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Effects of Tide on Tsunami-Induced Sediment Transportation: A Case Study of Nan'ao Island in the South China Sea

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Tsunamis, as short-term events, interact with various physical processes during their propagation through the ocean, such as tides, which can influence or modify their behavior. However, in most real-world scenarios, these interactions are often considered negligible when predicting tsunamis, as tsunami-induced wave movements are typically much stronger than the background motions. Nevertheless, previous studies, including observational analyses and numerical simulations of historical and synthetic tsunamis, have consistently demonstrated that tidal conditions significantly influence tsunami behavior. This is particularly evident in regions of high tidal energy, such as rivers, inlets, harbors, and estuaries, where tsunami propagation and penetration are notably affected. While these studies emphasize the importance of addressing tsunami-tide interactions in hazard assessment research, such interactions remain insufficiently integrated into the complete life cycle of a tsunami, from its generation and propagation to coastal inundation and induced sediment transportation. In addition to integrating tidal effects into tsunami hazard assessments, analyzing the frequency of past tsunami events is also a critical aspect of regional tsunami hazard evaluation. Tsunami deposits can provide crucial insight when estimating the frequency, size, and possible source of historical tsunamis and paleo-tsunamis. To address these gaps, our study utilizes numerical experiments to investigate tsunami-induced deposits under the influence of tidal forces, thereby providing a more comprehensive simulation of the entire process of tsunami wave propagation in the open ocean.

Our study focuses on the South China Sea (SCS), where geological records have been reported in the offshore islands, indicating that a large tsunami event may have occurred 1000 years ago. Whether the SCS has experienced an ocean-wide tsunami is still debatable due to intense human activity in the coastal region and the challenge of distinguishing tsunami deposits from storm deposits. Using a forward modeling approach, COMCOT-SED (COrnell Multi-grid COupled Tsunami Model-SEDiment), we examine Qing'ao Embayment on Nan'ao Island in the northern SCS, where a sandy deposit was reported as an example of a potential tsunami deposit. To capture the influence of tides, we simulate four typical tidal phases: high tide, low tide, flood tide, and ebb tide, which represent variations in tidal amplitude and current velocity. Two representative earthquake scenarios are modeled: a northern segment fault (Mw 9.0) and a central segment fault (Mw 9.2) originating from the Manila Trench. Individual and composite simulations are conducted to explore tsunami-tide interactions and their associated sediment transport processes under these tidal conditions.

Our results reveal that the general effects of changing total water depth and current velocity (speed and direction) due to tides on tsunami-tide interactions indicate that higher tsunami heights at all phases are obtained compared to those at only-tsunami scenario. The hydrodynamic patterns of composite tsunami-tide currents strongly dependent on the tidal conditions. Tsunami-tide interactions primarily influence sediment deposition and erosion by altering water depth and flow velocity, affecting friction and bottom shear stress.

By employing numerical simulations to analyze tsunami-tide interactions and their associated sediment transport processes for the first time, this study bridges the gap between hydrodynamic patterns and deposition results. It also provides quantitative insights into the formation processes of tsunami deposits. The tsunami-tide interaction and sea level elevation must be considered when reconstructing historical and paleo-tsunamis and comparing them with tsunami deposits. Such insights are critical for improving the reliability of tsunami hazard assessments and advancing paleo-tsunami research.

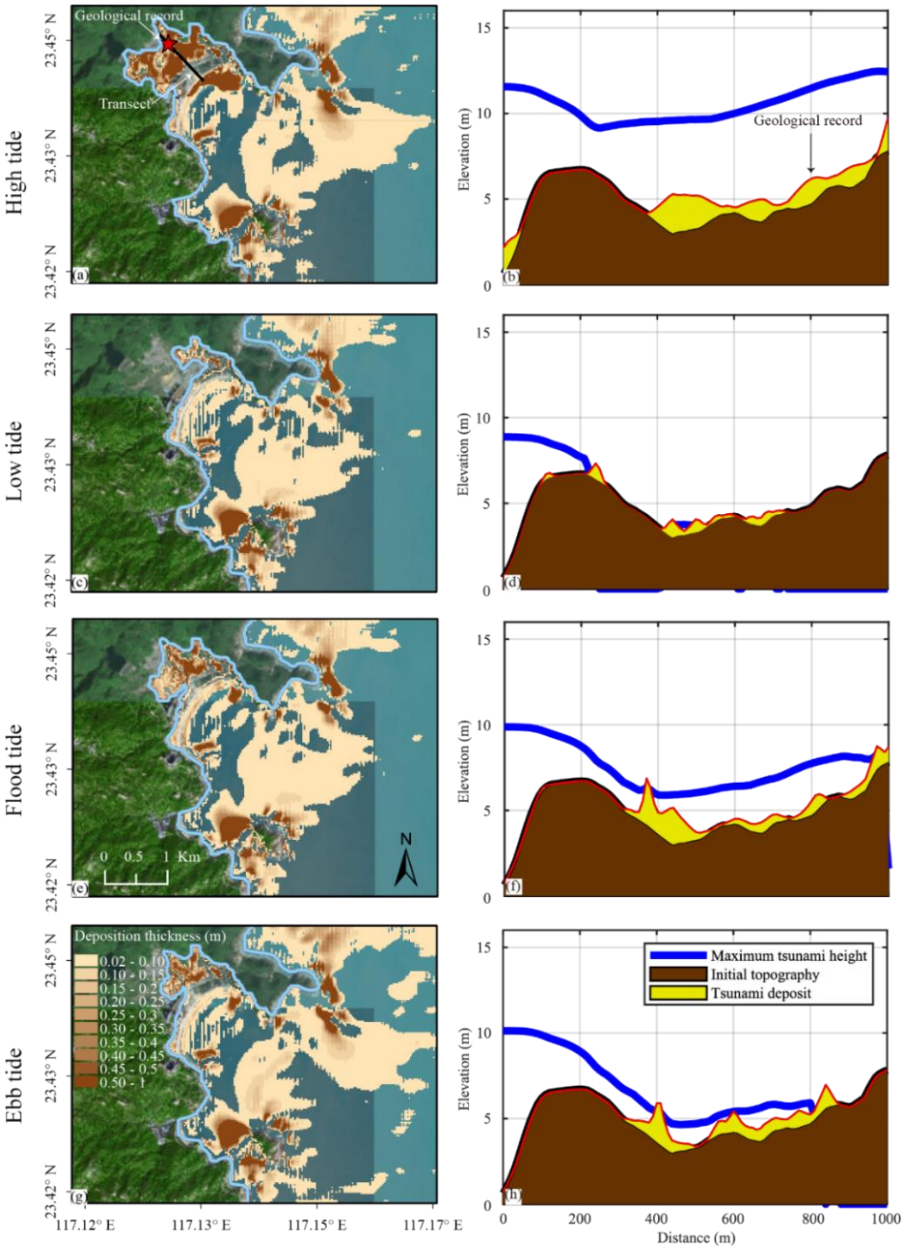

Figure 1 (a) The spatial distribution of tsunami deposit thickness under different tidal phases based on the northern segment fault model of MSZ. The pale bule line marks the run-up limitation. (b) Spatial distributions of tsunami deposits along the transect under four tidal phases. The position along transects are shown in Figure 1 (a) by black line. The location of suspected tsunami deposits proposed by Yang et al (2019) is at 800 m of transect.

Reference:

Yang, W., Sun, L., Yang, Z., et al. (2019). Nan’ao, an archaeological site of Song dynasty destroyed by tsunami. *Chinese Science Bulletin*, *64*(1), 107–120. https://doi.org/10.1360/N972018-00740