Air-Driven Tsunamis from Impacts and Airbursts: Is there Evidence in the Geological or Historical Record?

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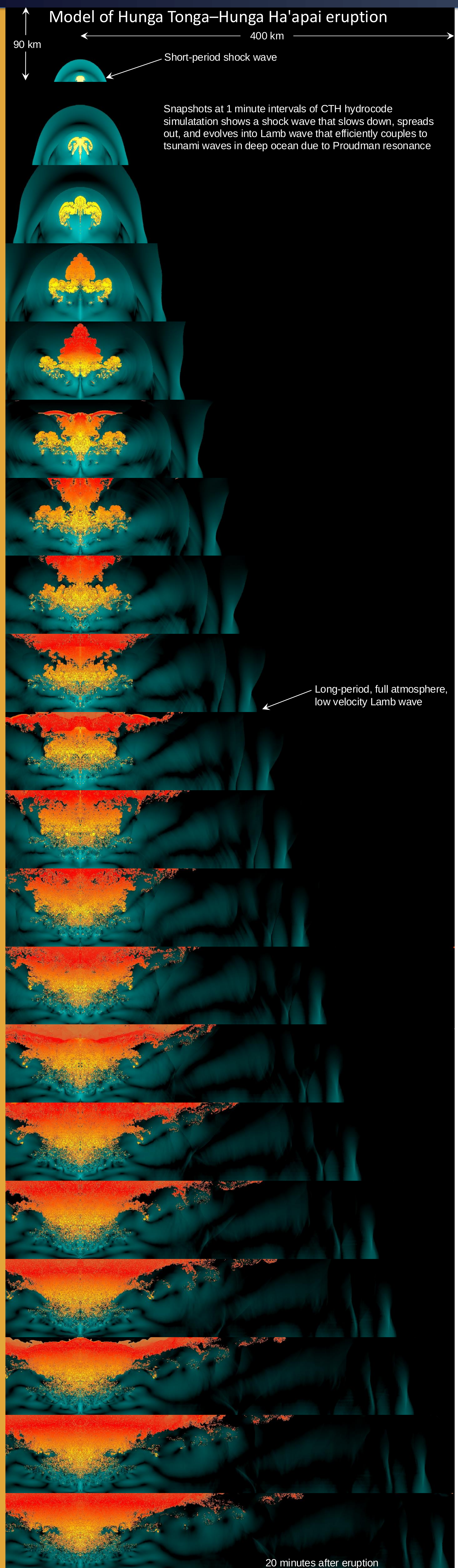
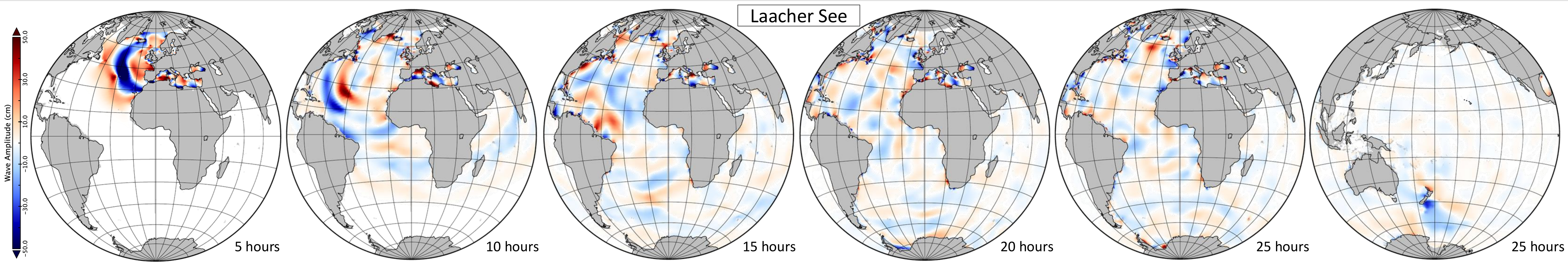
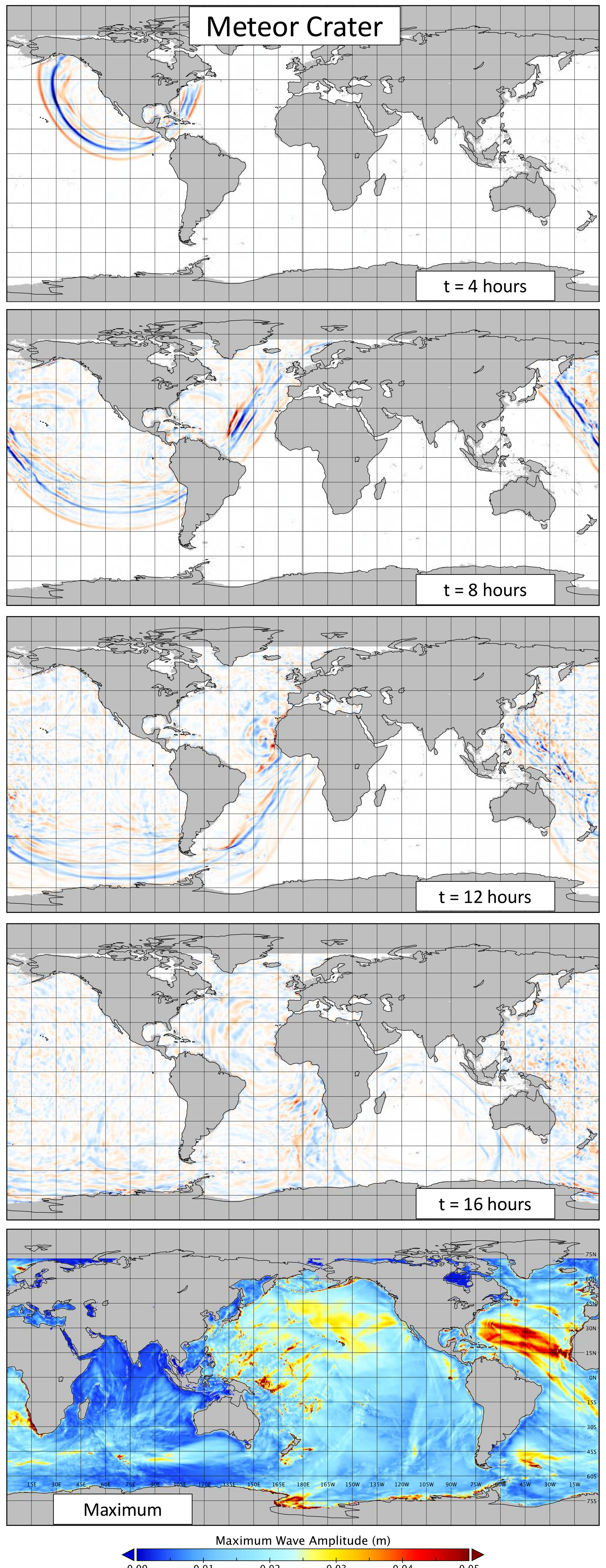
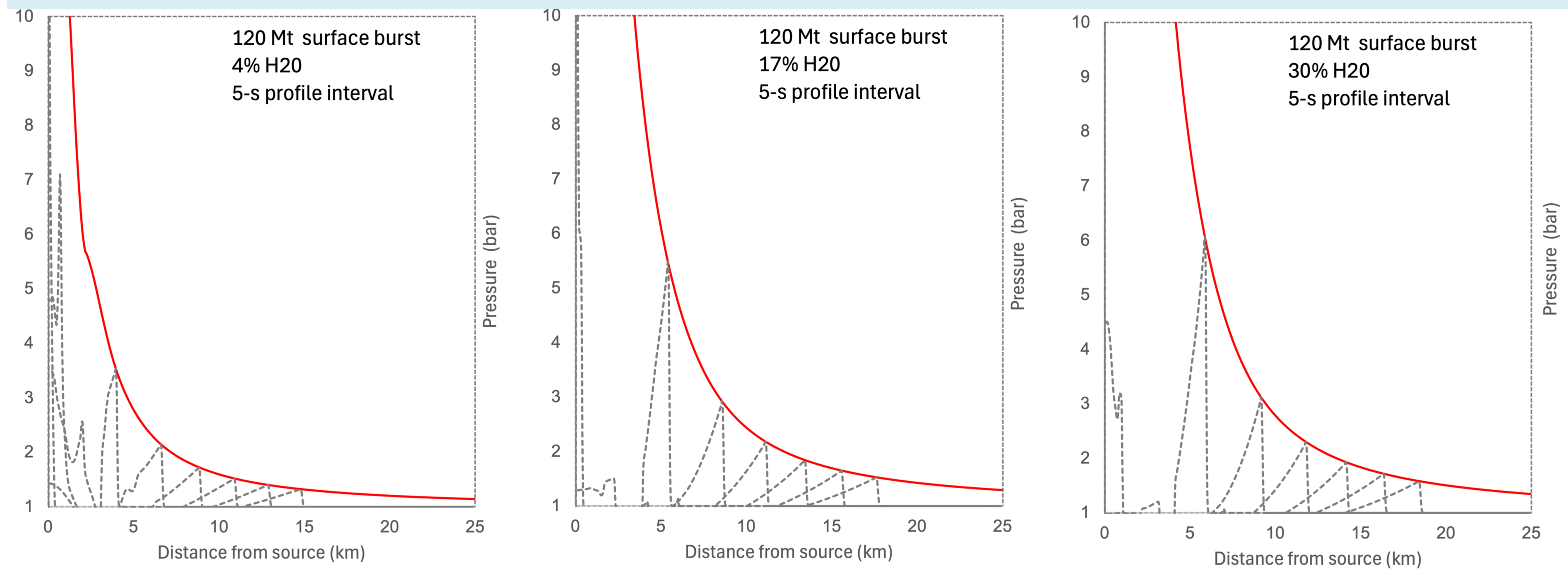




