Yet More GNSS Applications: Volcanic Hail Detection and Instantaneous Velocities for Rapid Earthquake Characterization

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Photo: Hans Kristjánsson, May 21, 2011
Ionosphere, Tectonics ... Snow Depth

Komjathy et al. (2016)
Ionosphere, Tectonics . . . Snow Depth

Komjathy et al. (2016)

Herring et al. (2016)
Ionosphere, Tectonics . . . Snow Depth

Komjathy et al. (2016)

Herring et al. (2016)

McCreight et al., (2014), Larson et al. (2009)
Eruption Close-Up: Grímsvötn 2011

- Subglacial basaltic volcano covered by the Vatnajökull ice cap
- Explosive eruption 21-28 May 2011 (VEI 4)
- Recorded displacement > 57 cm
- Produced eruption plumes > 20 km
Eruption Close-Up: Grímsvötn 2011

Eruption:

- Subglacial basaltic volcano covered by the Vatnajökull ice cap
- Explosive eruption 21-28 May 2011 (VEI 4)
- Recorded displacement of $>57$ cm
- Produced eruption plumes $>20$ km
How does GPS ‘see’ a plume?
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plume introduces phase delay
How does GPS ‘see’ a plume?

- Longer signal travel time
- Plume introduces phase delay
How does GPS ‘see’ a plume?

- Plume scatters signal, resulting in a weaker signal.
Plumes: Phase Delay and SNR

Grapenthin et al., JVGR (2013)
Plumes: Phase Delay and SNR

Grapenthin et al., JVGR (2013)

Larson, GRL (2013)
Plumes: Grímsvötn 2011

Hreinsdóttir et al. (2014)
Plumes: GFUM Phase Delay

Grapenthin et al., GRL (2018)
Plumes: GFUM Phase Delay

2011-05-20, 19:00-22:00 UTC

2011-05-21, 19:00-22:00 UTC

Grapenthin et al., GRL (2018)
Plumes: GFUM Phase Delay

Grapenthin et al., GRL (2018)
Plume Analysis: SNR & Phase Delay

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Plume Analysis: SNR & Phase Delay

Grapenthin et al., GRL (2018)
Grapenthin et al., GRL (2018)
Plume Analysis: 1-D Plumeria Model

- Plume Radius [km]
- Plume Height [km asl]
- Plume Mass Fraction: ash, water
- Plume Water [g/m³]: liquid, water, ice

Grapenthin et al., GRL (2018)
Plume Analysis: 1-D Plumeria Model

Grapenthin et al., GRL (2018)
Plume Analysis: 1-D Plumeria Model

Grapenthin et al., GRL (2018)
Plume Analysis: 1-D Plumeria Model

Grapenthin et al., GRL (2018)
Plume Analysis: Hail

Scale: 1 mm between ticks

Grímsvötn 2011 – Hagl-02
Macro-photo Pórður Arason 11 June 2011

photo: T. Arason
\[
\phi^{(s)} = \frac{1}{\lambda} (r^{(s)} + I + T) + \frac{c}{\lambda} (\delta t_u - \delta t^s) + N + MP + \epsilon
\]
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\( \phi^{(s)} \) - carrier phase to satellite \( s \), **in cycles, measured**

\( r^{(s)} \) - true range to satellite \( s \)

\( \lambda \) - carrier wavelength (L1: 19.05 cm, L2: 24.45 cm, L5: 25.48 cm)

\( c \) - speed of light

\( \delta t_u, \delta t^s \) - receiver, satellite clock biases

\( I, T \) - Ionospheric and tropospheric delays

\( N \) - integer ambiguity, number of full cycles not tracked

\( MP \) - Multipath (interference of reflected signals, see below)

\( \epsilon \) - unmodeled effects, measurement errors, etc.
\[ \phi^{(s)} = \frac{1}{\lambda}(r^{(s)} + I + T) + \frac{C}{\lambda}(\delta t_u - \delta t^s) + N + MP + \epsilon \]

*Misra and Enge (2011),
Colosimo et al. (2011),
Gaglione (2015),
Grapenthin et al. (2018)*
\[
\phi^{(s)} = \frac{1}{\lambda} (r^{(s)} + I + T) + \frac{C}{\lambda} (\delta t_u - \delta t^s) + N + MP + \epsilon
\]
\[
\Delta \Phi^s = (v^s - v_u) \times 1^s + \dot{b} + \delta \epsilon \Phi
\]

Misra and Enge (2011),
Colosimo et al. (2011),
Gaglione (2015),
Grapenthin et al. (2018)
Instantaneous Velocities

\[
\phi^{(s)} = \frac{1}{\lambda} (r^{(s)} + I + T) + \frac{C}{\lambda} (\delta t_u - \delta t^s) + N + MP + \epsilon
\]

\[
\Delta \Phi^s = (v^s - v_u) \times 1^s + \dot{b} + \delta \epsilon_\Phi
\]

\[
D = G \begin{bmatrix} v_u \\ \dot{b}_u \end{bmatrix} + \delta \epsilon_\Phi
\]

Instantaneous Velocities: 2016 Mw 7.1 Iniskin

Grapenthin et al., 2018
Instantaneous Velocities: 2016 $M_w 7.1$ Iniskin

(A) East-West Component (1 Hz)

- AC32.L1.IGU; $\Delta t=-2.5$ s
  - FIRE.AK.HNE
    - $d_s=46$ km $\Delta d_e=9.0$ km
- AC03.L1.IGU; $\Delta t=1.0$ s
  - HOM.AK.BNE
    - $d_s=17$ km $\Delta d_e=-11.0$ km
- AC15.L1.IGU; $\Delta t=0.5$ s
  - SWD.AK.BNE
    - $d_s=44$ km $\Delta d_e=-4.0$ km
- AC06.L1.IGU; $\Delta t=-3.0$ s
  - BRLK.AK.BNE
    - $d_s=1.5$ km $\Delta d_e=23.0$ km
- AC36.L1.IGU; $\Delta t=4.5$ s
  - FIRE.AK.HNE
    - $d_s=30$ km $\Delta d_e=-30.0$ km

(B) East-West Component (5 Hz)

- ATW2.L1.IGU
  - $\Delta t=-0.3$ s
  - AHOU.AK.HNE
    - $d_s=30$ km $\Delta d_e=2.0$ km
- AMJG.AK.BNE
  - $d_s=44$ km $\Delta d_e=5.0$ km
- AC44.L1.IGU
  - $\Delta t=1.8$ s
  - AJKS.AK.BNE
    - $d_s=1.5$ km $\Delta d_e=-12.0$ km
- AC53.L1.IGU
  - $\Delta t=-0.2$ s
  - AMJG.AK.BNE
    - $d_s=44$ km $\Delta d_e=5.0$ km

Grapenthin et al., 2018
Instantaneous Velocities: 2016 M$_w$7.1 Iniskin

Grapenthin et al., 2018
Instantaneous Velocities: 2015 $M_w 7.8$ Gorkha
Instantaneous Velocities: 2015 $M_w7.8$ Gorkha

NAST (L2,igs) $pgv_h(33s) = 92.6$ cm/s

KKN4 (L2,igs) $pgv_h(27s) = 64.5$ cm/s
GNSS has **broad impacts** touching many communities.
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With more to come . . . ?!