Characterizing the 2022 South Atlantic fireball using infrasound recordings of the International Monitoring System

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On 7 February 2022 around 20:00 UTC, a presumably large meteoroid entered the Earth's atmosphere ~500 km off the coast of Namibia and South Africa. NASA's Center for Near Earth Object Studies (CNEOS)[1] lists the event as a fireball with an impact energy of 7 kt of TNT equivalent. This energy estimate is about 60 times lower than for the 2013 Chelyabinsk fireball (440 kt, CNEOS), which was the strongest event ever recorded by the International Monitoring System (IMS) infrasound network at that time, when 20 out of 42 operational stations detected it[2]. Anyhow, due to the progress in IMS network coverage and array signal processing during the last ten years, the number of stations identifying the South Atlantic fireball is larger than the number of stations that detected the Chelyabinsk bolide.

Up to 25 IMS arrays detected the 2022 South Atlantic fireball

Infrasound from fireballs originates either from ablational waves of the hypersonic trajectory or the explosive fragmentation of an asteroid entering Earth's atmosphere. Signatures of the South Atlantic fireball have been identified at 25 stations using the Multi-Channel Maximum-Likelihood (MCML)[3] method and 21 (23) stations using the Progressive Multi-Channel Correlation (PMCC)[4] method (Fig. 1).

