with microbarometers in order to clean routinely the signal from the atmospheric pressure effect.

URL: http://geoscope.ipgp.jussieu.fr

U22B MCC: 2002-2004 Tuesday 1340h

Estimating the Consequences of Severe Geophysical Events I

Presiding: **A Nur,** Stanford University**; R L Wesson,** U.S. Geological Survey

U22B-01 1340h

Oil & War: Revisiting M. King Hubbert's predictions.

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Oil is, unlike almost any other natural resource on earth, not only finite but also irreversibly consumed. At the same time worldwide data shows that at least at present and for the foreseeable future oil consumption rate is directly proportional to the national standard of living. In 1956 and again in 1962, M. King Hubbert predicted, using a simple model based on the logistic equation, that oil production in the lower 48 United States will follow a bell shaped curve with a production peak around the year 1971 and a production level of 3 billion barrels per year, followed by a rapid decline. While his model approach was ridiculed at the time production data to date reveals a remarkable agreement with this prediction: US oil production did peak in 1971 at a level of 3.2.10 barrels a day and has been declining ever since. M. King Hubbert similarly estimated also the future of oil production worldwide - predicting peak production sometime between 1995-2010 (now!) at a level of 25 to 35 billion barrels per year. Current worldwide production is 27 billion barrels per year. Thus because about half of the oil in earth has already been discovered, the world is destined to face more and bigger conflicts over the control of global supplies. Although many economists and political scientists tend to dismiss the significance of Hubbert's thinking about the finiteness of recoverable oil as well as the consequent implications, it appears that without careful management these conflicts could turn into wars much bigger than in Kuwait in 1991 or in Iraq in 2003. It is therefore imperative for us as earth scientist to try to educate the public and our leaders about the basic geological reality of finite fossil energy resources, and the serious consequences of this fact.

U22B-02 1405h INVITED

Large Earthquakes in Developing Countries: Estimating and Reducing their Consequences

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Recent efforts to reduce the risk of earthquakes in developing countries have been diverse, earnest, and inadequate. The earthquake risk in developing countries is large and growing rapidly. It is largely ignored. Unless something is done - quickly - to reduce it, both developing and developed countries will suffer human and economic losses far greater than have been experienced in the past. GeoHazards International (GHI) is a nonprofit organization that has attempted to reduce the death and suffering caused by earthquakes in the world's most vulnerable communities, through preparedness, mitigation and prevention. Its approach has included raising awareness, strengthening local institutions and launching mitigation activities, particularly for schools. GHI and its partners around the world have achieved some success: thousands of school children are safer, hundreds of cities are aware of their risk, tens of cities have been assessed and advised, and some local organizations have been strengthened. But there is disturbing evidence that what is being done is insufficient. The problem outpaces the cure. A new program is now being considered that would attempt to improve earthquake-resistant construction of schools, internationally, by publicizing well-managed programs around the world that design, construct and maintain earthquake-resistant schools. While focused on schools, this program might have broader applications in the future.

U22B-03 1430h INVITED

Consequences of Predicted or Actual Asteroid Impacts

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Earth impact by an asteroid could have enormous physical and environmental consequences. Impactors larger than 2 km diameter could be so destructive as to threaten civilization. Since such events greatly exceed any other natural or man-made catastrophe, much extrapolation is necessary just to understand environmental implications (e.g. sudden global cooling, tsunami magnitude, toxic effects). Responses of vital elements of the ecosystem (e.g. agriculture) and of human society to such an impact are conjectural. For instance, response to the Blackout of 2003 was restrained, but response to 9/11 terrorism was arguably exaggerated and dysfunctional; would society be fragile or robust in the face of global catastrophe? Even small impacts, or predictions of impacts (accurate or faulty), could generate disproportionate responses, especially if news media reports are hyped or inaccurate or if responsible entities (e.g. military organizations in regions of conflict) are inadequately aware of the phenomenology of small impacts. Asteroid impact is the one geophysical hazard of high potential consequence with which we, fortunately, have essentially no historical experience. It is thus important that decision makers familiarize themselves with the hazard and that society (perhaps using a formal procedure, like a National Academy of Sciences study) evaluate the priority of addressing the hazard by (a) further telescopic searches for dangerous but still-undiscovered asteroids and (b) development of mitigation strategies (including deflection of an oncoming asteroid and on- Earth civil defense). I exemplify these issues by discussing several representative cases that span the range of parameters. Many of the specific physical consequences of impact involve effects like those of other geophysical disasters (flood, fire, earthquake, etc.), but the psychological and sociological aspects of predicted and actual impacts are distinctive. Standard economic cost/benefit analyses may not apply due to the exceptional rarity of major impacts.

