SnT 2023
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE
HOFBURG PALACE - Vienna and Online
19 TO 23 JUNE

Anlaysis of Anomalous Seismic Events in India

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INTRODUCTION

The US NDC observed 5 seismic events in India from September 2018 to October 2022 near a known coal mine. These events are of interest as they exhibit some explosive characteristics and their respective yields would be approximately equivalent to a 1 kiloton nuclear explosion.

METHODS/DATA

- Event location using IMS and USAEDS network
- Waveform correlation and event clustering using stations KBL (IM) and KKN (NK)
- InSAR analysis using GMTSAR and Sentinel Satellite Mission
- First-order modeling is done to determine source

START

RESULTS

- Events are located within 10 km of a known coal mine
- Waveforms for all events are significantly correlated
- Interferograms show deformations consistent with surface subsidence
- Observed radius of deformation is consistent with a collapse

CONCLUSION

From 2018 to 2022 the US NDC has observed 5 ambiguous seismic events in India near a known coal mine. The results of the analysis shows that these events are not consistent with underground nuclear explosions, but possibly collapses at the nearby mine.

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INTRODUCTION

- Since 2018 the US NDC has observed 5 anomalous moderate sized seismic events in the Chhattishgarh Province of India near the Churcha Underground Coal Mine.
- Initial analysis of the source type (explosion, earthquake, mine collapse, etc.) was ambiguous for all events, but the signals exhibited some explosive characteristics, as they are deficient in surface wave energy.
- These events would have a yield approximately equal to that of a 1 kiloton nuclear device (fully-coupled in hard rock, at standard-scaled-depth-of-burial).

OBJECTIVE

- To determine the events sources as natural (*e.g.*, earthquake, collapse) or man-made (*i.e.*, an underground nuclear explosion)

DATA & METHODS

- Event locations and parameters were pulled from the US NDC's EVAL1 bulletin, which uses seismic data from both the United States Atomic Energy Detection System (USAEDS) network, and the International Monitoring System (IMS) Network.

- Using data from station KBL (IMS) and KKN (NK), waveform correlation and clustering was conducted in Python, specifically with use of the ObsPy Toolbox.

- The Interferometric Synthetic Aperture Radar (InSAR) technique was conducted to evaluate if there was any detectable surface deformation associated with each event. Publicly available data from the Sentinel satellite mission was downloaded from the Alaska Satellite Facility. We utilized GMTSAR, developed by the USCSD Scripps Institution of Oceanography, for the analysis.

- We conduct first-order modeling of one of the events as both a collapse and an underground nuclear explosion in order to corroborate our observations.

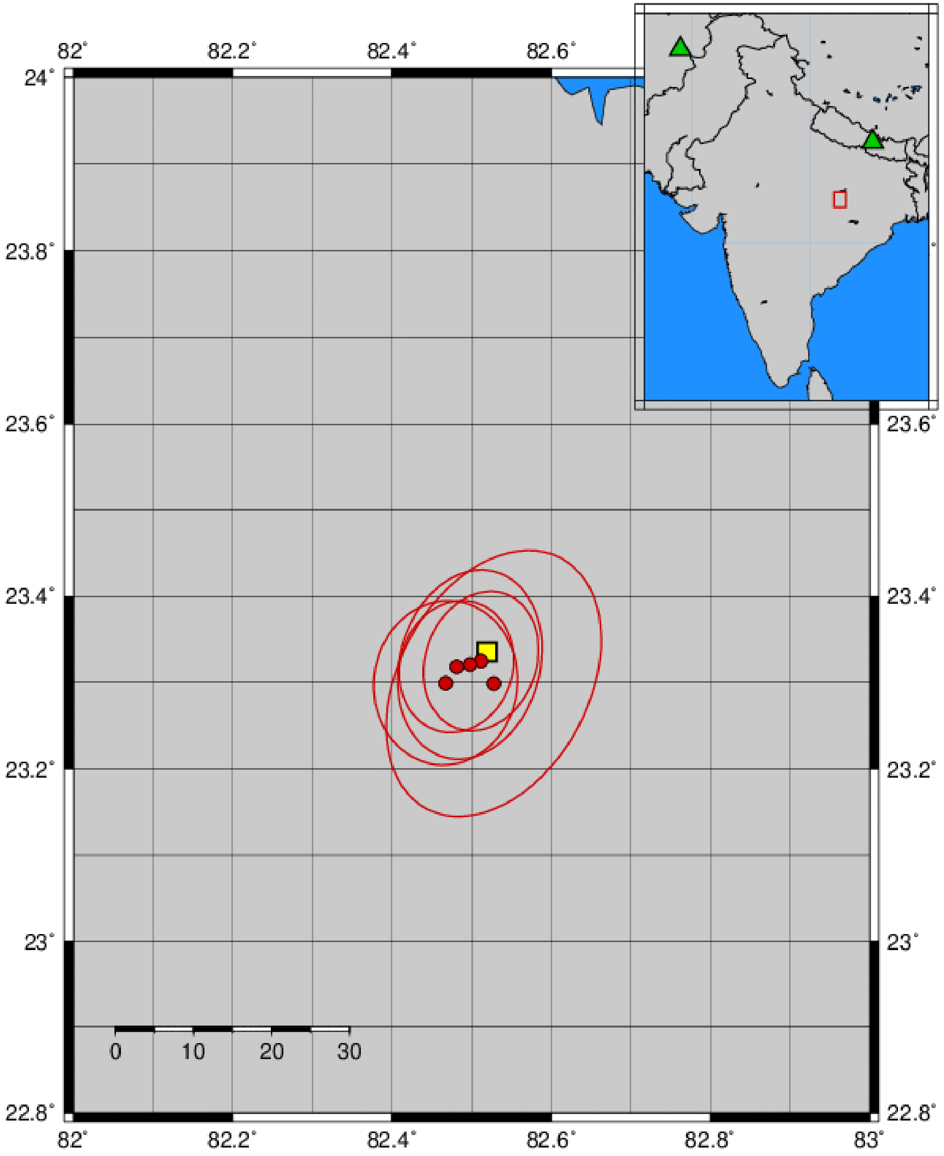
OBSERVED EVENTS

Event Table:

Origin Time (GMT)	LAT	LON	m_b	Ms
2018-09-01T18:09:53	23.3248	82.5120	4.34	-999
2022-05-14T15:46:41	23.2988	82.5279	3.83	-999
2022-07-11T02:39:59	23.3208	82.4979	4.30	-999
2022-07-28T19:26:44	23.2995	82.4676	4.44	-999
2022-10-13T23:58:21	23.3184	82.4812	4.59	3.08

In the event table (above), we note the lack of observable Ms for the first 4 events and a significant mb-Ms difference for the fifth event. The m_b for all events would equate approximately to an underground nuclear test with a yield of 1 kiloton.

