

# AUTOMATED DETECTION AND CATALOGING OF GLOBAL EXPLOSIVE VOLCANISM USING THE IMS INFRASOUND NETWORK

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## Introduction

Explosive volcanic eruptions are among the most powerful sources of infrasound observed on Earth, with recordings routinely made at ranges of hundreds to thousands of kilometers. These eruptions can also inject large volumes of ash into heavily travelled aviation routes, thus posing a significant societal and economic hazard. Detecting and counting the global occurrence of explosive volcanism helps with progress toward several goals in Earth sciences and has direct applications in volcanic hazard mitigation. We experiment with a new method to search systematically through multi-year data from the International Monitoring System (IMS) infrasound network to

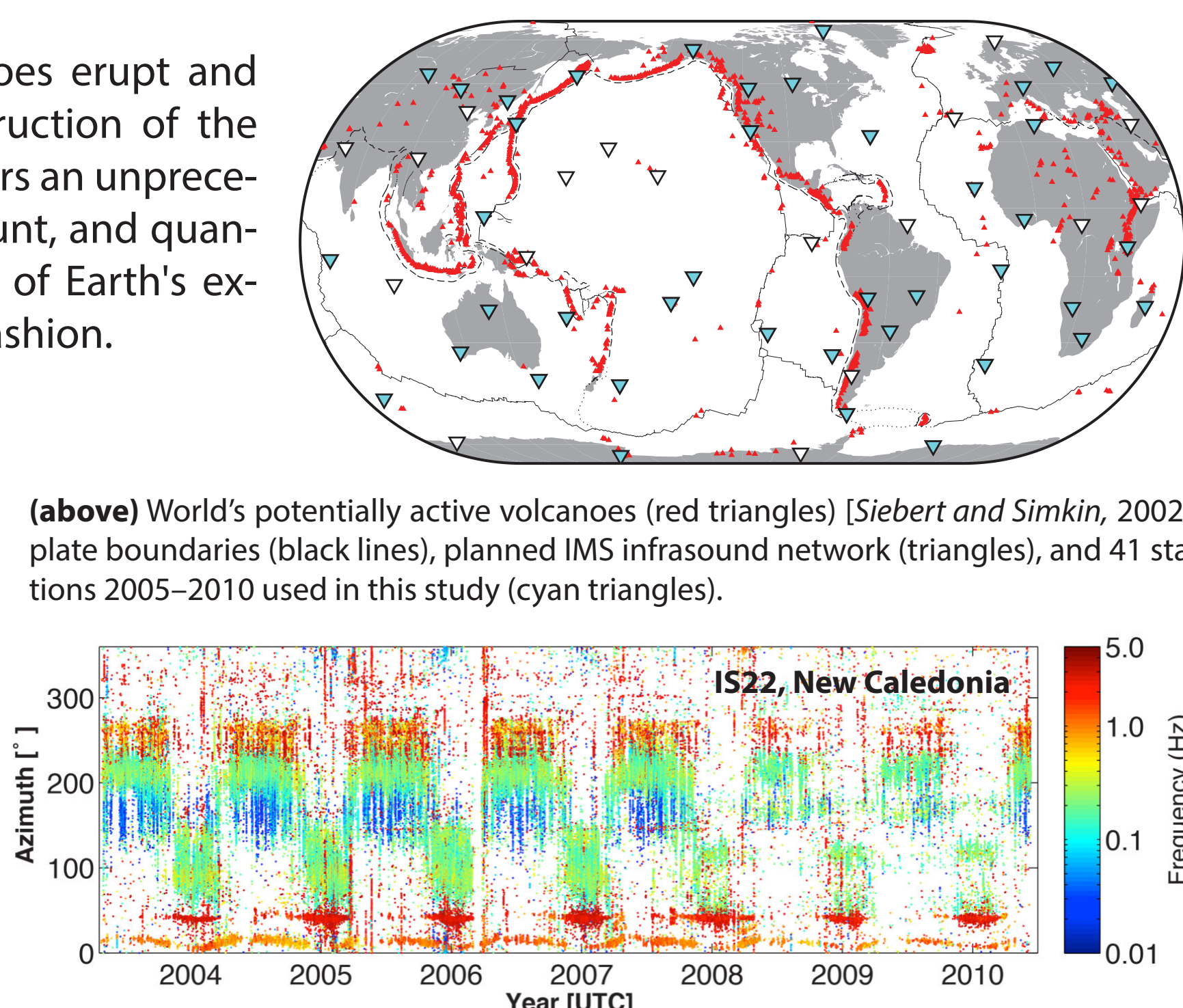
identify explosive volcanic eruption signals originating anywhere on Earth. We combine infrasound signal association across multiple stations with source location using a brute-force, grid-search, cross-bearings approach. We apply the method to global IMS infrasound data from 2005–2010 to construct a preliminary acoustic catalog that emphasizes sustained explosive volcanic activity (long-duration signals or sequences of impulsive transients lasting hours to days). This work represents a step toward the goal of integrating IMS infrasound data products into global volcanic eruption early warning and notification systems.

## 1. Background and Motivation

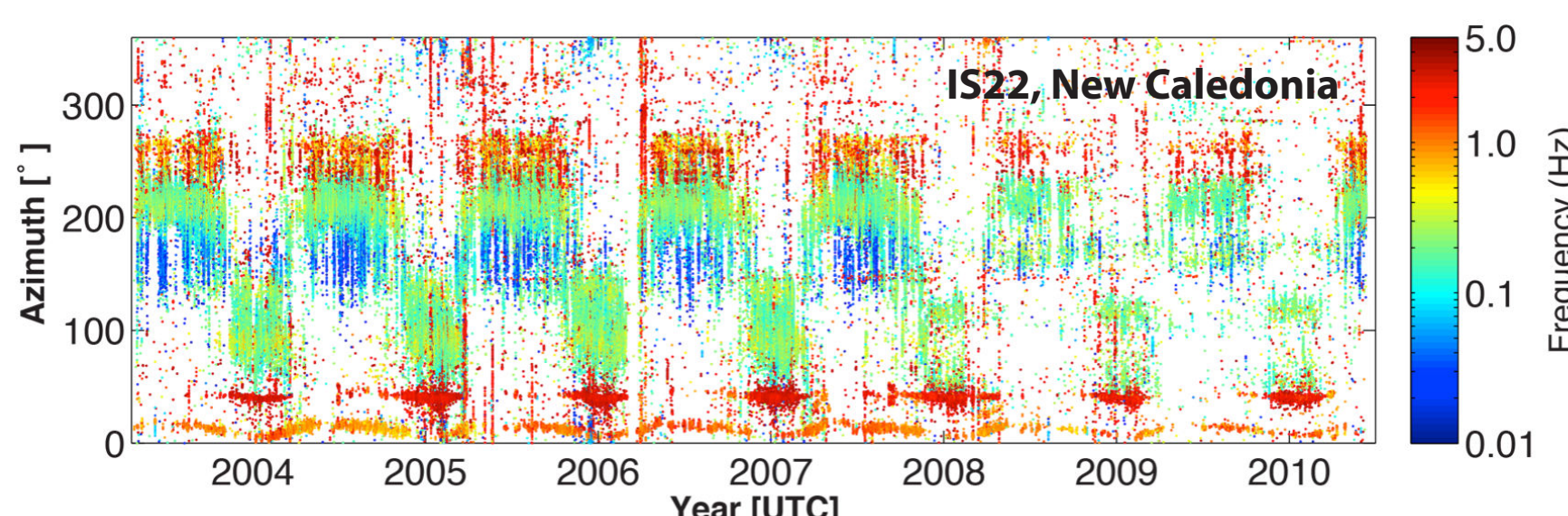
How often do the world's volcanoes erupt and with what magnitude? The construction of the global IMS infrasound network offers an unprecedented opportunity to catalog, count, and quantify the magnitude and frequency of Earth's explosive volcanism in a systematic fashion.