U22B-04 1455h

Hurricanes: The Consequences of the Energy Equivalent of a 10-megaton Nuclear Bomb Exploding Every 20 Minutes

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Through the ages tropical cyclones have killed and maimed millions of people, devastated economies, and profoundly altered physical and political landscapes. Both the nature of the threat and the human response have evolved. The largest losses of life have shifted with the population, from on the sea during the era of global exploration, to the coastline and, now, increasingly to inland areas. At the same time, the primary threat has changed from winds and waves to storm surge and freshwater floods. An international and multidisciplinary collaboration over the past half century has focused on identifying and minimizing tropical cyclone risks through advancing operational hurricane forecasting, improving communications systems, and heightening public awareness. In the United States, meteorologists and emergency managers work together closely to reduce the frequency of the most catastrophic outcomes. This paper reviews the most significant historical impacts, the contemporary challenges, and highlights of the most successful current mitigation strategies of the U.S. hurricane warning program.

U22B-05 1520h

Volcanic Catastrophes

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The big news from 20th century geophysics may not be plate tectonics but rather the surprise return of catastrophism, following its apparent 19th century defeat to uniformitarianism. Divine miracles and plagues had yielded to the logic of integrating observations of everyday change over time. Yet the brilliant interpretation of the Cretaceous-Tertiary Boundary iridium anomaly introduced an empirically based catastrophism. Undoubtedly, decades of contemplating our own nuclear self-destruction played a role in this. Concepts of nuclear winter, volcanic winter, and meteor impact winter are closely allied. And once the veil of threat of all-out nuclear exchange began to lift, we could begin to imagine slower routes to destruction as "global change". As a way to end our world, fire is a good one. Three-dimensional magma chambers do not have as severe a magnitude limitation as essentially two-dimensional faults. Thus, while we have experienced earthquakes that are as big as they get, we have not experienced volcanic eruptions nearly as great as those preserved in the geologic record. The range extends to events almost three orders of magnitude greater than any eruptions of the 20th century. Such a calamity now would at the very least bring society to a temporary halt globally, and cause death and destruction on a continental scale. At maximum, there is the possibility of hindering photosynthesis and threatening life more generally. It has even been speculated that the relative genetic homogeneity of humankind derives from an evolutionary "bottleneck" from near-extinction in a volcanic cataclysm. This is somewhat more palatable to contemplate than a return to a form of Original Sin, in which we arrived at homogeneity by a sort of "ethnic cleansing". Lacking a written record of truly great eruptions, our sense of human impact must necessarily be aided by archeological and anthropological investigations. For example, there is much to be learned about the influence of volcanism on humankind in the North Pacific, where Holocene time saw many caldera-forming eruptions in an area of comparatively intense human activity.

U22C MCC: 2002-2004 Tuesday 1600h

Estimating the Consequences of Severe Geophysical Events II

Presiding: **A Nur,** Stanford University**; R L Wesson,** U.S. Geological Survey