Model of Lamb-wave-driven tsunami generated by a VEI 7+ explosion at location of Laacher See in present-day western Germany. The actual magnitude estimate of the 13 ka BP eruption is VEI 6, so this simulation should be considered an upper bound on the size of the resulting global tsunami. Maximum amplitudes of about 5 meters occur near Iceland, South America, and in the Mediterranean. High amplitudes also occur along Greenland and the eastern margin of the Laurentide ice sheets. The antipode, near New Zealand, also experiences large waves. Paleotsunami deposits in of the correct age in these locations could be evidence for this event.



Plain Language Summary: We have performed hydrocode and shallow-water wave code simulations of air disturbances and tsunamis from known and hypothetical explosive sources, including explosive volcanic eruptions, crater-forming impacts, and cosmic airbursts. These sources include events that took place on land (e.g. Laacher See, Meteor Crater, and Tunguska) but nevertheless generate global Lamb waves that we suggest can drive distant tsunamis and seiches due to resonant forcing. We propose that heretofore undiscovered or unrecognized paleo tsunami deposits or historical gauge records, if they exist, could be used as validation for our models.



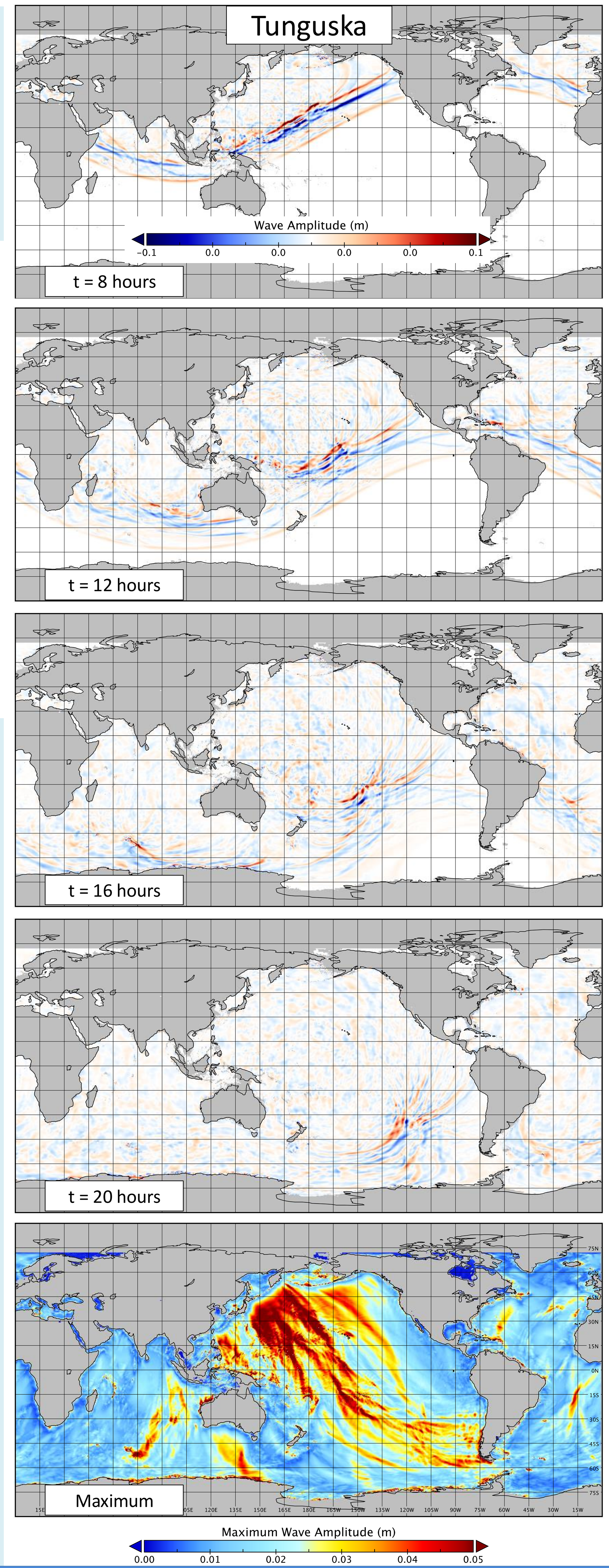
Intensity of explosive volcanic pressure wave depends on source volatile content. CTH simulations of 120 Mt magma explosions show that pressure wave amplitude increases with volatile content. This suggests that volatile-rich of target rocks generate stronger waves from impacts.

Before the 2022 explosive Hunga Tonga-Hunga Ha'apai eruption, our modeling of air-driven tsunamis from impacts and airbursts did not consider Lamb waves. We only contemplated air coupling in the vicinity of the source because blast waves and other atmospheric disturbances decay rapidly with distance from ground zero and none propagate at the Proudman resonant velocity except under