Reply to "Comment on Bunch et al., 2021: A Tunguska sized airburst destroyed Tall el-Hammam a Middle Bronze Age city in the Jordan Valley near the Dead Sea" by Boslough and Bruno.

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Boslough and Bruno[1] comment on four issues from Bunch et al.[2] that all concern the Tunguska airburst in Siberia in 1908; however, they only indirectly relate to Tall el-Hammam. In general, we agree with the points raised by Boslough and Bruno, with the clarification that none of their comments are relevant to the conclusion by Bunch et al. that a low-altitude, touchdown airburst occurred over Tall el-Hammam in the Middle Bronze Age. The four examples are addressed individually below.

<u>Example 4:</u> Boslough and Bruno wrote *"There is not a single source in the vast body of scientific literature on Tunguska that suggests "hypervelocity winds" (>3 km/s) at the surface.*" We agree. Notwithstanding the title of our article, Bunch et al.[2] did not propose that the Tall el-Hammam airburst was ***<u>exactly</u>*** the same size as the Tunguska event. Instead, we mention multiple times that the airburst at Tunguska is estimated to have been somewhat

smaller than and higher in altitude than the one at Tall el-Hammam. For example, the second sentence of the abstract reads "*The proposed airburst was larger than the 1908 explosion over Tunguska....*" and later reaffirmed: "*Based on this evidence, we propose that an aerial detonation likely larger than the one at Tunguska destroyed TeH at ~ 1650 BCE.*"

To quantify this size difference, Bunch et al. presented two larger-than-Tunguska models using the Earth Impact Effects Program (created by Collins, Melosh, and Marcus[3,4]). These models demonstrated that 12- to 23-megaton Tunguska-like airbursts [60 and 75 m in diameter, respectively] could theoretically account for all evidence observed at TeH[2]. For comparison, Boslough and Crawford[5] estimate Tunguska's energy yield at 5 megatons or lower, making their estimates ~2 to 4× times lower than what was modeled for Tall el-Hammam by Bunch et al.

Boslough and Bruno also question the statement in Bunch et al. that there were hypervelocity winds >3 km/s at the surface, compared to low-velocity winds of tens of m/s at Tunguska. Once again, Tall el-Hammam is proposed as being larger than Tunguska. Both the two airburst models created by Bunch et al. produced surface airspeeds ranging from 3.5 to 4.7 km/s[2], much higher than for Tunguska.

<u>Example 1:</u> Bunch et al. wrote "*The airburst generated a pressure wave that toppled or snapped >80 million trees…*" Boslough and Bruno state that citations of this number have a long history beginning in 1934, but they suggest the number is not confirmed but rather just an estimate. We agree. However, while this concern about the validity of cited information is correct, it is entirely peripheral to the TeH investigation, as fallen trees were not part of the evidence used to support the TeH airburst hypothesis.

For completeness, we note that an independent calculation of the modern trees in the Tunguska area supports a density of approximately 80 million trees/km^2. Schultze et al.[6] investigated eight Tunguska locations, reporting values ranging from 19,100 to 175,100 trees/km^2, with a mean of 102,740/km^2. For the sake of discussion, we assume that the tree density today is similar to that in 1908. Using the well-documented impact area of 2,150 km^2, Schulze et al.'s mean density is >220 million trees. After substantial reductions for natural clearings (20%), areas of lower density (20%), and non-uniform damage patterns (20%), the total is ~88 million trees. Even though this is just an estimate, it is based on data and supports the previously reported estimate as being reasonable.

However, this entire discussion of Tunguska tree damage is irrelevant to the TeH analysis, as the evidence for the TeH airburst relies on completely different lines of evidence, including architectural destruction, human remains, and melted materials. The Tunguska tree count, whether 80 million or any other number, has no bearing on our conclusions about TeH.

Example 2: Boslough and Bruno question the statement in Bunch et al. that Tunguska trees were "up to 1-m in diameter," noting that one researcher estimated maximum diameters of 88 cm. Bunch et al. cited a source that claimed one Tunguska researcher observed fallen trees "*up to three feet [91.4 cm] in diameter.*" While both estimates are slightly below 1 m, this minor discrepancy is irrelevant to the TeH investigation, as tree diameters were not part of the evidence used to support the TeH airburst hypothesis.

Example 3: Bunch et al. wrote *"Based on atomic testing and Tunguska, the fireball … reached temperatures exceeding 300,000 °C in the center."* Boslough and Bruno correctly point out that although Glasstone and Dolan[7] report an atomic detonation with an estimated temperature of 300,000 °C (their Figure 2.123), they do not relate it to cosmic airbursts. For infalling meteoroids, some models reported temperatures ranging up to approximately 100,000 K[8-11]. Boyd[12] modeled Leonid meteoroids and found the translational temperature close to the object's surface to be almost 1,000,000 K with an adiabatic stagnation temperature of 2,500,000 K, all much higher than 300,000° C. However, Boyd cautioned that for his model, an interpretation of these high temperatures is unclear, and thus, they must be considered as only approximations.

We agree with Boslough and Bruno that 300,000 °C for the center of the TeH fireball may be too high. Even so, Bunch et al.[2] and Silvia et al.[13] reported high-temperature melted pottery and melted surficial sediment at Tall el-Hammam, and so, we maintain that the exact temperature within the proposed airburst is irrelevant to the study's proposal that a low-altitude, touchdown airburst created extremely high-temperature conditions at the Earth's surface, unlike what occurred at Tunguska.

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