U22C-01 1600h

"Dangerous" Climate Change

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Current climate change mitigation policy decisions must be made despite layers of uncertainty. Modeling of future climate, projections for future economic growth and greenhouse gas emissions, and characterizations of the interactions and feedbacks within the coupled social-natural system all contain uncertain components. Researchers communicating with policymakers have learned that, instead of presenting "best guesses" or other point estimates, uncertainty assignments require such techniques as probability distributions of outcomes and quantitatively defined descriptions of subjective confidence. We present a quantification of "dangerous" climate change, a term important in policy discussions. Article 2 of the United Nations Framework Convention on Climate Change expresses the opinion of the signing Parties that steps be taken to "prevent dangerous anthropogenic interference with the climate system," but the Convention did not specify what constitutes the value judgment of being "dangerous." We present one possible definition. A threshold for "dangerous" climate change is a clear tool for evaluating the need for and impact of proposed climate policy. Monte Carlo analyses with a simple integrated assessment model demonstrate that endogenously calculated climate policy controls appreciably reduce the probability of "dangerous" climate change. Under mid-range assumptions, climate policy reduces the probability of "dangerous" climate change by 30-50%.

URL: http://www.stanford.edu/~shs

U22C-02 1615h

A "CLIPER" Risk Model for Insured Losses From US Hurricane Landfalls and the Need for an Open-Source Risk Model

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To plan for the consequences of hurricanes, earthquakes, and other natural hazards the public and private sectors use a variety of risk models. Model output is tailored for specific users and includes a range of parameters including: damage to structures, insured losses, and estimates of shelter requirements to care for people displaced by the catastrophe. Extensive efforts are made to tune risk models to past events. However, model "forecasts" of losses are rarely verified through a comparison with new events. Instead, new events generally are used to further tune a new version of the model. In addition, there has been no public attempt to determine which model has the most predictive skill, in part because there is no agreed upon reference forecast, and in part because most risk models are proprietary. Here I describe a simple risk model that can be used to provide deterministic and probabilistic exceedance probabilities for insured losses caused by hurricanes striking the US coastline. I propose that loss

estimates based on the approach used in this simple model can be used as a reference forecast for assessing the skill of more complex commercial models. I also suggest that an effort be initiated to promote the development of an open-source risk model. The simple risk model combines wind speed exceedance probabilities estimated using the historical record of maximum sustained winds for hurricanes at landfall, and a set of normalized insured losses produced by landfalling hurricanes. The approach is analogous to weather, or climate, forecasts based on a combination of CLImatology and PERsistence (CLIPER). The climatological component accounts for low frequency variability in weather due to factors such as seasonality. The analog to climatology in the simple risk model is the historical record of hurricane wind speeds and insured losses. The insured losses have been corrected for the effects of inflation, population increases, and wealth, and other factors. The persistence component of CLIPER forecast accounts for higher frequency variability induced by phenomenon such as storms that have time scales of a few days. The analog to persistence in the simple risk model is the ability to account for climate variability associated with changes in the El Nino-Southern Oscillation and the North Atlantic Oscillation. Over the past three years model estimates of insured losses from landfalling hurricanes compare well with actual insured losses. However, it is difficult to assess how the model compares with commercial models because of proprietary concerns and nondisclosure agreements. The wide range of risk model users is an indication of the value of risk models. However, the proprietary nature of most risk models can produce problem. For example, Florida is developing its own Hurricane Loss Projection Model for regulatory purposes in part because the proprietary risk models are not open to public scrutiny. An open-source risk model could benefit any such effort to develop a custom risk model and provide a standard that could be used for regulatory and financial purposes. In addition to the ongoing work by Florida, there are other efforts to develop parts of an open-source risk model. For example, the USGS and the Southern California Earthquake Center (SCEC) are developing open-source modules for seismic hazard analysis. A more formal community effort to develop components of an open-source risk model for a variety of hazards would benefit both the public and private sector, minimize duplication of effort, and maximize the use of limited resources.

U22C-03 1630h

A Volcano Population Index for Estimating Relative Risk With Example Data From Central America

