Oceanic Impacts – Types and characteristics of induced water waves. Kay Hofmann[1], Kai Wünnemann[1], and Robert Weiss[2], [1]Museum für Naturkunde, Humboldt Universität zu Berlin, Invalidenstraße 43, 10115 Berlin, Germany [2]Joint Institute for the Study of the Atmosphere and Ocean, University of Washington- National Center for Tsunami Research, Pacific Marine Environmental Laboratory, 7600 Sand Point Way NE, Seattle. WA 98115, USA. Contact: kay.hofmann@museum.hu-berlin.de.

Introduction: As Earth is covered by 2/3 of Water, it is most probable that meteorite impacts hit the ocean and generate impact induced water waves. These waves may cause great havoc to the surrounding coastline, and thus are subject to an ongoing debate, which circles around the question whether such waves can propagate on a global scale, as tsunamis generated by submarine earthquakes or whether they decay much faster due to their different wave characteristics and pose a threat only to the immediate proximity .

Some studies, e.g. by Hills [1] and Ward and Asphaug [2], imply that even small bodies, with a relatively high rate of fall, can produce a tsunami-like wave signal capable to spread out over thousands of kilometers without loosing much of their devastating force. In contrast, Melosh [3] and Korycansky and Lynett [4] argue that impact generated tsunamis are an overrated threat, because in shallow waters wave breaking and bottom friction consume a large fraction of wave energy [4].

The objective of this study is to constrain the parameters controlling the characteristics of impact induced waves close to and at some distance to the point of impact as a function of water depth relative to the size of the projectile. Previous studies focused either on specific examples of marine impact craters or they only account for the decay of the wave amplitude and the propagation velocity of the generated waves [5, 6]. The simplified assumptions for the characteristic of impact induced waves, used in studies of propagation and run-up, may not reflect the natural conditions well enough. The typical characteristic of impact-induced waves is as yet uncertain [4] and remains to be determined more thoroughly.

Numerical Model*:* We used hydrocode modeling to characterize impact induce large water waves. The iSALE [7] code has been used before in several studies of impact cratering, e.g. [8,9], and is well tested and validated against other numerical models and experimental studies. The code allows us to simulate vertical impacts on a three layer target consisting of water on top, a thin sedimentary layer in the middle, and an oceanic crust at the bottom.

Cratering mechanics and wave generation: For an average impactor [10,11,12] of stony composition (ρ = 2700 kg/m³), normal incidence and the mean impact velocity on earth of v = 18 km/s [13], only the ratio (γ=d/H) of the projectile diameter (d) and the water depth (H) defines the characteristics of the cratering process: for $\gamma < 0.1$ the water column is not completely penetrated by the projectile thus the ocean floor is only affected by the transmitted shock wave and strong water currents [11]. This type of impact is referred to as deep-water impact (DWI).

For $\gamma > 1.0$ the water column is negligible in terms of the cratering process in the ocean floor. Here we refer to shallow water impacts (SWI).

Gradual transition from DWI to SWI regime occurs within the range of γ = 0.1 to 1.0. There are two wave types that can be distinguished. One is referred to as rim wave (RW) that is generated by the ejecta flap plunging on the water. It plays an important role in SWI, but is negligible in DWI as it decays almost immediately. The water rushing back into the transient cavity in the water column, piles up to a central peak that subsequently collapses and gives rise to the Collapse Wave (CW) – due to oscillations of the central peak several generations of CW can occur.

Observed Wave Characteristics: The models are covering a γ-ratio range of 0.08 to 1.0. For describing the wave characteristic we measured surface profiles at different times, wave elevation at defined gauge points and the horizontal component of particle velocity along vertical profiles at certain distances and points of time.

In the idealized case of a long- or shallow-water wave, where virtually no dispersion occurs, the attenuation factor can be derived from linear wave theory and is proportional to $1/r^{0.5}$ for a spherically expanding wave. Dispersive waves decay much faster in proportion to $1/r^q$, where $0 \leq q \leq 1$ [2]. Attenuation coefficients larger than 1 clearly point to nonlinear effects such as dissipation via turbulence, wave breaking and wave group dynamics.

Fig. 1 shows examples of CWs in a DWI (a) and of a RW in a SWI (b). An important observation which applies for all DWI is that the 1st CW decays more rapidly and is less regular shaped for r < 26.5 km, while for r > 26.5 km a more regular shape and a slower attenuation occurs. The attenuation factor q ranges for the 1st CW from 1.8 to 3.36. For the SWI-case (γ=0.75) the RW is more important and the CW is negligible due to bidirectional water currents that lead to annihilation of the CW signal. The RW is best described by a solitary wave. Solitary waves are subject to a different decay behavior, where reduction of the amplitude is in proportion to q=2/3 [14]. For the rim wave in our models, q ranges from 1.38 for $\gamma = 0.6$ to 0.72 for $\gamma = 1.0$. Generally the attenuation factors are in good agreement with the results of previous modeling studies on oceanic impacts [5, 16].

