Current challenges of monitoring station height with GPS

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- Geophysical signals at various time scales in vertical site position time series
- Unknown systematic errors exist in GPS station height solutions
- Efforts of reducing the systematic errors are complicated due to the high correlation among the vertical parameters
- Interpretation of the observed vertical displacement field must consider various contributors
Vertical deformation on different time scales has different geophysical contributors

- **Secular**
  - Postglacial rebound, Sea level change
  - Erosion and sediment, Regional tectonics
  - Poros rock compaction and consolidation

- **Interseasonal**
  - Post-seismic deformation
  - Visco-elastic relaxation
  - Long term mass loading

- **Seasonal**
  - Surface mass loading
  - Sub-surface mass redistribution
  - Seasonal polar motion

- **Short period**
  - Tidal deformation
  - Co-seismic deformation
  - Magma activity
Current GPS vertical solutions are able to detect many vertical deformation signals

- Daily vertical relative coordinate accuracy: 10 mm (Heflin et al., 2002)
- Mass loading caused seasonal vertical displacement: ~5 mm
• GPS derived geocenter time series from network shift and degree-1 deformation approaches.
Unresolved systematic errors (2)

- Elevation cutoff angle related site height change (GGN) and seasonal term change (courtesy F. Webb, D. Morken & S. Nerem)
Unresolved systematic errors (3)

- Satellite antenna phase center offset (Bar-Sever, 1998; Zhu et al., 2003)
- Receiver antenna elevation-angle dependent phase center variation (anechoic chamber test and short baseline GPS measurement) and “15 ppb dilemma” (Rothacher et al., 1995; Springer, 2000; Hatanaka et al., 2001; Rothacher, 2001)
- Scale errors (1 ppb, 0.1 ppb/year) (Heflin et al., 2002; Zhu et al., 2003)
- Multipath and environment effect
High correlation among estimated parameters

\[ \Delta \text{Phase} = (\text{receiver clock offset}) - (\text{satellite clock offset}) \]

- height*\sin(elev) + bias + (\text{troposphere zenith delay})/\sin(elev)
- (\text{sat phase center offset})*\sqrt{1-0.0576\cos(elev)^2}

(troposphere gradient terms are not included)
Approaches to reduce vertical systematic errors

• Correction:
  Absolute correction
  Adoptive correction
  Elevation angle dependent weighting

• Reduce parameter correlation:
  Ambiguity resolution
  Using external atmospheric information
Sea surface topography (SST) and global sea level (GSL) variation measured from space geodesy

- Signal at 1-2 mm/yr level
- Related to center of mass (CM), while tide gauge records relative sea level
- Reliable vertical motion reference frame to sub-mm/yr level
- Sea floor vertical motion from ICE deglaciation model
- Steric correction
- Role of TIGA
Interpretation of observed vertical deformation field (1)

- Multiple contributors
- Historical and contemporary effects co-exist
- Many local variations
- Example
Interpretation of observed vertical deformation field (2)

- Courtesy Pollitz et al., 2001
Summary

- Systematic errors exist in current GPS analysis, in particular the satellite elevation-angle dependent errors
- Errors could be amplified in vertical direction due to high correlation among estimated parameters in vertical direction
- The request for reliable vertical motion reference frame has been raised
- Open question awaiting for further studies