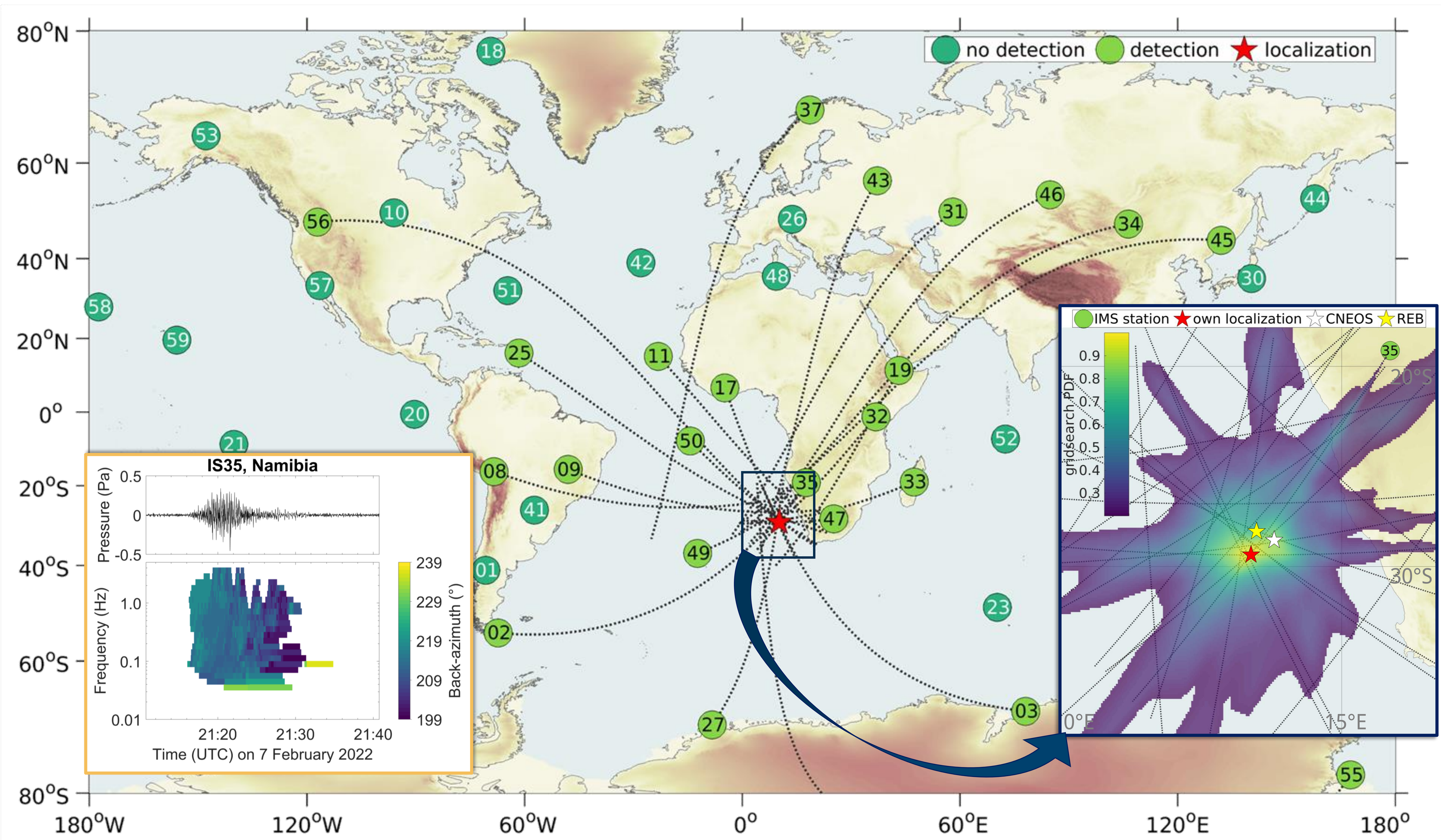

Fig. 1: Map of the certified IMS infrasound stations (circles with station number), short-orthodrome propagation paths (dotted lines), and location result (★) using a gridsearch method (right-hand inlet) based on back-azimuths and modelled celerities (considering only stations within 50° distance). The resulting origin time is approximately 19:52 UTC (CNEOS ☆ 20:06 UTC[1], REB – Reviewed Event Bulletin ☆ 20:10 UTC). Left-hand inlet: waveform beam and PMCC back-azimuth signature at the closest array IS35, Namibia.

Comparison of array processing methods: PMCC and MCML

The propagation conditions in the example (Fig. 2) were not ideal. Nonetheless, MCML provides more signal content at >2 Hz than PMCC (Fig. 3). MCML also detects potentially overlapping sources in the time-frequency domain, performing better at low signal-to-noise conditions.

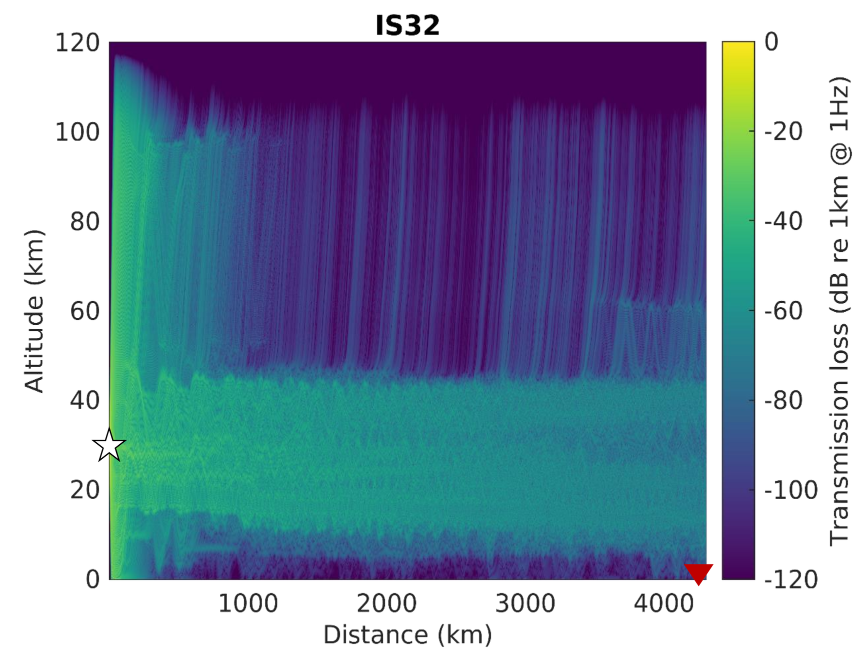

Fig. 2: 2D-PE simulation (NCPAprop[5]) at 1 Hz from a source at 30 km (☆) to IS32 (▼).

