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

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The Satellite Division Of The Institute of Navigation

11th International Technical Meeting

Nashville, Tennessee

September 15-18, 1998

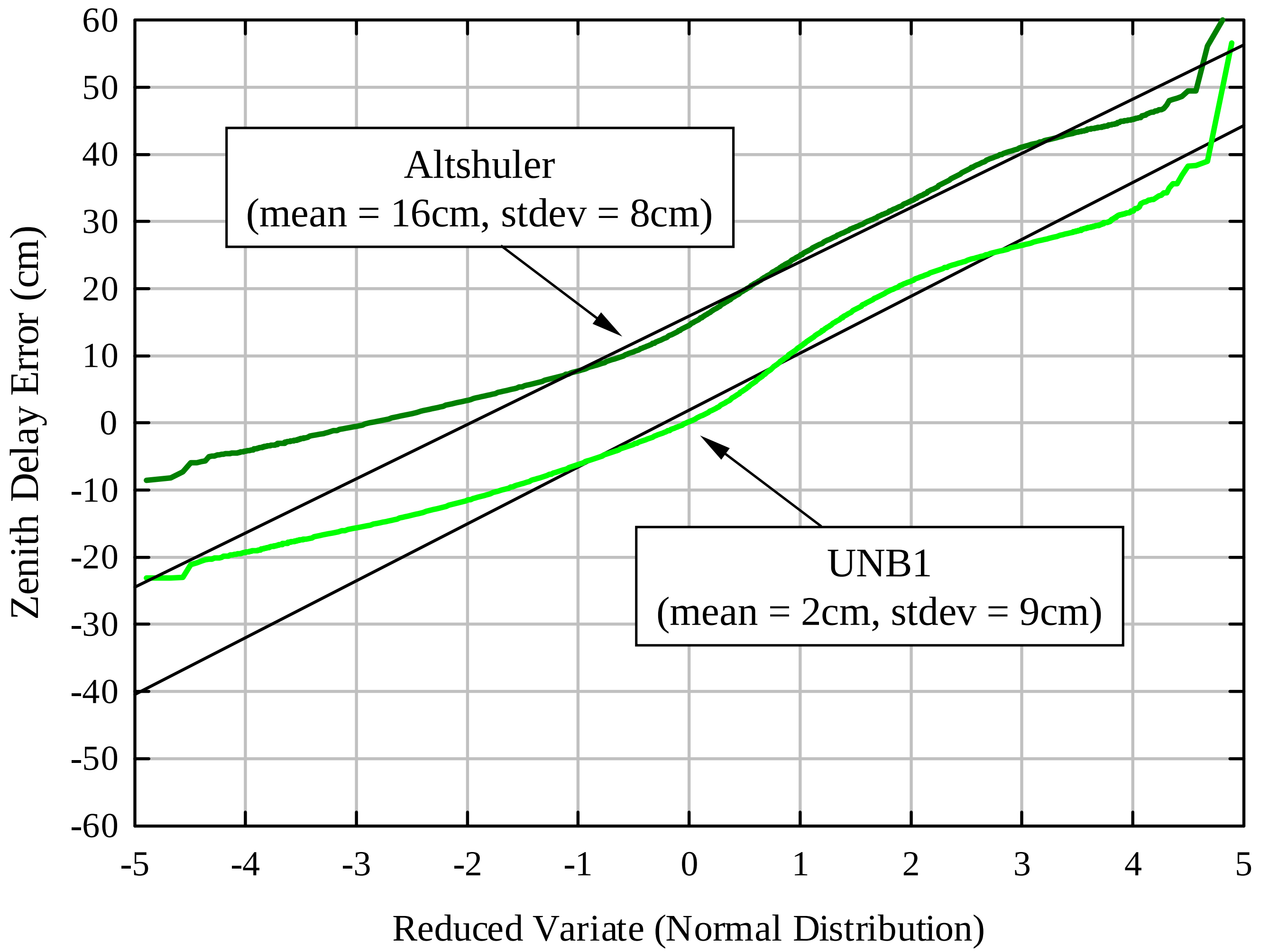
- Aim: to quantify the maximum possible error for tropospheric delay models.
- Specifically: for wide area differential GPS users,
  - who must determine their own tropospheric delay,
  - who maybe in a "position critical" environment,
    e.g. WAAS final approach.
- Types of model tested:

  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).