The map to the right shows the event locations (red dots) and there coverage ellipses at the 95% confidence level. We highlight stations KBL (Afghanistan) and KKN (Nepal), which were used for waveform correlation analysis. The yellow square denotes west adit entrance to the Churcha Underground Coal Mine.



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MEDIA REPORTS

Earthquake of 4.6 magnitude hits Korea district in Chhattisgarh; two suffer minor injuries, no major damage reported

This is for the second time this month that Chhattisgarh's Korea district has reported earthquake of above-4 magnitude. On July 11, a 4.3 magnitude earthquake had hit the same area in the district.

July 29, 2022 12:58 pm | Updated 12:58 pm IST - Ambikapur

A moderate earthquake of 4.6 magnitude hit some parts of Korea district in north Chhattisgarh in the wee hours of July 29, officials said. Two employees of South Eastern Coalfields Limited (SECL) suffered minor injuries when they fell while trying to move to safety on sensing the tremor inside an underground coal mine in the district.

This is for the second time this month that the district has reported earthquake of above-4 magnitude. On July 11, a 4.3 magnitude earthquake had hit the same area in the district.

"A 4.6-magnitude earthquake was felt in the area around Baikunthpur, the headquarters of Korea district adjoining Madhya Pradesh, at around 12.56 a.m. **The epicentre of the quake was 16KM deep from the surface of the earth," a government official in Ambikapur said.**

Earthquake of 4.8 magnitude jolts Chhattisgarh's Korea, no loss of life or damage to property reported

This is the 3rd time that an earthquake has hit Korea district in the last 3 months

PTI
Ambikapur, October 14

An earthquake of 4.8 magnitude shook parts of Korea district in the northern region of Chhattisgarh in the wee hours of Friday, officials said.

This is the third time that an earthquake has hit Korea district in the last three months.

"A 4.8 magnitude earthquake was felt in Chhindand area near Baikunthpur, the headquarter of Korea district, around 5.28 am. **The epicentre of the quake was 10 km deep from the earth's surface," a government official said.**

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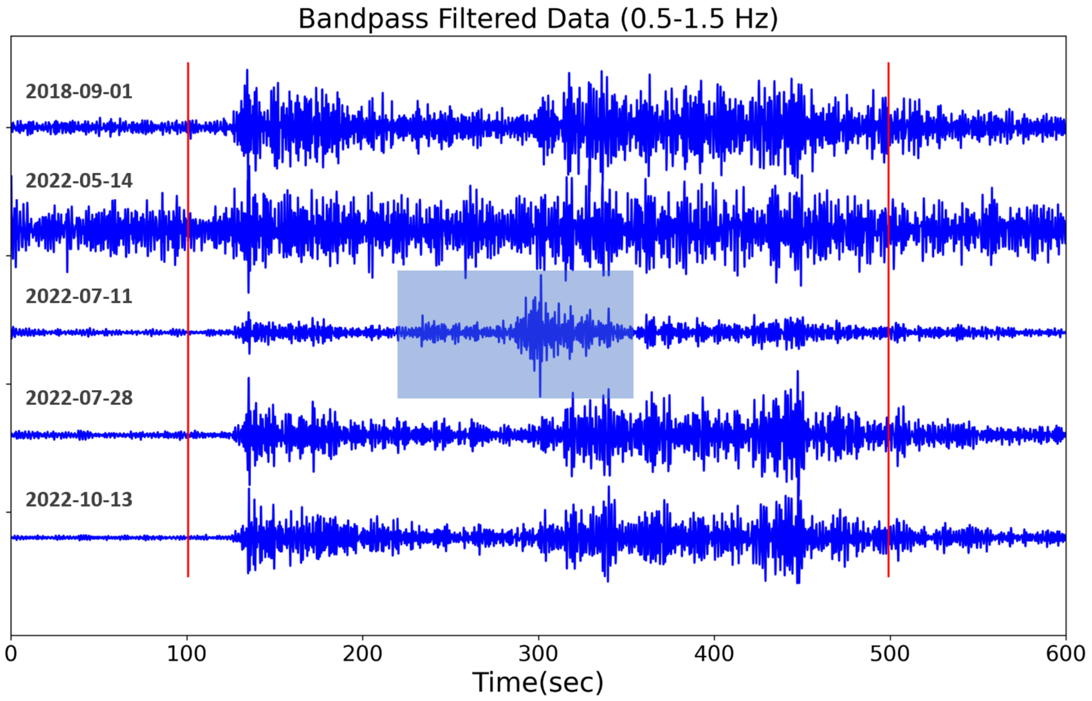
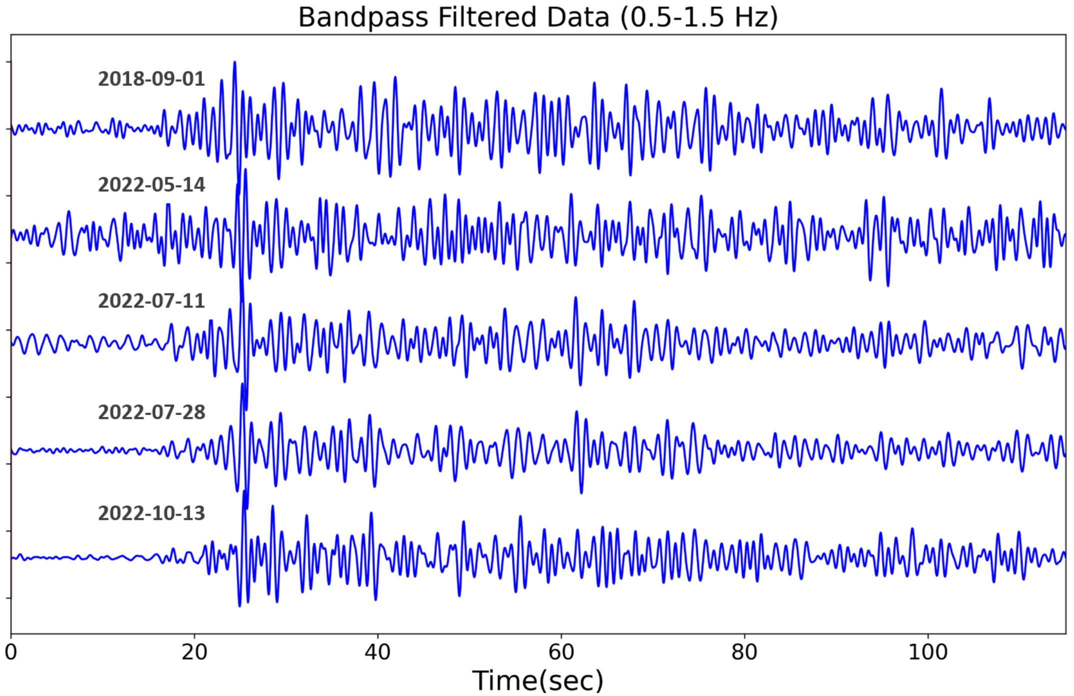
WAVEFORMS (KBL)



Above are full-waveforms from the 5 events observed at IMS station KBL. We note that the overall shapes are consistent, and it appears there is a small regional event (shaded area) is intermixed with the 2022-07-11 event.

