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.)

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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.

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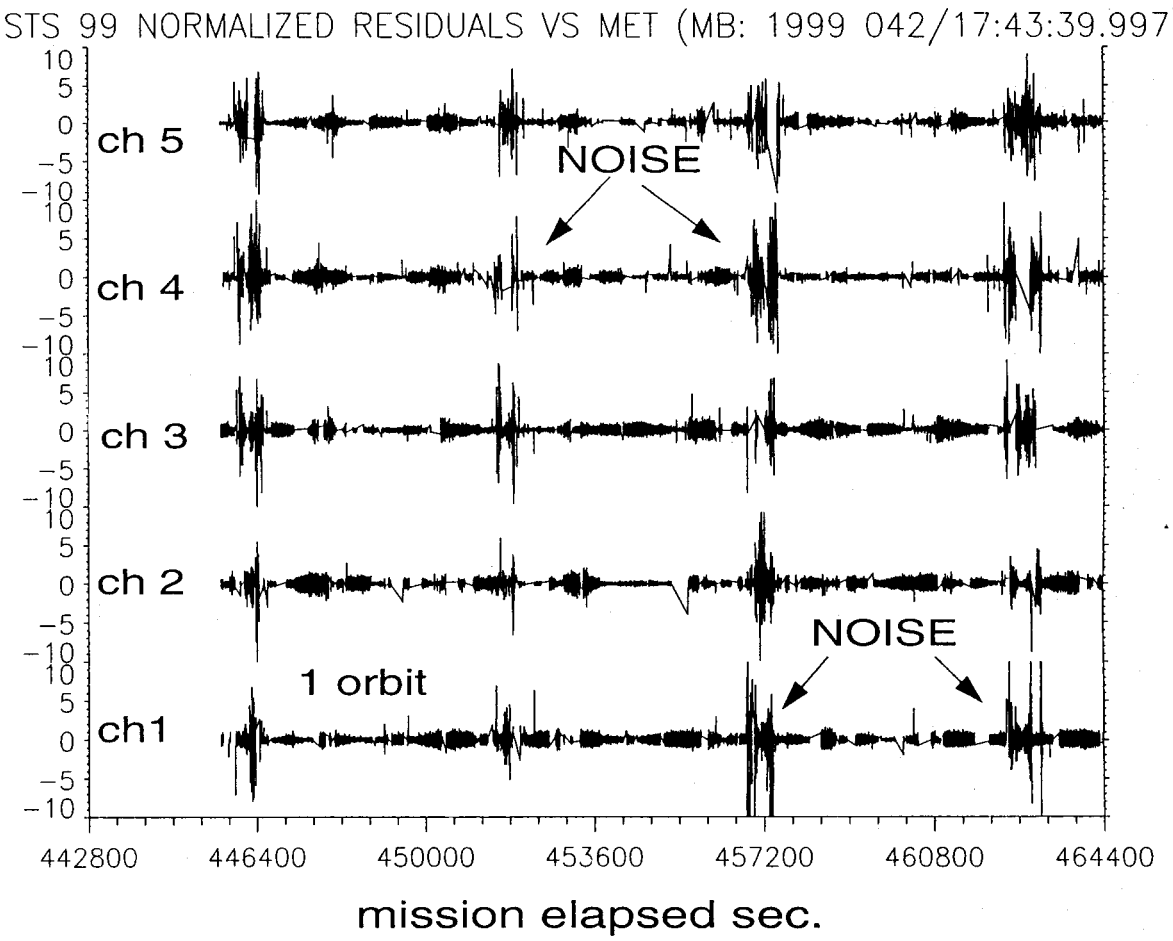
Scintillation in MAGR/S GPS used for Shuttle.

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.