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We have developed a Volcano Population Index (VPI) to make objective comparisons among individual volcanoes of populations that may be subject to volcanic hazards. We used volcano location data from the Smithsonian's Global Volcanism Program (GVP) with the LandScan 2001 gridded global population data base from the Oak Ridge National Laboratory to evaluate population distribution near potentially active volcanoes in Central America. The LandScan database reports global ambient population on a 30- by 30-arc second grid (about 1 km by 1 km). The countries in Central America with volcanoes of Holocene age (<10 ka) are Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama. The VPI is defined as the sum of the population values of all LandScan 2001 cells within 10 km (VPI_{10}) of the coordinates given for each Holocene volcano in the Smithsonian GVP catalog. An analysis of recent evacuations in the region in response to volcanic activity and a global compilation of eruption data by Newhall and Hoblitt (2002) prompted us to also evaluate population within 5 km of Holocene volcanoes and create a 5 km Volcano Population Index (VPI_5). The VPI5 is an estimate of the number of people who will almost certainly have to be evacuated and cared for over some time period while an eruption is underway. There will almost always be some volcanic phenomena that adversely affects people within 10 km of the vent, and if an eruption is big enough, acute hazards may easily reach 10 km or more in any direction. We view the VPI_{10} as an estimate of the number of people who may have to be evacuated and cared for, and we use the VPI_{10} as the principal population statistic for comparison among individual volcanoes. We calculated the VPI statistics for 75 Central American Holocene volcanoes and report a country by country summary of population within 10 km of Holocene volcanoes that shows the relative exposure to volcano hazards in Central America. We also analyzed the historically-active subset of the Holocene volcanoes. In the region, approximately 4,960,000 persons are located within 10 km of a Holocene-age volcano and of these approximately 2,270,000 persons are within 10 km of an historically active volcano. Fully one third of El Salvador's ambient population, approximately 2.3 million, is within 10 km of a potentially active volcano, and 1,390,000 of these are actually within 10 km of an historically active volcano. Populations in Guatemala and Nicaragua have the next greatest potential exposure to volcano hazards (over 1 million each). All three countries have at least one major urban area within 10 km of a potentially active volcano. Newhall CG, Hoblitt RP (2002) Constructing event trees for volcanic crises. Bull Volcanol 64:3-20

U22C-04 1645h

Earthquake Loss Estimation: What Matters?

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A simple earthquake loss model was developed and used to evaluate the relative importance of the different types of Earth science information that are required to estimate losses to single-family residences from earthquake shaking. The evaluation indicates that refining the characterization of the magnitude and frequency of future earthquakes and mapping surficial geology to enable predictions of regional variation of local site amplification are the most important contributions that the Earth sciences can make to improve earthquake loss estimates. The loss model that was used for the evaluation predicts damage to masonry and wood-frame single-family residences. Structural damage was predicted with both the ATC-13 and HAZUS methodologies. The loss model incorporated three aspects of Earth science information: (1) the earthquake source, (2) ground-motion attenuation, and (3) soil type. Properly characterizing the earthquake source has the greatest impact on loss estimation. Whereas large earthquakes are the most costly events, cumulative losses from moderate (M∼6.5) earthquakes can easily exceed the loss from a single large (M∼7.5) event. If the damaged properties are covered by typical earthquake insurance policies and deductibility is taken into account, the cumulative impact of moderate earthquakes may be even more severe from the perspective of the insured; much of the cumulative losses may not be covered by insurance because of the high deductible of the typical policy. Geographic variability of local site amplification, which can be inferred from surficial geologic maps, also may have a significant impact. Loss estimates, based on ground-motion amplification factors in the NEHRP site classification, may vary by almost threefold depending on soil type. Future refinements of ground-motion attenuation curves are not likely to substantially improve loss estimation in the western United States. The range of ground motion predicted by published attenuation curves does not produce significantly different estimates of loss. By contrast, the range of ground motion predicted by different attenuations relations proposed for the eastern United States, particularly for one-second spectral accelerations, produces significantly different estimates of loss.

