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

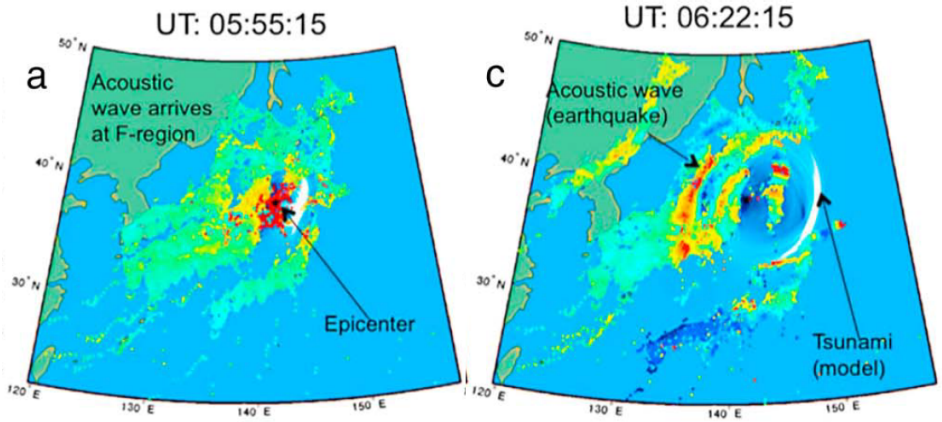
**Ronni Grapenthin (UAF-GI)**

**Collaborators:**
Sigrún Hreinsdóttir (GNS), Alexa Van Eaton (CVO),
Carl Tape (UAF), Mike West (UAF), Jeff Freymueller (MSU)



*Photo: Hans Kristjánsson, May 21, 2011*

# Ionosphere, Tectonics . . . Snow Depth




*Komjathy et al. (2016)*

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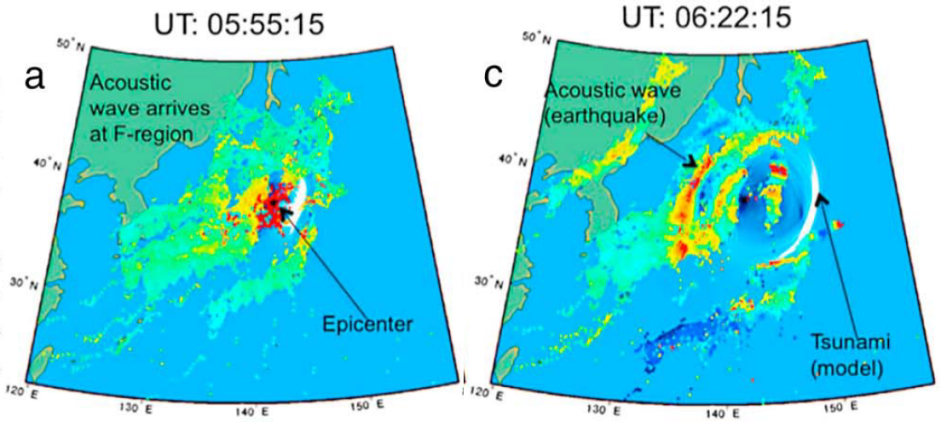


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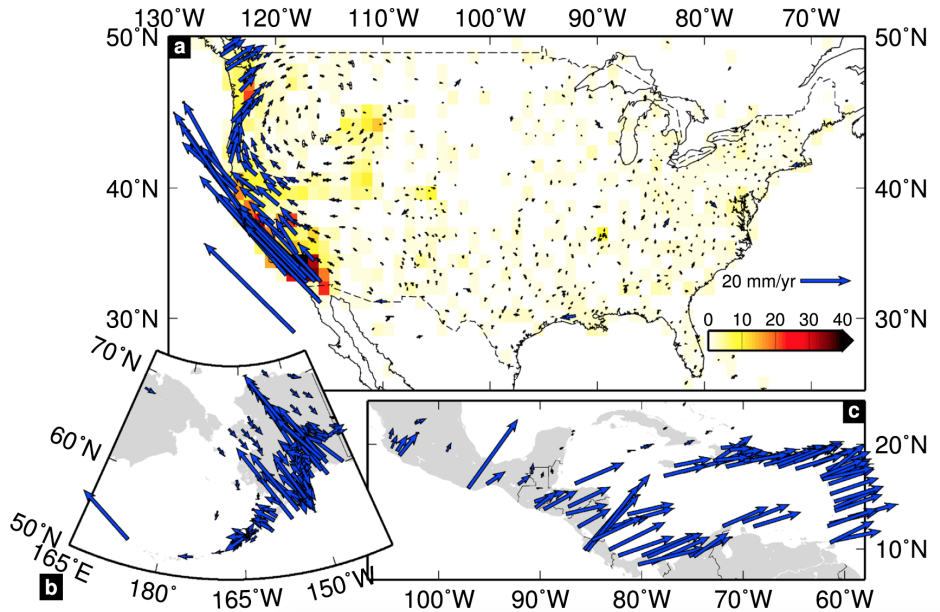


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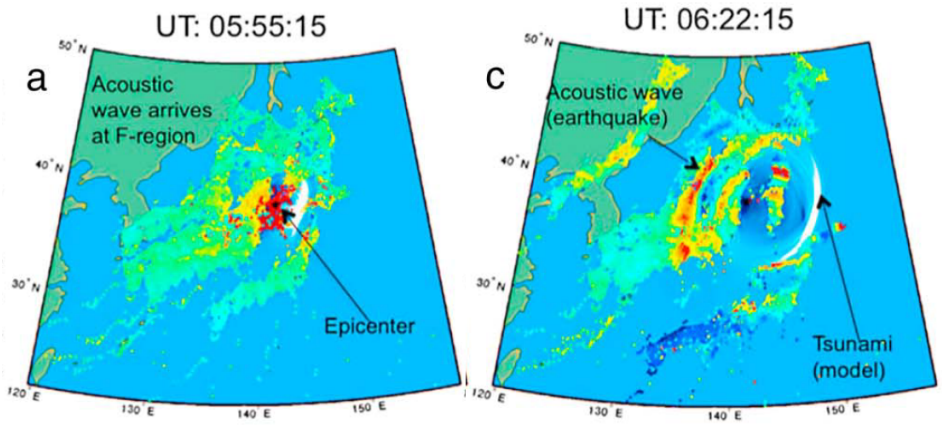


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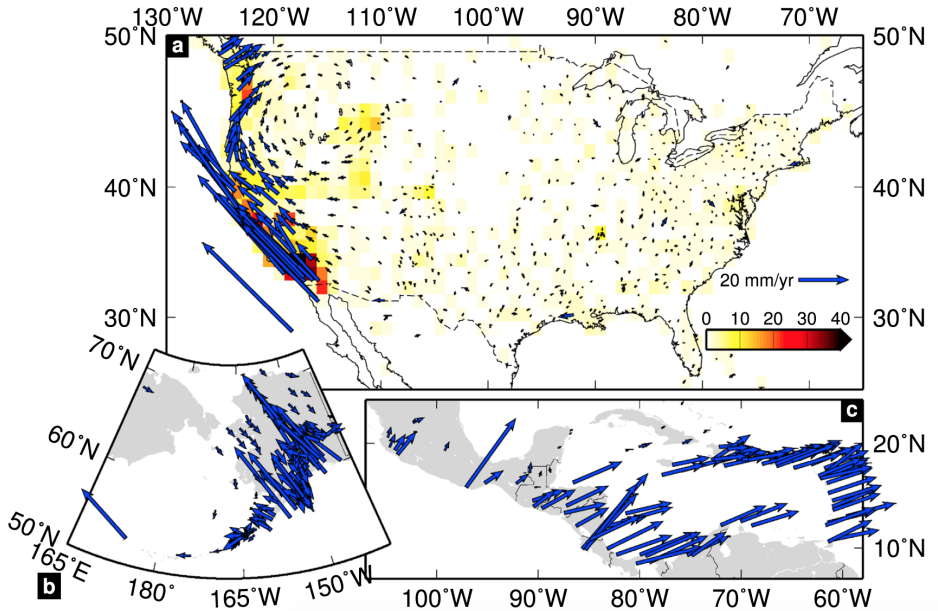


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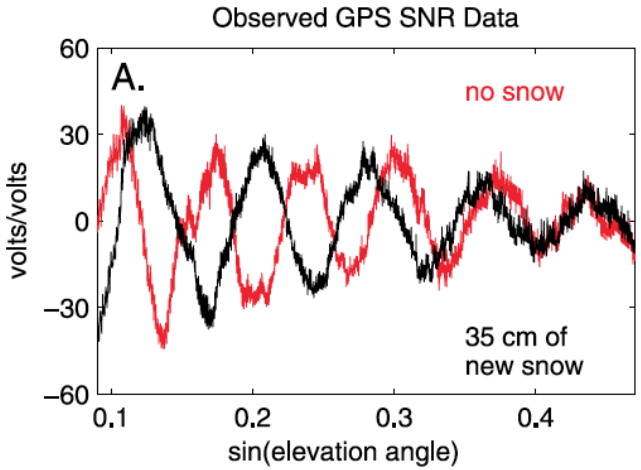


*McCreight et al., (2014), Larson et al. (2009)*

# Eruption Close-Up: Grímsvötn 2011

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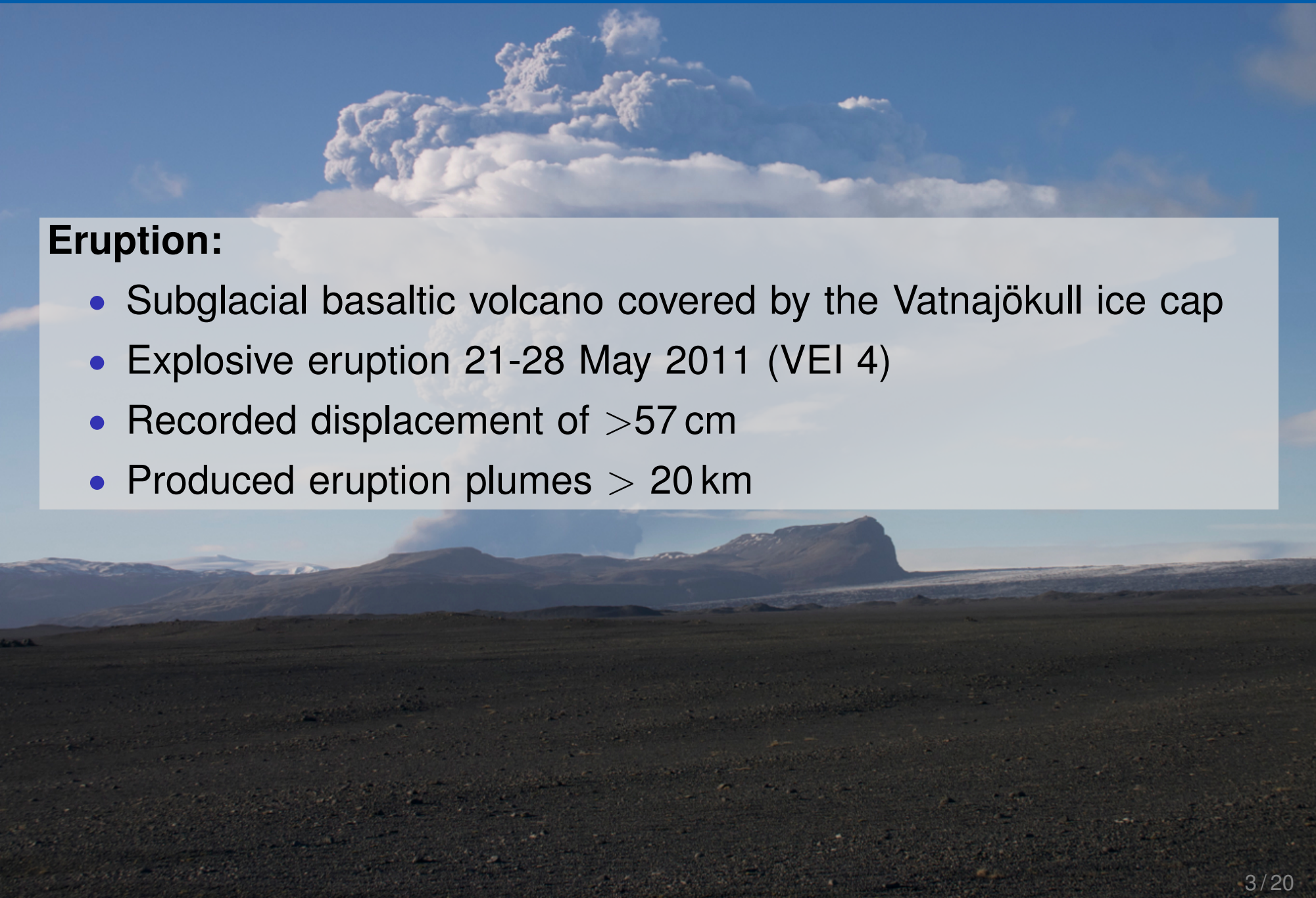
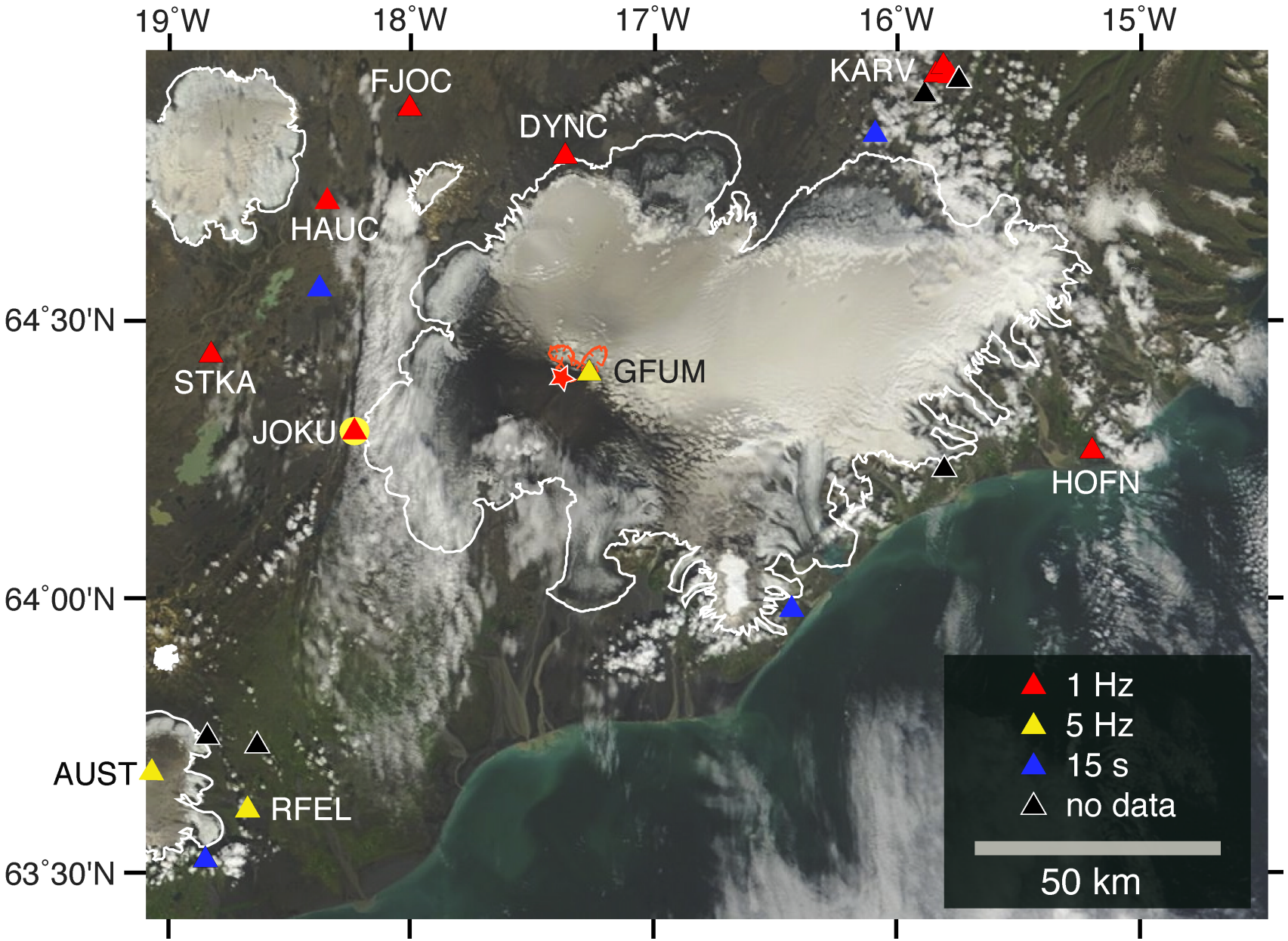