Below are the P-coda waveforms of the same events. We note similar features between all waveforms, but also some minor distinctness of the 2018-09-01 event.



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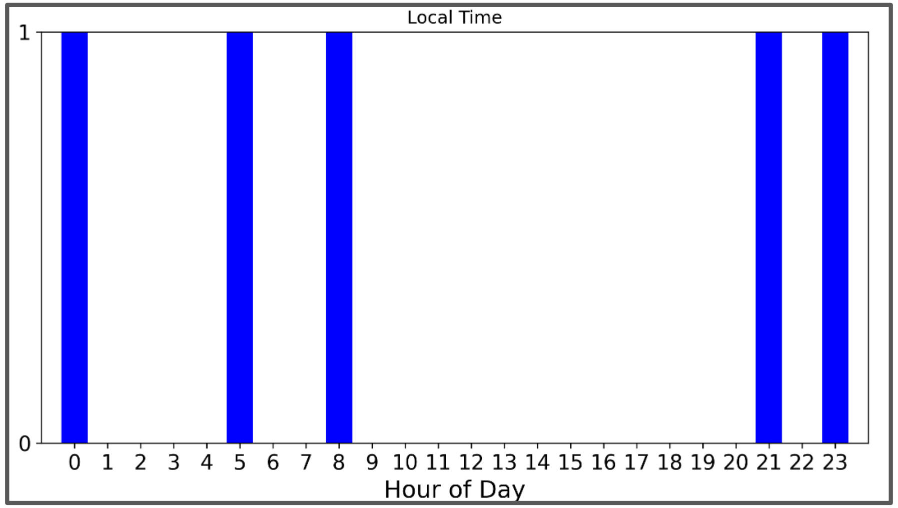
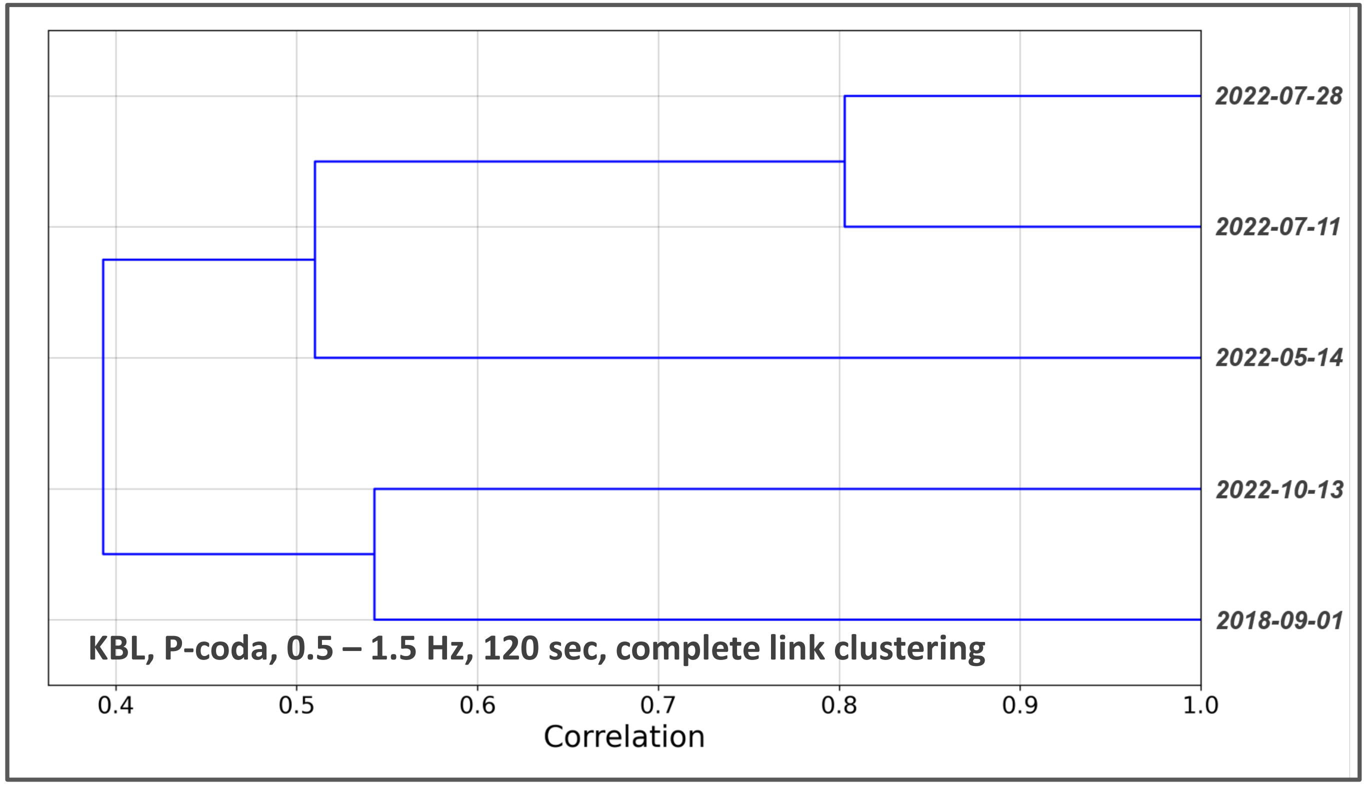
CORRELATION & CLUSTERING, TIME-OF-DAY (KBL)



(Right) is the corresponding dendrogram for the P-coda waveforms at KBL on the previous slide. We note that the waveforms cluster into two separate families. We assess the correlations to be significant despite the limited band-pass frequency.

(Above) is the corresponding local hour-of-day histogram. Although we have a small sample size the distribution suggests a random process.