U22C-05 1700h

Estimation of Future Earthquake Losses in California

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Recent developments in earthquake hazards and damage modeling, computing, and data management and processing, have made it possible to develop estimates of the levels of damage from earthquakes that may be expected in the future in California. These developments have been mostly published in the open literature, and provide an opportunity to estimate the levels of earthquake damage Californians can expect to suffer during the next several decades. Within the past 30 years, earthquake losses have increased dramatically, mostly because our exposure to earthquake hazards has increased. All but four of the recent damaging earthquakes have occurred distant from California's major population centers. Two, the Loma Prieta earthquake and the San Fernando earthquake, occurred on the edges of major populated areas. Loma Prieta caused significant damage in the nearby Santa Cruz and in the more distant, heavily populated, San Francisco Bay area. The 1971 San Fernando earthquake had an epicenter in the lightly populated San Gabriel Mountains, but caused slightly over 2 billion dollars in damage in the Los Angeles area. As urban areas continue to expand, the population and infrastructure at risk increases. When earthquakes occur closer to populated areas, damage is more significant. The relatively minor Whittier Narrows earthquake of 1987 caused over 500 million dollars in damage because it occurred in the Los Angeles metropolitan area, not at its fringes. The Northridge earthquake had fault rupture directly beneath the San Fernando Valley, and caused about 46 billion dollars in damage. This vast increase in damage from the San Fernando earthquake reflected both the location of the earthquake directly beneath the populated area and the 23 years of continued development and resulting greater exposure to potential damage. We have calculated losses from potential future earthquake, both as scenarios of potential earthquakes and as annualized losses considering all the potential earthquake sources included in the national seismic hazard maps. Initial results give an expected annual loss in California of 2.2 billion dollars. This estimate is based on the 2002 CGS-USGS ground motion data and the 1997 NEHRP soil amplification factors. It should be pointed out that these results are very sensitive to the soil amplification factors used in the analysis. Using amplification factors from Boore, Joyner and Fumal, 1997, which had been used in previous CGS loss estimation studies, the state wide estimated annual loss becomes roughly 3.3 billion dollars. The estimates presented in this study include only structural and non-structural damage to buildings. Experience with real earthquakes suggest that when associated losses, such as losses to contents, inventory and income, are included, the total expected annual would be considerably larger.

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U22C-06 1715h

REAL-TIME LOSS ESTIMATION USING HAZUS AND SHAKEMAP DATA

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This paper describes real-time damage and loss estimation using the HAZUS earthquake loss estimation technology and ShakeMap data, and provides an example comparison of predicted and observed losses for the 1994 Northridge earthquake. HAZUS [NIBS, 1999, Kircher et al., 1997a/1997b, Whitman et al., 1997] is the standardized earthquake loss estimation methodology developed by the National Institute of Building Sciences (NIBS) for the United States Federal Emergency Management Agency (FEMA). HAZUS was originally developed to assist emergency response planners to "provide local, state and regional officials with the tools necessary to plan and stimulate efforts to reduce risk from earthquakes and to prepare for emergency response and recovery from an earthquake." HAZUS can also be used to make regional estimates of damage and loss following and earthquake using ground motion, ShakeMap, data provided by the United States Geological Survey (USGS) as part of Tri-Net in Southern California [Wald et al., 1999] or by other regional strong-motion instrumentation networks.

U22C-07 1730h

Estimating System Impact of Earthquakes on a Major Metropolitan Roadway Network

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The impact of an earthquake on the Memphis, TN, roadway system has been estimated using a prototype computer program, REDARS (Risks from Earthquake DAmage to Roadway Systems). For scenario earthquakes, the program computes ground motions and ground deformations at bridges and other components throughout the system. Then, estimates of costs and times to repair this damage, together with the component's ability to accommodate traffic flows during repairs, are estimated, and these are used to establish modified post-earthquake system states at various times after the earthquake. Transportation network analysis procedures are then applied to each system state, in order to estimate how post-earthquake traffic flows and travel times are affected by these various roadway closures. Consequences of this damage to the roadway system, in terms of economic losses, reduced access to key locations in the regions (e.g., hospitals, airports, etc.) are then estimated. Uncertainties are incorporated throughout. Using Monte Carlo simulation in earthquake occurrence and modeled uncertainties, the program was used to produce a 50,000-year history of annual estimated drive-time loss in dollars, with nearly 800 non-zero loss years. The ordered list of annual losses makes up an empirical annual-rate loss

distribution function. From this list, likelihood functions for the 500-yr and 2500-yr losses can be obtained, yielding most likely values of about 300 million dollars and 600 million, respectively, with ranges of uncertainty (10th to 90th percentile) of about 10 and 20 percent. The ordered list of non-zero losses is nearly exponentially distributed. This simple structure permits estimation, through the employment of bootstrapping with variance-reduction techniques, of the average conditional loss around several tens of times more precise than the average of the simulated losses. The model for earthquake magnitude, locations, and occurrence frequency has been taken from the US Geological Survey sources used for national hazard mapping in the central United States.