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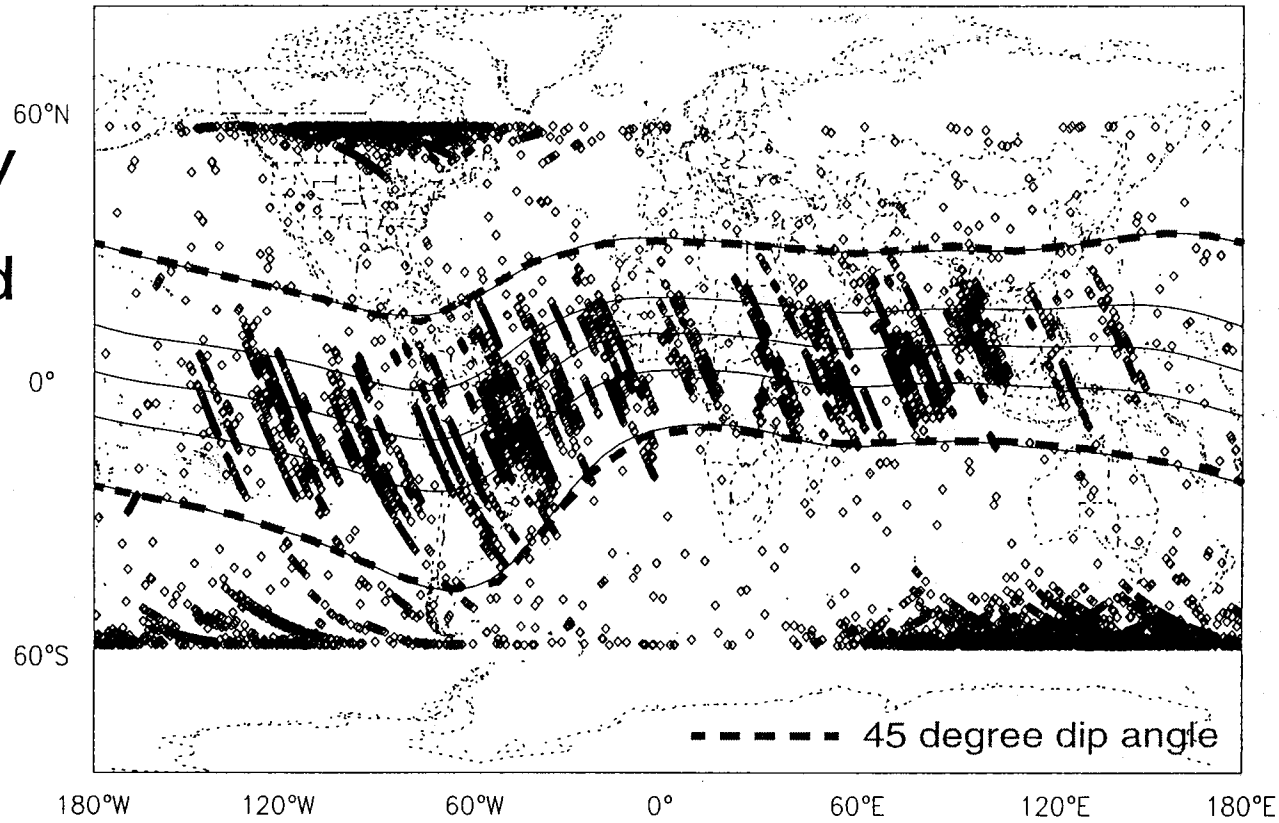
Geographic Distribution of Scintillation

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.



STS 99 "scintillation" events Feb. 11-22, 2000.