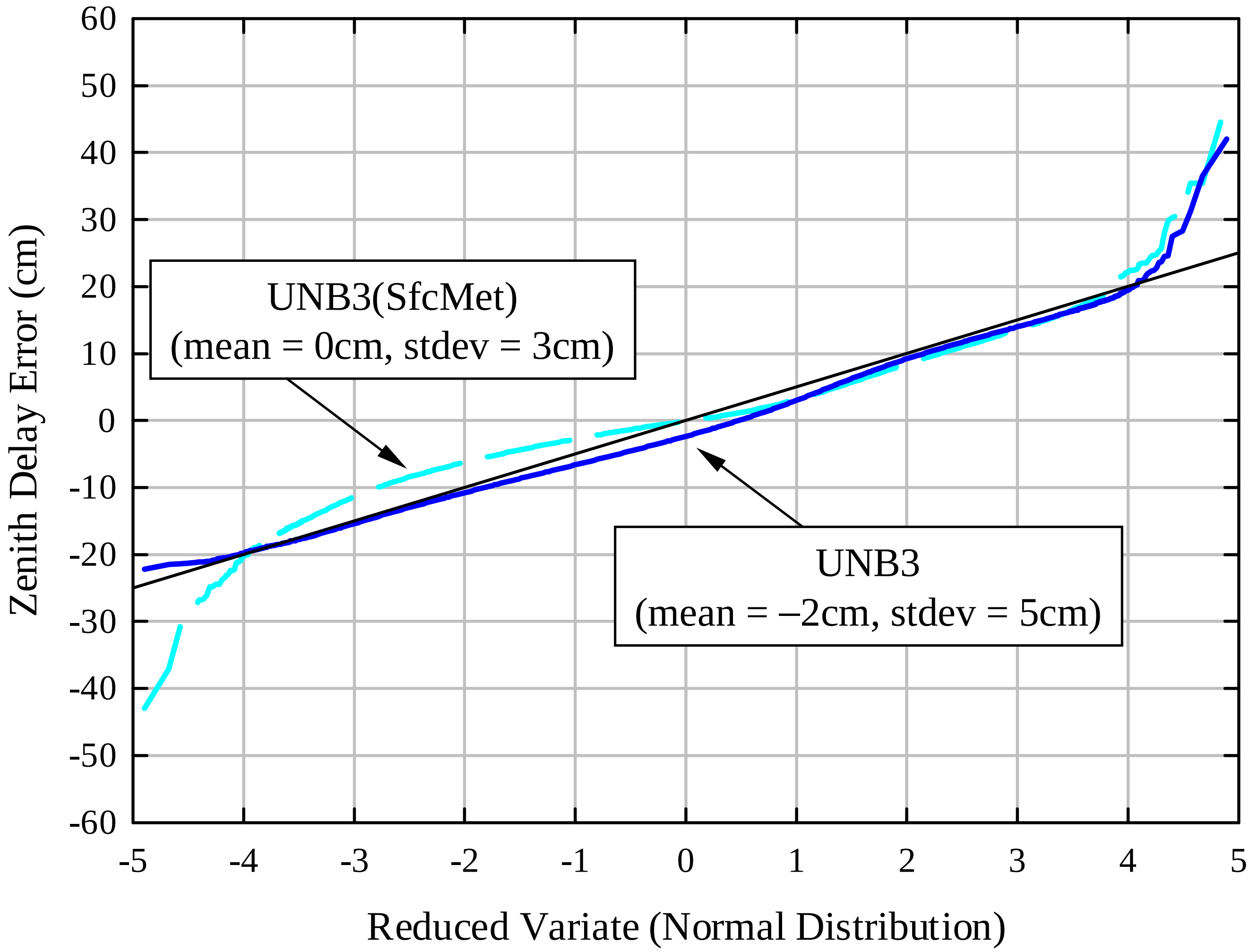
Methodology

- 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)



Residual Distribution (2)



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:

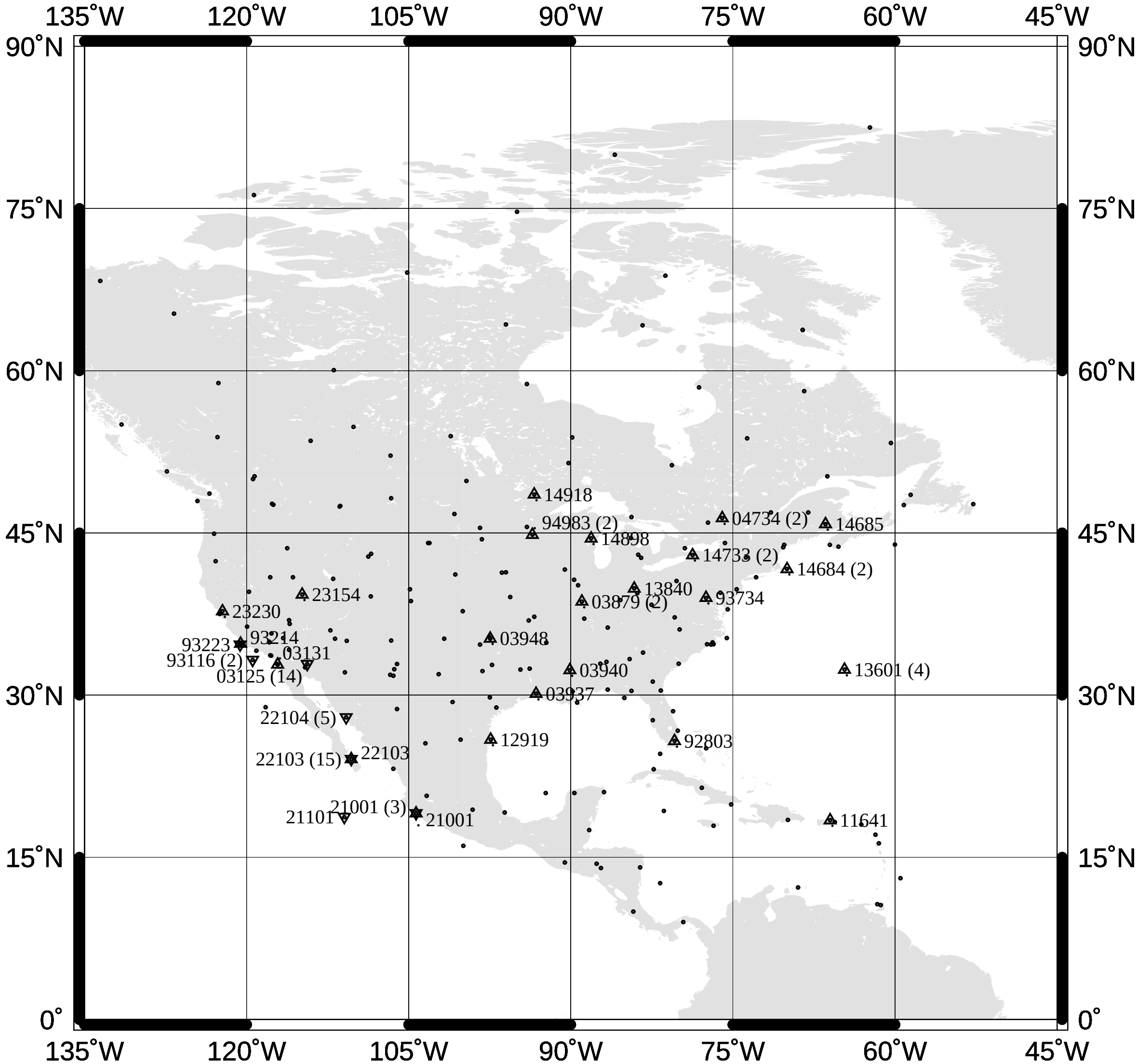
  UNB3 $\rightarrow$ mean = –2 cm, standard deviation = 5 cm,

  UNB3(SfcMet) $\rightarrow$ mean = 0 cm, standard deviation = 3 cm.
- Both can be reasonably represented by a zero-mean Normal distribution upto $\pm 4\sigma$ (~±20 cm).
- Real-time met. inputs degrade performance, especially in the lower tail:

  UNB3 $\rightarrow$ 72 residuals greater than ±20 cm,

  UNB3(SfcMet) $\rightarrow$ 106 residuals greater than ±20 cm.