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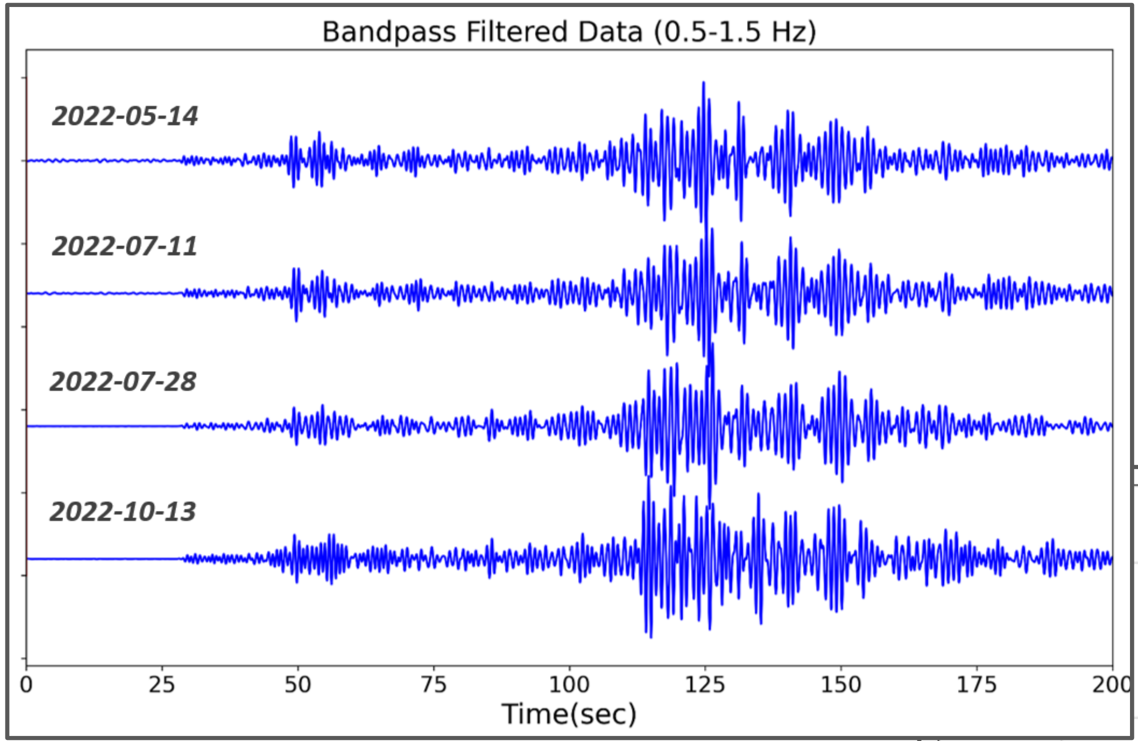
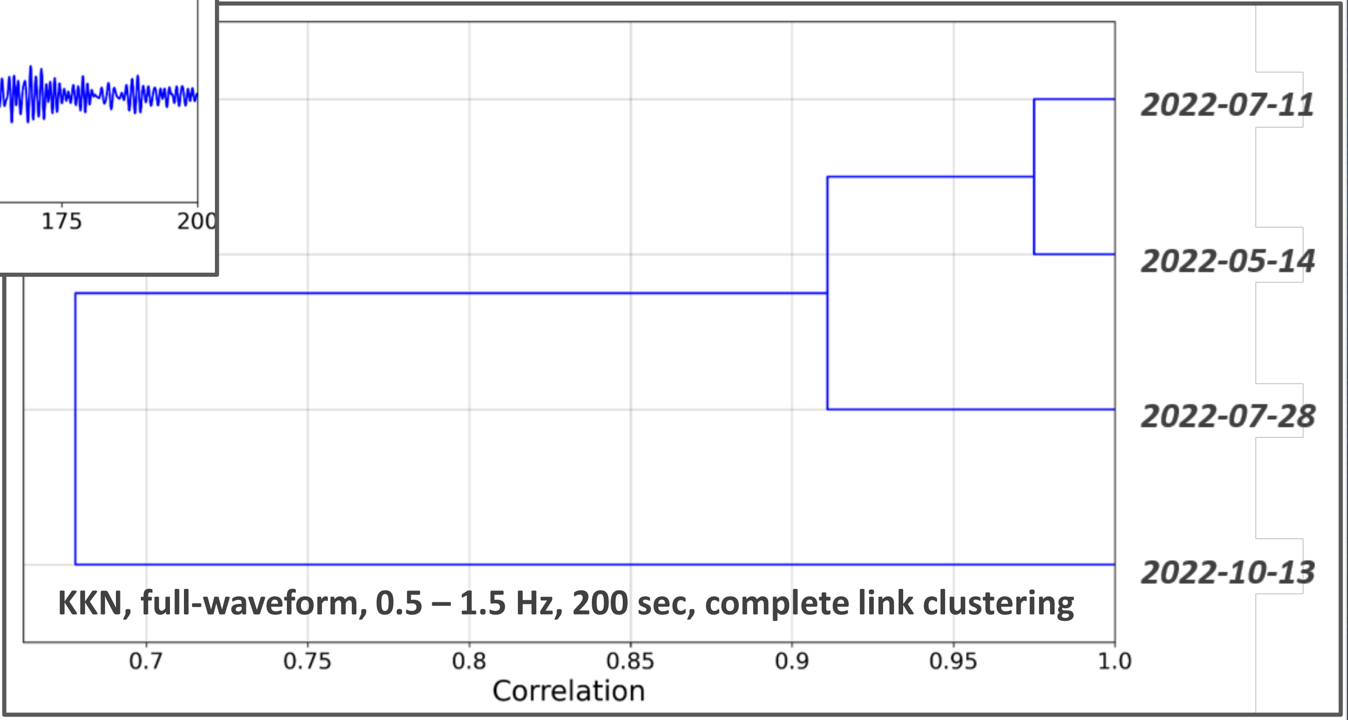
WAVEFORMS, CORRELATION & CLUSTERING (KKN)



(Left) are full waveforms for the last four events observed at station KKN in Nepal, and (below) is the corresponding dendrogram from these waveforms. We note significant correlations between all events and that the these results corroborate the correlation analysis at KBL.