**Eruption:**

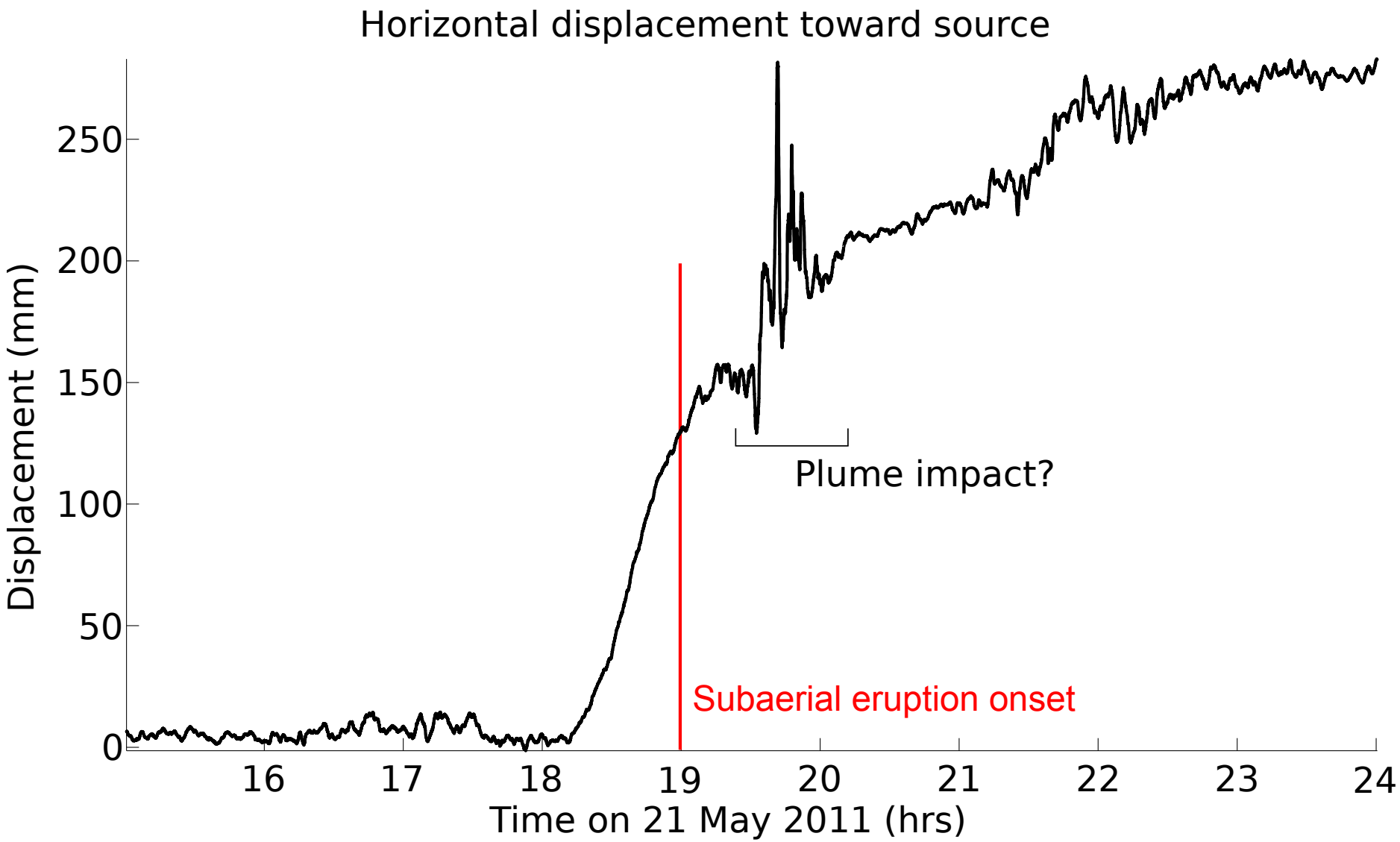
- Subglacial basaltic volcano covered by the Vatnajökull ice cap
- Explosive eruption 21-28 May 2011 (VEI 4)
- Recorded displacement of $>$57 cm
- Produced eruption plumes $>$ 20 km

# 2011 Grímsvötn Eruption



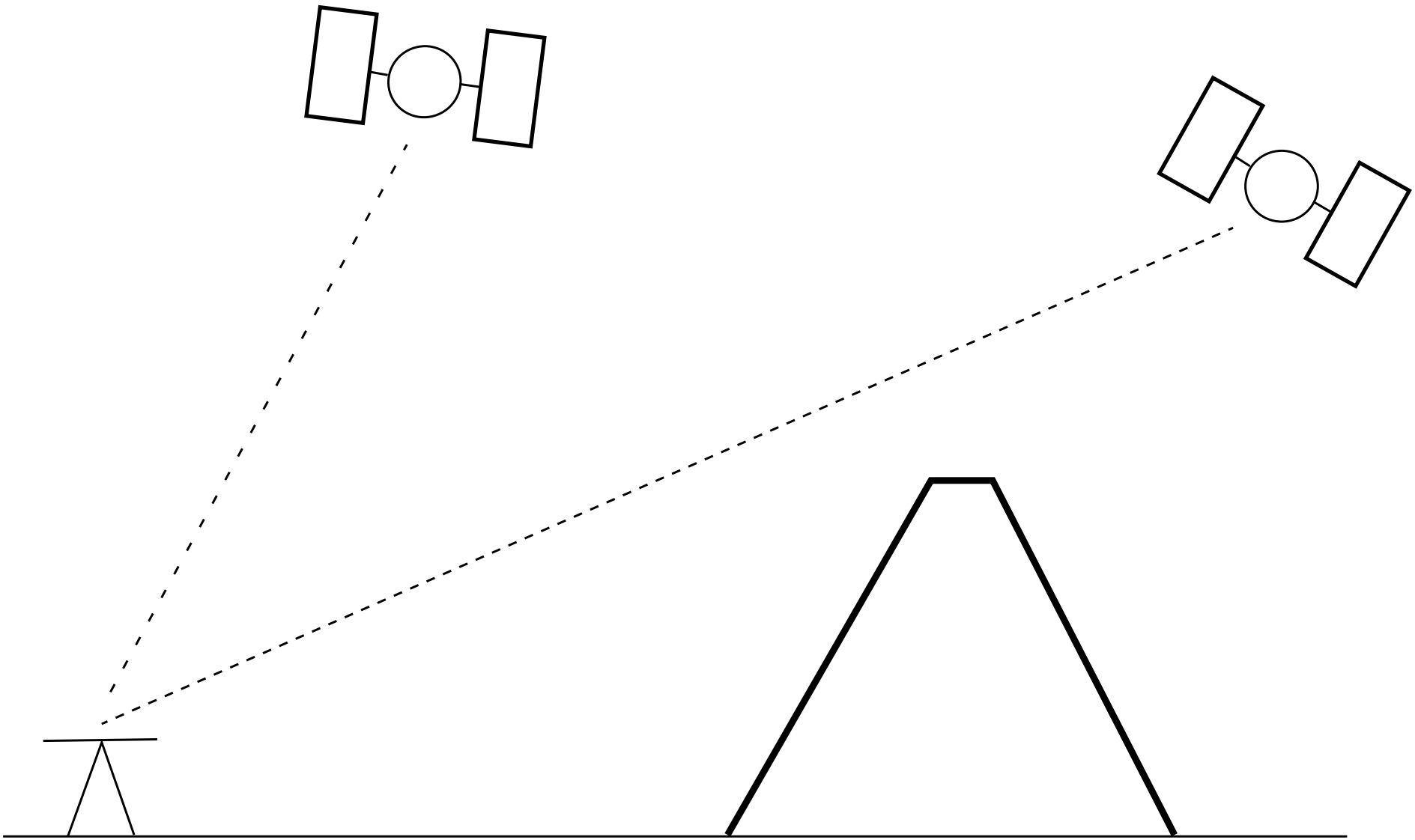

*Hreinsdóttir et al. (2014)*

# 2011 Grímsvötn: Plume Analysis




*Sigmundsson et al. (2017)*

# How does GPS ‘see’ a plume?



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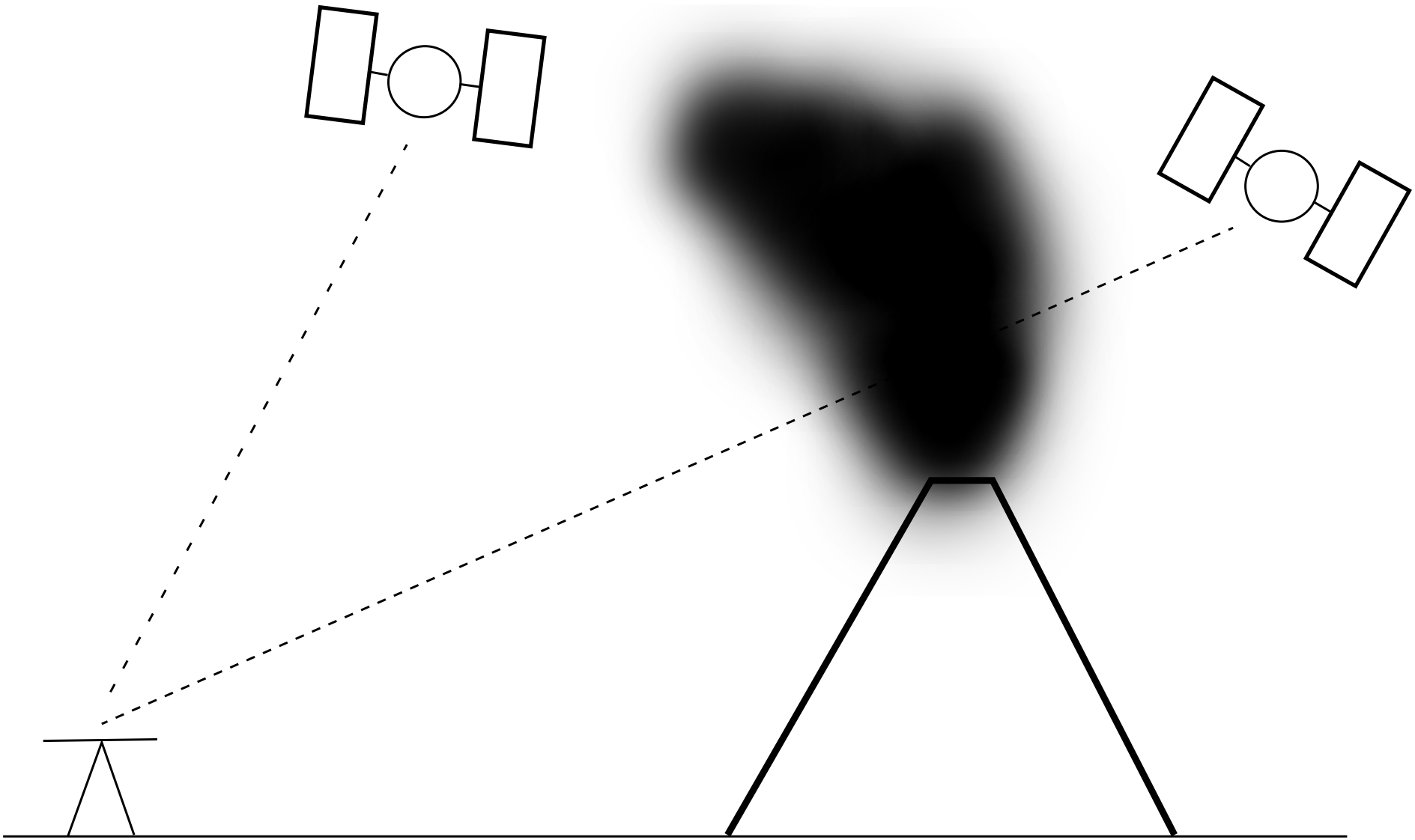

