Enhanced Broadcast Ephemeris for High Accuracy Assisted GPS Positioning

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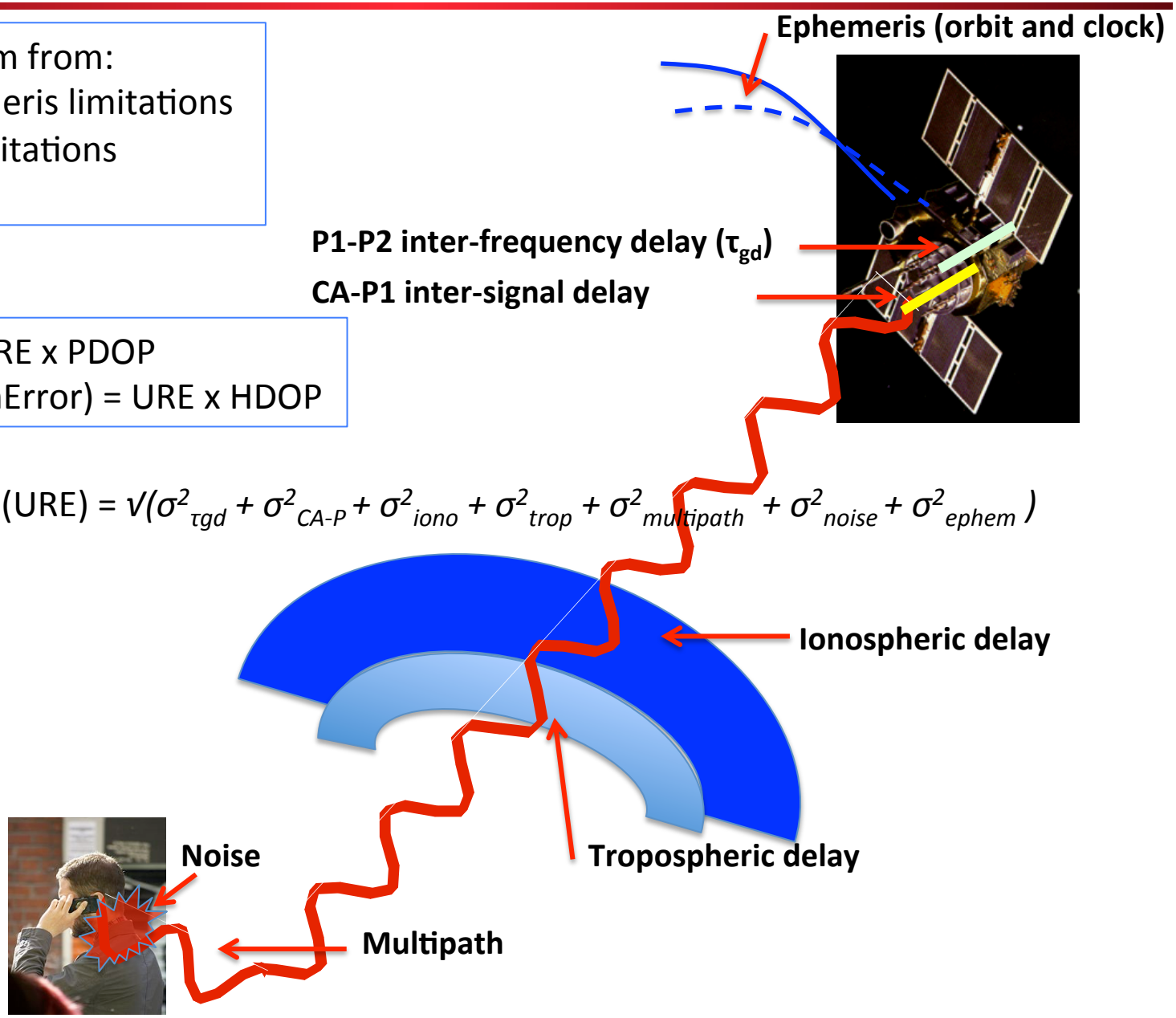
Errors Impacting PND-Based Positioning