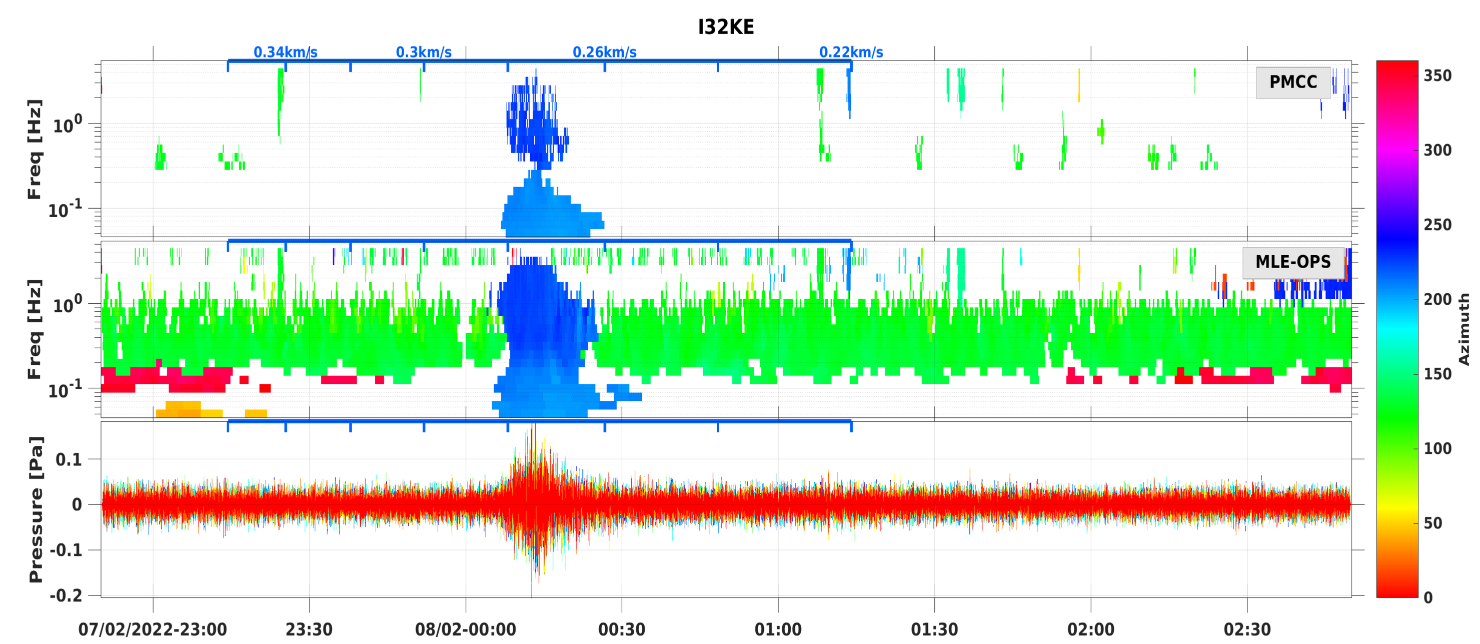

Fig. 3: Comparison of detections at IS32, Kenya, using the array signal processing methods PMCC (top) and MCML (center). The signal in blue (back-azimuth pointing to the southwest) aligns with the transient signal recognizable in the waveforms (bottom).

Revisiting the 2013 Chelyabinsk case using MCML

When applying MCML to the IMS data of the 2013 fireball, we find associated detections at 22 stations now – two more than before!

Infrasound-based yield estimate (preliminary)

An important information about explosive events is the yield. The most common empirical relation for high-altitude events uses the dominant period at the maximum amplitude (ReVelle[6]), as the period is considered being a relatively stable parameter during propagation. For a preliminary estimate, we obtain both the maximum amplitude and the period from PMCC output. The mean of the three closest stations fairly matches the **overall mean of 10 kt TNT** (Fig. 4). The standard deviation is of the same order.