Explosive volcanic eruptions generate powerful infrasound, which propagates over thousands of kilometers in atmospheric waveguides with low attenuation and is routinely recorded by the IMS [e.g., Matoza et al., 2011a; 2011b].

(right) We start with PMCC (Progressive Multi-Channel Correlation) array processing results, available for each IMS infrasound station (here IS22 for example) [Matoza et al., 2013].

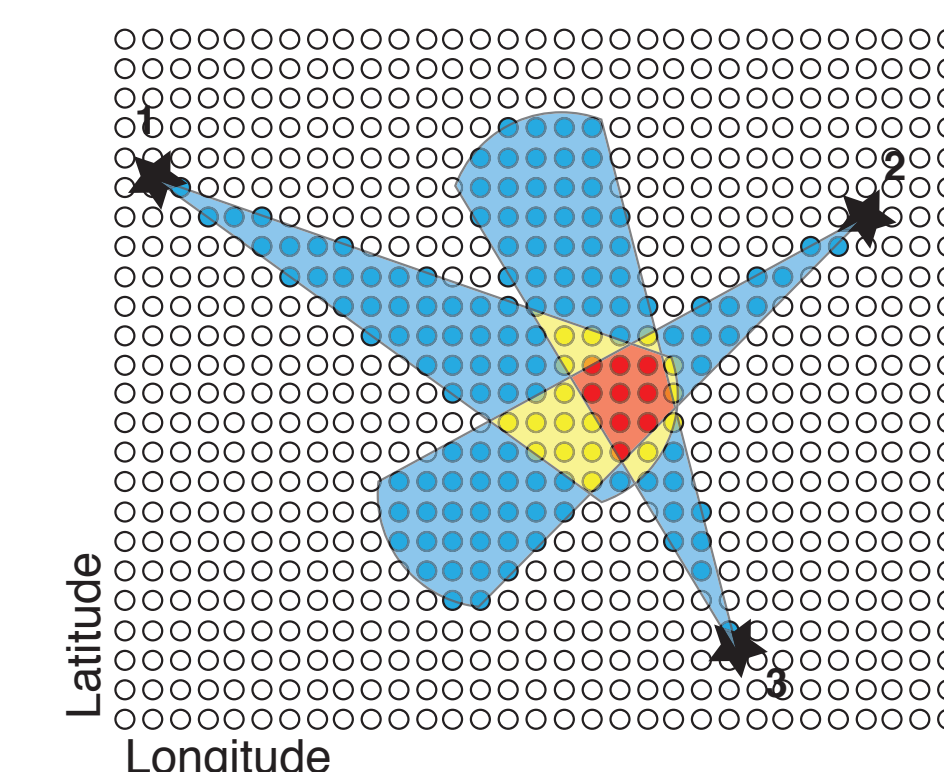


(above) World's potentially active volcanoes (red triangles) [Siebert and Simkin, 2002], plate boundaries (black lines), planned IMS infrasound network (triangles), and 41 stations 2005–2010 used in this study (cyan triangles).