rare conditions. In support of risk assessment for planetary defense and volcanic hazards, we have now modeled tsunamis driven by Lamb waves generated by explosive sources at various geographic locations, including volcanic eruptions, airbursts, and impacts. We suggest that models can potentially identify locations of paleo-tsunami deposits or historic tsunami records from known events.

We used the CTH hydrocode to model scenarios and scale resulting Lamb waves for time dependent boundary conditions in shallow-water wave propagation codes. Our sources include volcanoes (Tonga, Krakatau, Laacher See, and Toba) impacts (hypothetical PDC asteroids, Meteor Crater) and an airburst (Tunguska). Global Lamb waves can be generated by sources that are nowhere near the ocean, so tsunamis can result from crater-forming impacts or airbursts over land.

Preliminary simulations have shown, as expected, that volatile content of a volcanic magma or impact target rocks govern the efficiency by which the explosion transfers energy to the Lamb wave. For a given explosive yield, atmospheric wave amplitudes increase with water content of a magma. We expect that the Lamb wave from Meteor Crater would have high coupling efficiency due to carbonate-rich Kaibab Limestone and water-saturated Coconino Sandstone and would therefore yield larger tsunamis than an impact of the same magnitude into target rocks that are volatile poor.

We suggest that this hypothesis can be tested by performing tsunami simulations for other recent (Quaternary) known large explosive events (both impact and volcanic) in the geological record with known timing and source locations, and generating maps of peak tsunami amplitudes around the world. These maps will reveal the likely locations and ages of Lamb-wave coupled tsunami deposits from these events, which would provide confirming evidence for the hypothesis if found at the predicted locations with the right ages.



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