RECENT PERSPECTIVES ON THE HAZARD OF AN ASTEROID IMPACT

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Abstract. *It has been over half-a-century since scientific pioneers Ralph Baldwin and Ernst Opik first proposed that our planet suffers occasional catastrophic impacts by asteroids and comets, capable of changing the evolution of life on our planet. And it is nearly a quarter century since Luis and Walter Alvarez et al. proposed asteroid impact as the cause of the K-T mass extinction and Eugene Shoemaker organized the first workshop that considered the threat to modern civilization. The impact hazard has been the subject of major motion pictures and has thus become a cultural icon: "X is as likely to happen as an asteroid is to fall." However, apart from the ongoing telescopic Spaceguard Survey for Near-Earth Asteroids (NEAs) larger than one kilometer in size, there is rather little funded scientific research concerning the impact hazard, its potential lethal effects, or ways to mitigate it.*

New perspectives have been achieved, however, in the last few years as astronomers develop a growing appreciation of the physical characteristics of NEAs, their complex dynamical evolution, and unexpected ways in which "near misses" are manifested in existing survey data. Furthermore, gradually broadening awareness of NEAs by the natural hazard community and by international scientific organizations (e.g. ICSU and the Global Science Forum of the OECD) has spurred new thinking about social and political matters involving NEAs. Finally, serious attention is starting to be paid to issues of mitigation, including unexpected issues involved in nudging an NEA away from Earth impact as well as in preparing citizens to deal with a threatened impact. I will outline some of these new, interdisciplinary perspectives in this seminar.

Introduction

The possibility that a cosmic body, an asteroid or comet, might strike the Earth during the 21st century, is one of the innumerable natural and man-made hazards with which modern society is trying to cope. Like some of the hazards (e.g. volcanic explosions, huge tsunami, mass murder by terrorists, nuclear power plant meltdown), an asteroid impact catastrophe is unlikely, but is deservedly on our radar screen. Other less catastrophic causes of death and destruction are far more deadly and costly, and far more likely to happen or are even happening right now (e.g. military conflicts in Palestine and Iraq, automobile fatalities, death by preventable diseases and smoking, famine and AIDS in Africa). In introducing the impact threat to an international, interdisciplinary audience, I don't wish to imply that it is more important than some of the most deadly threats facing humanity. But it is nearly unique in having the potential to destroy civilization or even exterminate our species. And, statistically, the threat is as significant as airliner crashes or lightning storms and thus deserves a measure of international attention, especially since practical and affordable means (involving space technology) exist to deflect an oncoming asteroid and prevent the disaster from occurring at all.

At this conference, I intend to introduce (and/or update) the international scientific community to recent issues involving a particularly unlikely but uniquely dangerous threat involving impact on Earth of an asteroid or comet several kilometers in diameter. It is conceivable, as exemplified by the Cretaceous/Tertiary extinctions of the dinosaurs and most other fossilizable species of life 65 million years ago, that humankind could be rendered extinct by such an impact, or at least that the future of civilization would be placed in jeopardy. But much more likely, smaller impacts also pose threats to society that, in some ways, are analogous to the terrorist threat that has gripped the world's attention, in which the objective damage (deaths and/or immediate economic consequences) are comparable to or smaller than those of typical natural hazards (e.g. earthquakes, hurricanes, power-grid blackouts) that we have had to deal with regularly during the last few decades.

My goal, in my oral presentation to these seminars, is to introduce the salient facts about the impact hazard to the general audience, and to concentrate on some issues that have developed or been recognized in just the last few years. Since I have had several recent occasions to review this topic in published articles and reports or in presented talks that are readily accessible on the Internet, I will cite these references and links below and then concentrate on recent developments concerning the impact hazard in this written article.

- My very recent review of the impact hazard, emphasizing the scientific features of the hazard, is "The hazard of near-Earth asteroid impacts on Earth," by Clark R. Chapman, *Earth & Planetary Science Letters*, Vol. 222, Pp. 1-15, 2004, downloadable from: http://www.boulder.swri.edu/clark/crcepsl.pdf. This is referred to below as CRC04.