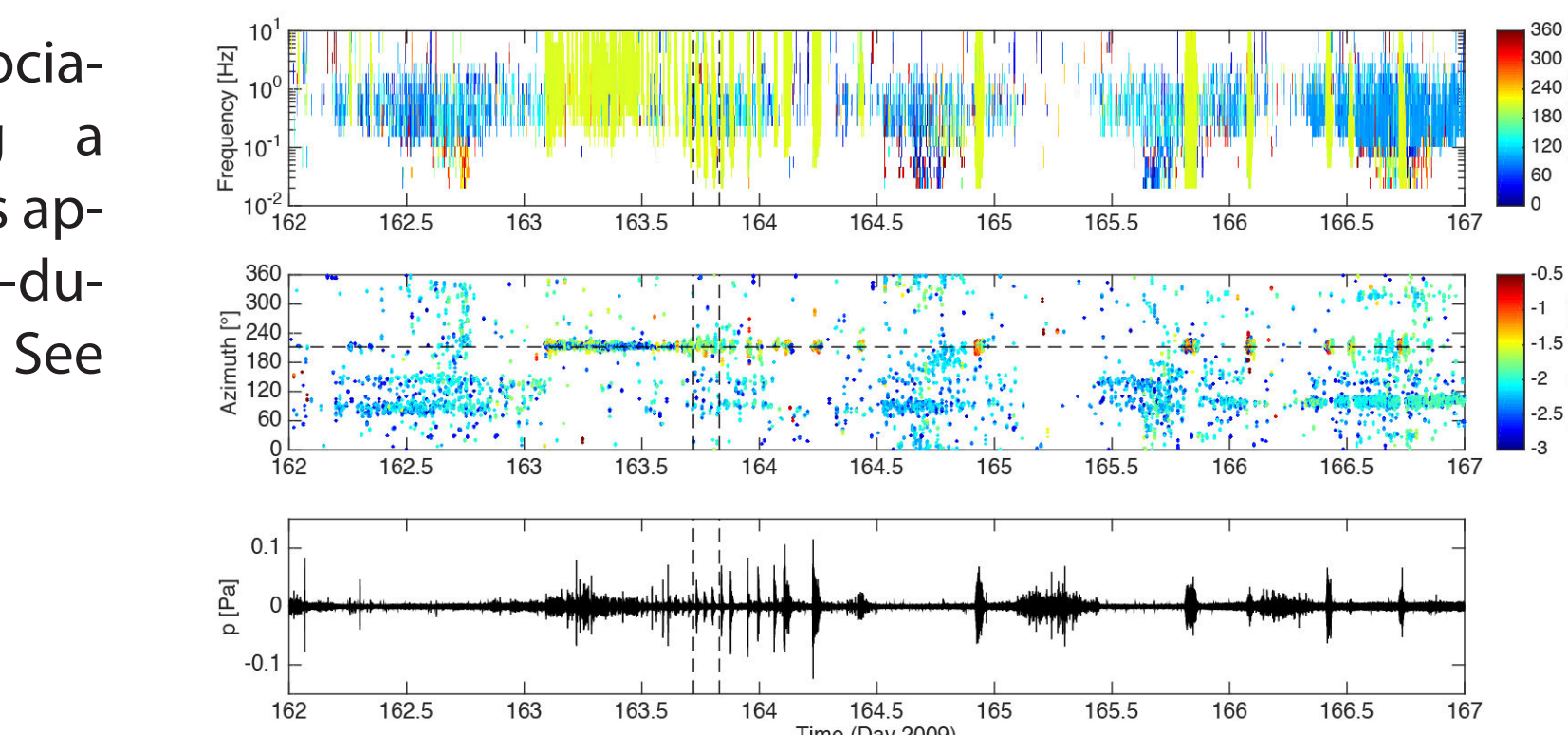


## 2. Association and Location Method

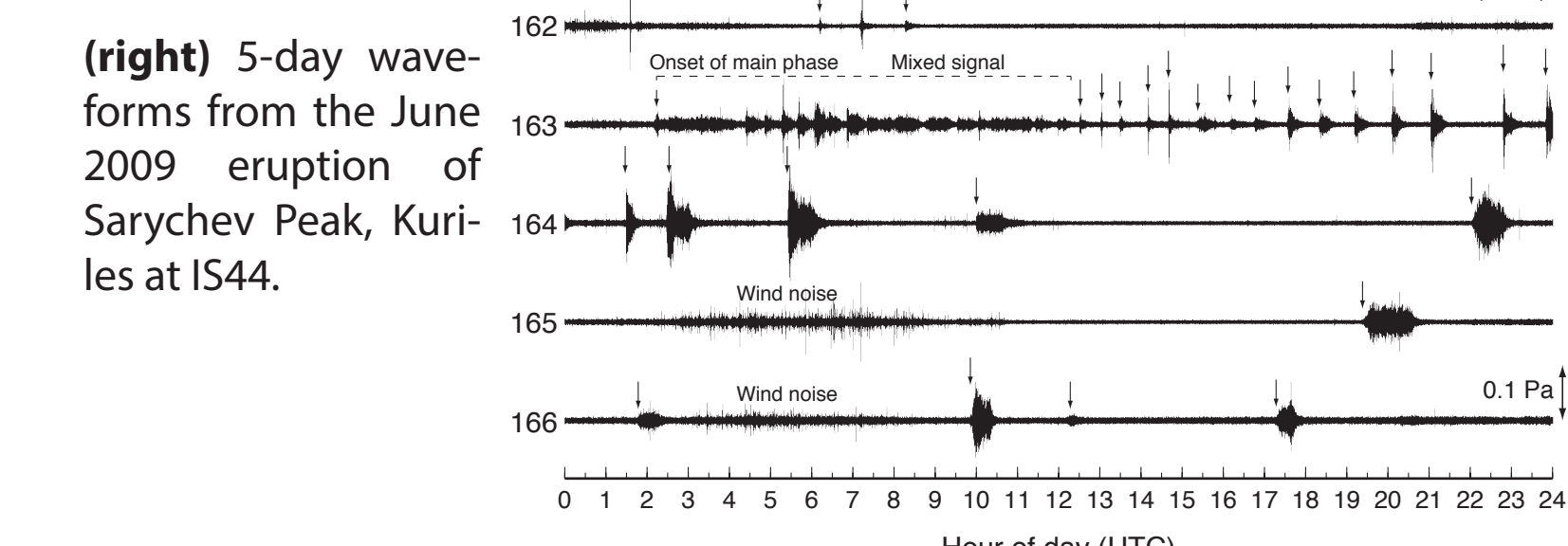
We combine multi-station signal association and source location using a brute-force, grid-search, cross-bearings approach. The method emphasizes long-duration, broadband volcanic signals. See Matoza et al. [2017] for more details.



(above) Cartoon illustrating the algorithm. Three stations are indicated by stars, and trial source locations on the Earth's surface are indicated by circles. Detection backazimuth is used to define a sector on the Earth within a specified azimuth deviation and maximum distance. Detections from 2 days are stacked using a constant celerity assumption.



(above) June 2009 eruption of Sarychev Peak at IS44. Large sustained explosive eruptions produce long-duration, broadband jet noise signals or sequences of multiple transients. At a given array, we expect a large number of detections from the same backazimuth.