Station Locations



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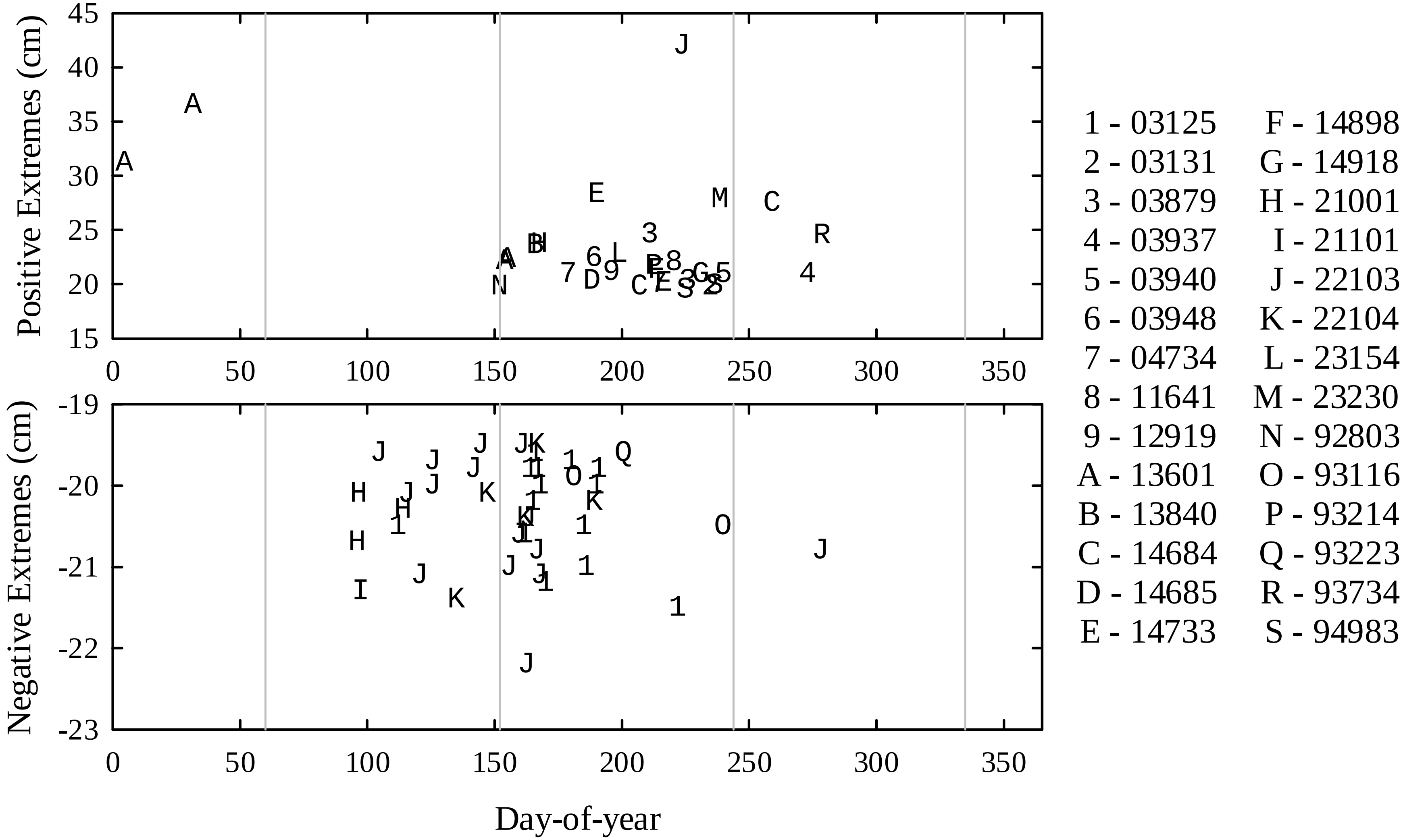
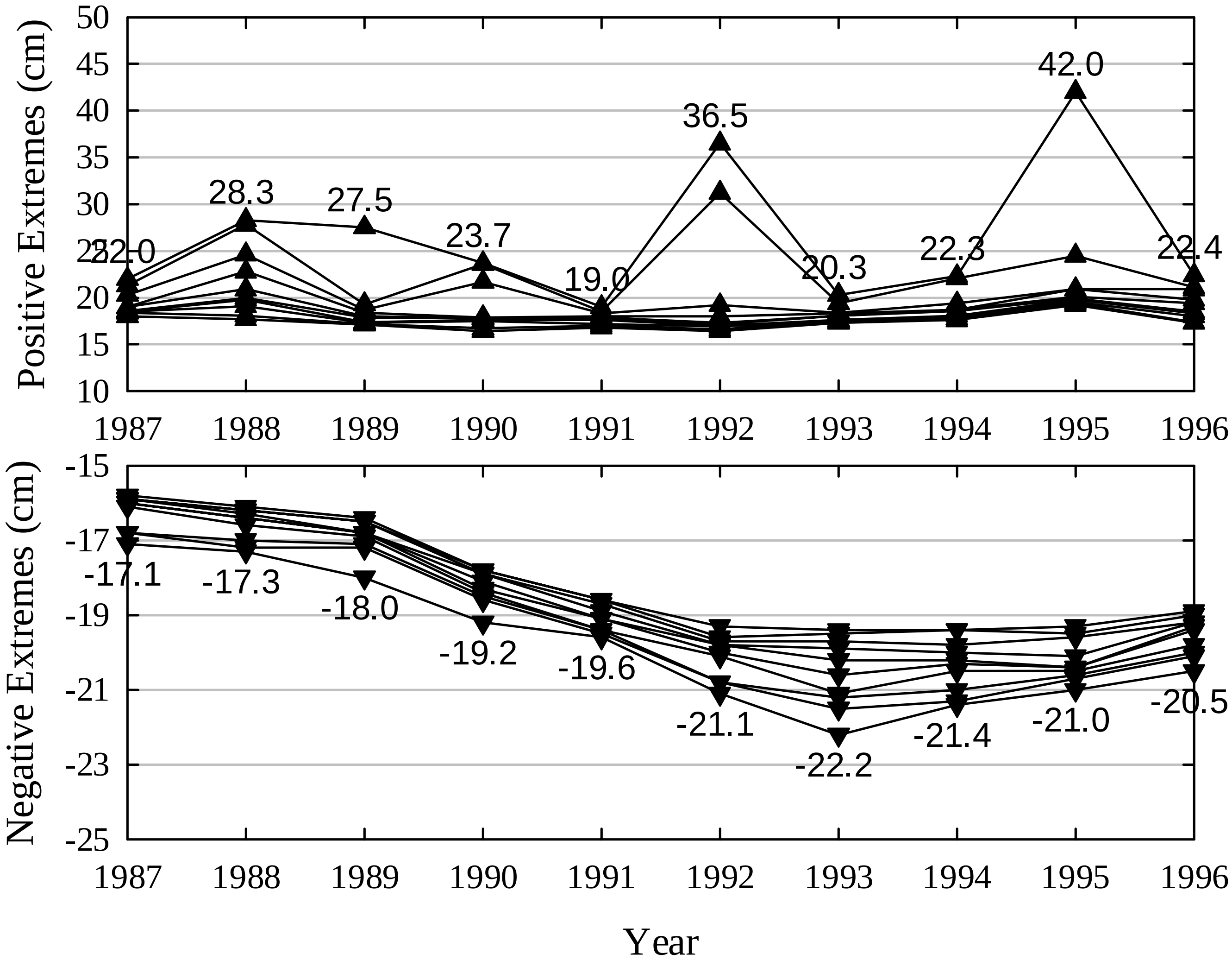
Seasonal Trend Of Extremes