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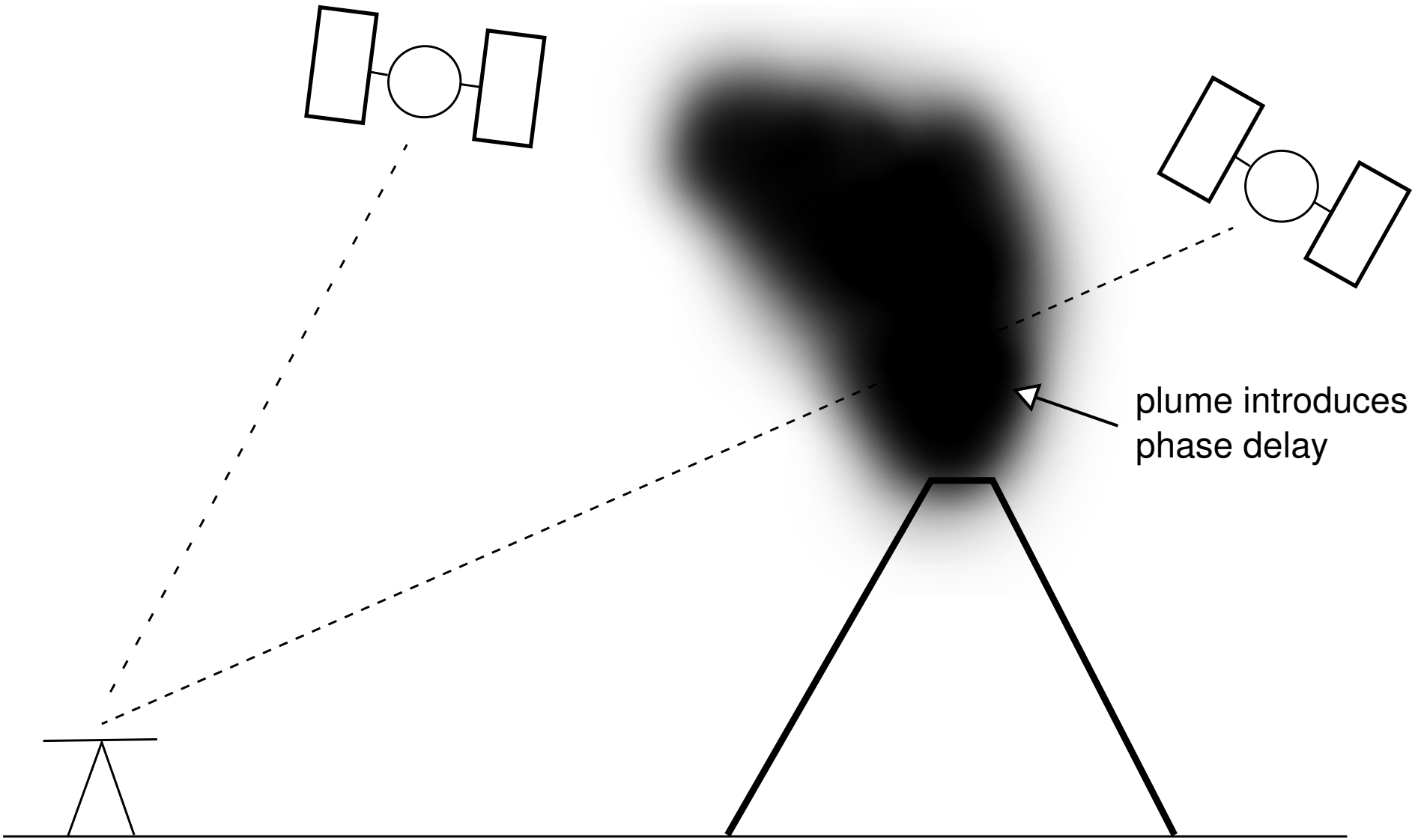

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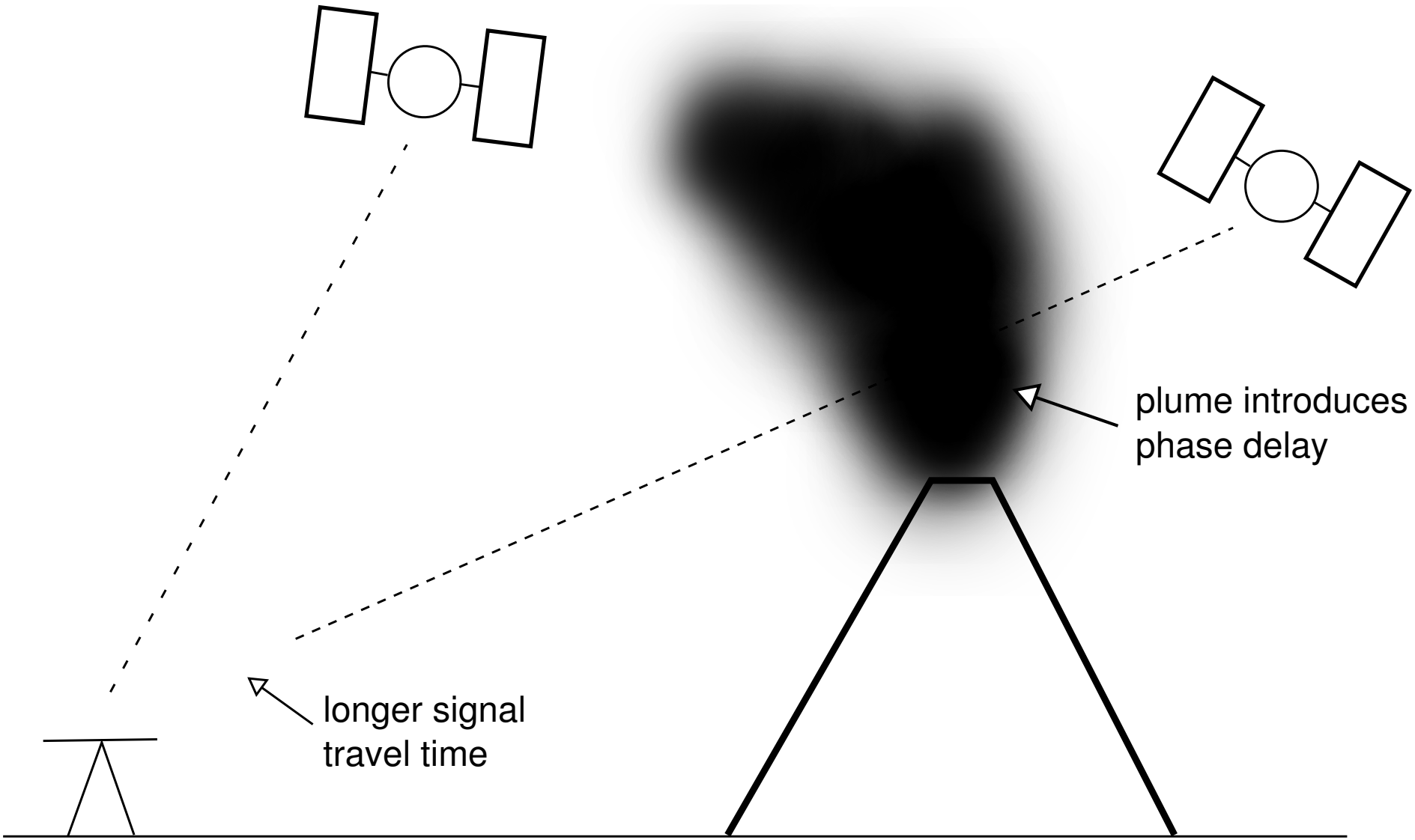

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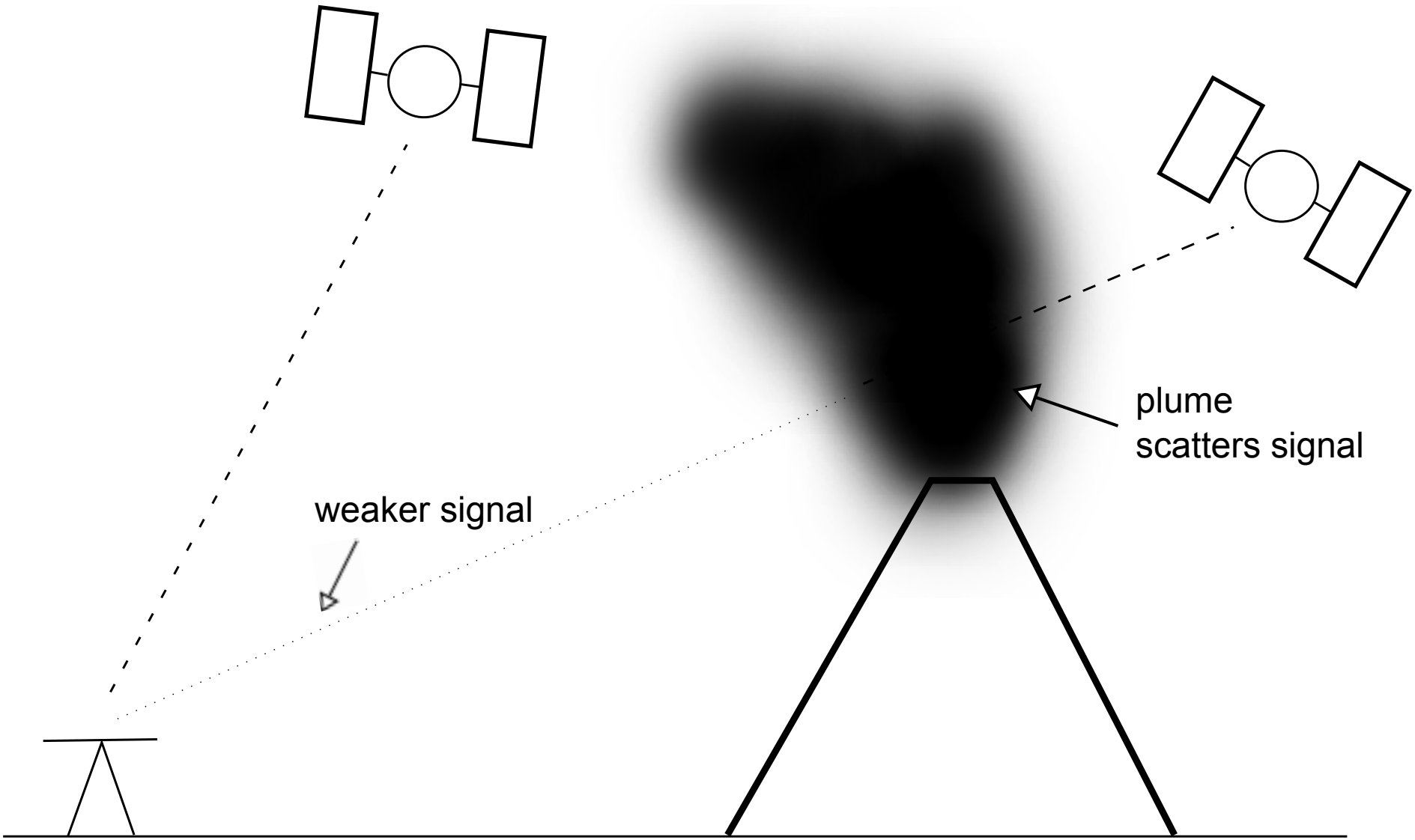
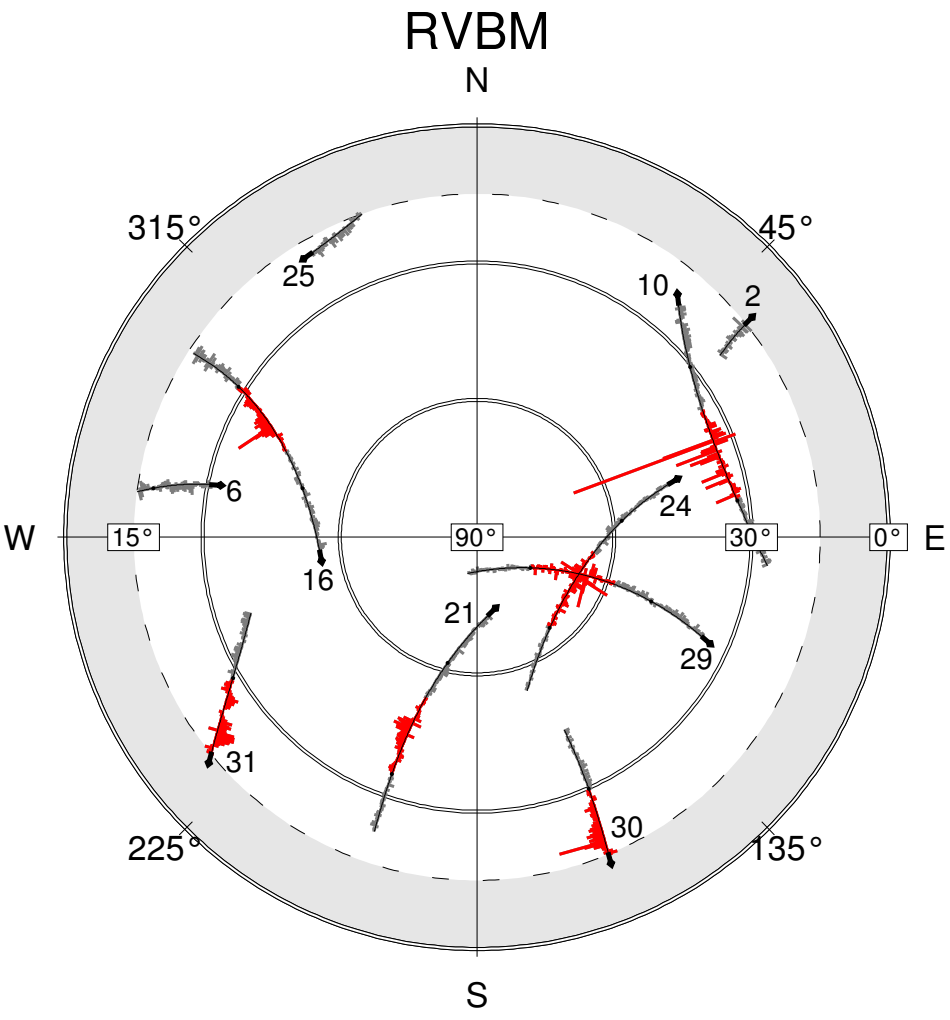