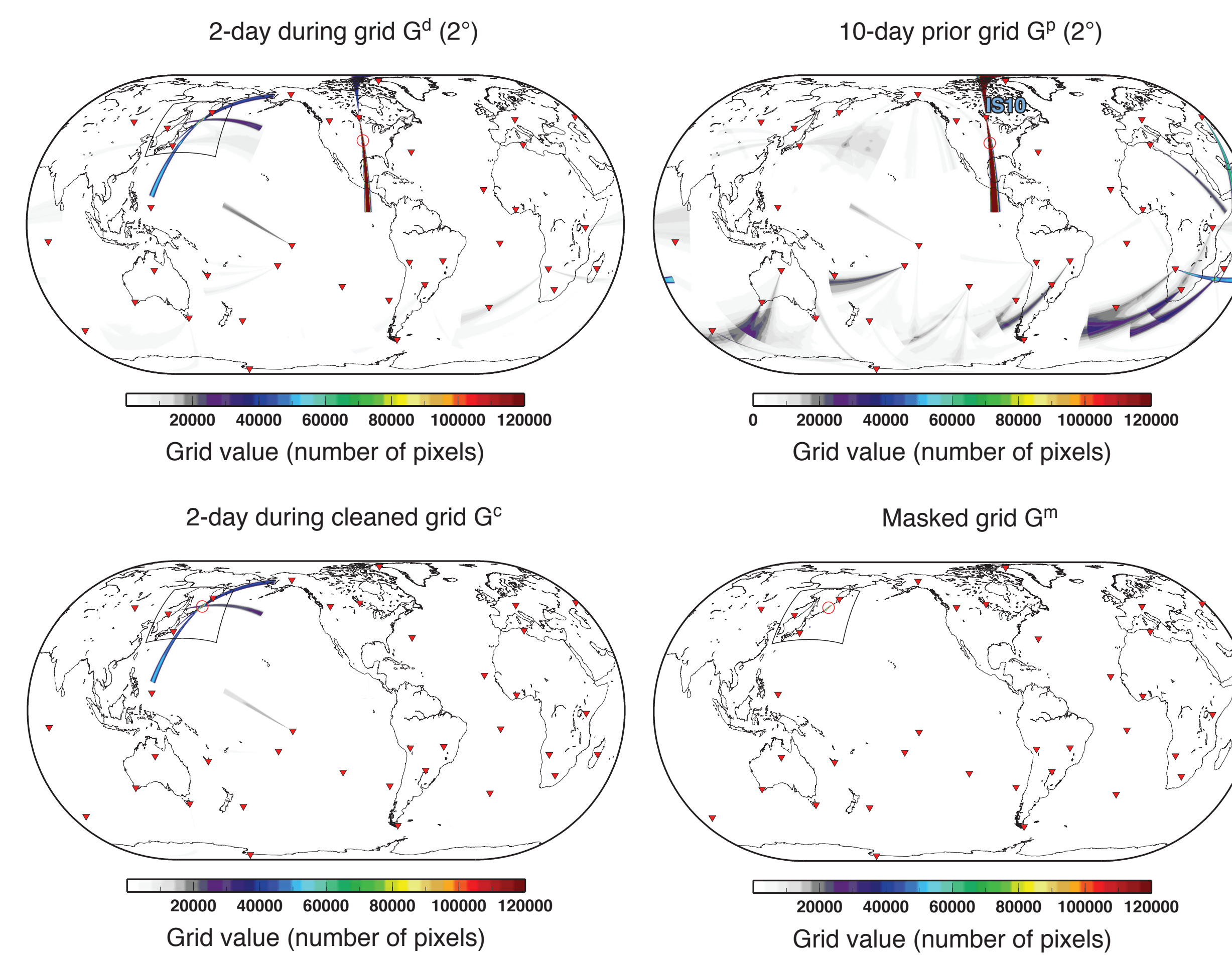
(right) 5-day waveforms from the June 2009 eruption of Sarychev Peak, Kuriles at IS44.

## 3. Global IMS application

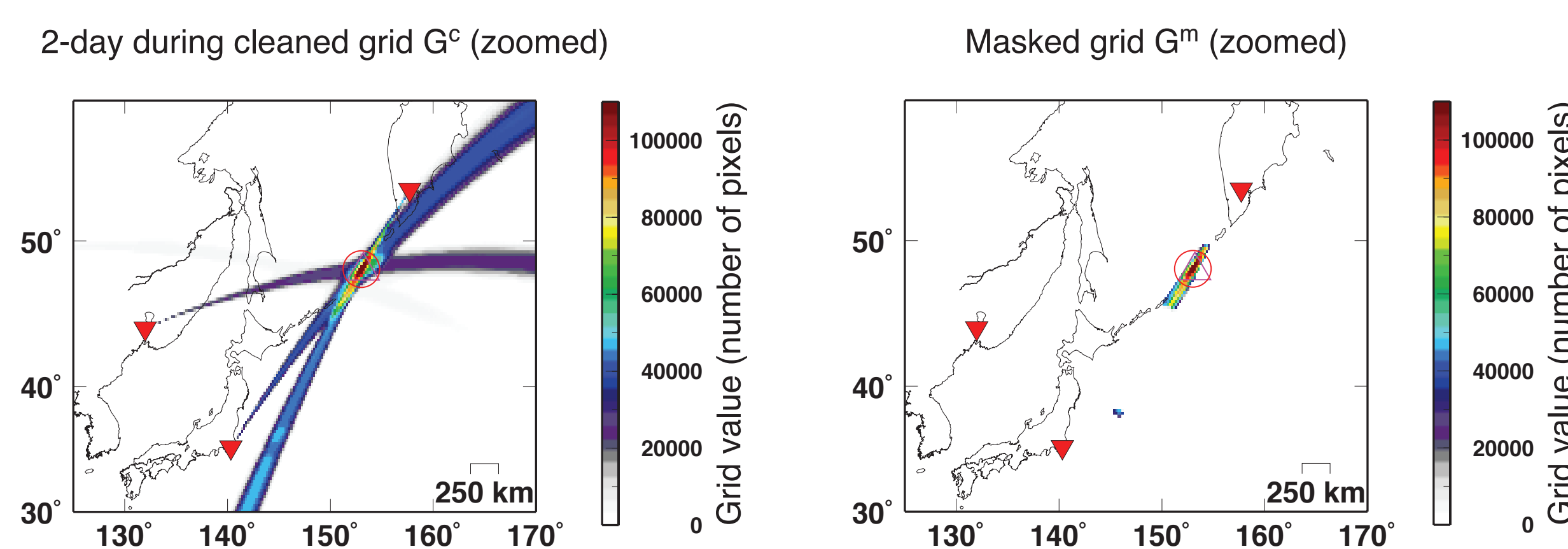
- Globally, grid functions can be dominated by clutter at individual stations
- We remove a background rate of clutter (grid), estimated using data from prior 10 days
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$$\text{Corrected grid} \rightarrow \mathbf{G}^c = \mathbf{G}^d - \alpha \frac{\tau_d}{\tau_p} \mathbf{G}^p \leftarrow \text{Prior grid}$$

During duration (2 days)      During grid      Parameter, e.g., 1.5      Prior duration (10 days)



(above) Global 0.2° grid using 37 IMS infrasound stations for the June 2009 Sarychev Peak eruption. "During grid" is for 11–13 June 2009. "Prior grid" is for 1–10 June 2009. Red circle is the location of the global maximum in each case. Note that 3-station detection and azimuthal gap constraint significantly cleans the grid function.



(above) A global search considering 37 IMS stations finds a peak within 19 km of the true Sarychev Peak volcano location. Persistent "clutter" from a dam at IS10 is successfully removed.