Modeling errors stem from:
- Broadcast ephemeris limitations
- PND software limitations
- Random noise

σ(PositionError) = URE x PDOP
σ(HorizontalPositionError) = URE x HDOP

User Range Error (URE) = $\sqrt{(\sigma^2_{\tau gd} + \sigma^2_{CA\text{-}P} + \sigma^2_{iono} + \sigma^2_{trop} + \sigma^2_{multipath} + \sigma^2_{noise} + \sigma^2_{ephem})}$



Error Budget for a Typical PND-based Positioning

Typical modeling errors (m)

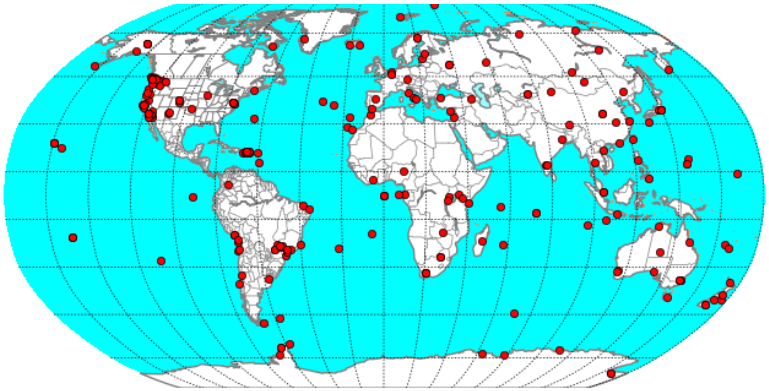
1.5 0.8 0.4 0.1 0.2 0.3 0.1 => **URE = ~1.8 m**

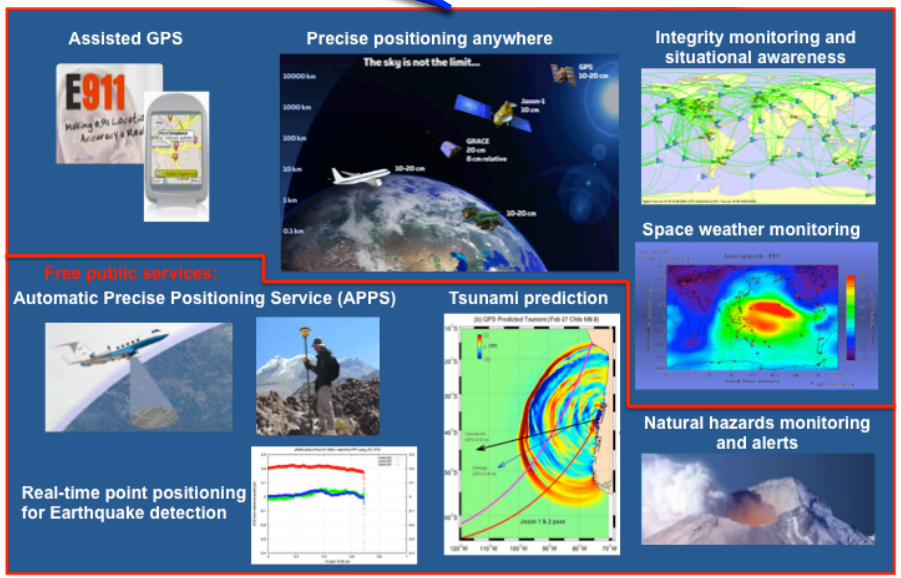
$$URE = \sqrt{(\sigma^2_{iono} + \sigma^2_{ephem} + \sigma^2_{CA\text{-}P} + \sigma^2_{\tau gd} + \sigma^2_{trop} + \sigma^2_{multipath} + \sigma^2_{noise})}$$

0.5 0.2 0.1 0.0 0.2 0.3 0.1 => **URE = ~0.7 m**

Modeling errors after GDGPS corrections
With 5 minutes iono and ephemeris prediction

