The residual tropospheric propagation delay: How bad can it get?

J. Paul Collins and Richard B. Langley
pcollins@unb.ca; lang@unb.ca

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Introduction

• Aim: to quantify the maximum possible error for tropospheric delay models.
• Specifically: for wide area differential GPS users,
  – who must determine their own tropospheric delay,
  – who maybe in a “position critical” environment,
    e.g. WAAS final approach.
• Types of model tested:
  Altshuler → “first generation” navigation model,
  UNB1 → “constant value” model based on U.S. Standard Atmosphere,
  UNB3 → table of parameters interpolated over latitude and day of year
    (current WAAS-user model),
  UNB3(SfcMet) → same model supplied with recorded meteorology
    (surface mets. – pressure, temperature, humidity).
Methodology

• Processed 10 years of North American radiosonde data, from 1987–1996.

• Between 151 and 197 stations per year, operating in Canada, the U.S.A., Mexico, the Caribbean and Central America.

• Approximately 100,000 profiles per year, ~1,000,000 in total.

• Tropospheric delay model values at the zenith are subtracted from the zenith ray-trace values to give the residual tropospheric delay and model error.
Residual Distribution (1)

Altshuler
(mean = 16cm, stdev = 8cm)

UNB1
(mean = 2cm, stdev = 9cm)
Residual Distribution (2)

UNB3(SfcMet)  
(mean = 0 cm, stdev = 3 cm)

UNB3  
(mean = −2 cm, stdev = 5 cm)
Model Results, Average Conditions

- First-generation models performance can be poor.
- Constant-value models can give zero-mean performance, but standard deviation is large.
- UNB3 models have very good “average” performance:
  \[ \text{UNB3} \rightarrow \text{mean} = -2 \text{ cm}, \text{standard deviation} = 5 \text{ cm}, \]
  \[ \text{UNB3}(\text{SfcMet}) \rightarrow \text{mean} = 0 \text{ cm}, \text{standard deviation} = 3 \text{ cm}. \]
- Both can be reasonably represented by a zero-mean Normal distribution up to \( \pm 4\sigma \) (\( \sim \pm 20 \text{ cm} \)).
- Real-time met. inputs degrade performance, especially in the lower tail:
  \[ \text{UNB3} \rightarrow 72 \text{ residuals greater than } \pm 20 \text{ cm}, \]
  \[ \text{UNB3}(\text{SfcMet}) \rightarrow 106 \text{ residuals greater than } \pm 20 \text{ cm}. \]
Seasonal Trend Of Extremes

Positive Extremes (cm)

Negative Extremes (cm)

Day-of-year

1 - 03125  F - 14898
2 - 03131  G - 14918
3 - 03879  H - 21001
4 - 03937  I - 21101
5 - 03940  J - 22103
6 - 03948  K - 22104
7 - 04734  L - 23154
8 - 11641  M - 23230
9 - 12919  N - 92803
A - 13601  O - 93116
B - 13840  P - 93214
C - 14684  Q - 93223
D - 14685  R - 93734
E - 14733  S - 94983

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Positive And Negative Order Statistics

Year

Positive Extremes (cm)


Negative Extremes (cm)


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Statistical Predictions

Positive Extremes

Return Period (years)

- Zenith Delay Error (cm)
  - Frequency (year⁻¹)
  - Reduced Variate (Frechet Distribution)

Negative Extremes

Return Period (years)

- Zenith Delay Error (cm)
  - Frequency (year⁻¹)
  - Reduced Variate (Weibull Distribution)

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UNB3 Model Results, Extreme Conditions

• Use ±20 cm as “non-extreme” cut-off range for UNB3 zenith model error.
• 72 residuals (extremes) outside this range, ~0.007% (99.99288% within this range).
• Beyond −4σ, Normal distribution is conservative (residuals appear to level off).
• Beyond +4σ, Normal distribution is unreliable (residuals diverge significantly).
• Negative extremes limited by magnitude of wet zenith delay (~27 cm).
• Positive extremes predict ~58 cm error once every 25 years, on average.
Impact On Vertical Position Determination

Zenith delay error = 21 cm, Brownsville, Texas, Stn. no. 12919.
Summary

• Weighted solution reduces unweighted solution vertical biases by between one- and two-thirds to the metre, or sub-metre level.

• Height error approximately equal to error on lowest elevation satellite in an unweighted solution.

• Bias of weighted GPS solution tends to unweighted bias if satellites are concentrated at approximately the same elevation angle.

• VDOP is not a good indicator of vertical bias.

• Hence, a “rule of thumb”: maximum possible height bias due to the residual tropospheric delay
  \[ = 10 \times \text{zenith error}, \text{where } 10 \approx 5^\circ \text{ mapping function.} \]
Conclusions

• Fortunately, things don’t get “too bad” too often,
  – as long as a good model is used,
  – i.e. one that accurately models latitude and seasonal
dependence of the tropospheric delay.

• No improvement from real-time mets. because of
  problems representing atmospheric water vapour.

• But, potential exists for height biases on the order of
  several metres or more, due to mis-modelled
tropospheric delays alone.

• More processing (i.e. at least a further 10 years of
  data) is required to improve confidence in statistical
forecasts of maximum error.