## 4. Multi-year application

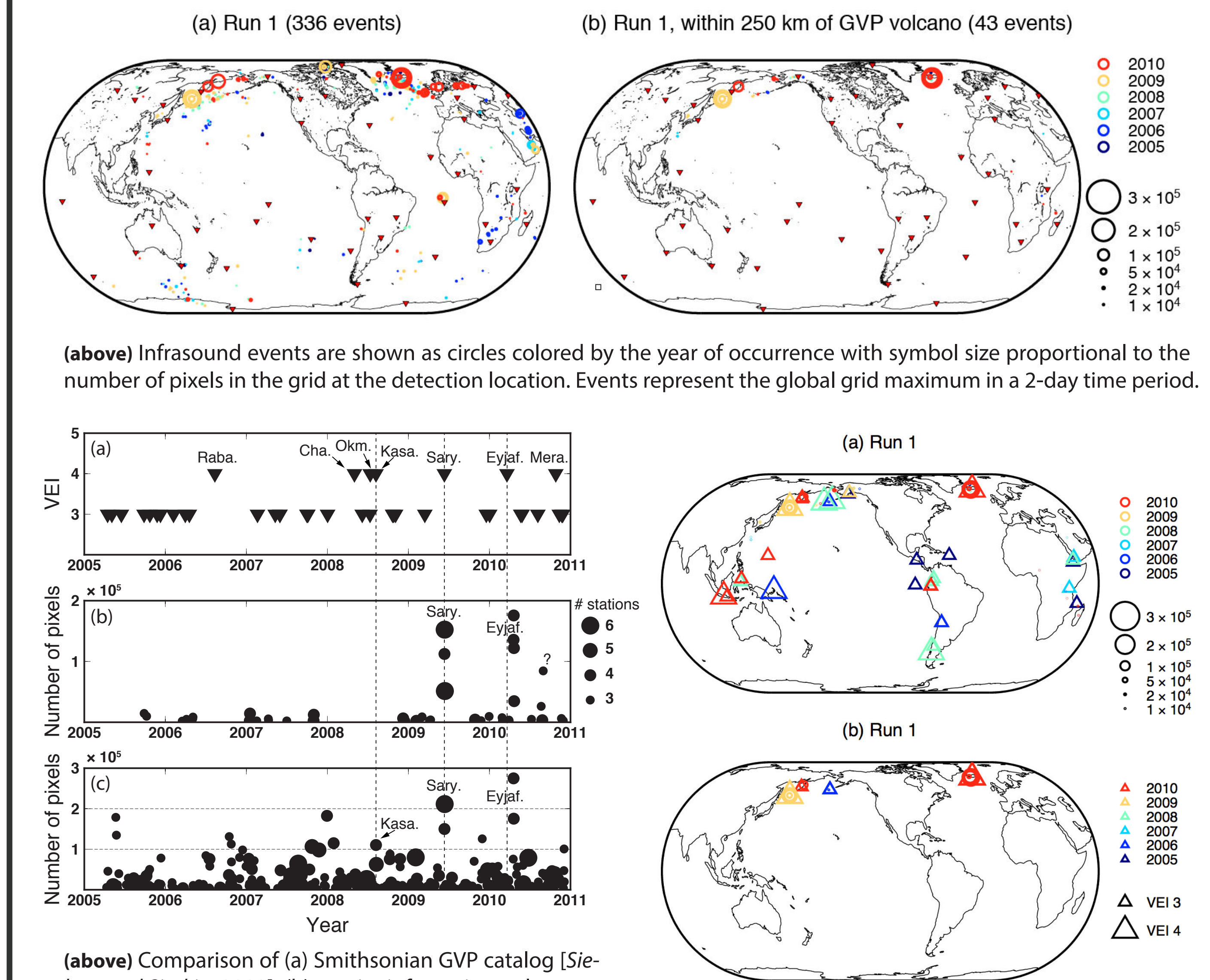
Our algorithm works with array processing detection lists rather than raw waveform data and can be efficiently applied to global multi-year IMS data. We use PMCC detection bulletins produced using a log-frequency band configuration for 41 IMS arrays available from 2005–2010 [Matoza et al., 2013; Ceranna et al., in prep.]. We ran the algorithm 16 times on the global 2005–2010 data to investigate the effects of different parameter choices on the association and location procedure [Matoza et al., 2017].

(right) Data availability at the 41 stations considered between 1 April 2005 and 31 December 2010. Green boxes correspond to days during which at least one PMCC family was registered at the station indicated on the vertical axis.



## 5. Global acoustic catalog

The June 2009 eruption of Sarychev Peak and the April–May 2010 eruption of Eyjafallajökull represent the largest events identified by a blind search through the global multiyear 2005–2010 IMS dataset, demonstrating that this method is well adapted to emphasizing signals from sustained explosive volcanic eruptions. Our global search also blindly identified an eruption in Kamchatka consistent with Kluchevskoi.



(above) Infrasound events are shown as circles colored by the year of occurrence with symbol size proportional to the number of pixels in the grid at the detection location. Events represent the global grid maximum in a 2-day time period.

(above) Comparison of (a) Smithsonian GVP catalog [Siebert and Simkin, 2002], (b) a strict infrasonic catalog run, and (c) a more sensitive infrasonic catalog run in the time from 2005 to 2010. In (b) and (c), only events within 250 km of a known GVP volcano are shown. In (a), only events with Volcanic Explosivity Index (VEI) ≥ 3 are shown. VEI 4 eruptions are labeled: Raba. (Rabaul), Cha. (Chaiten), Okm. (Okmok), Kasa. (Kasatochi), Sary. (Sarychev Peak), Eyjaf. (Eyja allajökull), and Mera. (Merapi).

## Conclusions

We have experimented with a brute-force, grid-search, cross-bearings method to search systematically through global multiyear data from the IMS infrasound network and identify sustained explosive volcanic eruption signals originating anywhere on Earth. The algorithm corrects for a background prior clutter rate in a global grid. We applied the algorithm to IMS infrasound data available at the CTBTO IDC from 1 April 2005 to 5 December 2010, a time when the IMS infrasound network was in relatively early stages of

development. Our algorithm automatically detects, associates, and locates three of the seven VEI 4 eruptions reported globally during this time period by the Smithsonian GVP. We anticipate significant improvements in results when applying this algorithm to more recent data from 2011 to present, in future as the IMS infrasound network achieves full 60-station global coverage, and by incorporating data from additional infrasound arrays in regions of dense volcanism.