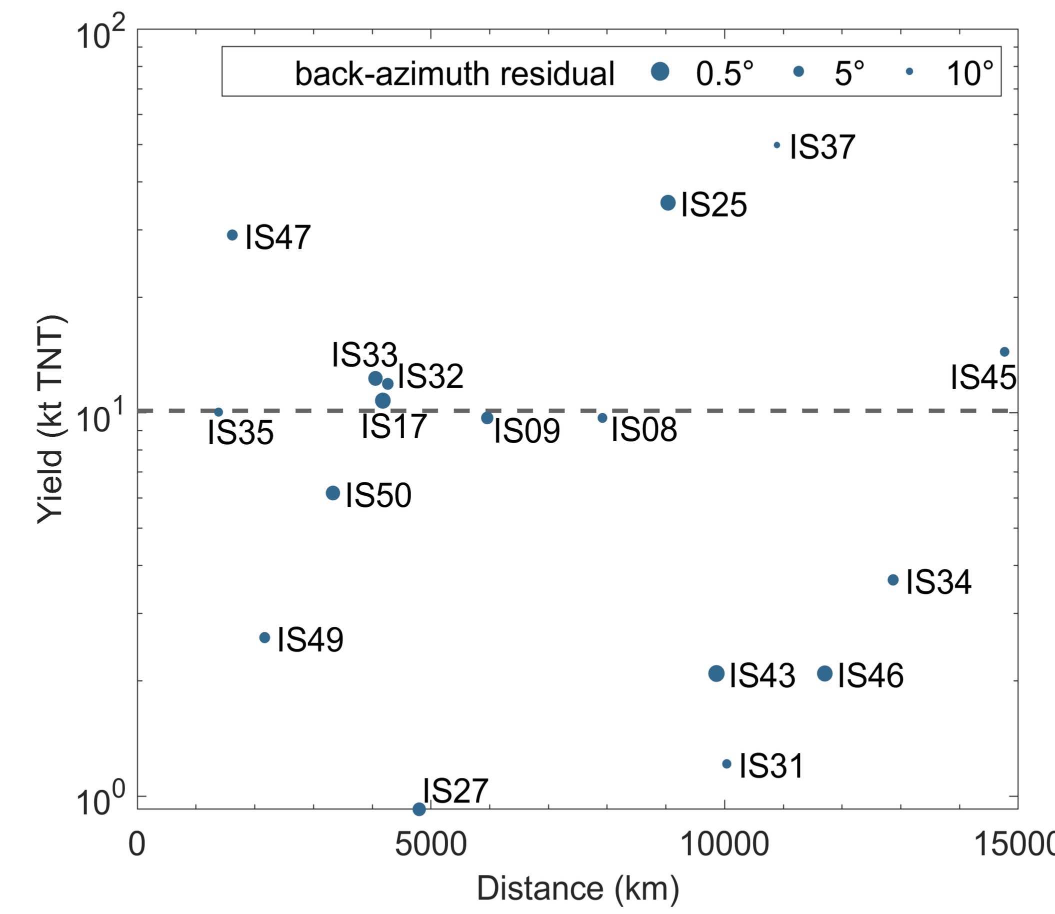

Fig. 4: Yield calculation for 17 infrasound stations based on ReVelle's period-yield relation[6]. The scatter size depicts the back-azimuth residual, where IS37 as the only outlier (28°, see also Fig. 2) is not considered for the mean yield calculation (dashed line). The closest station IS35 matches the mean estimate of 10 kt.

Conclusions

- Rarely observed event but well captured by remote IMS infrasound stations
- Infrasound-based **preliminary yield estimate ~10 kt TNT**
- State-of-the-art processing method MCML provides more signal characteristics during low signal-to-noise conditions, encouraging to revisit past events
- Location and yield estimation uncertainties for this high-altitude source are still under assessment

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6. ReVelle, D.O. (1997), Historical detection of atmospheric impacts by large bolides using acoustic-gravity waves. Annals New York Acad. Sci., 822, 284–302.