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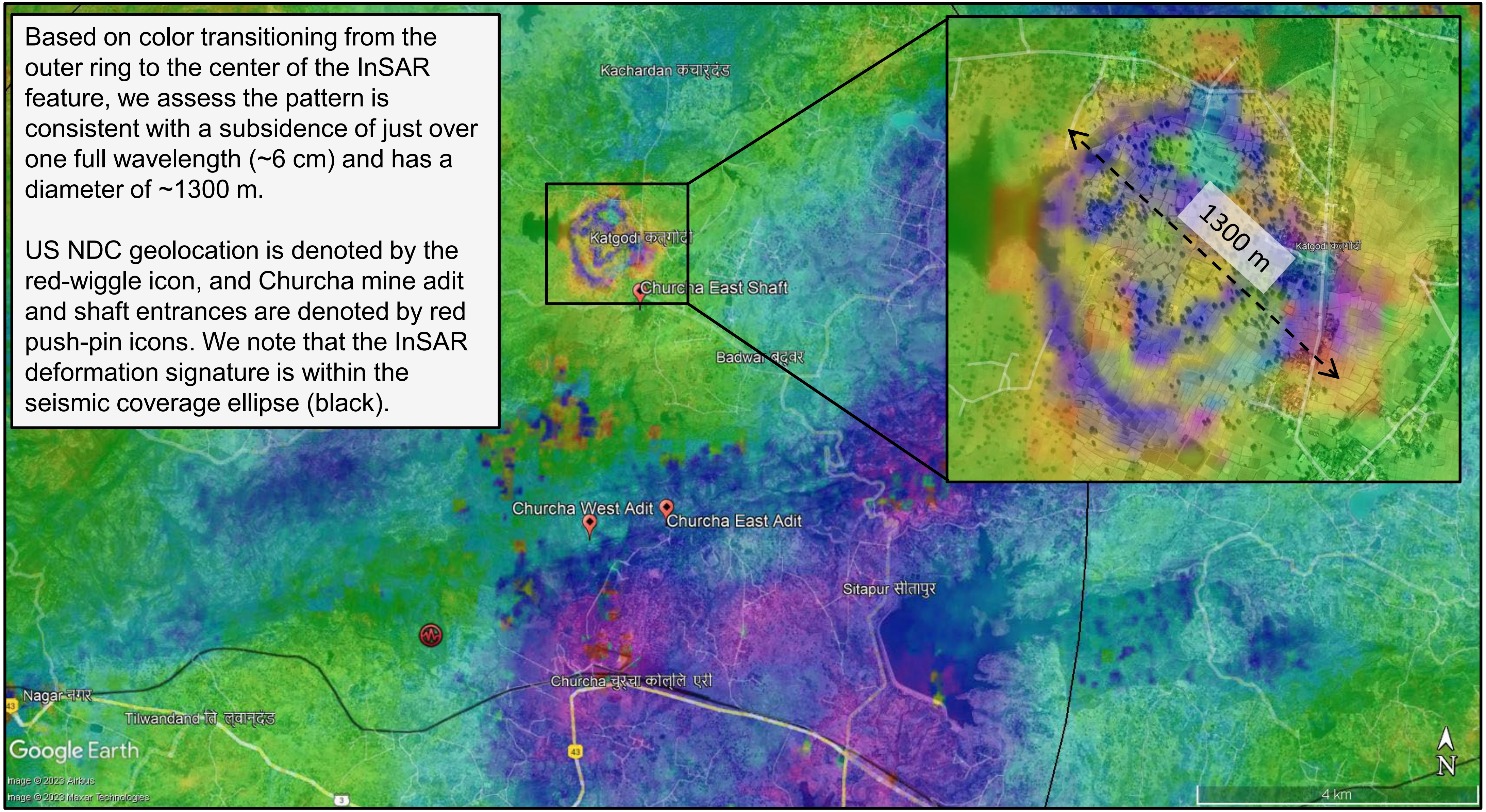
InSAR ANALYSIS (2022-07-11)

Based on color transitioning from the outer ring to the center of the InSAR feature, we assess the pattern is consistent with a subsidence of just over one full wavelength (~6 cm) and has a diameter of ~1300 m.

US NDC geolocation is denoted by the red-wiggle icon, and Churcha mine adit and shaft entrances are denoted by red push-pin icons. We note that the InSAR deformation signature is within the seismic coverage ellipse (black).



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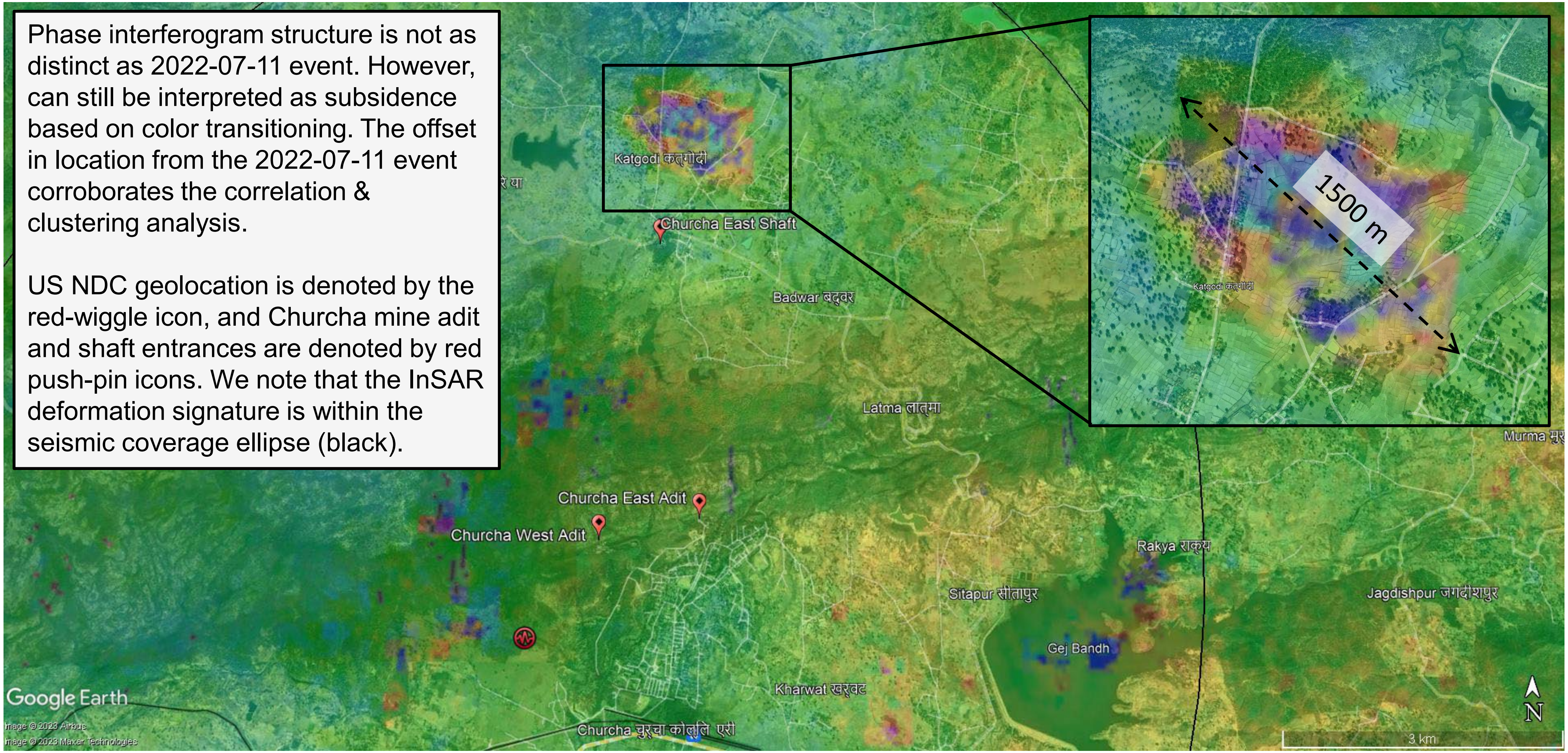
InSAR ANALYSIS (2018-09-01)