## Acknowledgements

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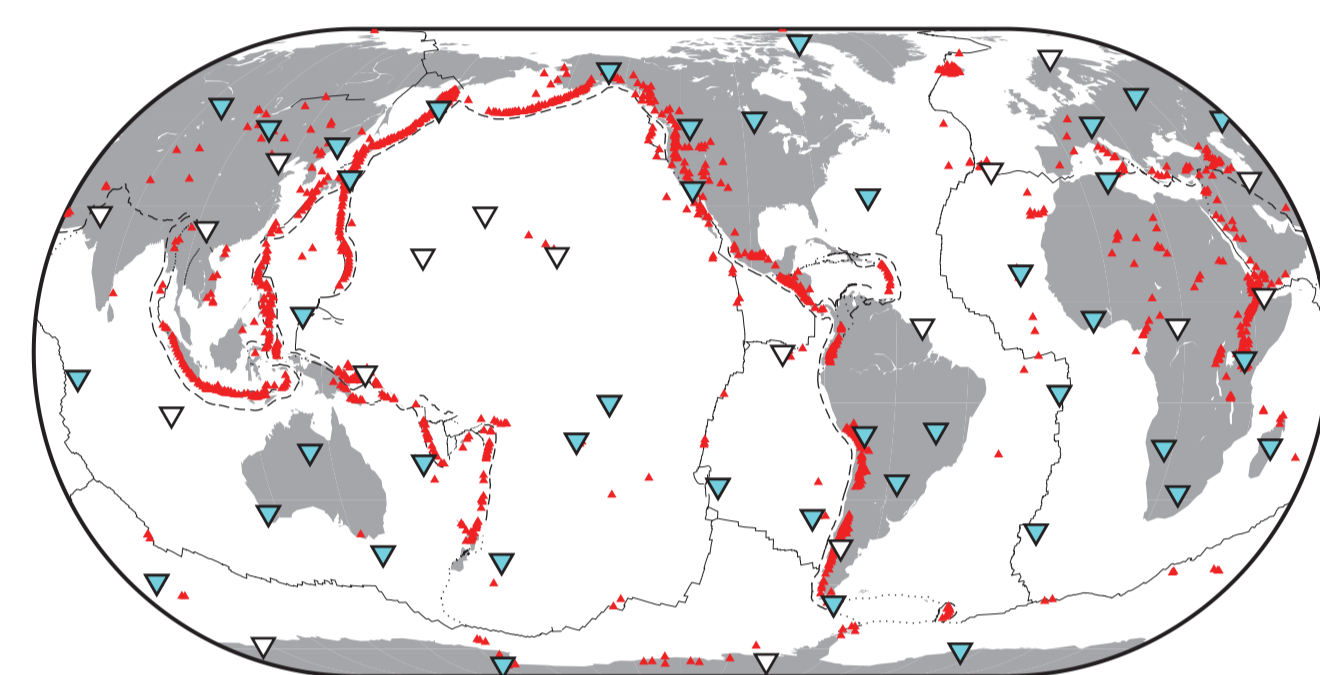
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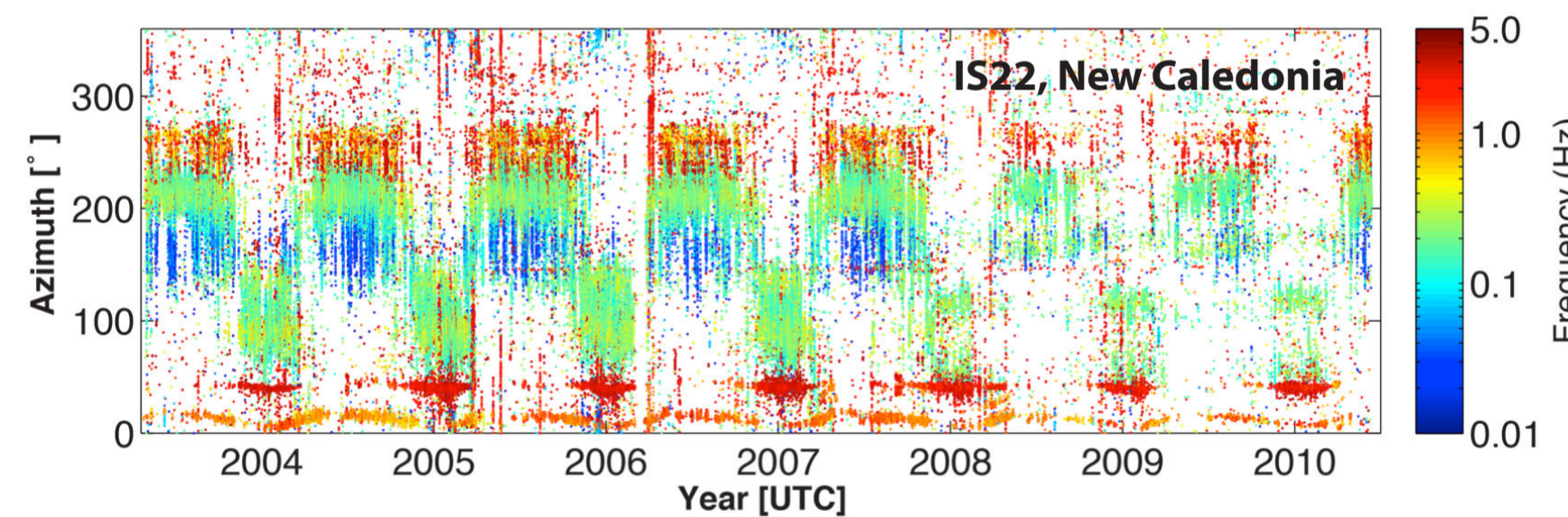
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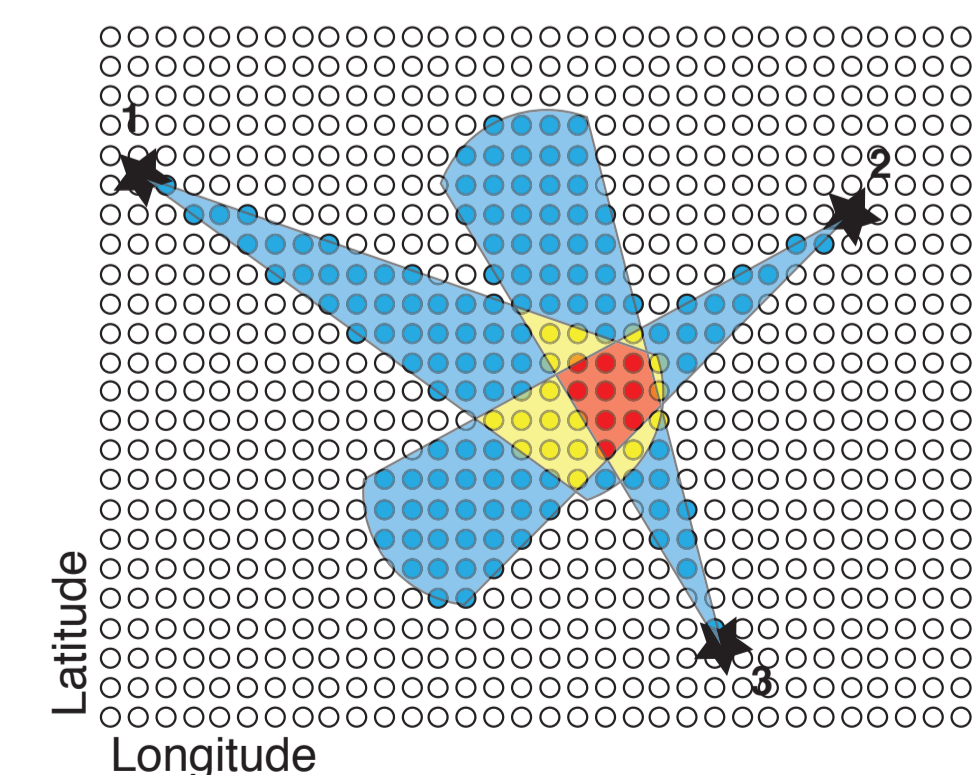