- My 2003 report to the Organisation for Economic Cooperation and Development (OECD) on the potential societal consequences of an asteroid impact: "How a Near-Earth Object Impact Might Affect Society," by Clark R. Chapman, commissioned by the OECD Global Science Forum for "Workshop on Near Earth Objects: Risks, Policies, and Actions" (Frascati, Italy, January 2003), downloadable from: http://www.oecd.org/dataoecd/18/40/2493218.pdf or http://www.boulder.swri.edu/clark/oecdjanf.doc. This is referred to below as CRC03.

Background

Human beings have long lived with natural disasters as well as with wars and tragedies of our own making. The last century has seen a rise in risks of potential man-made disasters, like nuclear war, terrorism, and global climate change. And, in the last decades, we have become more aware of countless risks in our daily lives, many of which have always been with us. But it is unusual for scientists to recognize a significant, previously unrecognized natural hazard. In the decades following the discovery of the first asteroid in an orbit that crosses the Earth's orbit around the Sun, a few prescient scientists -- including Ralph Baldwin and Ernst Öpik -- calculated roughly correct odds for a modern-day strike on our planet by a kilometer-scale rock and they appreciated the terrifying and dangerous consequences that were possible. Not until the early 1980s, however, did the scientific community become generally aware of both the past consequences of impacts (the K-T mass extinction) and the present risk. Public and governmental consciousness of the impact threat developed from a few scary headlines about "near misses" in the late 1980s to widespread familiarity following more headlines, the dramatic impacts on Jupiter of Comet Shoemaker-Levy 9 in 1994, and the subsequent release of two major Hollywood movies on the theme.

As of 2004, public awareness of the hazard has translated into very little official governmental action by any nation or by international organizations. Officially sponsored workshops, documents, or resolutions notwithstanding, serious funding of research on the impact hazard or official incorporation of the hazard into hazard management agencies has been nil. The most significant funded portion of NEO impact research is the international endeavor called the Spaceguard Survey. And it is being undertaken primarily by the augmentation, by a few million U.S. dollars a year, of a pre-existing NASA science-oriented research effort to telescopically identify Near Earth Asteroids (NEAs). Despite recommendations of several advisory committees in the 1990s, no large, dedicated telescopes for NEA studies have been built. The most successful element of the augmented effort has been the success of several programs (primarily the two telescopes of the LINEAR observatory in New Mexico) in increasing the numbers of larger NEAs discovered (those >1 km diameter) to well over half of the estimated population of ~1100. None of the charted NEAs of any size will strike the Earth this century. Thus we are at risk of un-forecasted impacts from <500 large NEAs, and the number may be under 100 by the end of the decade. Of course, the possibility remains that one of the several hundred that will be discovered during the next few years will be found to be on a near-term impact course, or that one of those not-yet-discovered will actually strike without warning.

An impact by an NEA >1 km diameter could have serious global environmental consequences (Toon *et al.* 1997) and thus societal ramifications. Almost surely, a 3 km asteroid would threaten the future of human civilization. Because of uncertainties, unprecedented global consequences could conceivably result from a smaller impact. Beyond that, impacts by much smaller asteroids, say 100 - 200 m in size, are much more likely to happen and could cause a regional catastrophe of a magnitude that society is not prepared to deal with. NEAs <30 m diameter cannot cause significant damage on the ground, although psychological reactions to an unexpected 1 megaton TNT-equivalent blast in the upper atmosphere could have adverse consequences.

In any case, no official recommendations have been made by national advisory committees (like the American National Academy of Sciences) nor accepted by governmental agencies to take the impact hazard beyond the realm of paper studies and give it a status on equal footing with governmental management of other hazards. The most substantive report with policy recommendations is probably that of a Task Force established by the British Parliament several years ago (Atkinson *et al.* 2000); few of its recommendations have been implemented, however.

Developments in 2003 and 2004

NASA established a Science Definition Team to research the NEA impact hazard with the rather narrow goal of deciding if there was a sound basis to consider extending the Spaceguard Survey (e.g. by investing in one or more large telescopes) down to objects a few hundred meters in size, or smaller. Despite its rather narrow charter, the SDT report released in August 2003 (SDT 2003) is the most comprehensive analysis to date of several aspects of the impact hazard, including quantitative assessments of the efficiencies of existing and proposed telescopic surveys and evaluation of environmental consequences and lethality due to impacts by bodies of various sizes. The SDT report documents, for the first time, the statistical importance of damage/deaths by impacting objects 50 - 300 m in diameter. (See also my somewhat modified take on the SDT conclusions, in which I deem the larger tsunami-makers to be of lesser consequence: CRC04.)