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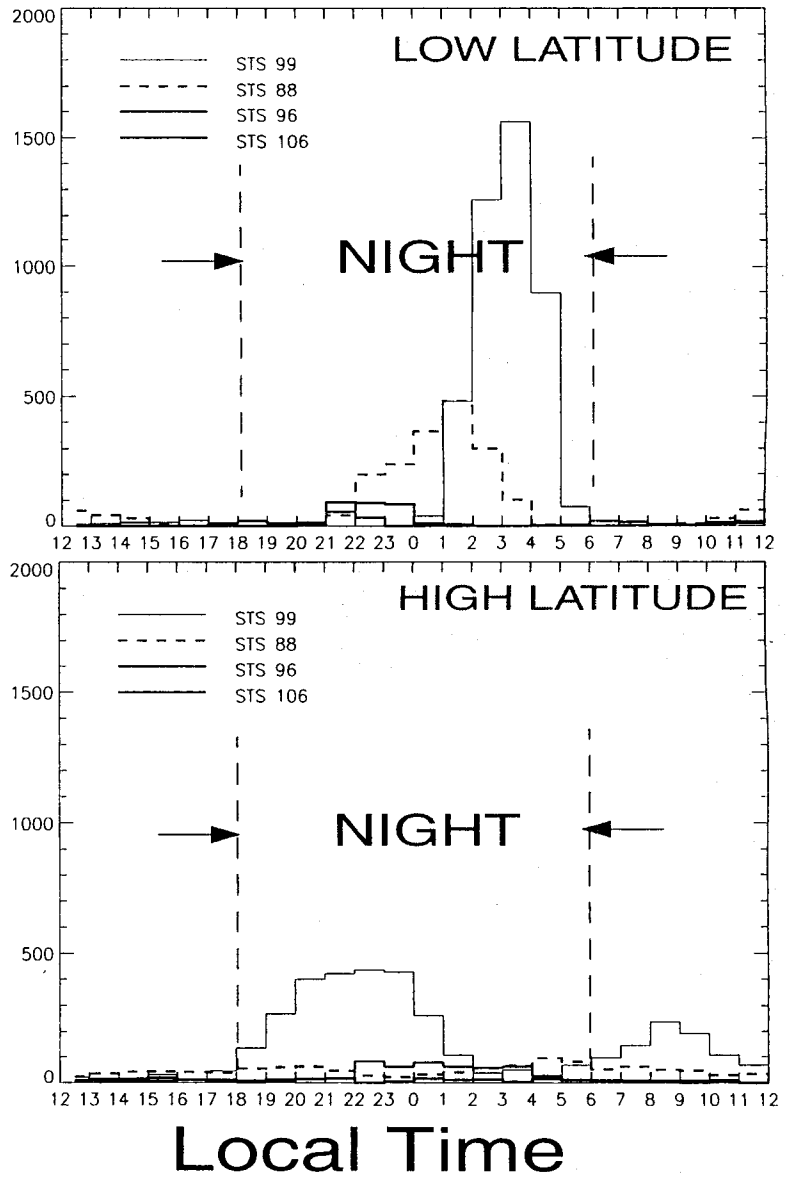
Diurnal Variability

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 un-ambiguously cluster on night side.
- Polar events resolve non-dipole auroral asymmetry.