U22C-08 1745h

A Probabilistic Benefit Cost Analysis of Seismic Retrofitting of Apartment Houses in Turkey

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Three different seismic retrofitting measures for a common and vulnerable type of apartment building in Istanbul are studied in this paper. A probabilistic cost benefit analysis is carried out by means of obtaining the fragility curves of the structure in its retrofitted configurations. These curves are calculated using a Monte Carlo simulation, that is subjecting the three dimensional nonlinear model of the structure to 400 ground motion acceleration time histories compatible with the site specific elastic response spectrum. Considering a time independent probabilistic distribution of the peak ground accelerations for the region and a given discount rate, the expected losses can be estimated in present value terms for the desired time horizon. Even considering only direct losses, mitigation is shown to be cost effective for all but the very short time-horizons provided that the cost of life is far higher than the material costs. The methodology presented here is attractive for application at a regional level incorporating different types of soils and different types of structures and it may be of use to support urgent decisions on retrofitting strategies. A time dependent probability distribution of accelerations can be readily implemented in the methodology.

U31A MCC: 3016 Wednesday 0800h

Health, Air Pollution, and Climate I

Presiding: **T Holloway,** Gaylord Nelson Institute for Environmental Studies, University of Wisconsin-Madison**; G McKinley,** Princeton University

U31A-01 0800h

Overview of Issues in Health, Air Pollution, and Climate

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Air pollution contributes to mortality and respiratory disease worldwide, with developing countries at highest risk. The World Health Organization estimates that between 1.4 and 6 million people die each year from air pollution, and in some populations up to 30 % of all respiratory disease may be linked to air pollution. As the climate changes, increasing temperatures and changing precipitation patterns are expected to yield new health challenges and may worsen existing risks. This talk provides an overview of issues linking health impacts of air pollution and climate change, as an introduction for the session. Increasingly, health-driven projects are employing state-of-the-art modeling and measurement methodologies. We discuss how quantitative assessment methodologies have been used to understand the connections between health, air pollution and climate.

U31A-02 0820h INVITED

Health Impacts of Air Pollution Under a Changing Climate

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Outdoor air pollution remains a serious public health problem in cities throughout the world. In the US, despite considerable progress in reducing emissions over the past 30 years, as many as 50,000 premature deaths each year have been attributed to airborne particulate matter alone. Tropospheric ozone has been associated with increased daily mortality and hospitalization rates, and with a variety of related respiratory problems. Weather plays an important role in the transport and transformation of air pollution. In particular, a warming climate is likely to promote the atmospheric reactions that are responsible for ozone and secondary aerosol production, as well as increasing emissions of many of their volatile precursors. Increasingly, efforts to address urban air pollution problems throughout the world will be complicated by trends and variability in climate. The New York Climate and Health Project (NYCHP) is developing and applying tools for integrated assessment of health impacts from air pollution and heat associated with climate and land-use changes in the New York City metropolitan region. Global climate change is modeled over the 21st century based on the Intergovernmental Panel on Climate Change (IPCC) A2 greenhouse gas emissions scenario using the Goddard Institute for Space Studies (GISS) Global Atmosphere-Ocean Model (GCM). Meteorological fields are downscaled to a 36 km grid over the eastern US using the Penn State/NCAR MM5 mesoscale meteorological model. MM5 results are then used as input to the Community Multiscale Air Quality (CMAQ) model for simulating air quality, with emissions based on the Sparse Matrix Operator Kernel Emissions Modeling System (SMOKE). To date, simulations have been performed for five summer seasons each during the 1990s and the 2050s. An evaluation of the present-day climate and air quality predictions indicates that the modeling system largely captures the observed climate-ozone system. Analysis of future-year predictions shows an increase in temperature and humidity as well as mean and extreme ozone concentrations under the IPCC A2 emission scenario. To address public health impacts, a risk assessment framework is used to estimate ozone-related mortality in the region, with a focus on comparing health impact estimates for the 1990s versus the 2050s. This endpoint represents a potentially appreciable public health impact resulting from climate change-induced alterations in regional air quality profiles. Concentration-response functions from the epidemiological literature describing ozone-mortality relationships are used to estimate numbers of regional deaths in a typical 1990s summer and a typical 2050s summer. Preliminary analysis of future-year ozone-related mortality suggests a subtle increase in the number of summer ozone-related deaths in the New York region in the 2050s as compared to the 1990s. A parallel evaluation of heat-related mortality in a typical summer of the 2050s suggests a greater relative increase as compared to the 1990s, with a doubling to tripling of regional summer heat deaths possible by the 2050s.