# Plumes: Phase Delay and SNR




*Grapenthin et al., JVGR (2013)*

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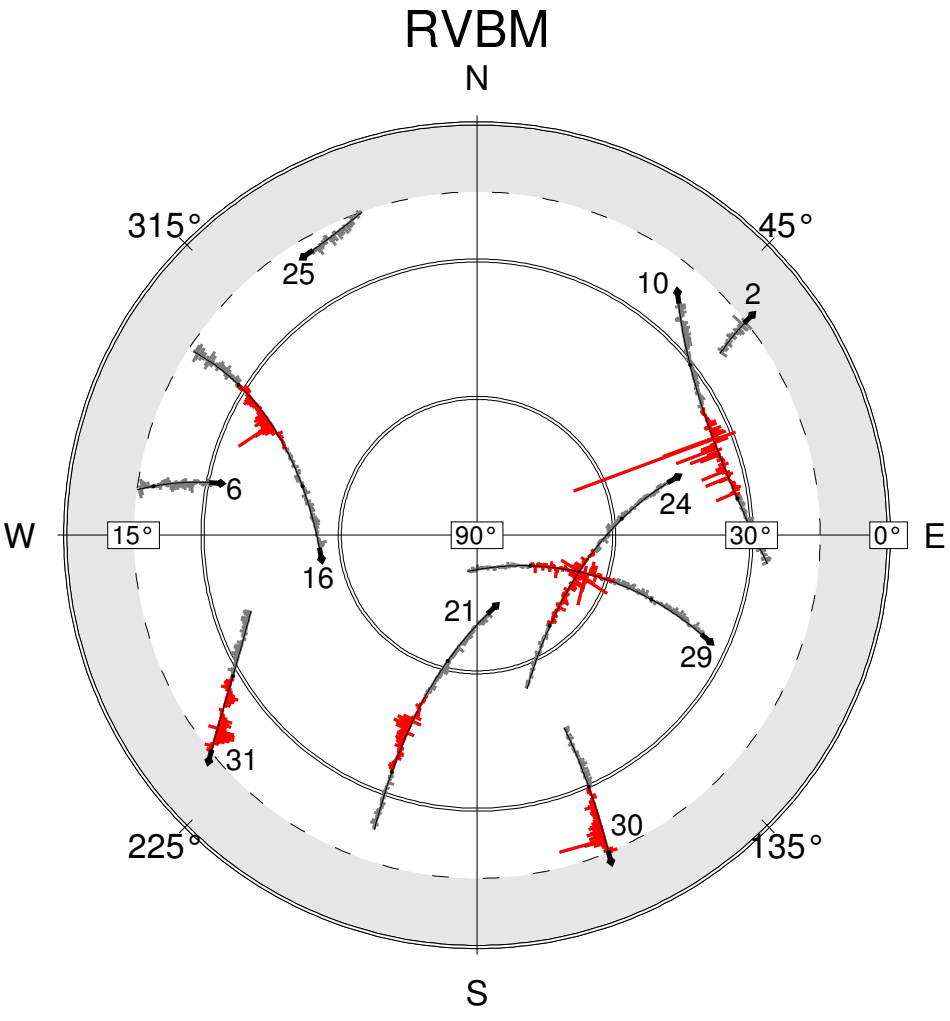


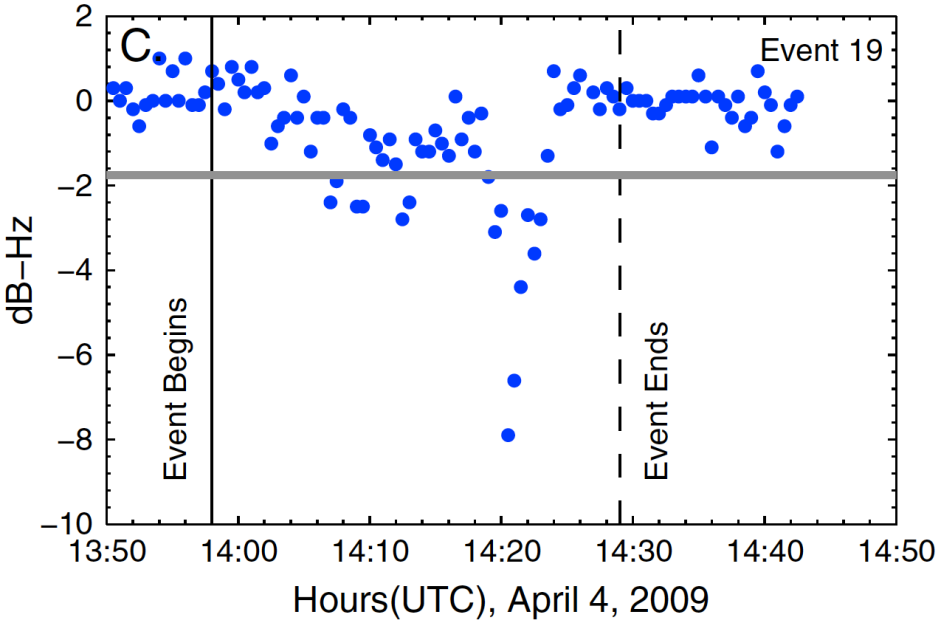


*Larson, GRL (2013)*

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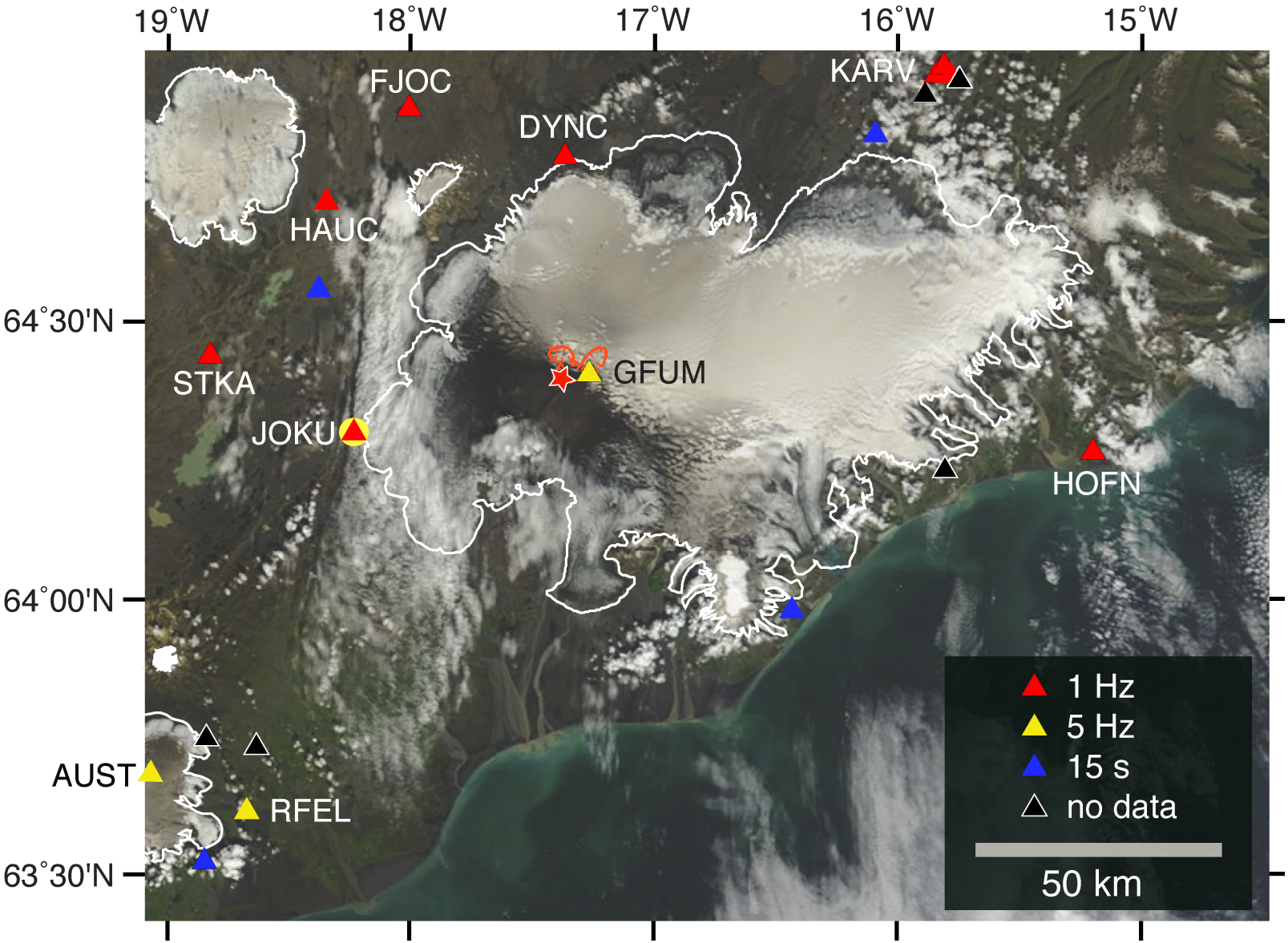
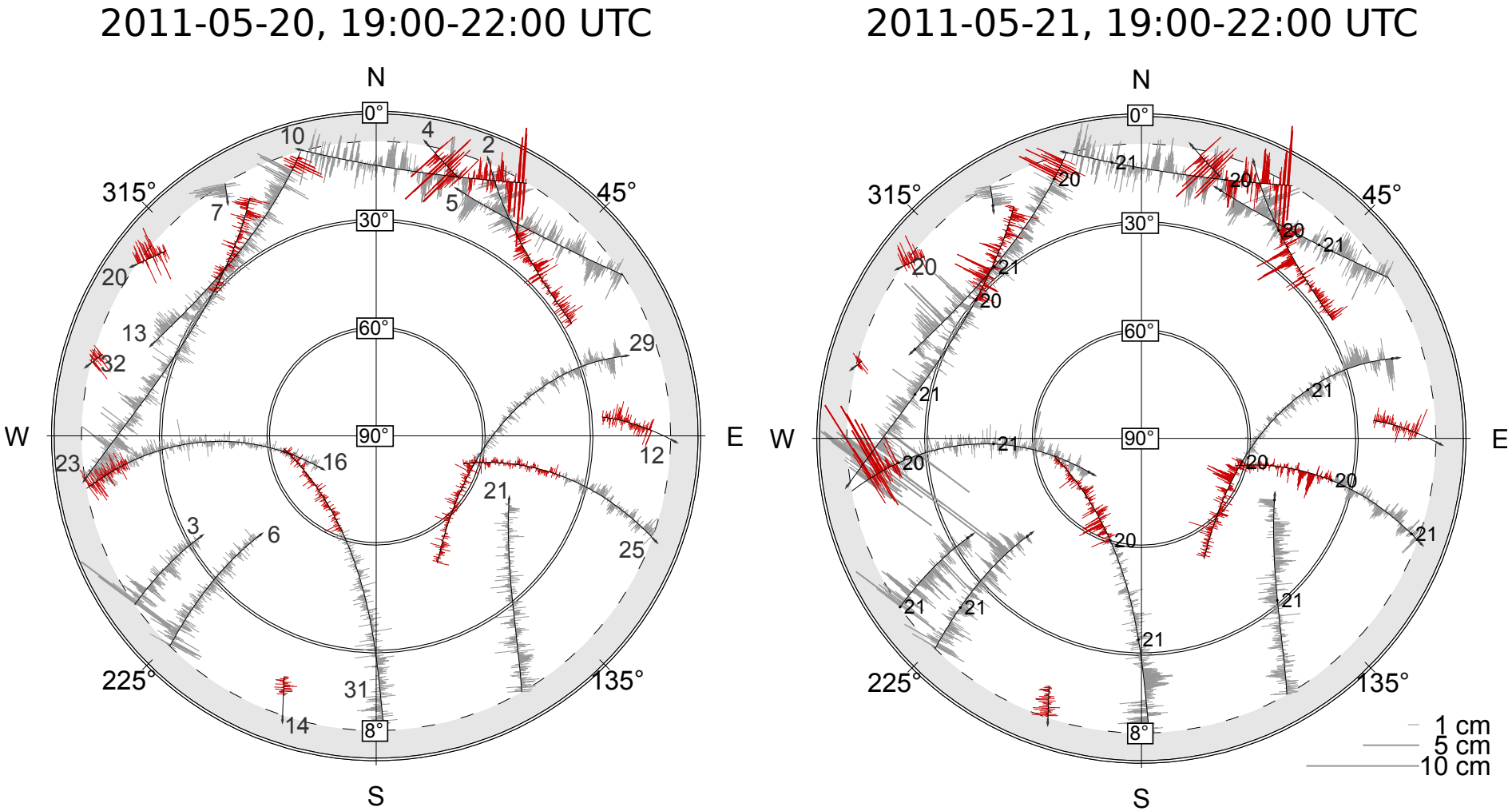
# Plumes: Grímsvötn 2011