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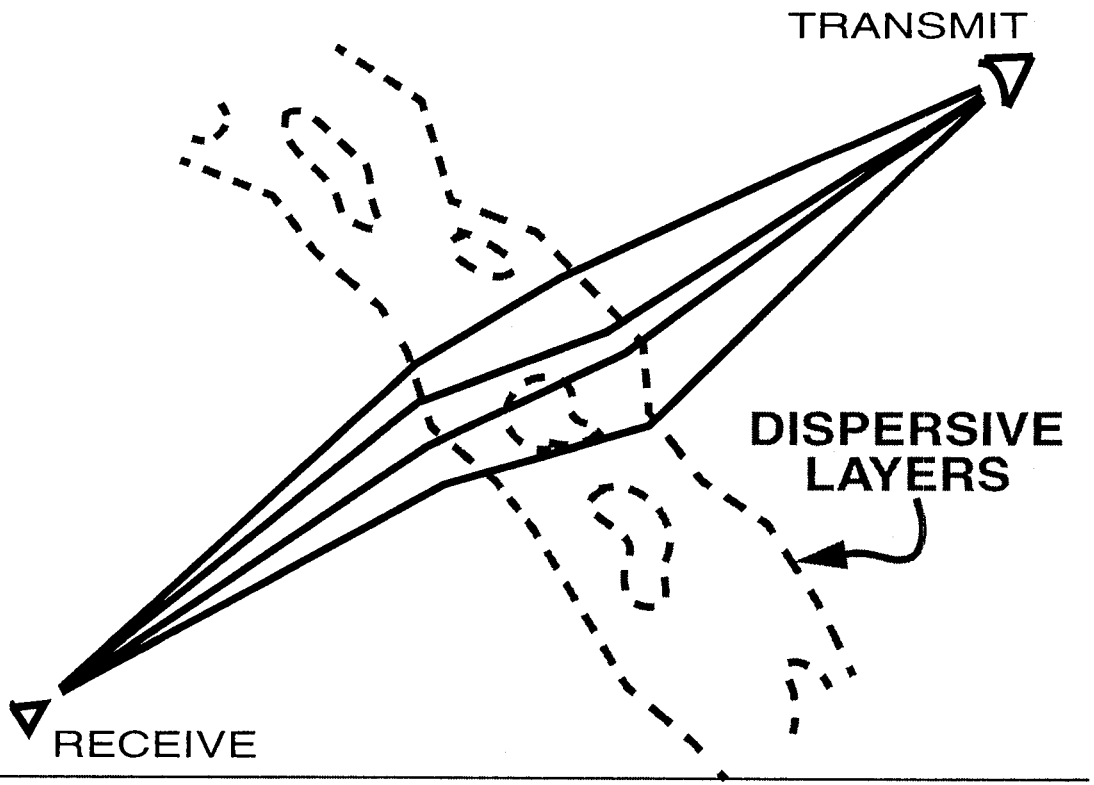
Feynman's interpretation of interference

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.



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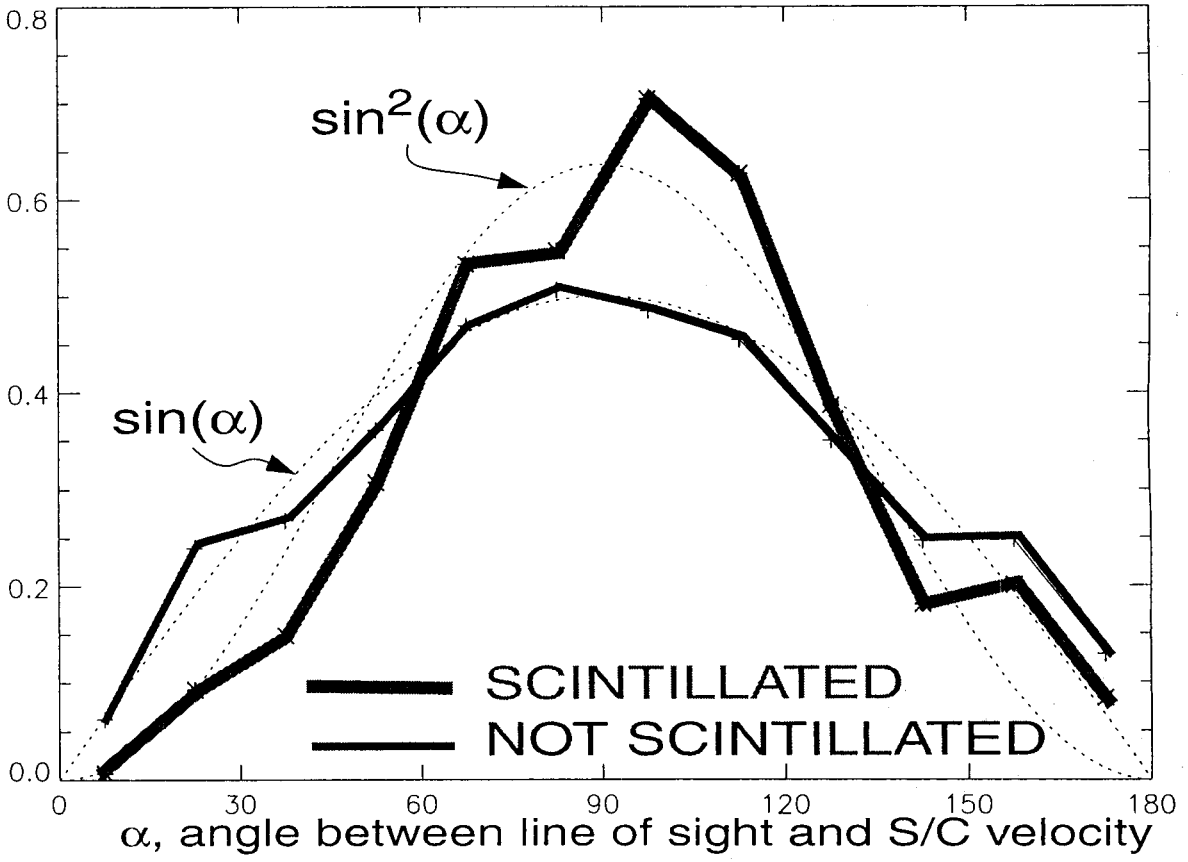
Angle between line of sight and S/C velocity.