U31A-03 0845h INVITED

Greenhouse Gas and Particulate Emissions and Impacts from Cooking Technologies in Africa

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In much of Africa, the largest fraction of energy consumption occurs within the residential sector and is derived primarily from woodfuels burned in simple stoves with poor combustion characteristics. Many of the products of incomplete combustion (PICs) are damaging to human health, particularly when they are concentrated in poorly ventilated indoor environments. Incomplete combustion also has potentially harmful impacts on the climate. Prevalent PICs include methane, a potent greenhouse gas (GHG) that is among the pollutants subject to controls under the Kyoto Protocol as well as carbon monoxide (CO), non-methane hydrocarbons (NMHCs) and particulate matter (PM), which can all have an effect on climate, but are not subject to controls under Kyoto. In addition, when woodfuels are used at a rate that reduces standing stocks of trees over the medium or long term, the CO2 released by combustion also has an impact. The choice of stove and fuel technology can have a significant impact on the emission of GHGs as well as on human exposure to health damaging pollutants. In this paper we analyze the emissions of different household energy technologies on a life-cycle basis. We use emission factors to estimate the emissions associated with production, distribution and end-use of common household fuels and assess the likely impacts of these emissions on public health and the global environment. We focus largely on charcoal, a popular fuel in many sub-Saharan African countries. Charcoal is produced by heating wood in the absence of sufficient air for complete combustion to occur. This process removes moisture and most of the volatile compounds. The compounds driven off in the process consist of condensable tars as well as many gaseous hydrocarbons, including 40 g CH4 per kg of charcoal produced. Combining upstream and end-use emissions, every meal cooked with charcoal has 2-10 times the global warming effect of cooking the same meal with firewood and 5-12 times the effect of cooking the same meal with LPG or kerosene. When charcoal is produced in large quantities, as it is in Africa, the net warming effect can exceed the impact from the "modern energy sector" (transportation and industry) by 50-100 percent, even if charcoal is produced on a sustainable cycle so that all of the wood harvested for charcoal production is allowed to regenerate. However, while charcoal may be worse than firewood with respect to greenhouse gas emissions, it is an improvement with respect to exposure to health damaging pollutants, particularly particulate matter (PM). Levels of PM in households using charcoal are over 90 percent lower than households using open wood fires (316 -(159) mg/m3 for households using charcoal in a common improved stove compared to 3764 (360) mg/m3) for households using wood in open fires: mean (standard error)). These differences in exposure are consistent with 30 and 50 percent reductions in the incidence of acute respiratory infection (ARI) in adults and children under 5 respectively. Reconciling the costs and benefits of different household energy technologies creates a difficult policy challenge, particularly with the severe budgetary and resource constraints that household consumers and government agencies face in sub-Saharan Africa.

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Climate Change, Air Pollution, and the Economics of Health Impacts

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Climate change and air pollution are intricately linked. The distinction between greenhouse substances and other air pollutants is resolved at least for the time being in the context of international negotiations on climate policy through the identification of CO2, CH4, N2O, SF6 and the per- and hydro- fluorocarbons as substances targeted for control. Many of the traditional air pollutant emissions including for example