **Reference receivers use semi-codeless technique for tracking L2**
- **Prior to that, SBAS must estimate (and correct for) satellite and reference receiver L1/L2 inter-frequency biases**
  - **This is done by processing all available iono delay measurements generally using a Kalman Filter and an appropriate ionospheric delay model**
    - **E.g., rotating triangular grid, 2-D polynomial model**

SBAS Ionospheric Grid



SBAS World-Wide Ionospheric Grid (without Bands 9 and 10) -- SBAS MOPS

GBAS Mitigation Technique

- **GBAS broadcasts pseudorange corrections for each satellite in view**
  - **The corrections correct for common errors between the ground station and the user**
  - **They account for a combination of ranging errors including ionospheric delay errors, and satellite clock and ephemeris errors**

- **A current area of intense research is concerned with the effect of potentially large, local gradients during ionospheric storms**
  - **These gradients could result in a large difference between the ionospheric delays seen by the ground station and those seen by the user**

Dual-Frequency Operations

1 of 2

- In the near future (officially in about 2014, but it may be a few years later), GPS and GALILEO will broadcast civil signals at two or more frequencies
  - GPS L1 and L5; GALILEO E1, E5a and E5b
- User receivers will then be able to compute iono-free pseudorange measurements
  - i.e., eliminate the ionospheric delay without requiring a model, or external information
- This will open many new possibilities
  - APV without the need for SBAS ionospheric corrections
    - In the equatorial area and during ionospheric storms

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Dual-Frequency Operations

2 of 2

- **Additionally, using GPS and GALILEO in combination will provide higher accuracy, availability and continuity of service**
  - **This will reduce the role of SBAS to an integrity monitoring function**

- **In the longer term (2030?), GPS III promises even greater accuracy, faster response time, and improved integrity**
  - **RAIM may then be sufficient to fly LPV-200 procedures (current area of research)**
  - **New RAIM algorithms capable of dealing with all LPV-200 requirements are being investigated**

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