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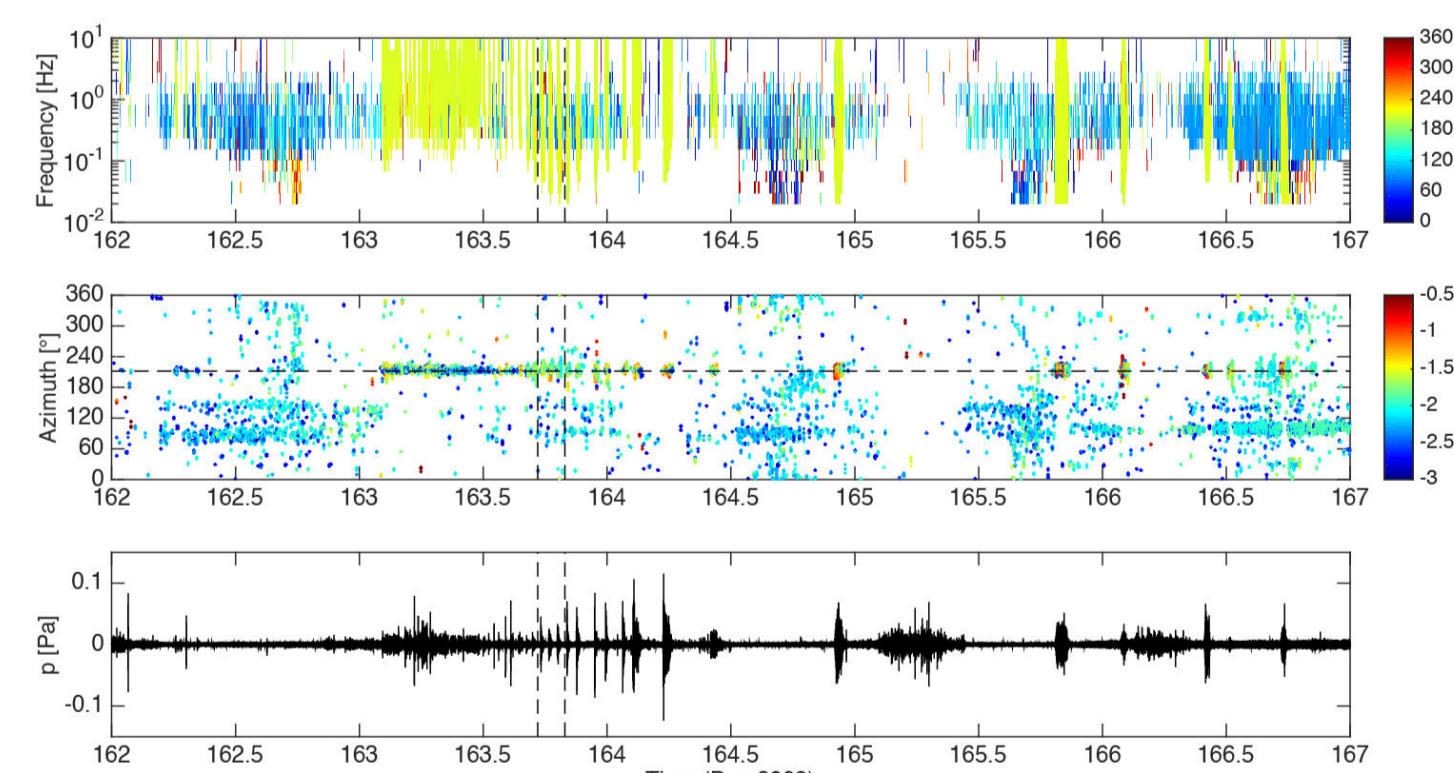


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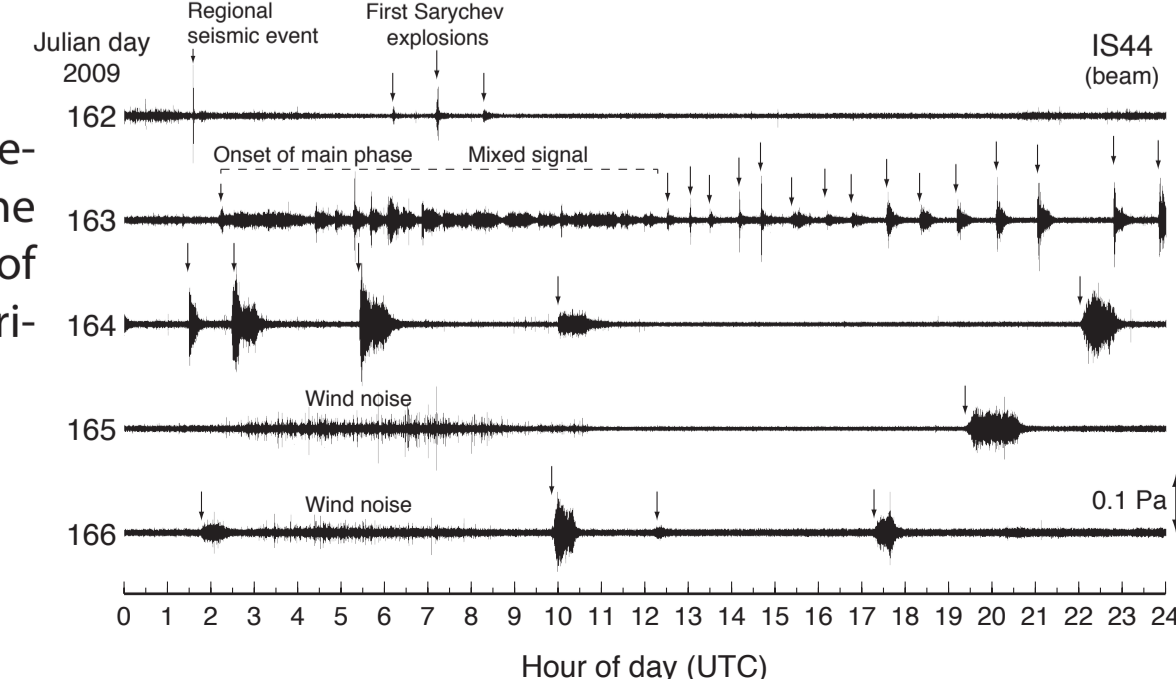