US UNITED STATES NATIONAL DATA CENTER NDC

Phase interferogram structure is not as distinct as 2022-07-11 event. However, can still be interpreted as subsidence based on color transitioning. The offset in location from the 2022-07-11 event corroborates the correlation & clustering analysis.

US NDC geolocation is denoted by the red-wiggle icon, and Churcha mine adit and shaft entrances are denoted by red push-pin icons. We note that the InSAR deformation signature is within the seismic coverage ellipse (black).



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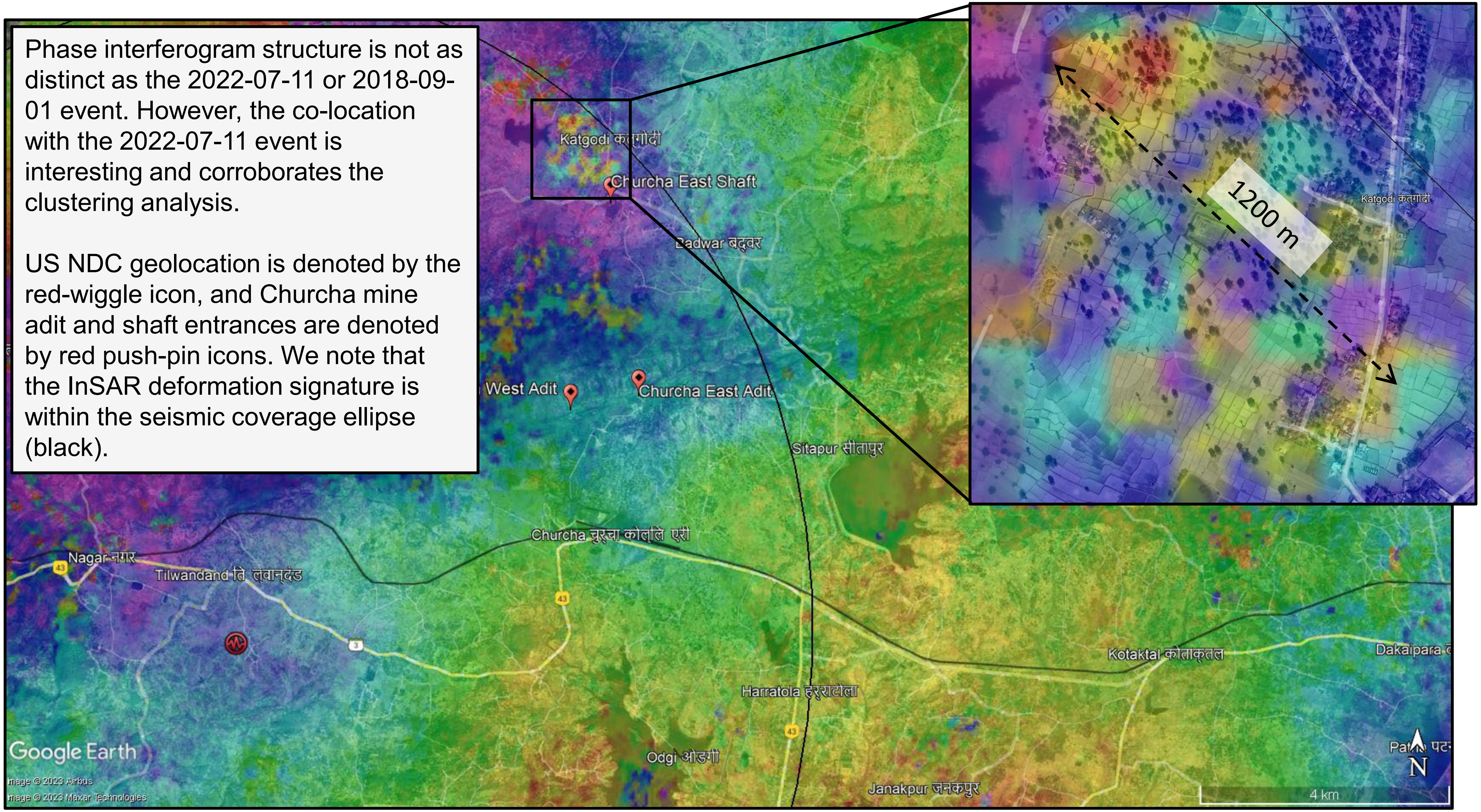
InSAR ANALYSIS (2022-07-28)

Phase interferogram structure is not as distinct as the 2022-07-11 or 2018-09-01 event. However, the co-location with the 2022-07-11 event is interesting and corroborates the clustering analysis.

US NDC geolocation is denoted by the red-wiggle icon, and Churcha mine adit and shaft entrances are denoted by red push-pin icons. We note that the InSAR deformation signature is within the seismic coverage ellipse (black).



