QUANTIFYING THE PERTURBATION OF ATMOSPHERIC CHEMISTRY FROM MEDIUM-SIZED ASTEROID IMPACTS IN THE OCEAN. E. Pierazzo[1], R. Garcia[2], D. Kinnison[2], D. Marsh[2].
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Introduction: According to the Spaceguard program about 80% of all Near-Earth Objects (NEOs) larger than 1 km in diameter have been discovered and catalogued. While currently there are no asteroids capable of causing mass extinctions threatening Earth, there is still a large number of undiscovered NEOs between 500m and 1km in diameter that are looming in the Earth's neighborhood. The consequences of a collision of a NEO in this size range with the Earth have never been explored in detail. If headed on a collision course with Earth, such NEOs will be about 4 times more likely to hit the Earth's oceans than continental areas. Birks et al [1] carried out simulations with an upper atmosphere general circulation model coupled with an interactive chemistry model to investigate ozone depletion from oceanic impacts. This study, however, could not characterize the perturbation of the atmosphere below about 30 km, nor could it calculate its impact on the chemistry of the chlorine or bromine families, two important ozone catalysts. Here we present initial results of an investigation aimed at characterizing the effects of a medium-size oceanic impact on the lower and middle atmosphere using a whole atmosphere general circulation model with an interactive chemistry model.

Impact Simulations: We used the 3D shock physics code SOVA [2] coupled with tabular equations of state built from the ANEOS package [3] to model an asteroid impact into a 4km deep ocean. We modeled the impact of idealized spherical asteroids 500m and 1km in diameter, reaching the lower atmosphere with a velocity of 18km/s at an impact angle of 45° from the surface. The simulations started with a spatial resolution of 20 cells-per-projectile-radius over a central region around the impact point to accurately resolve the shock wave in the target (e.g., see [4]). As the simulation covered few minutes after the impacts, the mesh size boundaries were extended upward and outward to follow the expanding impact plume while the resolution decreased. For accurate estimates of the water shock state (which characterizes the amount of vaporization) we distributed several hundred thousands of lagrangian tracers in the ocean around the impact point. The fraction of water vaporized in the impact was determined by estimating the volume of water ocean shocked above 25 GPa (roughly half-way between the pressures for incipient, 5 GPa, and complete vaporization, 45 GPa, of water).

Impact Simulation Results. Overall, about 4.4×10^{12} kg and 4.4×10^{13} kg of water was ejected in the middle atmosphere (above about 15 km) in the 500m and 1km asteroid impact respectively. We assume that liquid water is removed on a short timescale, leaving about 10^{12} kg and 10^{13} kg of water vapor entrained in the upper atmosphere in the 500 and 1km asteroid impacts. The water is mostly dirstributed over a vertical column over a region a few hundreds of km in diameter. Although the impacts affected the ocean crust, no crustal material is ejected in the upper atmosphere by the impacts, and only a small component of projectile is entrained in the expansion plume

Atmospheric Model: To investigate the effects of water injection on the chemistry and dynamics of the atmosphere, we use the Whole Atmosphere Community Climate Model (WACCM) [5]. WACCM is one of a few high-top GCMs, that allow for studies of chemical, dynamical and radiative coupling processes between the lower and upper atmosphere. At all altitudes, it incorporates a fully interactive chemical mechanism (65 species) that describe reactions and photolytic processes in the middle and upper atmospheres [6].

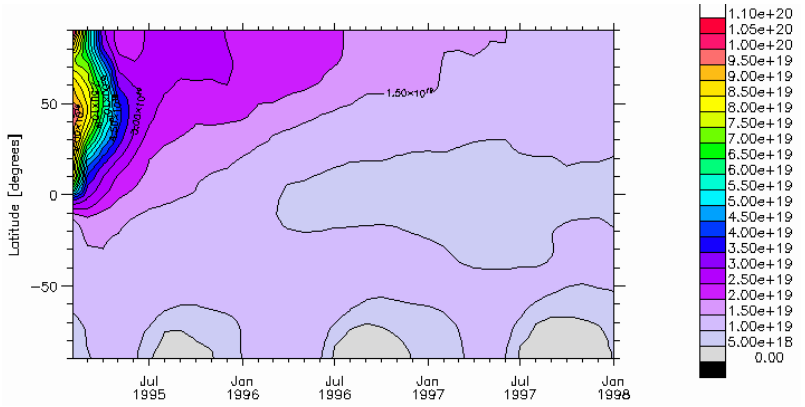

Fig. 1: Evolution of the column density (cm^{-2}) of water vapor in the WACCM domain for a 1km asteroid impact into a 4km deep ocean.