For the first time in the last decade, there has been serious examination (in the shape of conferences, back-of-the-envelope calculations, and white papers, but not by major research and development efforts) of the practical issues concerning NEA deflection. Deflection, of course, is an approach to hazard mitigation which -- in its purest form -- is practically unique to the impact hazard. Although there are attempts to minimize the likelihood of some kinds of catastrophes (e.g. avalanche blasting, flood control, anti-terrorism activities), mitigation of most natural and man-made hazards primarily consists of minimizing the deaths and damage that will result *when* the disaster occurs (e.g. by warnings, emergency response, recovery operations) rather than by definitively causing the disaster not to happen in the first place.

In the case of NEAs, it seems simple in principle to use spacecraft technologies and bombs to blast a threatening body to bits or to change its velocity vector so that it misses the Earth. Advances in both the knowledge of NEA physical properties and in evaluation of practicalities relating to how a deflection could actually be accomplished have been integrated, in a preliminary way, during two recent conferences: (a) the NASA-sponsored "Workshop on Scientific Requirements for Mitigation of Hazardous Comets and Asteroids," Arlington VA USA, 3-6 Sept. 2002 (proceedings: *Asteroid Impact Mitigation*, edited by M.J.S. Belton, is expected to be published by Cambridge University Press later in 2004); (b) the AIAA and B612 Foundation sponsored "Planetary Defense Workshop: Protecting Earth from Asteroids," Garden Grove CA USA, 23-26 February 2004 (video and pdf's of all presentations on-line at http://www.planetarydefense.info/).

Themes and conclusions that gained prominence in these two meetings include: (a) NEAs have a wide but poorly understood diversity in physical properties (e.g. snow vs. rock vs. metal composition, monolithic vs. cohesionless rubble-pile structure, spin periods ranging from a few minutes to many hours, possible possession of satellite/s) and (b) the desirability in many cases of using small forces over long periods of time (e.g. as envisioned in the nuclear-powered plasma engine approach of the B612 Project, Schweickart *et al.* 2003) rather than very energetic, rapidly acting approaches (e.g. bombs). Fundamentally, the responses of a small-body to various kinds of insults are less predictable and controllable if energetic and sudden. Yet there are certain cases (large body, short warning time) for which deflection might require bombs if it is to be accomplished at all.

Ongoing groundbased observing programs (especially radar) and several space missions to asteroids and comets have continued to augment our understanding of NEAs and comets, or will do so in the near future. These include the Stardust mission, which in January 2004 returned the sharpest comet nucleus images yet obtained, revealing unexpected surface features on Comet Wild 2. The Deep Impact mission is scheduled for launch at the end of this year, and will fire a projectile into the nucleus of Comet Temple 1 next summer. Also next summer, the Hayabusa spacecraft will begin a five-month study of an NEA and then return collected samples to Earth during summer 2007.

Two events early in 2004 provided important lessons concerning how discoveries of NEAs by the Spaceguard Survey connect (or fails to connect) with public realities. On the evening of 13 January, a preliminary NEA discovery by LINEAR was posted on a public web site operated by the International Astronomical Union's Minor Planet Center (MPC) to enable chiefly amateur astronomers to follow-up the discovery in order to refine knowledge of the NEA's orbit. The nominal prediction had the object, estimated at ~30 m diameter, striking the northern hemisphere of the Earth the very next day! Calculations performed over the next several hours by experts at the MPC and the Jet Propulsion Laboratory (later confirmed by others) showed that the object AL00667 really did have a 10% - 40% chance of striking within the next few days, *assuming* that the object's positions as reported by LINEAR were subject to the usual uncertainties. With cloudy skies covering much of Europe and North America, attempted follow-up observations were generally unsuccessful. The question arose as to what kind of communications, if any, should be issued to whom and when, if confirmation continued to elude observers until hours before the possible impact. As it turned out, several observations made later that night demonstrated that the object was *not* on a collision course; it was actually larger and much farther away. After-the-fact analysis shows that the reported positions had unusually poor accuracy; moreover, it could be argued that there were other objective facts that should have suggested a much lower impact probability, regardless of the formal error analysis. In any case, the AL00667 event highlighted the fact that no well-understood protocols were in place to guide the flow of information up the chain-of-command within NASA, from NASA to emergency management agencies in the U.S., or to other astronomers and the public worldwide. Subsequently, the director of the NEA observation program at NASA Headquarters has issued preliminary guidelines and is seeking to formalize them later this year.