*Hreinsdóttir et al. (2014)*

# Plumes: GFUM Phase Delay




*Grapenthin et al., GRL (2018)*

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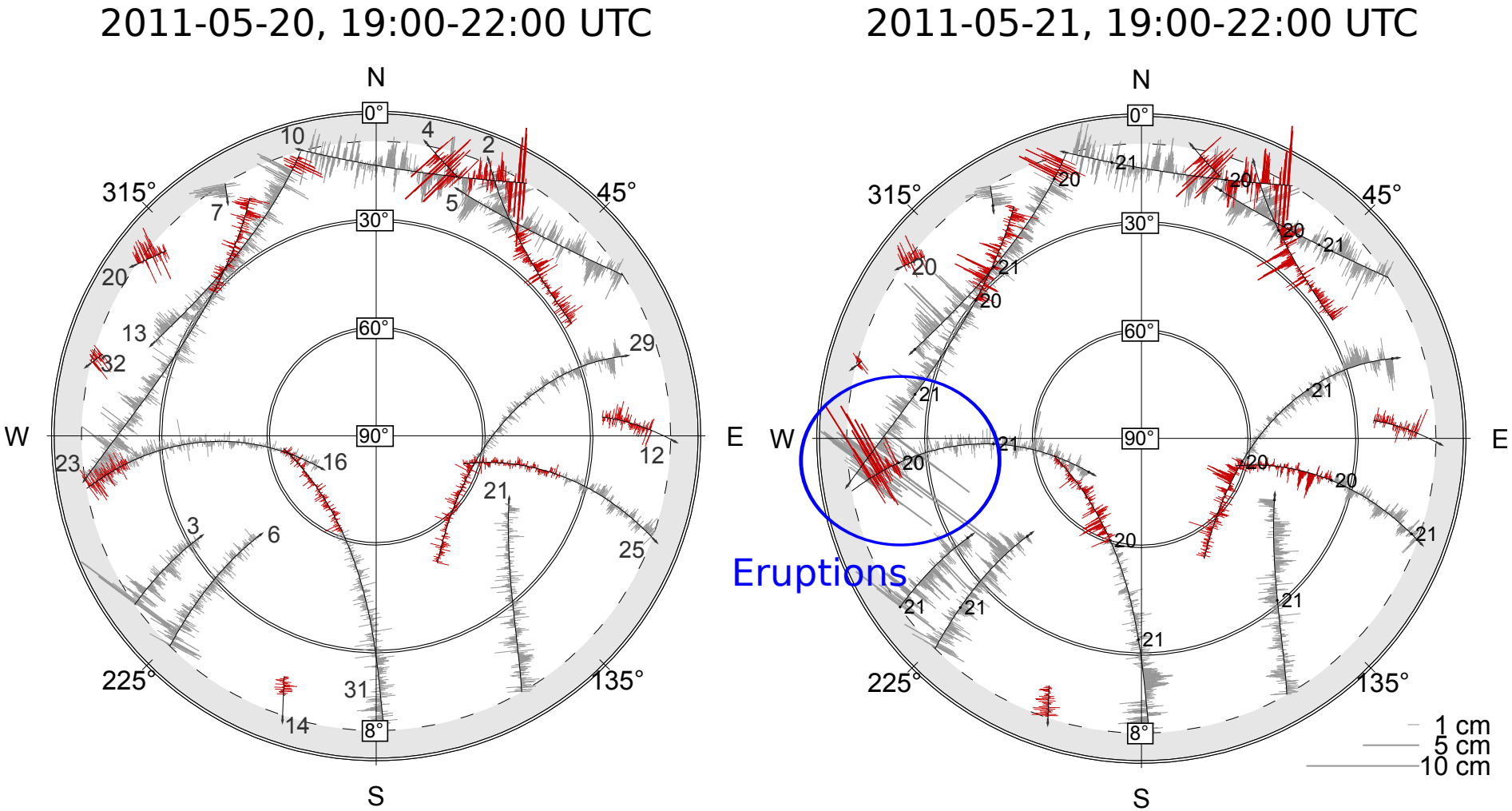


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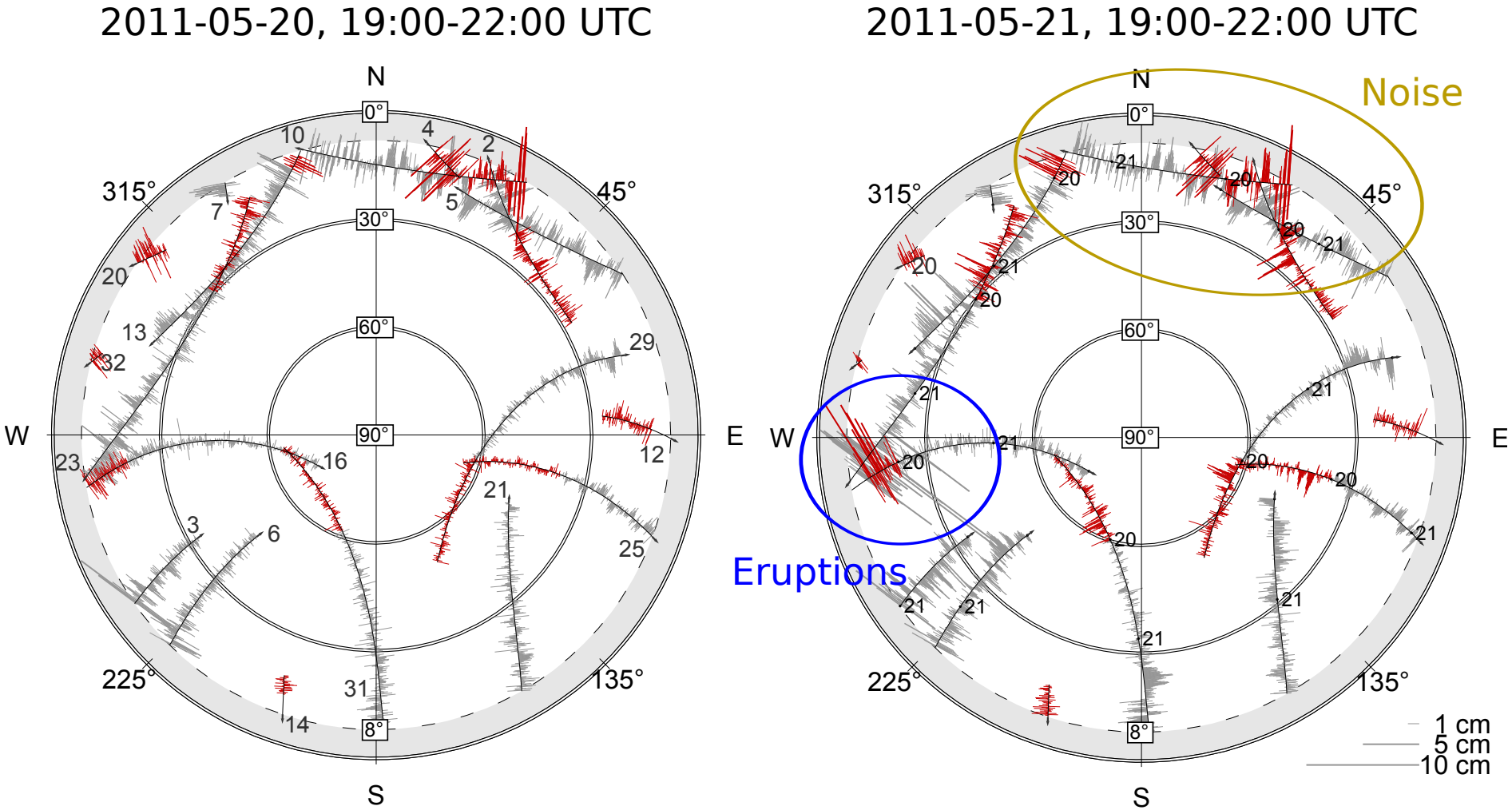
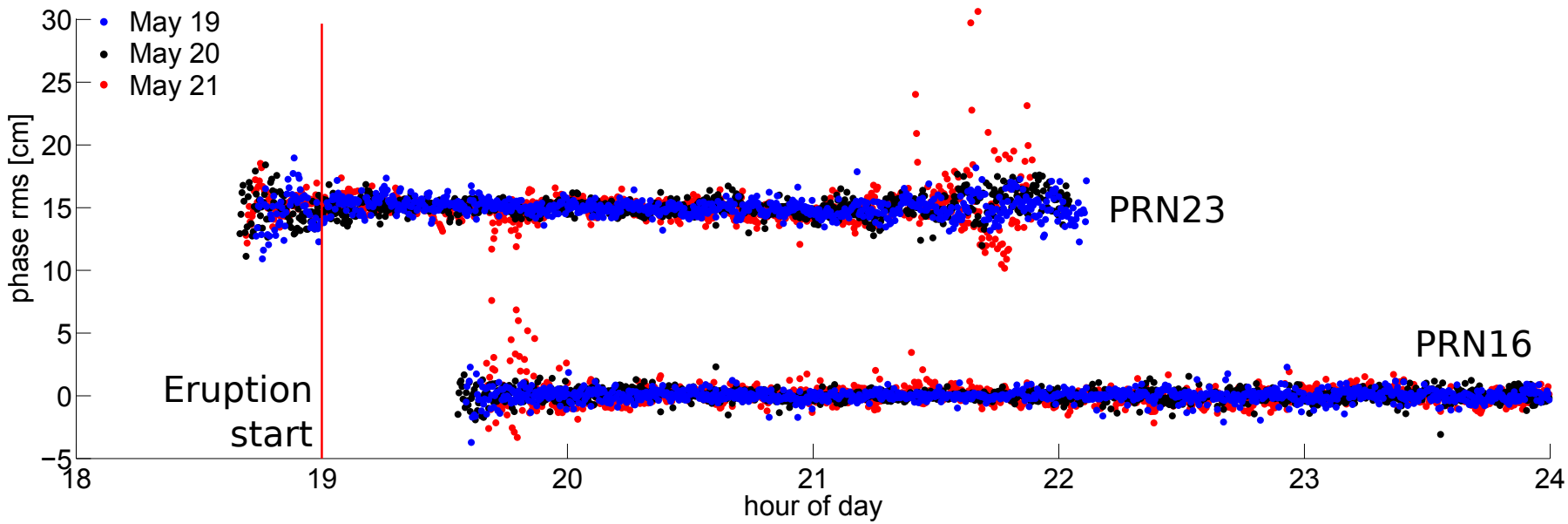



*Grapenthin et al., GRL (2018)*

# Plume Analysis: SNR & Phase Delay




*Grapenthin et al., GRL (2018)*

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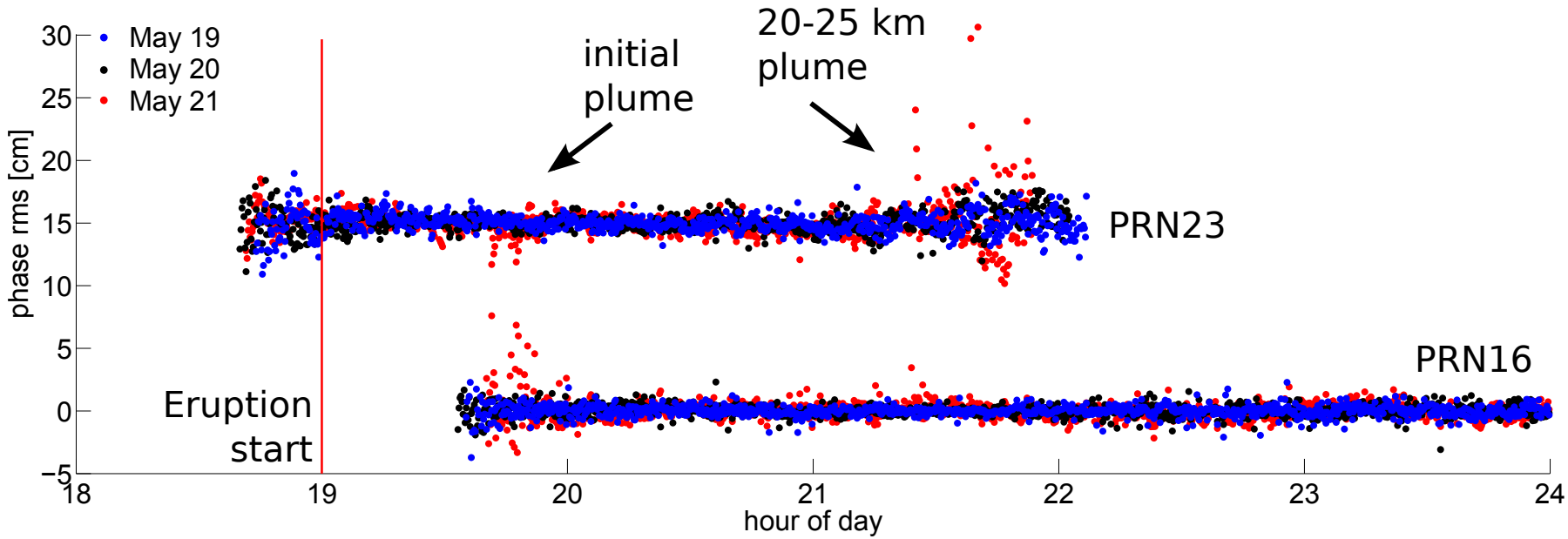


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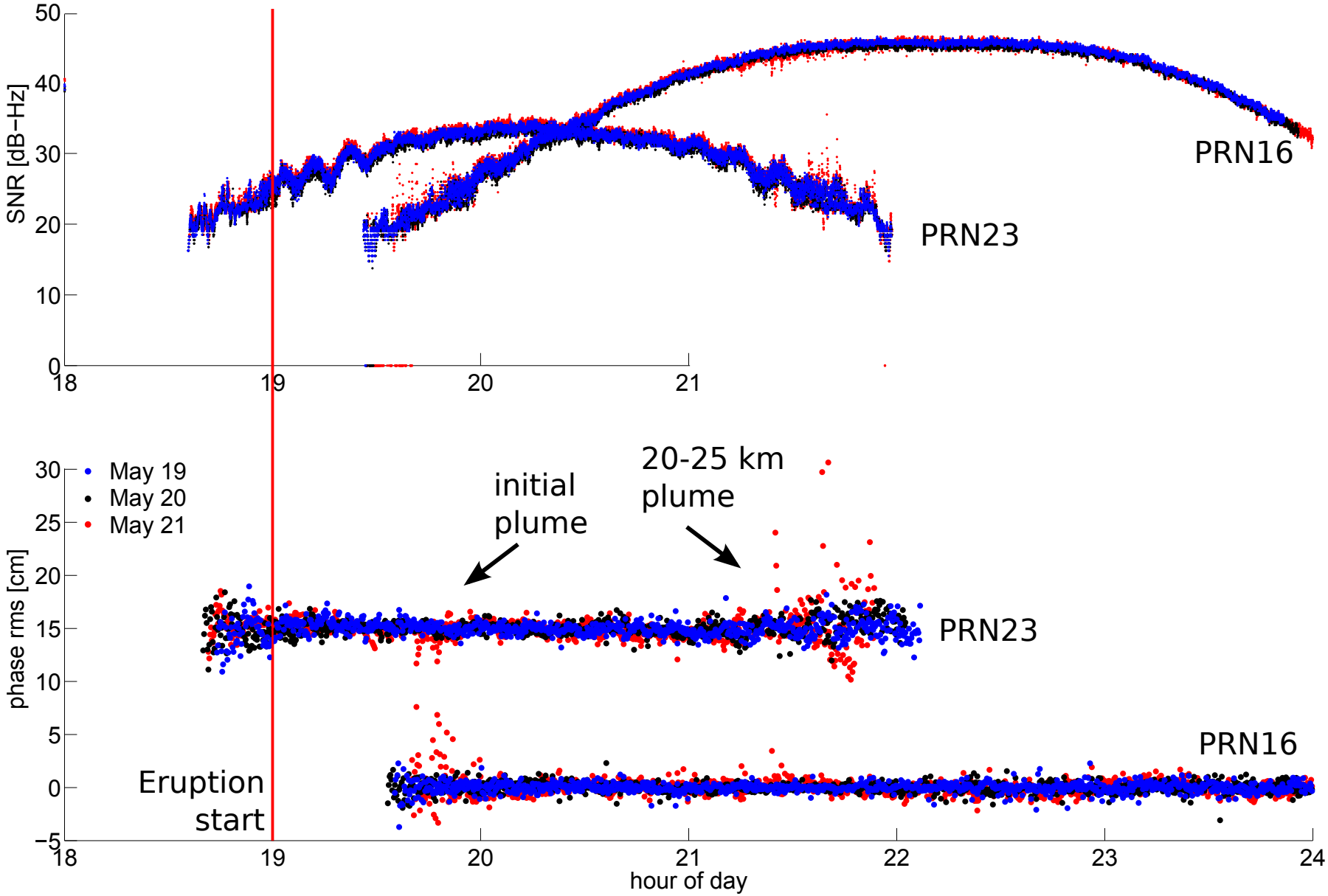