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POSSIBLE COLLAPSE SCENARIO

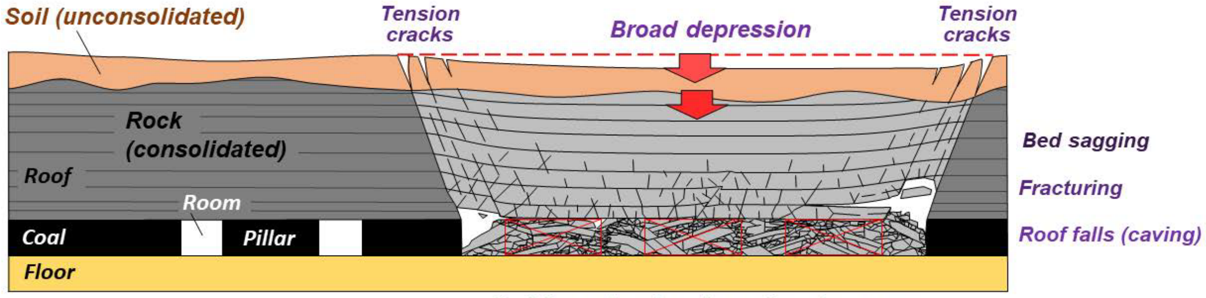
The Environmental Audit Statement of 2018-19 for the Churcha Underground Mine states, "Depillaring is done by a caving method". This indicates retreat mining is being practiced

Retreat Mining is where coal pillars that were initially left intact to support the roof are mined of their coal as the miners retreat from the unsupported area.

- Under ideal conditions the unsupported roof will collapse systematically before a large amount of overburden stress can accumulate
- If the systematic collapse does not occur, then a larger section can collapse all at once producing a seismic event that can be observed regionally and teleseismically

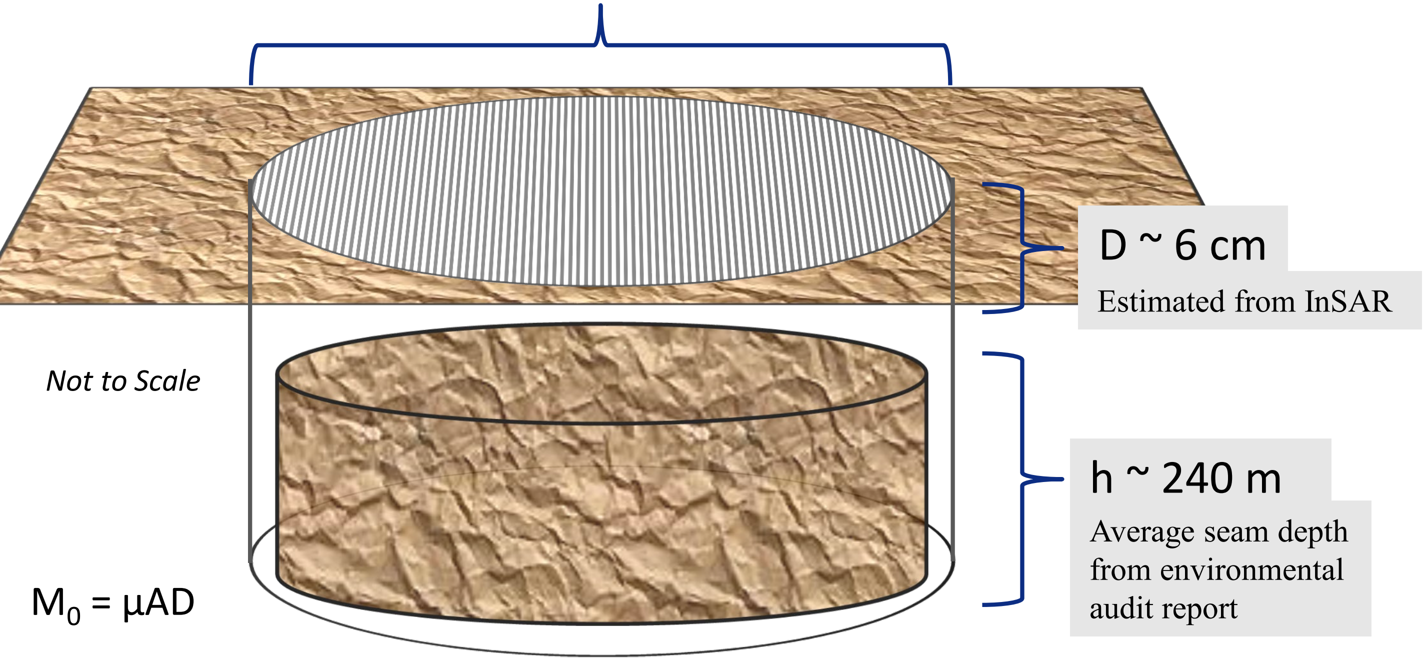
Examples of comparable collapses are the 2007 Crandall Canyon mine collapse in Utah, (M_L) 3.9 (Pechmann et al., 2008) and the 1995 mining collapse in the Trona Mining District in Wyoming, (M_L) 5.1 (Pechmann et al., 1995)

Coal shuttle car inside the Churcha W. Mine



Rock layers break and sag above large area of pillar removal or failure

MOMENT – MAGNITUDE SCALING (Event 2022-07-11)



$M_0 = \mu AD$

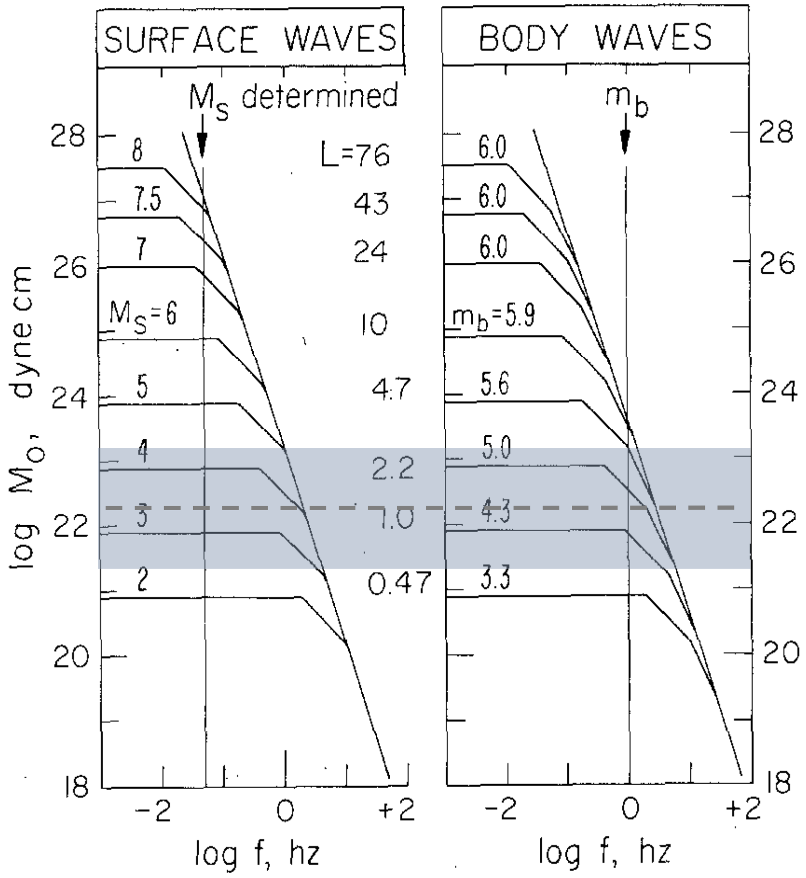
$\mu \sim 20$ Gpa $= 2 \times 10^{10}$ N • m $^{-2}$ (average for crustal rocks)