GDGPS Real-Time Tracking Network





GDGPS Product Line and Services

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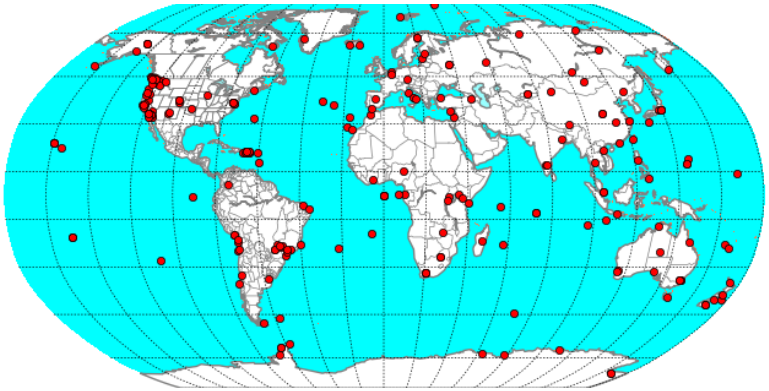
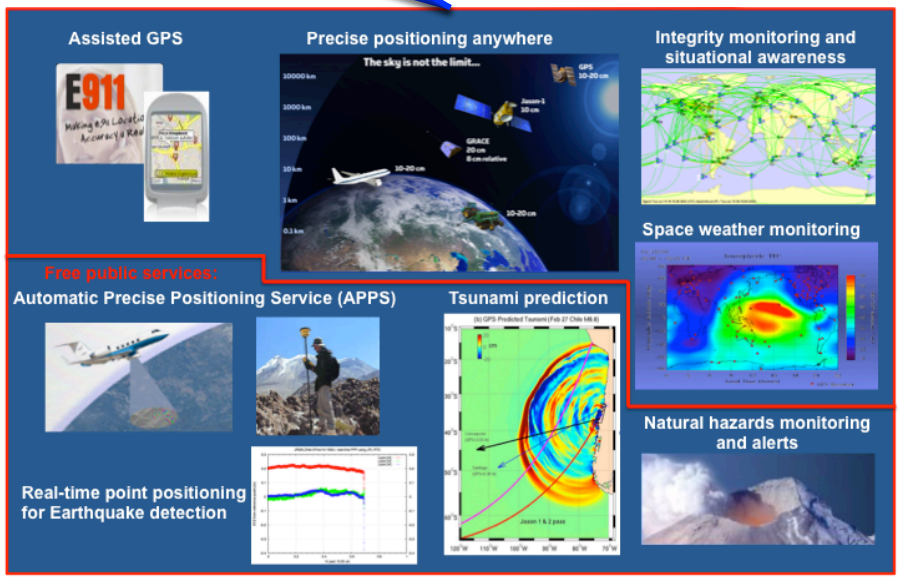
0.6 0.3 0.1 0.0 0.2 0.3 0.1 => **URE = ~0.8 m**

Modeling errors after GDGPS corrections
(with 2 hours iono & ephemeris prediction)

GDGPS Real-Time Tracking Network





GDGPS Product Line and Services

Locally-Optimized Enhanced Broadcast Ephemeris

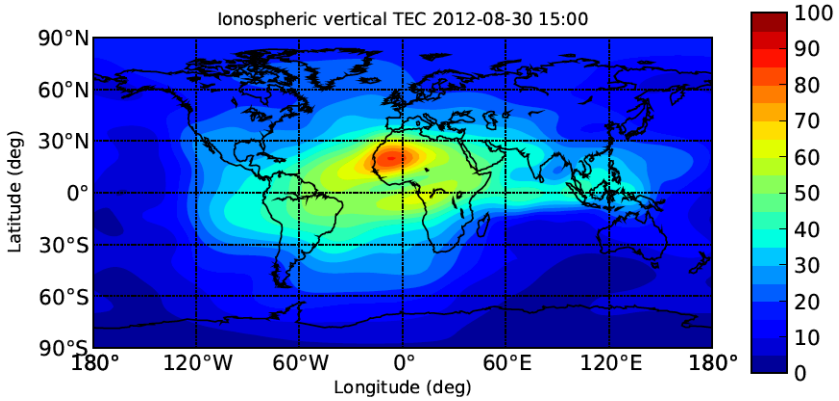
Step 1: Apply global corrections: orbit, clock, Klobuchar parameters, covering 2 hours into future
Srep 2: Apply slowly varying global corrections for τ_{gd}, adding to it CA-P corrections
Step 3*: Add residual line of sight ionospheric corrections to clock parameters* (regionally)