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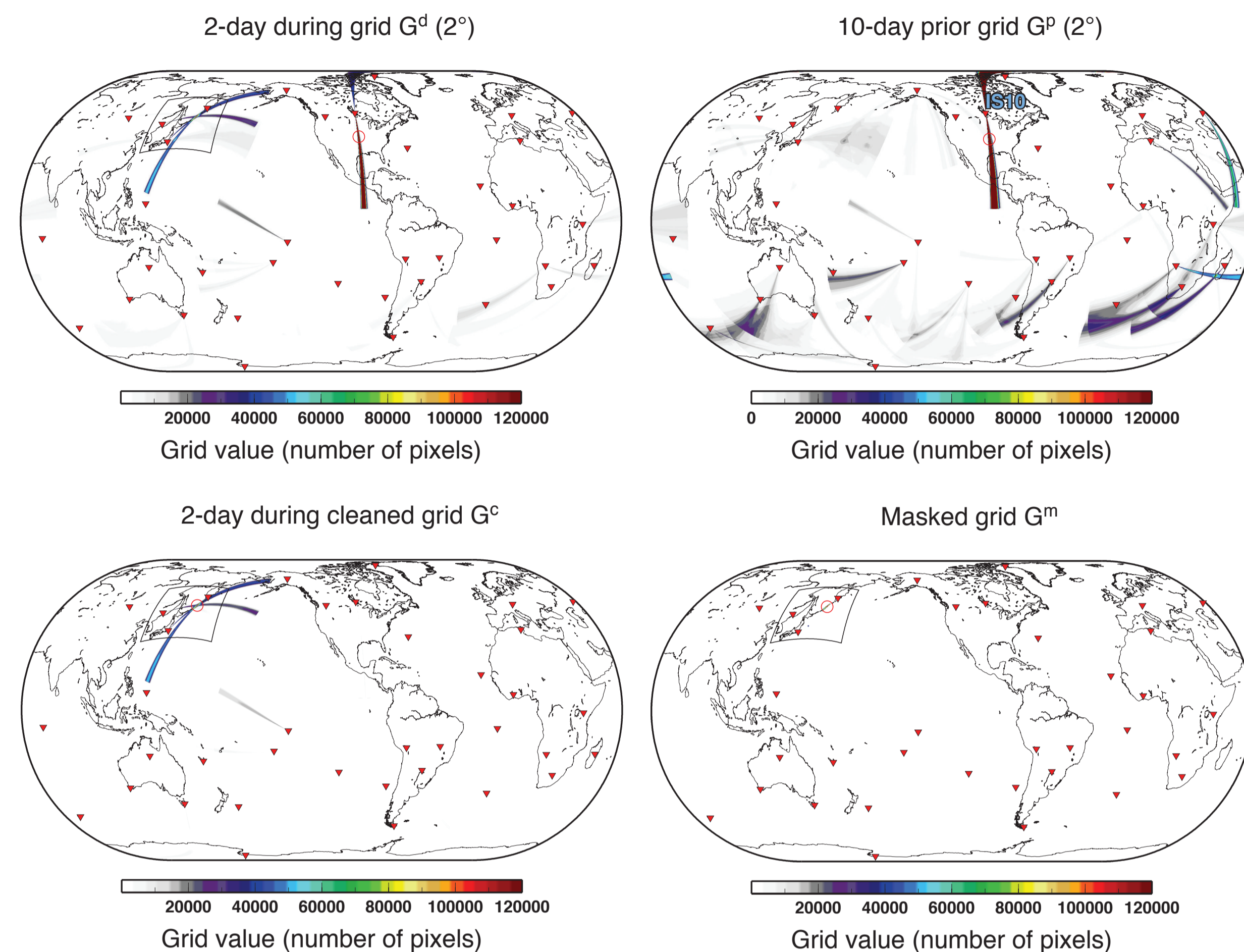


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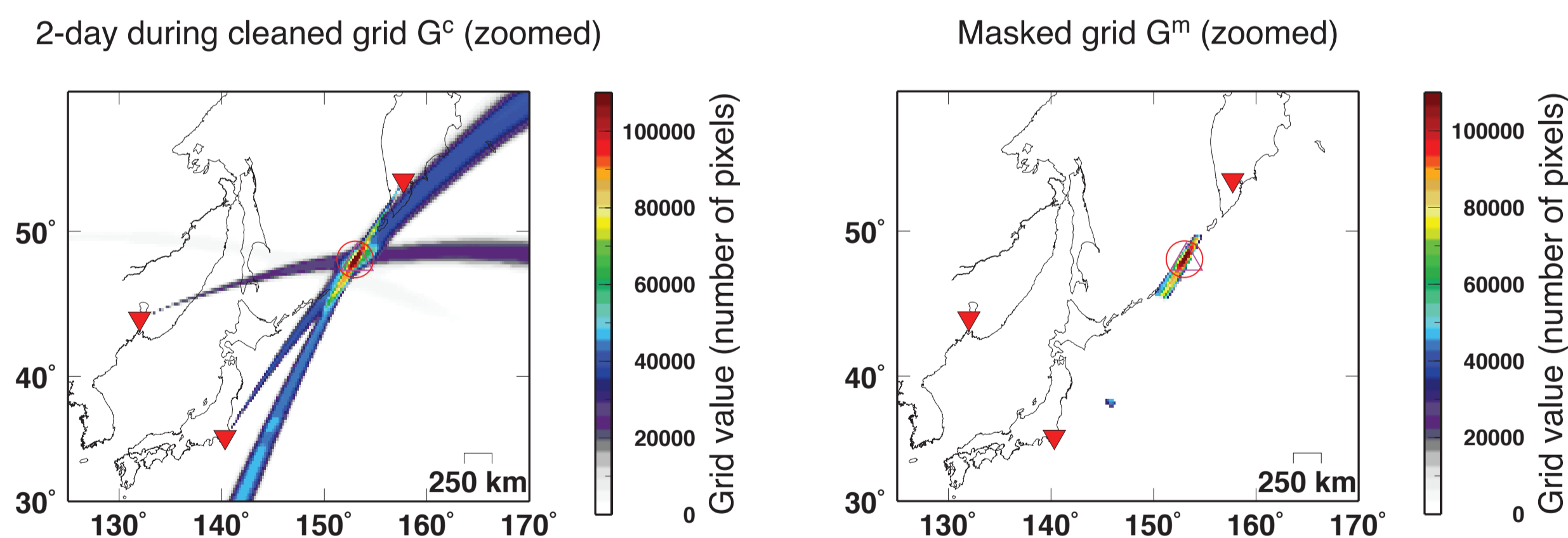
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