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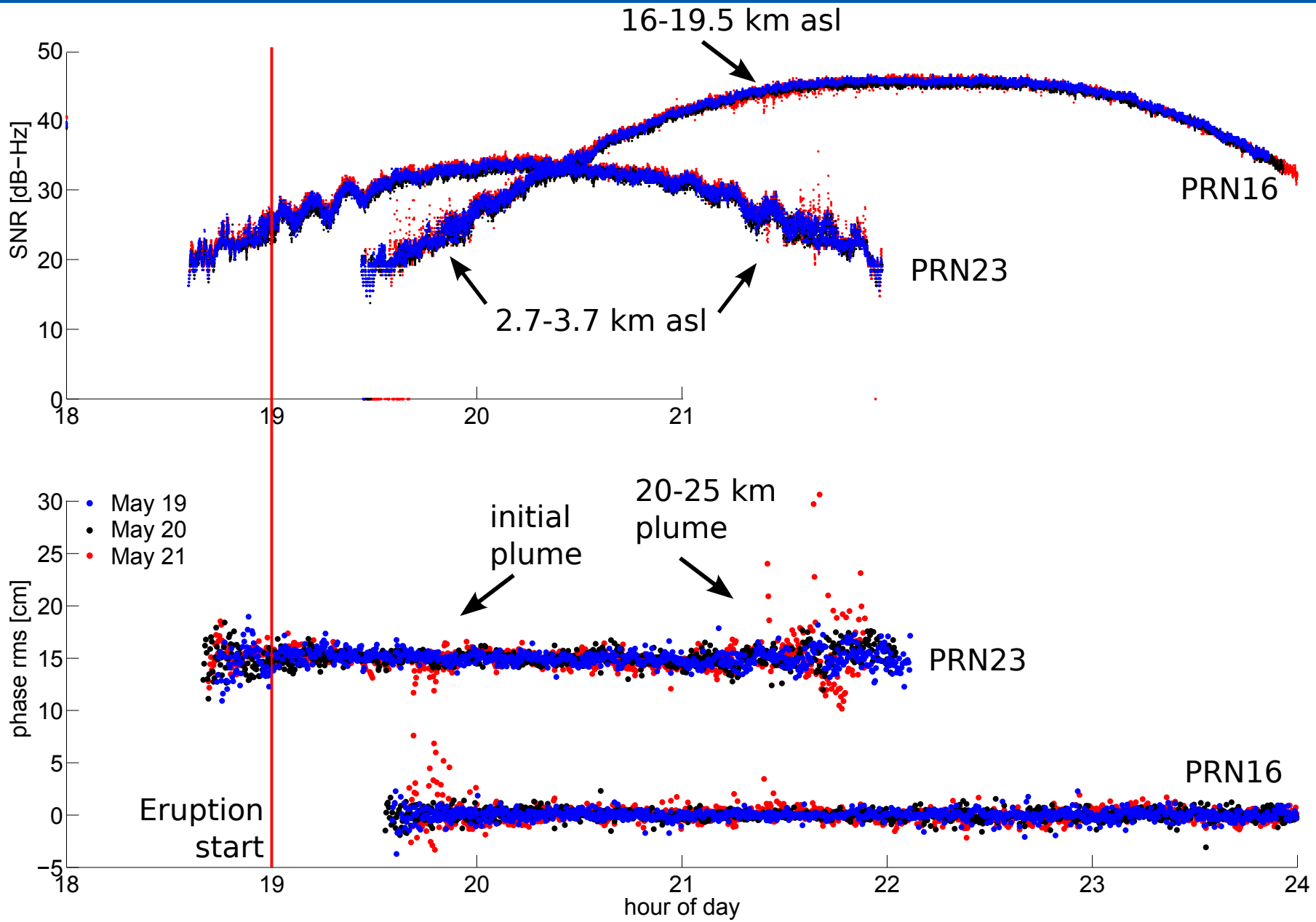
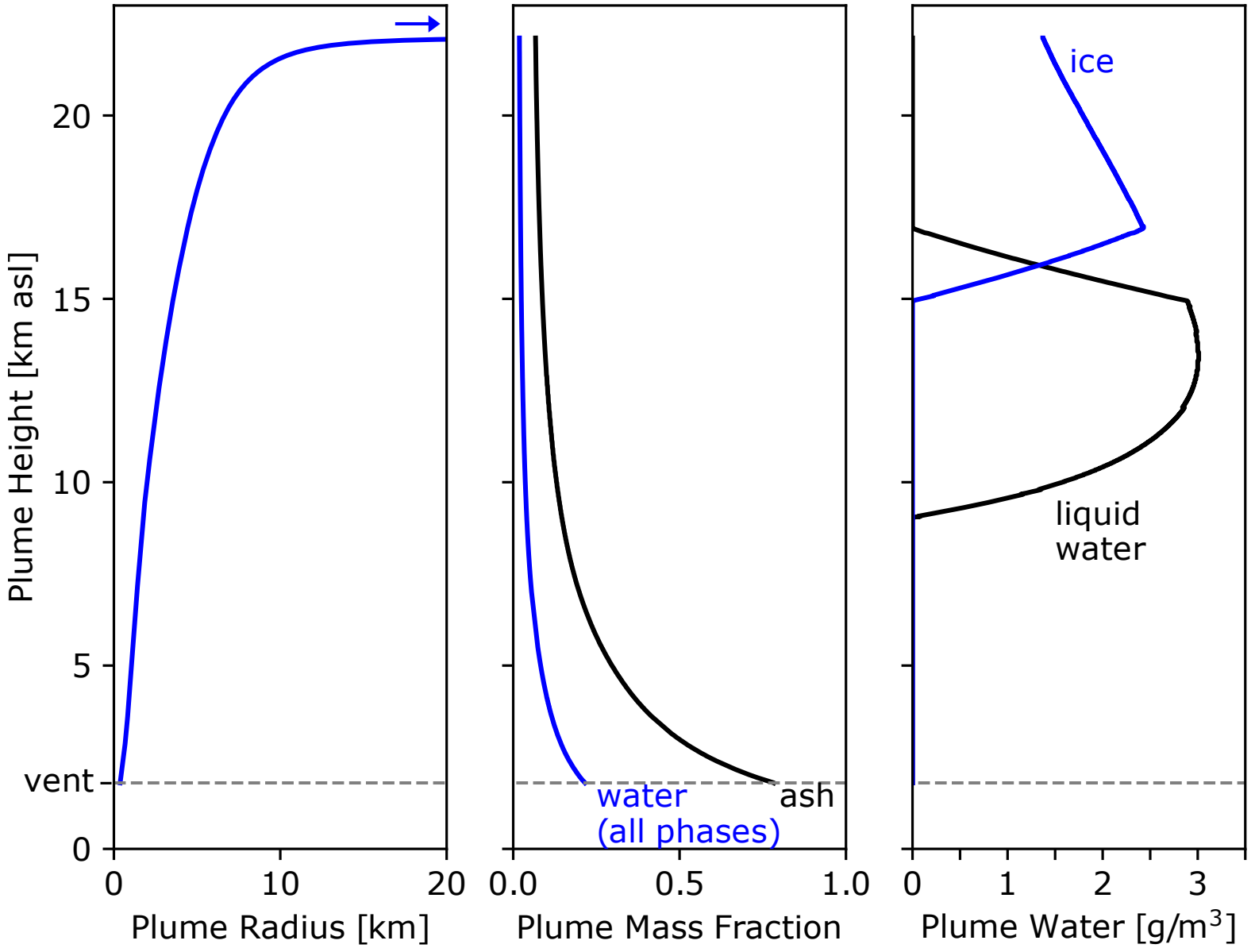



*Grapenthin et al., GRL (2018)*

# Plume Analysis: 1-D Plumeria Model

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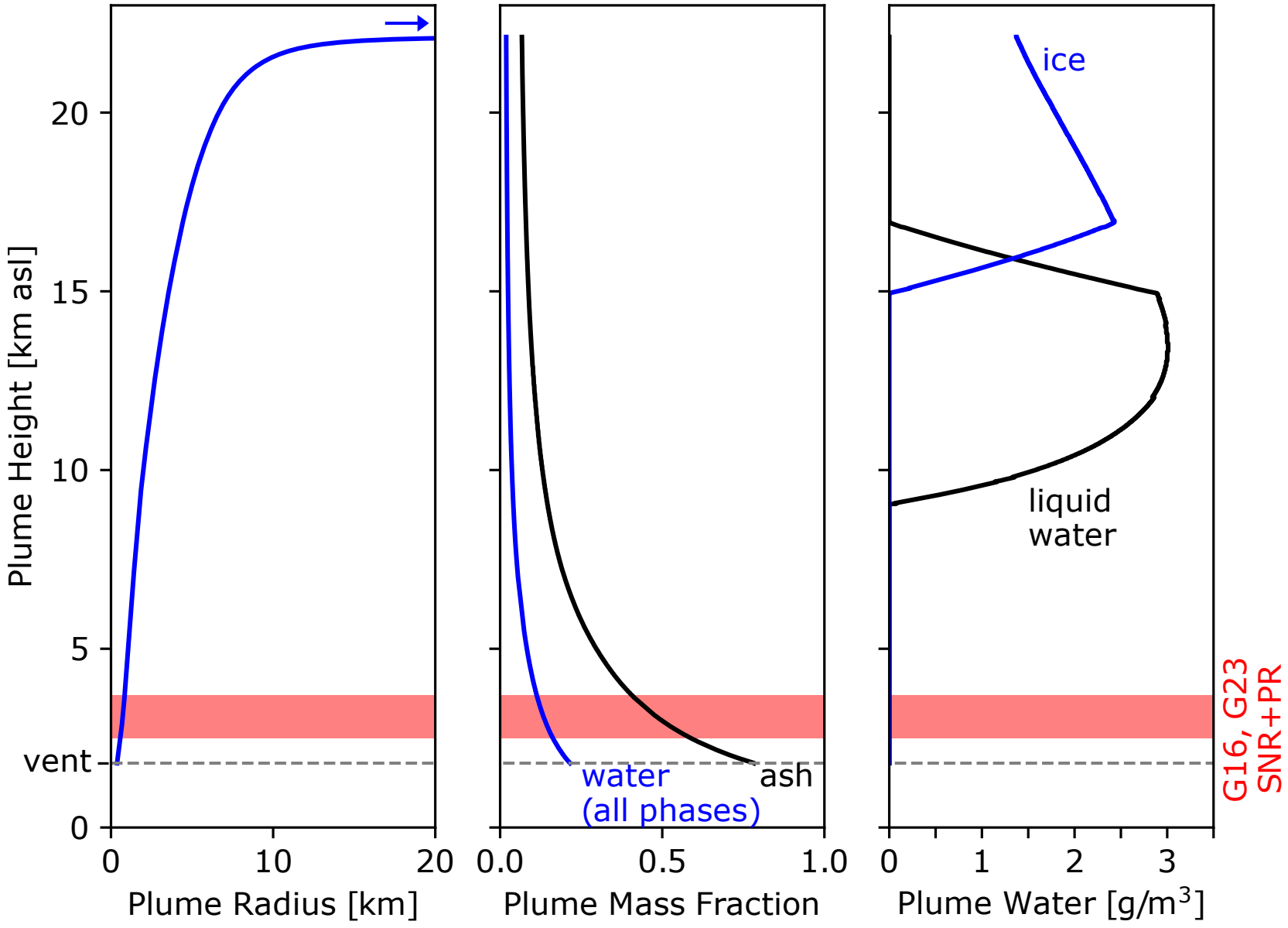