Update the file every 5 minutes with fresh orbit, clock, and iono data

```
  2.10           N: GPS NAV DATA                         RINEX VERSION / TYPE
 nav_50              JPL-GDGPS              1208241859 UTC   PGM / RUN BY / DATE
     9.3132e-09  2.2352e-08 -5.9605e-08 -1.1921e-07          ION ALPHA
     9.2160e+04  1.1469e+05 -1.3107e+05 -5.8982e+05          ION BETA
     4.656612873077e-09 1.065814103640e-14    61440     1703 DELTA-UTC: A0,A1,T,W
     16                                                     LEAP SECONDS
                                                            END OF HEADER
  1 12  8 24 20  0  0.0 2.709170803428E-04 1.477928890381E-12 0.000000000000E+00
IODE 1.060000000000E+02-8.531250000000E+00 4.911633160665E-09 1.213825973387E+00
    -2.868473529816E-07 1.094968640245E-03 7.573515176773E-06 5.153637516022E+03
     5.040000000000E+05 8.754432201385E-08-2.739209816387E+00 2.980232238770E-08
     9.603986560704E-01 2.306875000000E+02 3.481763593086E-01-8.144267812873E-09
    -2.278666344171E-10 1.000000000000E+00 1.702000000000E+03 0.000000000000E+00
     2.000000000000E+00 0.000000000000E+00 8.381903171539E-09 1.060000000000E+02 τgd
     5.003760000000E+05 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00
  2 12  8 24 20  0  0.0 4.008412361145E-04 1.136868377216E-12 0.000000000000E+00
     1.040000000000E+02-1.521875000000E+01 5.338436653029E-09 2.136212767345E+00
    -8.083879947662E-07 1.138912211172E-02 7.396563887596E-06 5.153740154266E+03
```