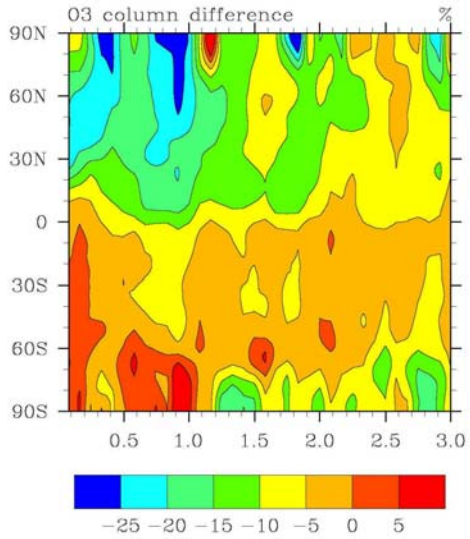

Fig. 2: Zonally averaged monthly mean differences (from unperturbed) atmospheric ozone column over the 3 years following the impact of a 500m asteroid impacting the central Pacific at 18 km/s.

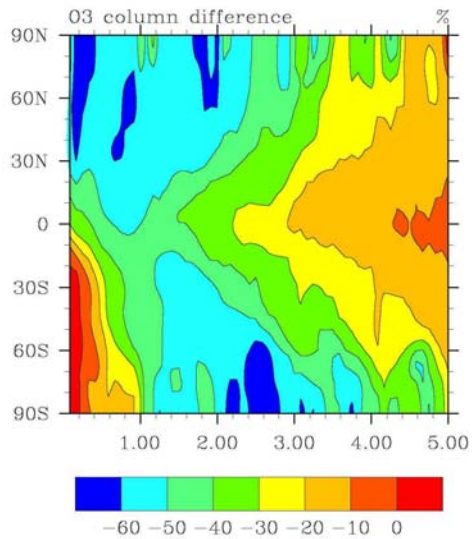

Fig. 3: Zonally averaged monthly mean differences (from unperturbed) atmospheric ozone column over the 3 years following the impact of a 1km asteroid impacting the central Pacific at 18 km/s.

Atmospheric dynamics and physics, and the interactive chemistry and physical parameterizations of the upper atmosphere are solved at each time step on a horizontal grid of 1.9°x2.5º degrees and a vertical domain of 66 levels extending from the ground to about 140 km.

Initial Conditions. Impact-released water vapor expands beyond the lower thermosphere, but the impact simulations indicates that over 60% remains below the upper limit of the WACCM model and is used as the water vapor input for the WACCM simulations. We neglect any water in the troposphere, as we assume it will be quickly removed on a timescale of a few days. We maintain a conservative approach by neglecting any water beyond WACCM's upper level, even though that water will eventually rain back down to the lower atmosphere. To maintain the water vapor mixing ratio to values compatible with the requirements of the chemistry package (chemical species are trace amounts with mixing ratios lower than 10^{-3}) we distribute the impact-generated water vapor over an area equivalent to 11 and 31 WACCM cells for the 500m and 1km asteroid impact respectively.

NO_Y and Halogens. Besides water vapor, the injection of large amounts of nitric oxides and halogens chemically activated from sea salt contained in vaporized sea water can produce significant stratospheric ozone depletion. Chlorine and bromine are injected initially as sea salts and then converted into gaseus Cl and Br species [6]. Following the approach of Birks et al. [6] we estimated amounts of impact released NO_Y, Cl and Br as fractions of water vapor released in the impact: $m_{NO} \sim 10^{-3} \times m_{H2O}$; $m_{Cl} \sim 2 \cdot 10^{-3} \times m_{H2O}$; $m_{Br} \sim 3 \cdot 10^{-6} \times m_{H2O}$. Chlorine and bromine were initially introduced in WACCM as HCl and HBr.

The impact perturbation was introduced in the subtropics, 30°N, in the Pacific Ocean in northern hemisphere winter (January).

Results: WACCM simulations were carried out respectively for 3 and 5 years after impact for the 500m and 1km diameter impactors. The evolution of the water vapor perturbation in the atmosphere (>15km) for the larger impactor is shown in Fig. 1. Figures 2 and 3 show zonally averaged monthly means of the atmospheric ozone column for the 500m and 1km asteroid cases as percentage differences from an equivalent simulation without perturbation. The 1km impact produces a significant global ozone depletion that persists for over 5 years. Recovery begins in the lower latitudes after about 4.5 years after the impact. Ozone depletion in the southern atmosphere is as sever as in the northern hemisphere, but the effect is delayed by almost 1 year. As expected, ozone depletion is milder in the 500m asteroid case and mostly limited to the northern hemisphere, with a recovery time of about 2-3 years.

This work is supported by NASA Grant NNX09AM83G.

References: [1] Birks J.W. et al. (2007) in *Comet/Asteroid Impacts and Human Society* (Bobrowsky-Rickman Eds.), Springer Pub., 225. [2] Shuvalov V.V. (1999) *Shock Waves*, *9*, 381-390; [3] Thompson and Lauson (1972) ; [4] Pierazzo E. et al. (2008) *MAPS*, *43*, 1917-1938; [5] Garcia R.R. et al. (1997) *JGR*, *112*, doi: 10.1029/2006JD007485; [6] Kinnison D.E. et al. (2007) *JGR*, *112*, doi: 10.1029/2006JD007879;