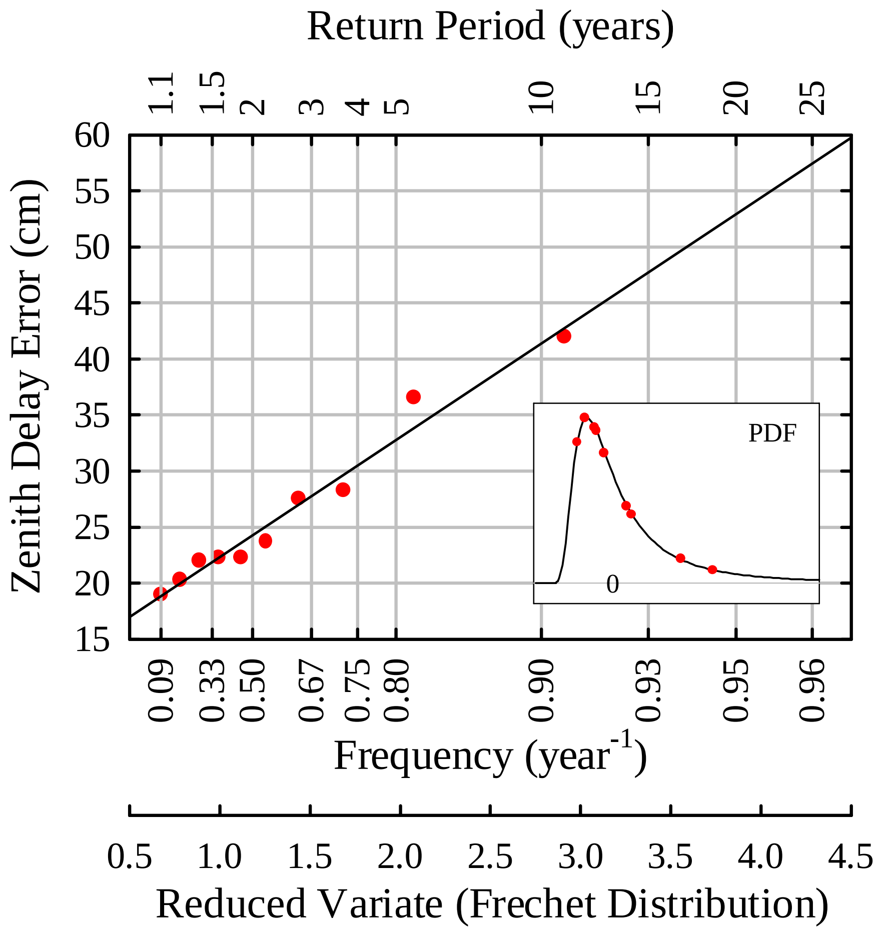


Positive And Negative Order Statistics

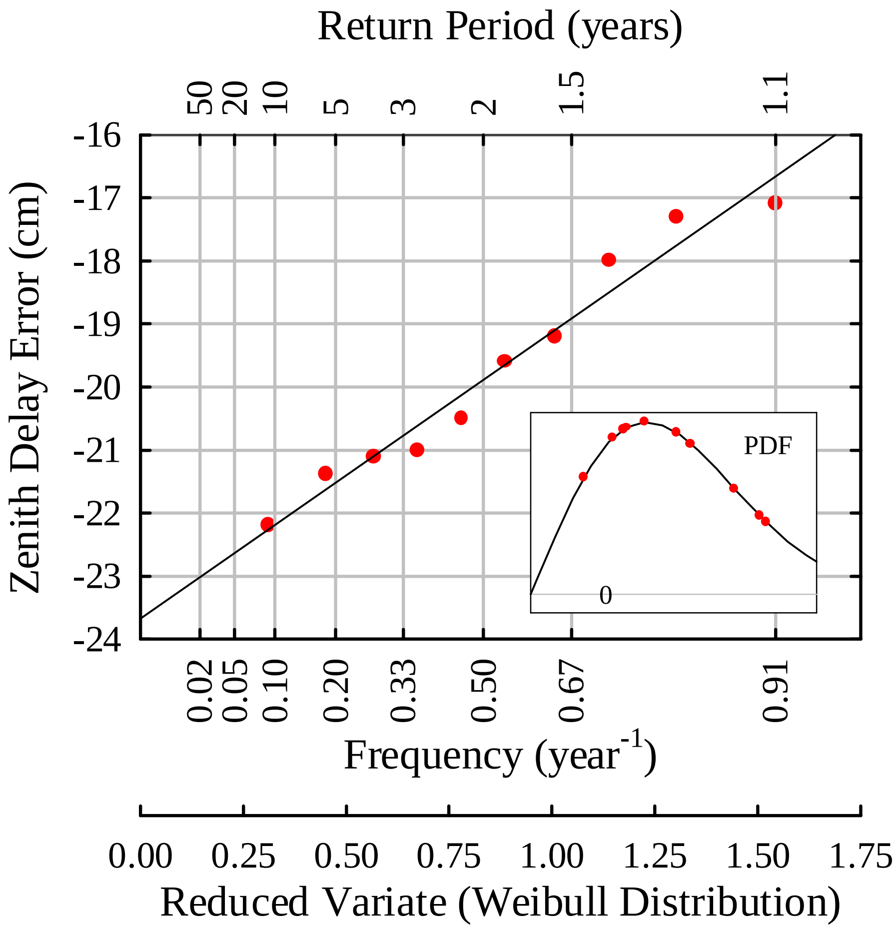


Statistical Predictions

<u>Positive Extremes</u>



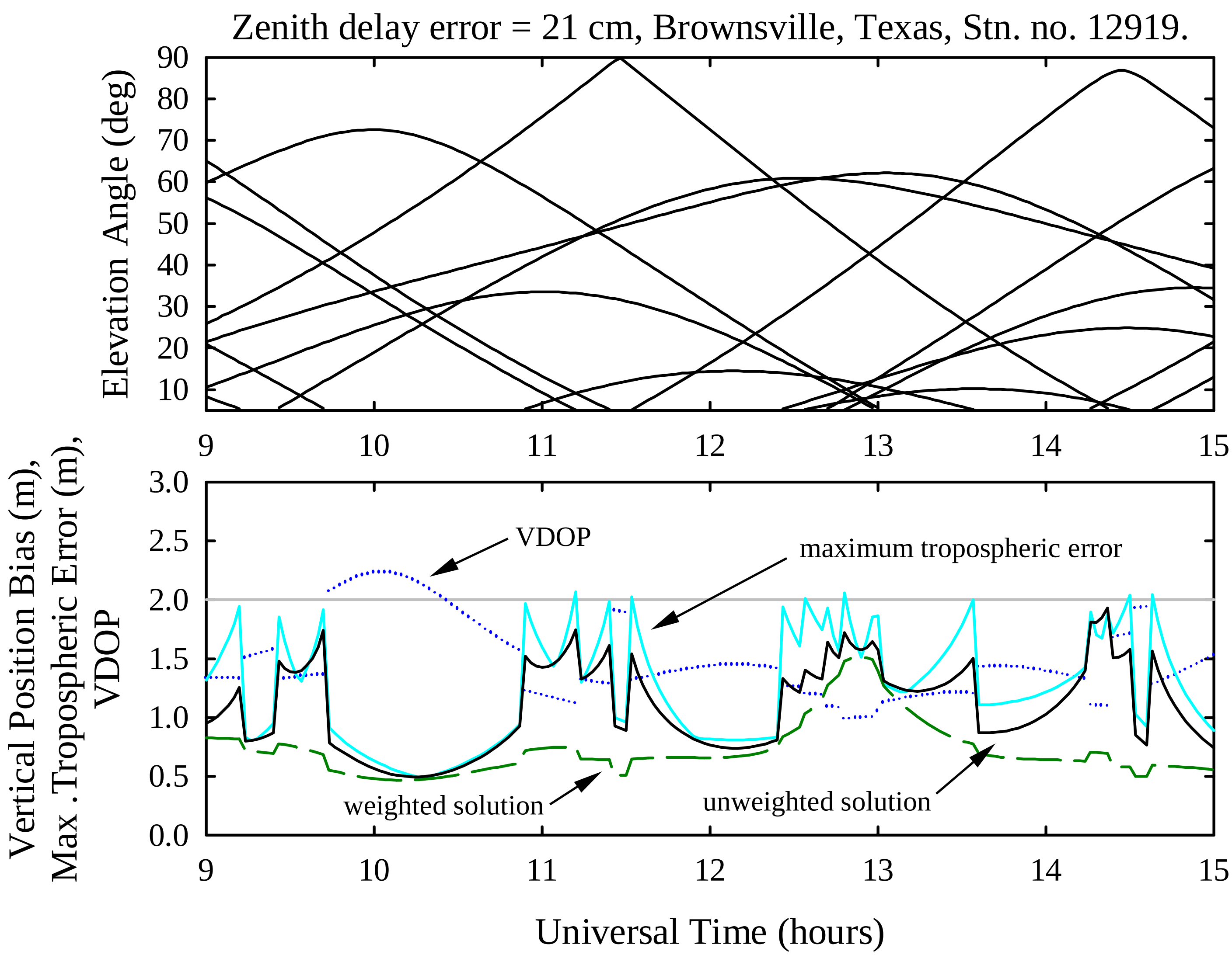
<u>Negative Extremes</u>



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



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

  $= 10 \times$ zenith error, where $10 \approx 5^{\circ}$ 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.