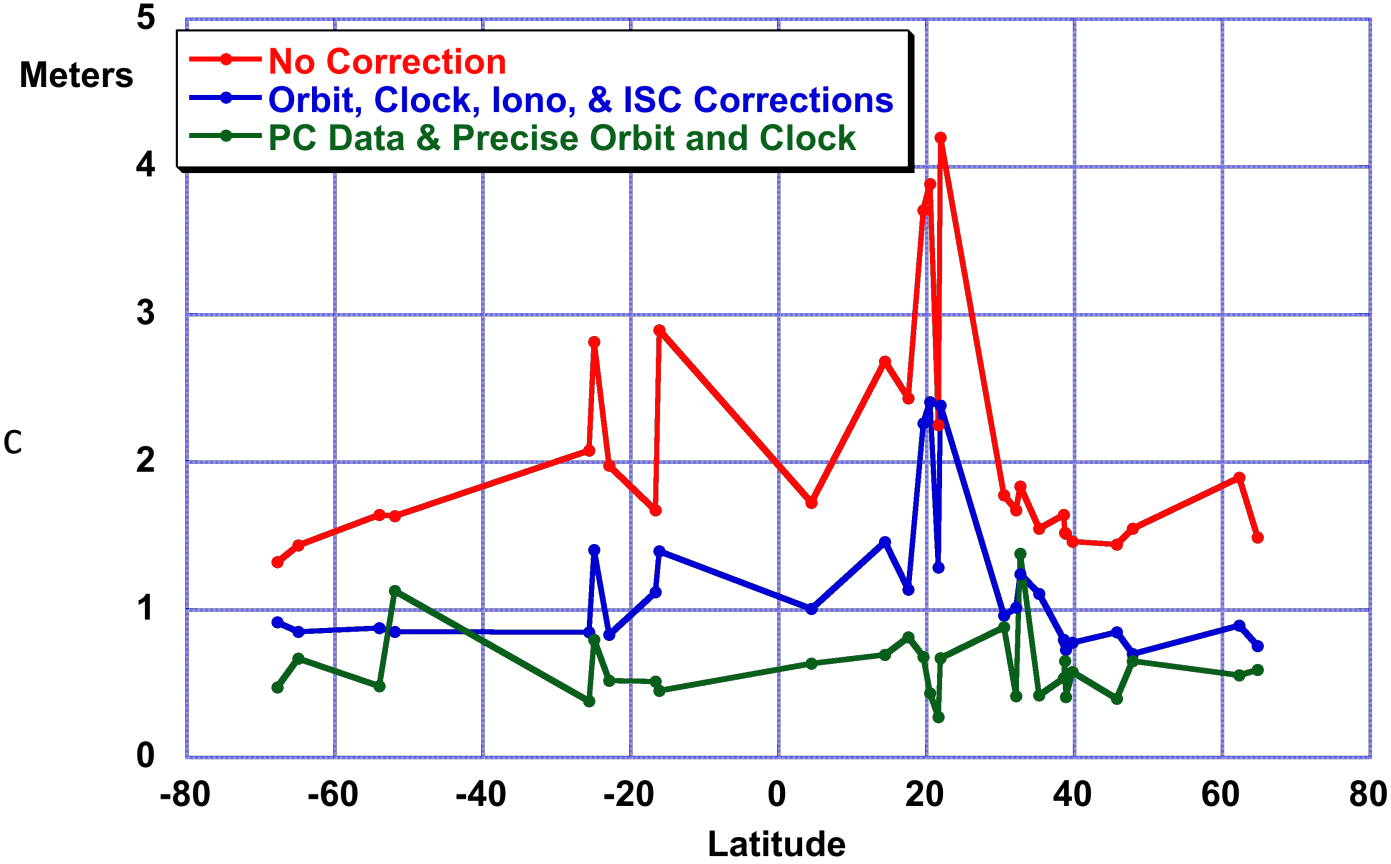
Clock: a_0, a_1, a_2

Performance Assessment

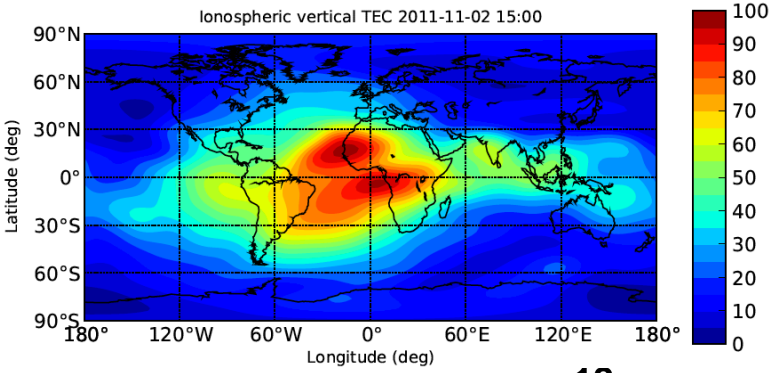


Point Positioning Accuracy:
Moderate Ionosphere Activity; 2 hours predictions

Tested on 26 globally-distributed sites equipped with geodetic quality receivers



Performance Assessment



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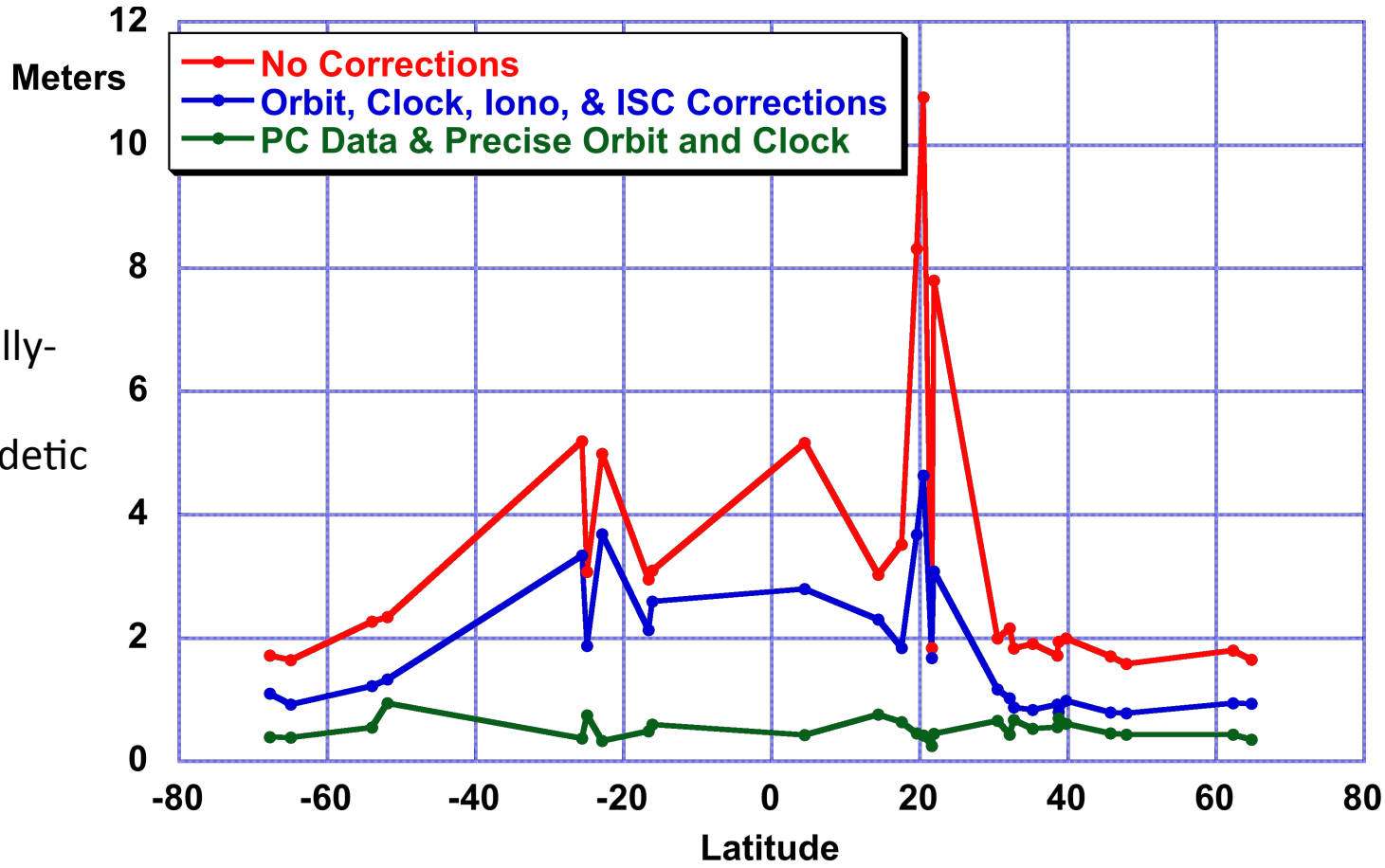
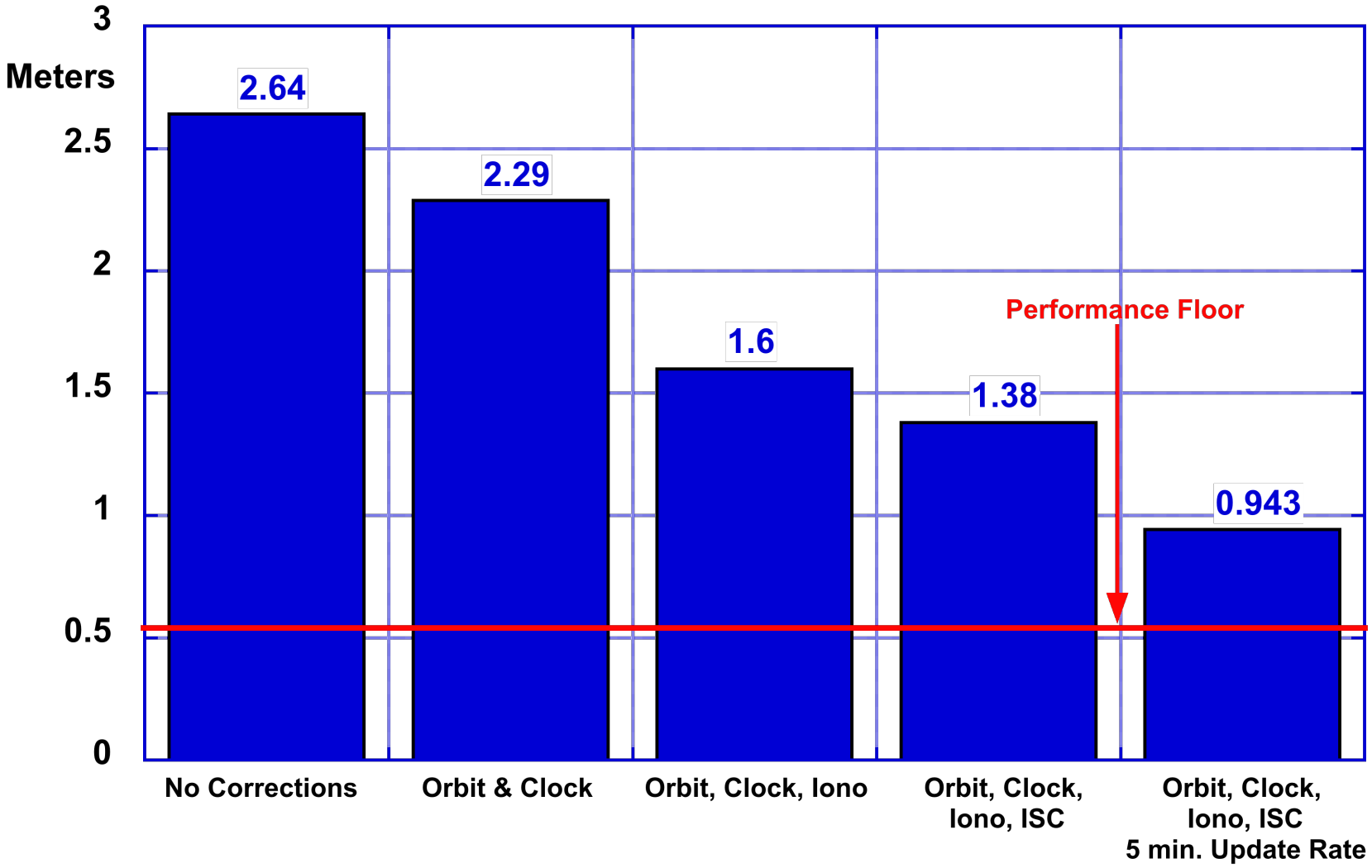