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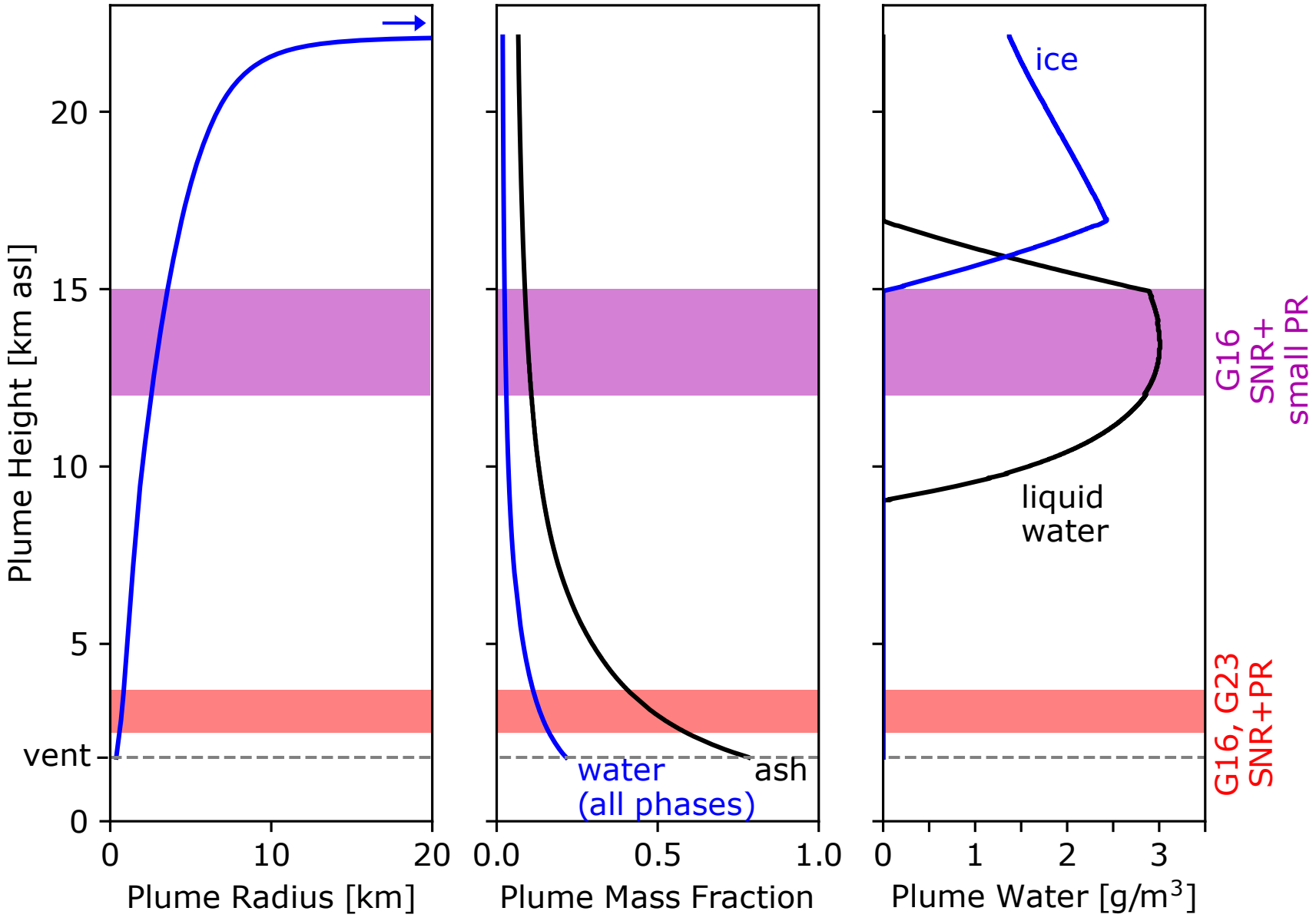


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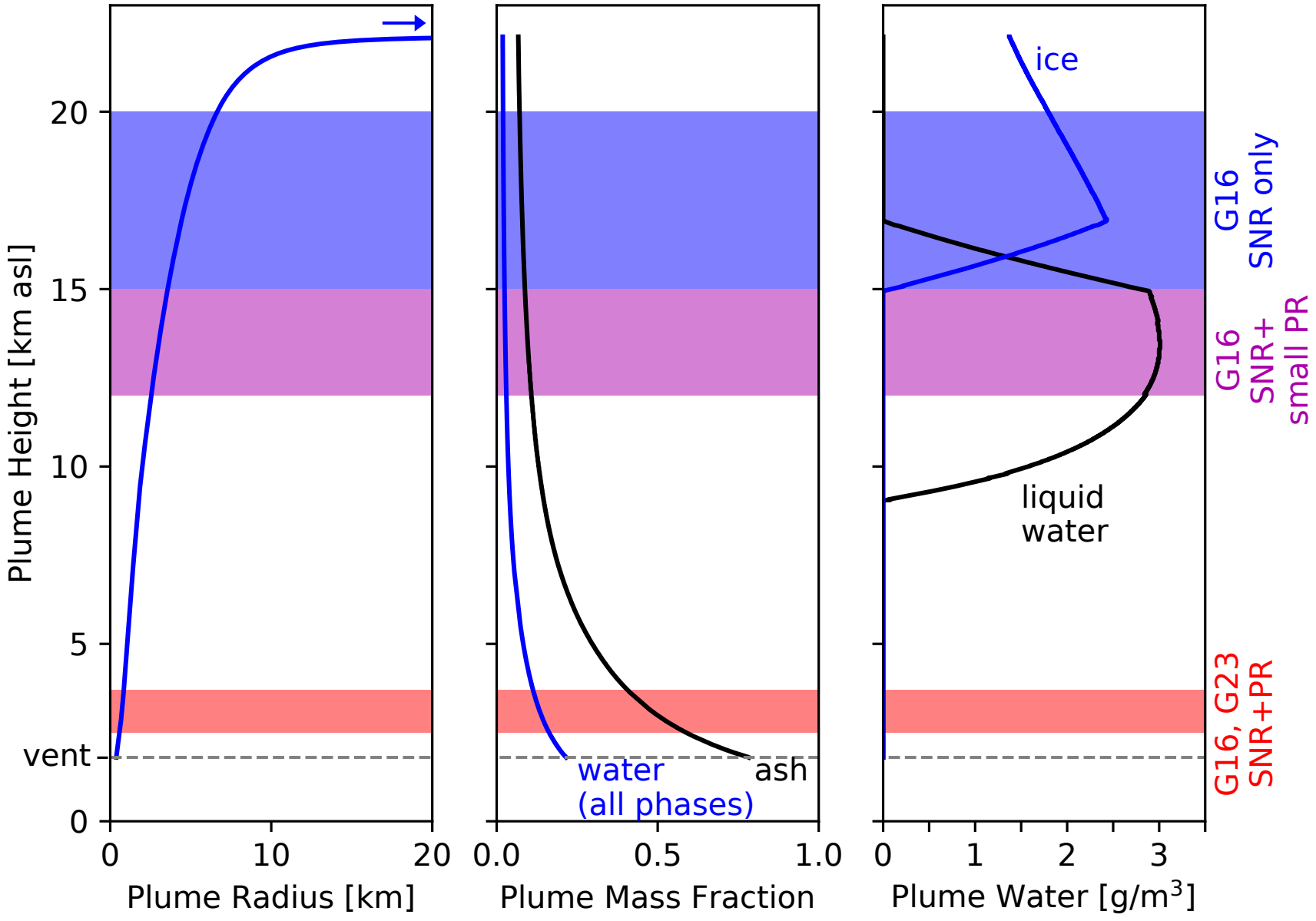


*Grapenthin et al., GRL (2018)*

# Plume Analysis: Hail


*photo: T. Arason*

# Instantaneous Velocities - Phase Observation Model

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

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

$\phi^{(s)}$ - 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.

# Instantaneous Velocities

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

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

# Instantaneous Velocities

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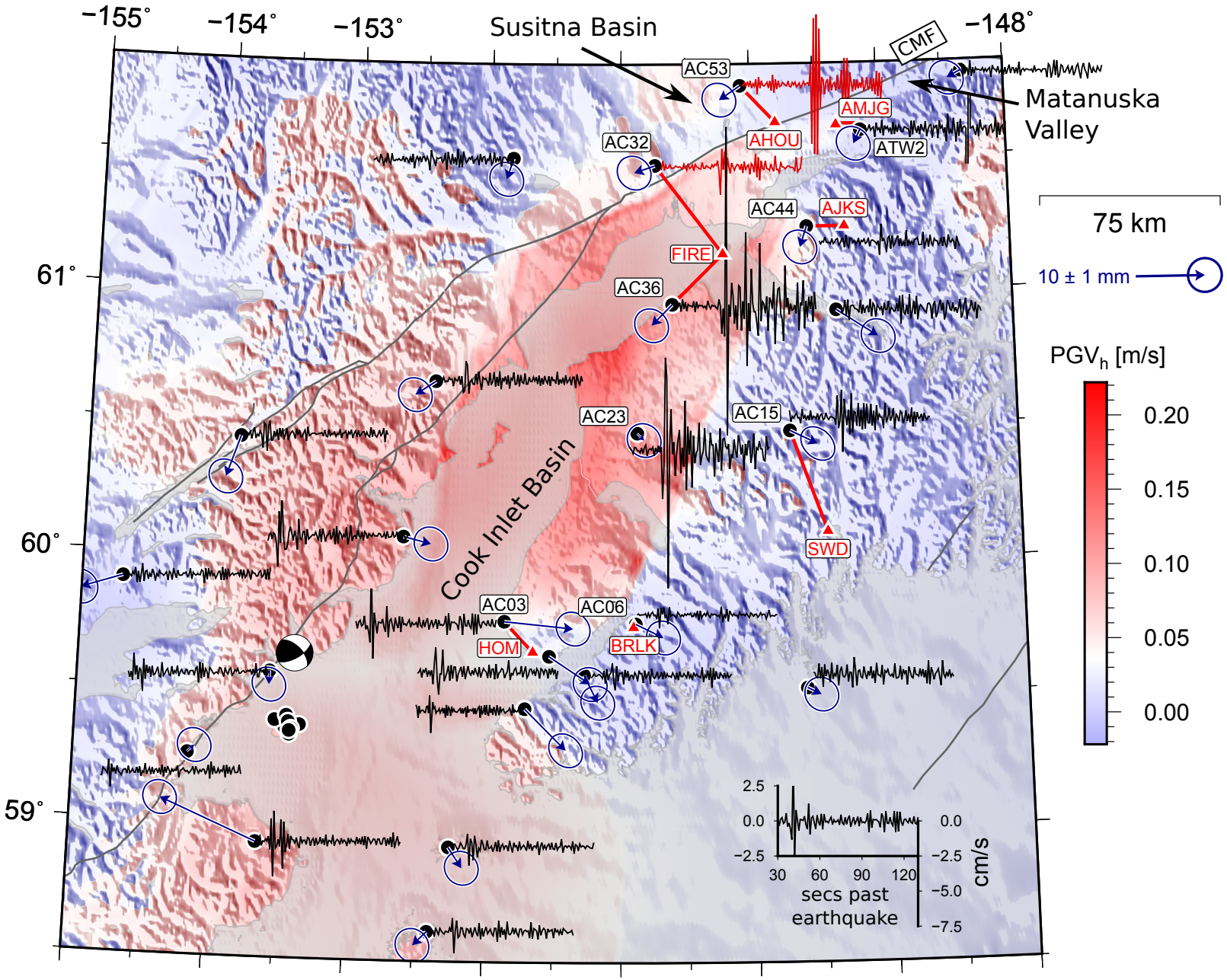
\mathbf{D} &= \mathbf{G}\begin{bmatrix} \mathbf{v}_u \\ \dot{b}_u \end{bmatrix} + \delta\epsilon_\Phi
\end{aligned}
$$

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

# Instantaneous Velocities: 2016 $M_w$7.1 Iniskin

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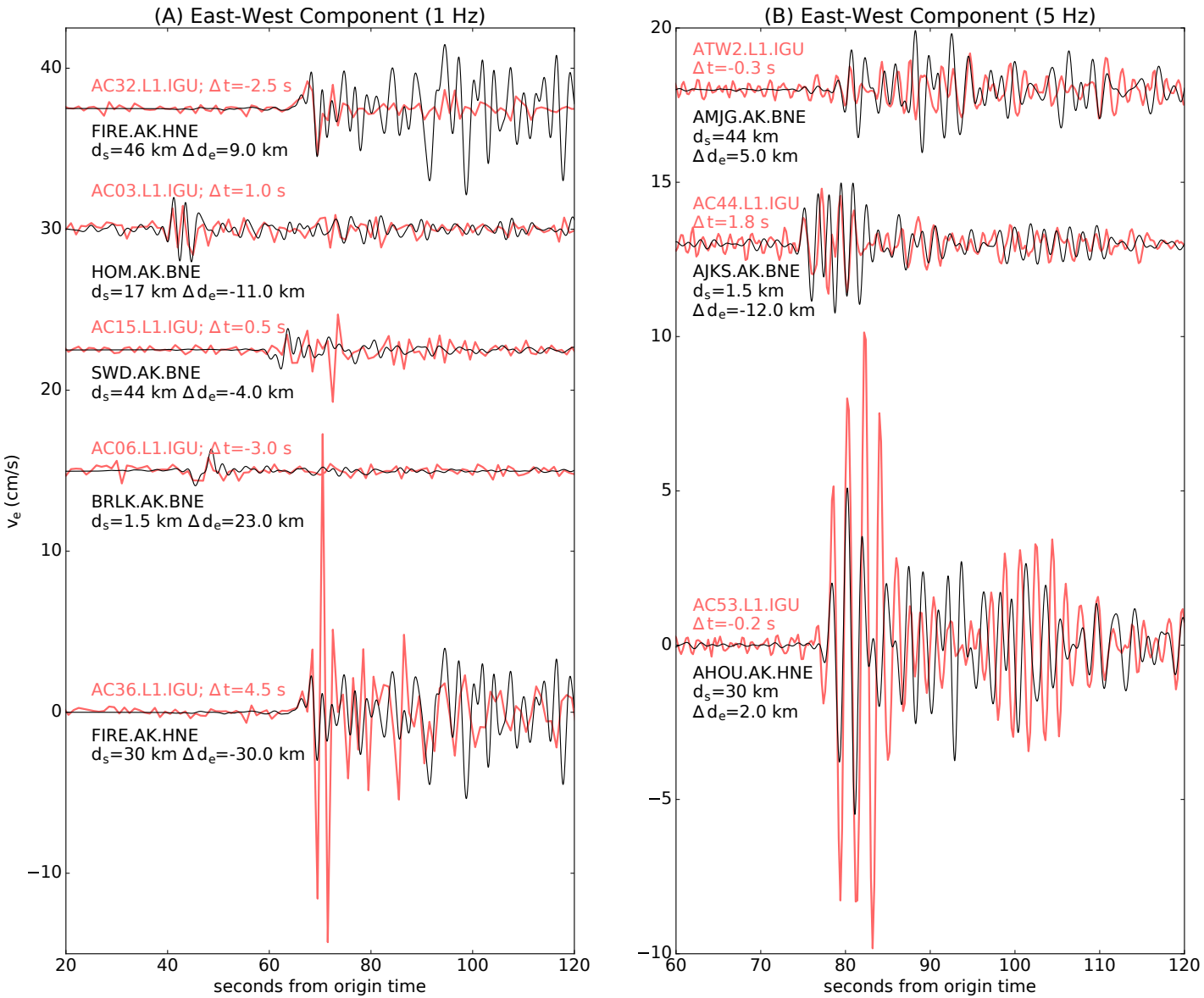