Another important aspect is the horizontal velocity component of water particles along a vertical profile during the passage of the waves. A shallow water wave is expected to have a constant particle velocity. As Fig. 2 illustrates, in case of the CW the velocity decreases rapidly down from the surface and is almost zero at $0.5\times H$. In comparison the RW shows a constant velocity profile supporting the assumption that in this case the shallow-water wave theory is applicable. The CW does not reach down to the ocean bottom and thus decays faster than shallow water waves.

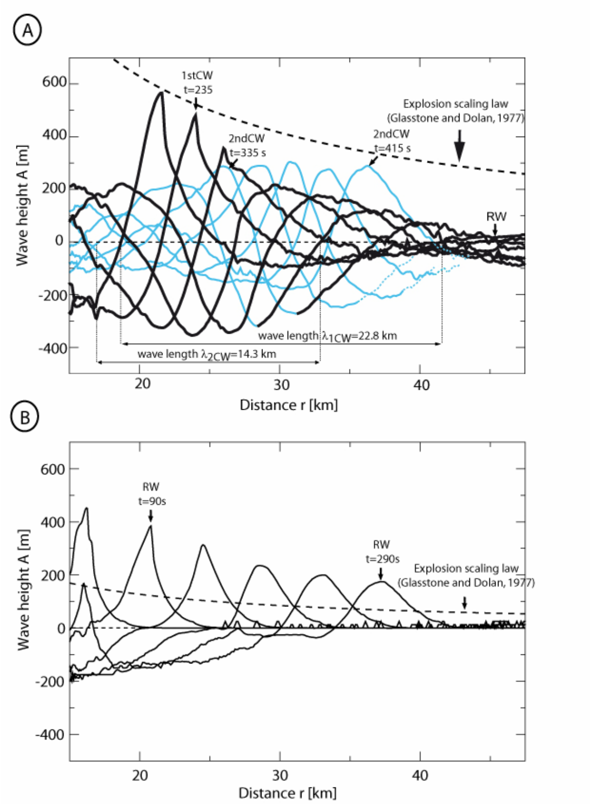

Fig. 1: *Wave profiles (distance r versus wave amplitude A) for γ=0.15 (DWI; a) and γ=0.75 (SWI; b). a) DWI, time between profiles Δt=20 s, transition between different decay regimes of 1st CW (black curves) at r_t=26.5 km. 2nd CW (light blue b) SWI, Δt=50 s, RW has got the shape of a solitary wave. Dashed line marks the wave decay after Glasstone and Dolan [15].*

Conclusion: Detailed analysis of impact generated water waves by numerical modeling demonstrates the complex characteristics and different mechanisms that are involved in the generation of large impact induced water waves. Naturally a DWI is the most likely scenario for future meteorite impacts and therefore the generation of collapse waves are of great interest for an assessment of hazardous effects of such events. The results of this study show that these waves decay much more rapidly than previously assumed [2,6,17]. However as our model characterizes only the near field up to 150 projectile radii from point of impact, we cannot rule out that the generated waves eventually evolve into shallow water waves at greater distance with much smaller attenuation rates. For a more realistic assessment of the impact tsunami hazard further work is required to investigate how wave characteristics may change with distance.

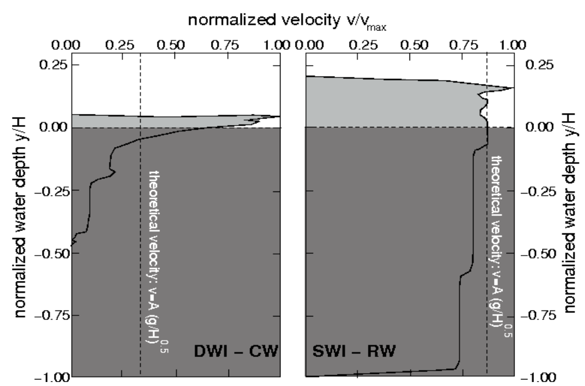

Fig. 2: *Vertical profile through the water column of the radial velocity component for the CW (r=19.6 km, t=300s) at a DWI (γ=0.15) and for the RW (r=38 km, t=300s) at a SWI. The dashed lines mark the theoretically determined velocity of a shallow water wave.*

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