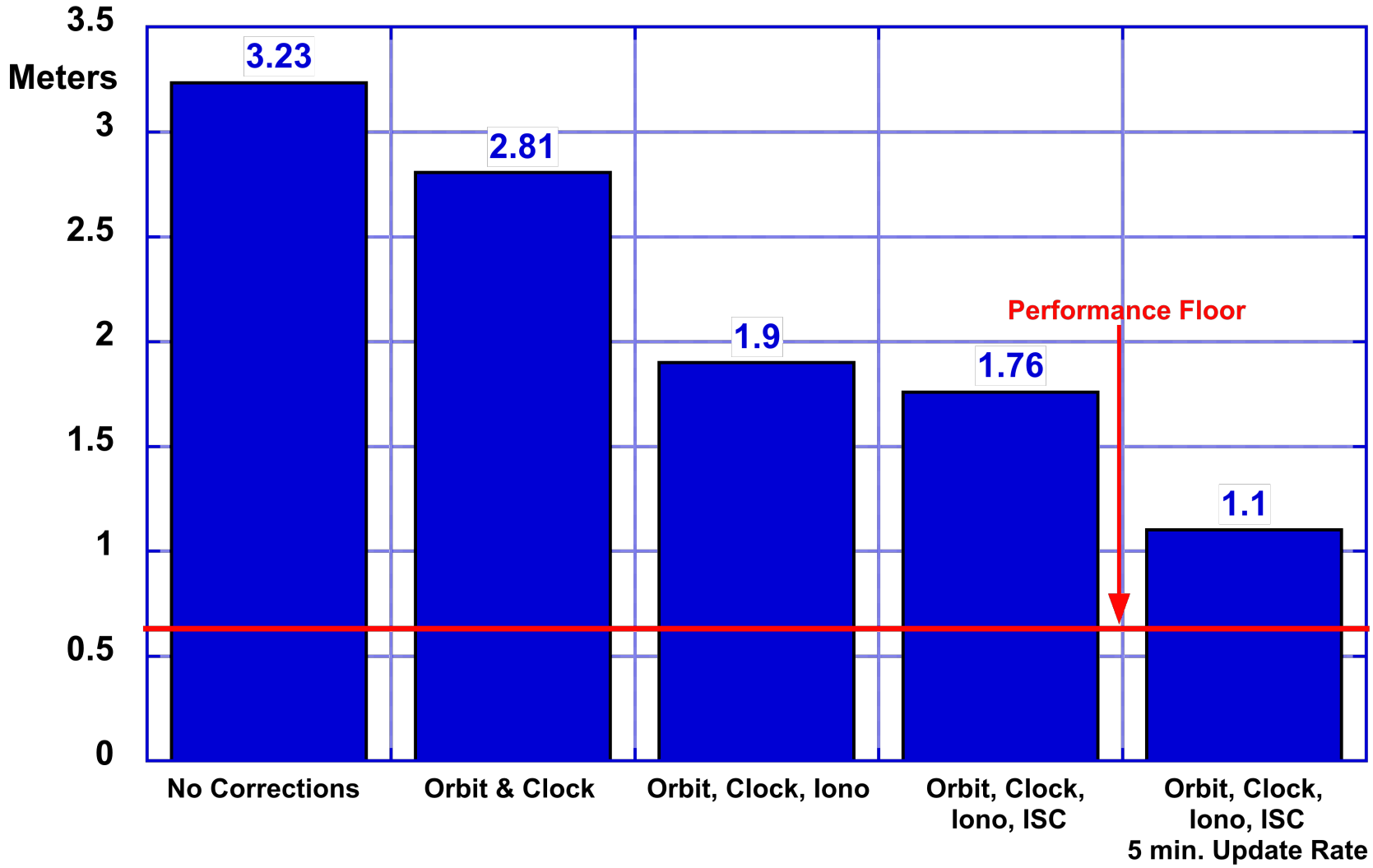
Performance Assessment

Horizontal Positioning Accuracy as a Function of Correction Types
(Mean over all test sites and ionosphere conditions)



Performance Assessment

Horizontal Positioning Accuracy as a Function of Correction Types
(Elevated ionospheric activity; Mean over all test sites)



Implementation Considerations

Ability to communicate Enhanced Ephemeris updates at high rates will strongly impact positioning accuracy

Inter-operability with the actual broadcast at the PND may depend on embedded software or on A-GPS server software

Geographical resolution depends on server capability and user location identification
- Currently 2°x2° geographical 'bins' are optimal

Similar concept may apply to other A-GPS protocols and to A-GNSS protocols

Summary

Factor of ~2 horizontal positioning improvement is realized with the new Enhanced Ephemeris product from the GDGPS System

Factor of ~3 horizontal positioning improvement can be realized with a higher rate (5 minutes) updates for Enhanced Ephemeris

Benefits will increase toward the peak of the solar cycle

Product will be available from GDGPS in Q1 2013

Many future improvements in performance are anticipated

Performance Assessment

Horizontal Positioning Accuracy as a Function of Correction Types
(Mean over low latitude sites: -40° - 40°)