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.



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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)

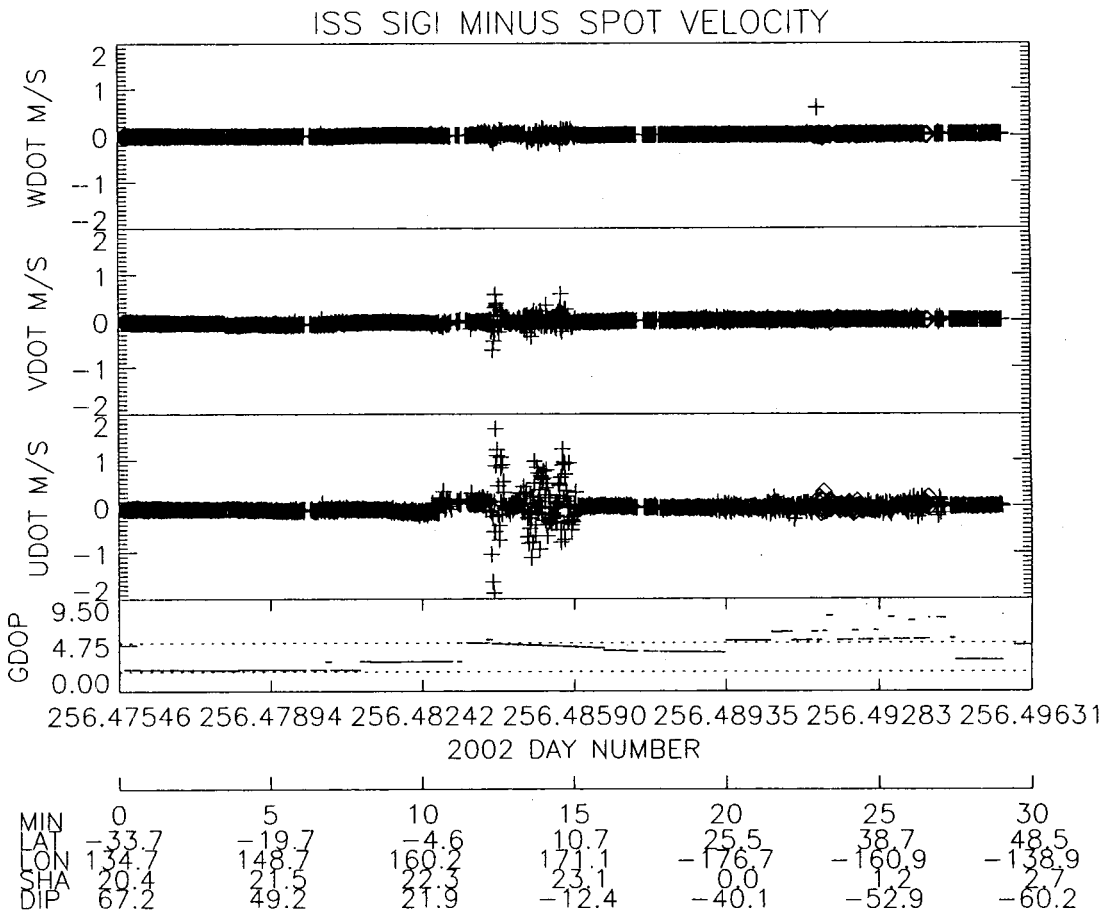
- recently developed downstream telemetry processor used to improve the quality GPS states on orbit.
- solves for inertial vehicle state using the GPS positions X,Y,Z in earth centered earth fixed coordinates.
- constrains state to free fall orbit incl. drag, high fidelity gravity model and sun-moon perturbations.