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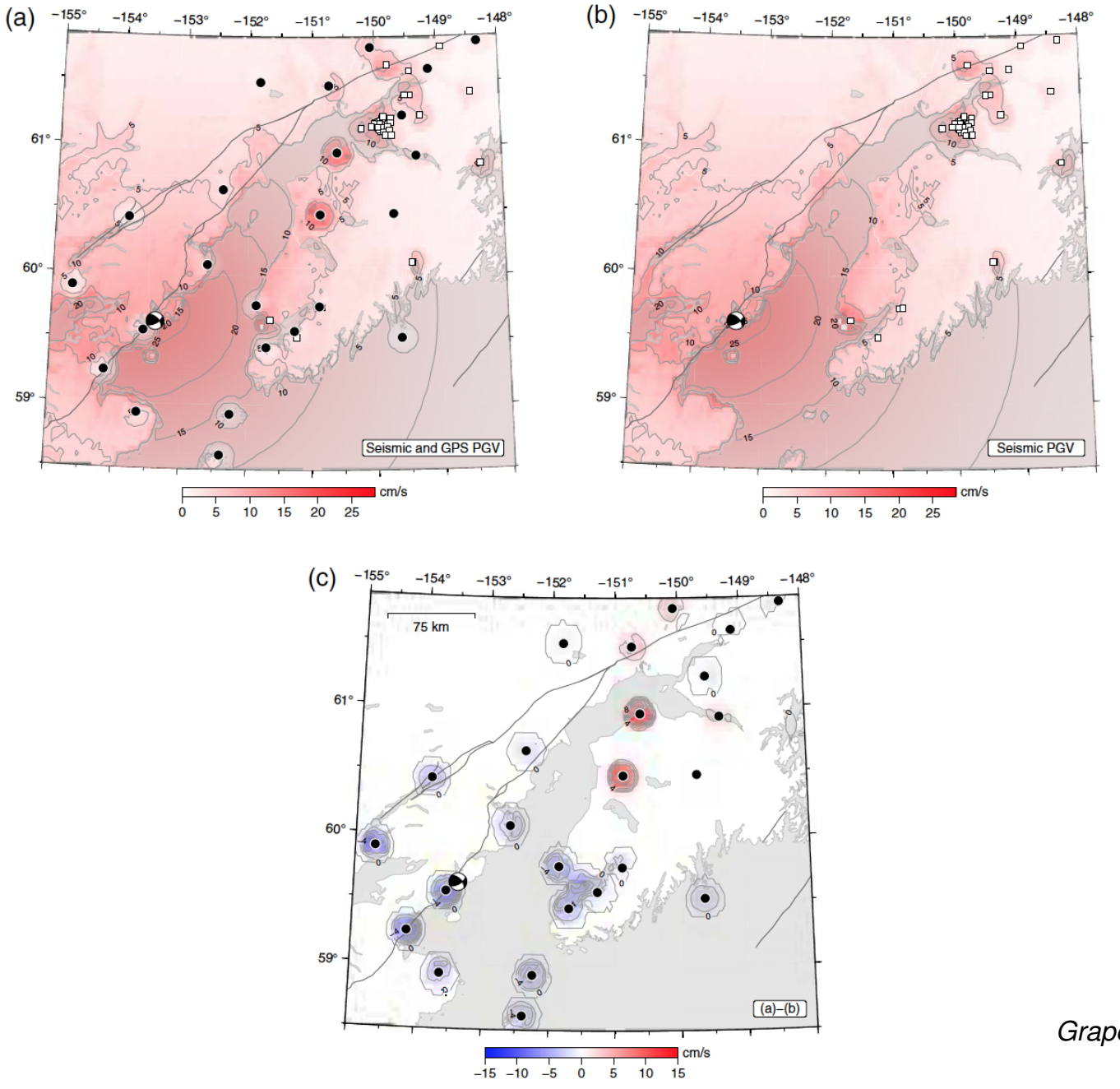


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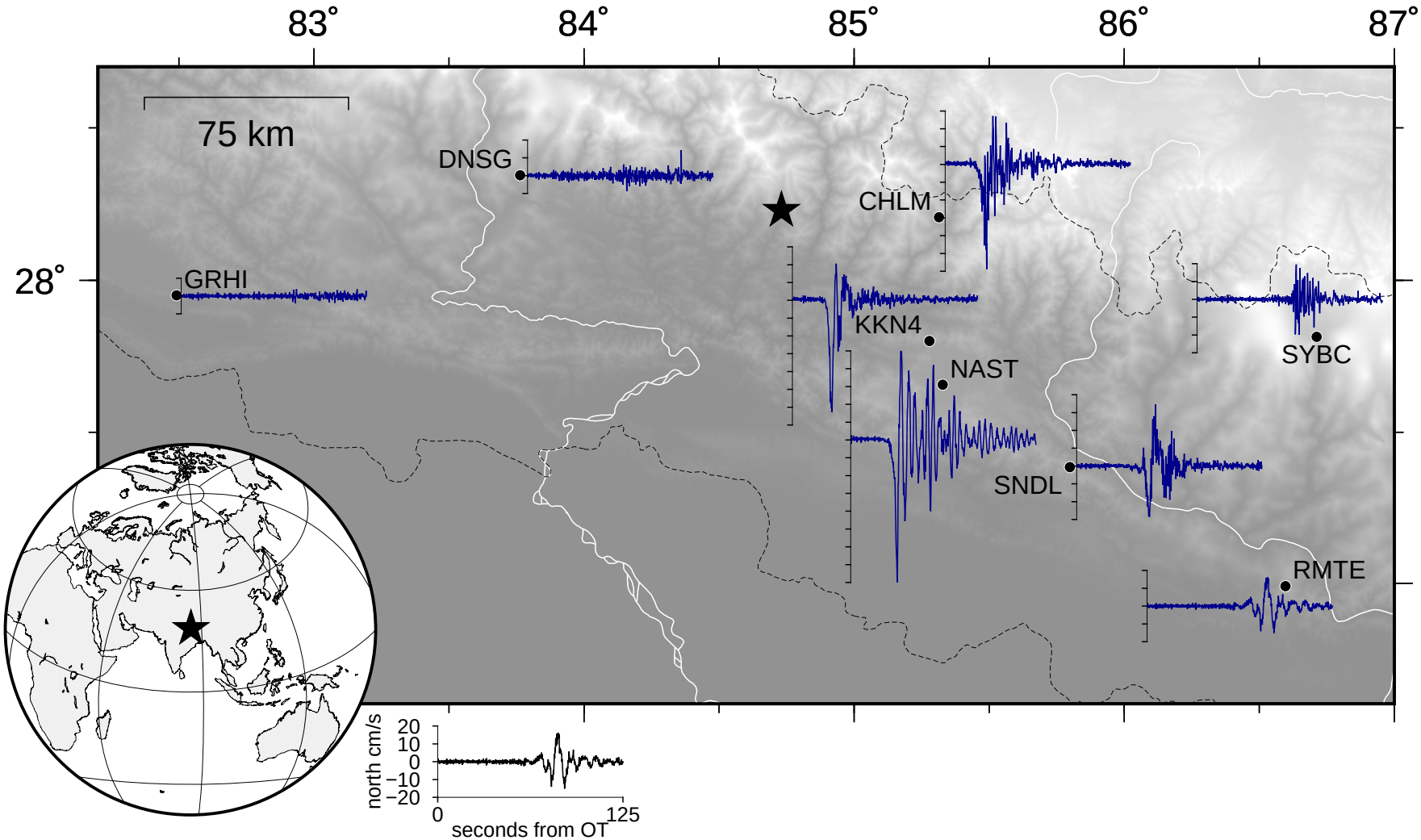
# Instantaneous Velocities: 2015 $M_w$7.8 Gorkha



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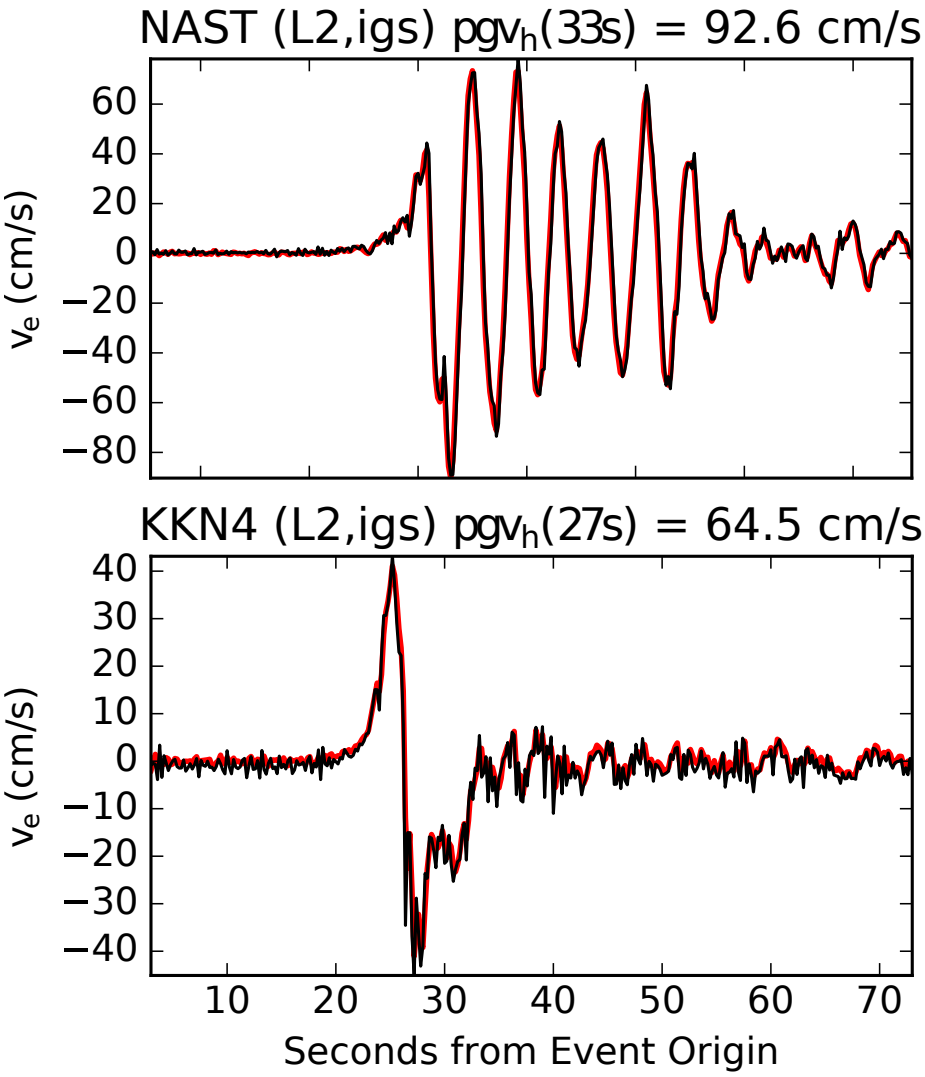


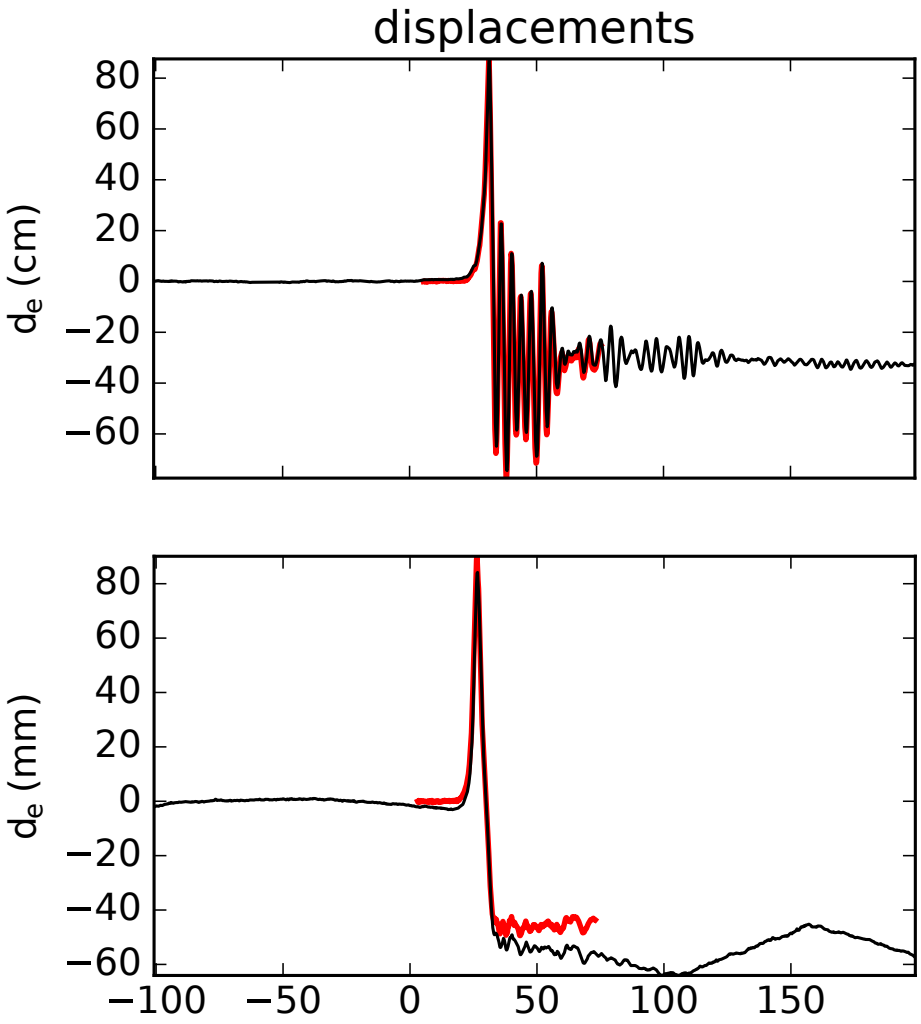

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With more to come . . . ?!