$A = C \bullet h = 2\pi r \bullet h = (\pi \times 1300 \text{ m}) \bullet (240 \text{ m}) \approx 9.8 \times 10^{5} \text{ m}^2$

$D \sim 6 \text{ cm} = 6 \times 10^{-2} \text{ m}$

$M_0 = \mu AD = (2 \times 10^{10}) \bullet (9.8 \times 10^{5}) \bullet (6 \times 10^{-2}) = 1.2 \times 10^{15} \text{ N} \bullet \text{m} = 1.2 \times 10^{22}$ dyn cm

Observed m_b = 4.3, theoretic m_b from moment scaling ≈ 4.5



Geller, R. (1976) BSSA, 66, 1501-1523

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THEORETIC SUBSIDENCE RADIUS for UNE (Event 2022-07-11)

For detonations in volcanic and alluvial rocks, where most Nevada National Security Site detonations were situated, cavity radius (R_C) is calculated using the Containment Evaluation Panel (CEP) formula (Tehrune and Glenn, 1977; Olsen, 1993; Pawloski, 1999):

$$R_C = 70.2 \frac{W^{1/3}}{(\pi h)^{1/4}}$$

From Carle, et al., 2021

where:

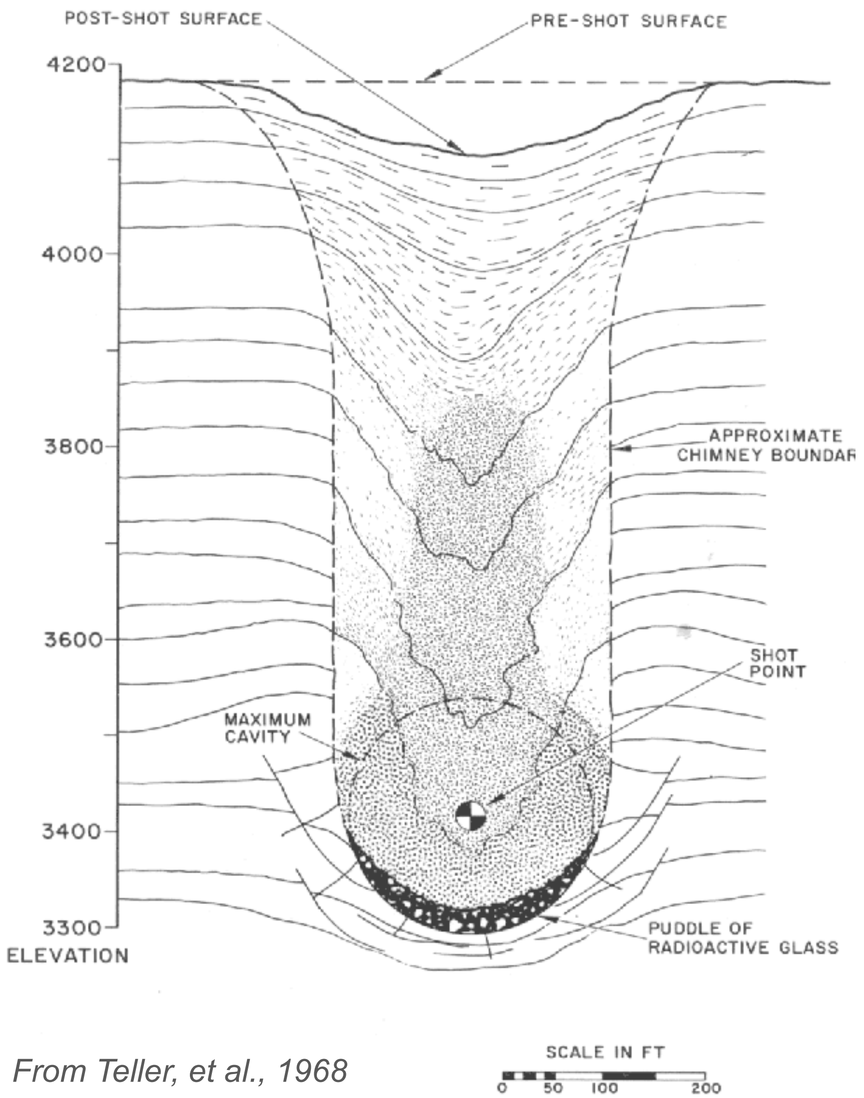
Assumptions in Blue

R_C = cavity radius in meters (m)
W = detonation yield, in kilotons (kt), *(1 kt – based on m_b)*
π = overburden (bulk) density, in grams per cubic centimeter (g/cc), *(2 g/cc – value for alluvial rocks)*
h = overburden thickness in meters (m), *(122 m – standard scaled depth of burial at 1 kt)*

Chimney radius is generally 10 – 20% greater than original cavity radius, which should be roughly equal to the radius of the surface subsidence

Theoretical radius of surface subsidence if 20220711 event was UNE ≈ 21 m

Observed radius of surface subsidence ≈ 650 m



From Teller, et al., 1968

CONCLUSIONS

- ❖ Since 2018 AFTAC has observed 5 events in the Chhattisgarh Province of India, all evidence eliminates the possibility of the events being nuclear in nature, but suggests that these events could be collapses at the nearby Churcha Underground Coal Mine
- ❖ Events are of interest as they exhibit some explosive characteristics, and their respective yields are approximately equivalent to a 1 kiloton underground nuclear explosion
- ❖ InSAR analysis for these events show interference patterns consistent with a subsidence (collapse) within the footprint of the mine
  - Based on the radius of the observed InSAR signatures, we are able to show that the seismic energy from such events are consistent with an earthquake of the observed magnitudes and not consistent with a similar sized Underground Nuclear Explosion (UNE).
- ❖ Correlation and cluster analysis show significant correlation between all observed events and corroborate InSAR locations
- ❖ The Churcha Mine is known to use retreat style coal mining techniques that have been associated with known collapses at other mines
- ❖ Time-of-day suggests a random process

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