Space Station GPS

Subtract SPOT states from raw GPS states.

ISS velocity in SPOT de-trended U, V, W velocity defects. 2002 Day 256 ~12:25 to 12:55.

- 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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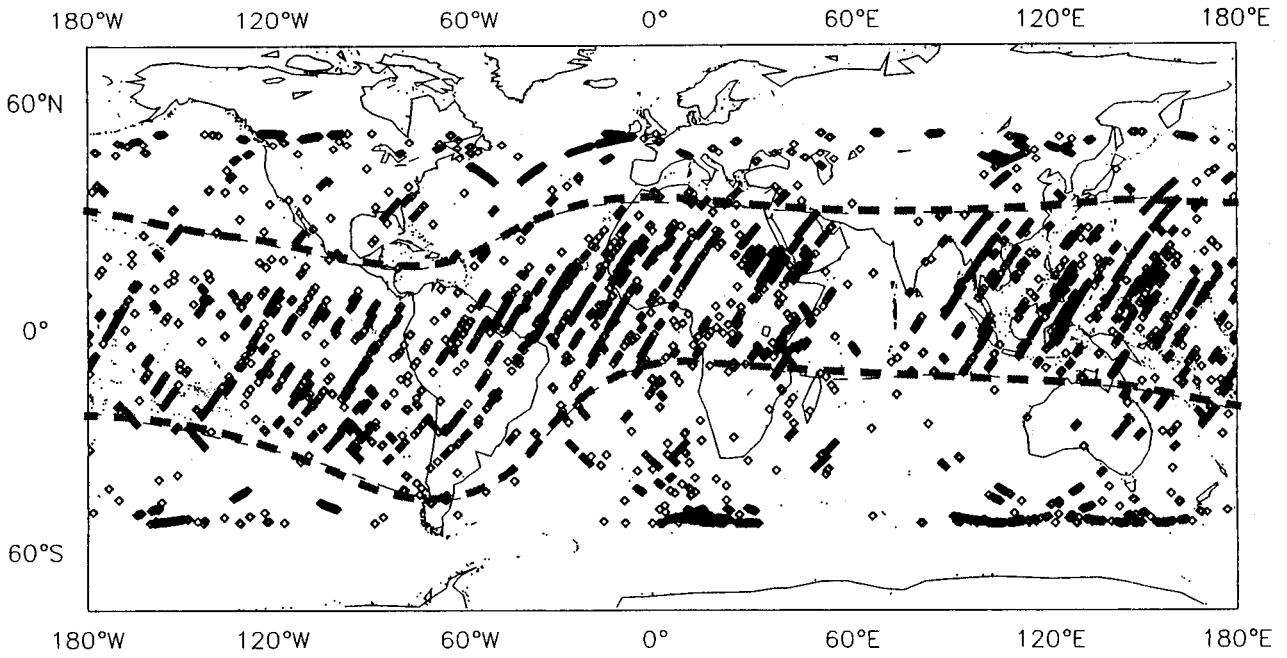
Space Station GPS

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.

2002 Day 256 through 266



longitude degree

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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 geo-magnetic 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.

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