Close-RTK:
An investigation of network RTK performance

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Background

- SWEPOS network-RTK service,
  - based on the VRS-concept,
  - ~70 km station distance
  - ~170 stations
  - ~1200 users
- Approximate accuracy (1σ)
  - vertical: ~25-30 mm
  - horizontal: ~10-15 mm
- Users always want better, faster, more accurate etc, but:
  - In general happy with the horizontal
  - Asks for improvements in the vertical
Main questions

• What is the quality of real-time measurements with GNSS based on a detailed studies of the contributing error sources?

• What measures are needed in order to improve the accuracy?
Terminology

• All listed errors in this presentation corresponds to the square root of the variance of the difference between the measured and the true value. (1σ values)

• This means that the reported errors can be used to estimate the measurement uncertainty of the corresponding measurements.
Error Sources

- Satellite clocks
- Satellite orbits
- Ionosphere
- Troposphere
- Local effects
Satellite clocks
Satellite orbits

70 km
Ionosphere

400 km

70 km
Ionosphere

Variation during half a solar cycle

Model for how the value of TEC influence the RTK performance (in a statistical sense)
Troposphere

10 km

70 km
Local effects

Reference station

Rover
Local effects

Experiment

Model
## Error budget - Vertical

<table>
<thead>
<tr>
<th>Error source</th>
<th>Error Nominal situation (mm)</th>
<th>Error 5% (mm)</th>
<th>Error 95% (mm)</th>
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</thead>
<tbody>
<tr>
<td>Satellite clocks</td>
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<tr>
<td>Satellite orbits</td>
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<td>Ionosphere</td>
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<td>Troposphere</td>
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<td>Local Effects</td>
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<td></td>
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<tr>
<td>Rover</td>
<td>5.5</td>
<td>3.3</td>
<td>11.1</td>
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<td>Reference sites</td>
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<tr>
<td>Total (rms)</td>
<td><strong>27.3</strong></td>
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## Error budget - Horizontal

<table>
<thead>
<tr>
<th>Error source</th>
<th>Error Nominal situation (mm)</th>
<th>Error 5% (mm)</th>
<th>Error 95% (mm)</th>
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</thead>
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<td>Satellite orbits</td>
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<td>Troposphere</td>
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<td>7.0</td>
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<tr>
<td>Local Effects</td>
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<tr>
<td>Rover</td>
<td>3.5</td>
<td>2.1</td>
<td>7.0</td>
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<tr>
<td>Reference sites</td>
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<tr>
<td>Total (rms)</td>
<td>12.0</td>
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</table>
What can we do?

• Combination of observables (L1 or L3 ?)
• Satellite constellation
• Elevation cutoff
• Network density
• Reference network interpolation
Vertical Error

Present  New GNSS  Densified  Combined

RMS
L1 - Processing

Total 27 mm

Ionosphere 25
Troposphere 20
Local Effects 15

Total 27 mm
L3 – Processing (ionosphere free linear combination)

Total 28 mm

Ionosphere  Troposphere  Local Effects
Vertical error

Present, New GNSS, Densified, Combined

RMS
**Satellite constellation**

Present (GPS+GLONASS)
8-18 svs > 13° elevation
2-8 svs > 45° elevation

Future (GPS+Glo+Galileo..)
26-38 svs > 13° elevation
8-15 svs > 45° elevation
Elevation cutoff

Vertical
Present
Future

Horizontal
Present
Future
L1 - Processing

![Bar chart](chart.png)

- **Current**
- **New GNSS (13°)**
- **New GNSS (24°)**

Categories:
- Ionosphere
- Troposphere
- Local Effects

Values:
- Ionosphere: Current = 15, New GNSS (13°) = 10, New GNSS (24°) = 5
- Troposphere: Current = 20, New GNSS (13°) = 20, New GNSS (24°) = 10
- Local Effects: Current = 10, New GNSS (13°) = 5, New GNSS (24°) = 5
Vertical error

Present | New GNSS | Densified | Combined

from 70 km to 35 km

RMS
Vertical error – Densification (current satellite constellation)

- 70 km: RMS 30
- 35 km: RMS 25
- 20 km: RMS 15
- 10 km: RMS 10
Vertical error

![Graph showing vertical error for Present, New GNSS, Densified, and Combined categories with RMS values indicated.]
Summary

- The theoretical simulation confirms Empirical values for vertical uncertainty
  (-network program performs well)
- The Ionosphere is periodically a dominant error source
  - The use of the L3 combination removes these errors at the expense of local effects
- The availability of future systems will reduce the vertical error from 27 mm to 20 mm
  - Future system allows for higher cutoff angle!
- A condensed network (35 km) reduces the vertical error from 27 mm to 20 mm
- The combination of a condensed network (35 km) and new satellite systems will result in a vertical error of 14 mm
- The combination of a condensed network (10 km) and new satellite systems will result in a vertical error of 8 mm