Velocity Noise in Space Shuttle and ISS GPS from the Ionosphere

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United States operational use of GPS in low earth orbit:

- for Space Shuttle...replaces TACAN system for landing:
- International Space Station...required for TDRSS antenna pointing.

Both systems are terrestrial based:

- COTS legacy.
- meet coarse requirements.
- have been disappointing (expectations exceed requirements.)
Noisy velocity is often observed on orbit:

- clusters geographically. Seen on consecutive orbits.
- for Shuttle...source of concern...exceeds system requirement thresholds.
- for ISS ...shown here for first time...impact is unknown.
Scintillation in MAGR/S GPS used for Shuttle.
Velocity Noise related to phase rate measurements.

Notice:

- Residuals are normalized to the “Kalman” filter receiver state.
- Levels exceeding 2 are profoundly corrupt.

Our Approach:

- Scan data for high residuals.
- Evaluate and examine distributions of geophysical interest.
Geographic Distribution of Scintillation

Shuttle GPS.

Easily resolve two major regions separated by 45 degree geomagnetic dip angle.

- Equatorial events created in ionosphere by mechanism same as Spread F, “Rayleigh-Taylor” mode post sunset instability.

- Polar events within known auroral zones. STS-99 goes to 57 degrees.

Solar hour angle determines occurrence of equatorial plasma instability.

- not sampling solar angles evenly but...roughly equal opportunity to observe in darkness and daylight.

Nevertheless:

- Equatorial events unambiguously cluster on night side.

- Polar events resolve non-dipole auroral asymmetry.
Feynman’s interpretation of interference

Ionosphere is a refractive medium. Radiation does not follow a single path... actually follows ALL paths...

- interference deletes contribution from most paths.
- received signal comes from paths over which first order variation in the phase is least.

...distinction from usual view that signal follows one ray through ionosphere.

- cannot model scintillation based on single ray.
- no signal attenuation or loss in plasma theory.
Angle between line of sight and S/C velocity.

We have theory that scintillation should prefer line of sight at right angles to velocity ... therefore let us accumulate a histogram of lines of sight vs. angle.

- null hypothesis is that line of sights are random...will distribute as the \( \sin(\alpha) \) because the available solid angle distributes this way.

- Scintillated line of sight will scale according to \( \sin^2(\alpha) \) on 'count of the theory.'
Space Station GPS

Shuttle experience encourages us to look for scintillation among down-listed ISS data.

- Internal engineering data is unavailable.

- Our approach to ISS data ... de-trend the velocities using “SPOT” ground filter.

Introduce SPOT (Space Position Optimal Tracking)

- recently developed downstream telemetry processor used to improve the quality GPS states on orbit.

- solves for inertial vehicle state using the GPS positions X,Y,Z in earth centered earth fixed coordinates.

- constrains state to free fall orbit incl. drag, high fidelity gravity model and sun-moon perturbations.
Space Station GPS

Subtract SPOT states from raw GPS states.


- filter converged residuals usually distribute ~1 cm/s.

- noise events similar in characteristic to those for shuttle.

- prominent in "up" component.

- Noise: ~1 m/s.

- many examples.

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Space Station GPS

Preliminary composite of many "Up" component velocity defects extracted using SPOT from deterministic ISS GPS receiver solutions.

- Similar to shuttle result geo-magnetic organization.
- Polar events present (ISS extends to 51 degrees.)
- Indication of non-polar daytime events.
- TDRSS Z.O.E. is apparent.

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Conclusion: External environment noise from ionosphere irregularities significantly affect U.S. GPS velocity measurements on both ISS and Shuttle.

- consistent with equatorial and polar ionosphere processes... Cause of highly variable occurrence is uncertain.

- noise easily observed - augmented by speed of space craft in accord with our theory.

- equatorial events occur in darkness - polar events have hemispheric asymmetry ... indicates geomagnetic field control.

- Need internal ISS GPS parameters to test theory about origin of ISS scintillation. Predict cycle slip or phase noise. Prominence in up velocity component not understood.