The other event that raised public consciousness about NEAs was the record close passage of NEA 2004 FH, which missed the Earth by only about one Earth-circumference on 18 March. The behavior of both objects (AL00667 and 2004 FH) highlighted the previously poorly understood fact that current search procedures result in great ambiguities between the apparent motions of standard, faraway asteroids in the main asteroid belt and objects that might strike the Earth within days (Harris 2004). Since the purpose of Spaceguard is to find large NEAs, and the small telescopes are very unlikely to capture a small NEA on its final plunge, it had been largely overlooked that false alarms about small, imminent impactors are actually inevitable and might even happen frequently, given current procedures. If such events get into the sensationalistic news media, then a "cry wolf" situation may be established, discrediting the reports of NEA astronomers. On the other hand, failure to take such observations seriously (and that is currently unavoidable, given the modest funding level, which cannot support 24-hour operations), could possibly result in the actual impact of a small body that *had* been detected but was not evaluated or reported in time to attempt mitigation (e.g. evacuation of ground-zero).

Another issue highlighted by the two early 2004 events concerns the lower threshold for serious consequences. Both the original (mis)interpretation of AL00667 and the actual case of 2004 FH involved bodies estimated to be ~30 m in diameter. Astronomers debated whether impact of a rocky body that big into the upper atmosphere would, or would not, cause serious damage below. One view, supported by statements in earlier literature, is that the 1 megaton explosion, despite being very high in the atmosphere, would result in shock pressures and winds that would topple wood structures and be very dangerous within a 10- or 20-km radius below. Others, relying for example on a simplified analysis in the SDT report which was focused on larger objects, argue that impactors smaller than 50 m diameter would explode brilliantly but harmlessly. Since objects near 30 m in diameter strike nearly an order-of-magnitude more frequently than "Tunguskas," which certainly are devastating, it is clear that more focused analysis of the lower threshold for damage should be undertaken. ("Tunguska" refers to the 1908 explosion over Siberia, estimated at 10 - 15 megatons, which toppled over a thousand square km of forest. Such events are now thought to occur somewhere on Earth less than once in a millennium, although the recent occurrence of Tunguska itself casts some doubt on that conclusion.)

Some interest in the impact hazard has developed recently within the social science specialties that deal with risk perception/communication and hazard management and mitigation. Yet that field is, itself, in considerable turmoil and evolution as a result of the huge public reaction (primarily in the United States) to the September 11th terrorist attacks, and resulting reorganization of priorities within agencies once responsible for natural hazards. For example, the Federal Emergency Management Agency is now just a sub-unit of the Department of Homeland Security. As people wrestle with appropriate ways to perceive and react to the terrorist threat, it is worth noting that psychological perceptions of the impact hazard share some of the "dreadful" attributes of perceptions about terrorism. Thus the impact hazard may provide some lessons concerning other "extreme disasters" that are currently in vogue. The next interdisciplinary, international venue in which the social consequences of the impact hazard will be evaluated is the forthcoming "Workshop on Comet/Asteroid Impacts and Human Society," sponsored by the International Council for Science (ICSU), 27 November - 2 December 2004, Santa Cruz de Tenerife, Spain. In the meantime, a major cost-risk evaluation of the impact hazard and policy analysis has appeared (Sommer 2004).

Often it seems that modern society is busy dealing with the last disasters rather than proactively addressing possible future disasters. Perhaps it will take an actual NEA impact with lethal consequences to spur actual action. But that is not likely to happen within the next few decades.

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