facilitate detailed dynamical investigations of response to small-scale wind forcing, dense water formation, and Adriatic general circulation. Likewise, multi-disciplinary measurements and modeling promise to characterize the biological and sediment response to bora-induced dynamics.

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Author Information

Craig M. Lee, University of Washington, Seattle; Farid Askari, NATO SACLANT Undersea Research Center, La Spezia, Italy; Jeff Book, Naval Research Laboratory, Stennis Space Center, Miss.; Sandro Carniel, National Research Council, Institute of Marine Science, Venice, Italy; Benoit Cushman-Roisin, Dartmouth College, Hanover, N.H.; Clive Dorman, Scripps Institution of Oceanography, La Jolla, Calif.; James Doyle, Naval Research Laboratory, Monterey, Calif.; Pierre Flamant, University of Hawaii, Manoa; Courtney K. Harris, Virginia Institute of Marine Sciences, Gloucester Point; Burton H. Jones, University of Southern California, Los Angeles; Milivoj Kuzmic, Rudjer Boskovic Institute, Rovinj, Croatia; Paul Martin, Naval Research Laboratory, Stennis Space Center, Miss.; Andrea Ogston, University of Washington, Seattle; Mirko Orlic, University of Zagreb, Croatia; Henry Perkins, Naval Research Laboratory, Stennis Space Center, Miss; Pierre-Marie Paulain, Istituto Nazionale di Oceanografia e Geofisica Sperimentale, Trieste, Italy; Julie Pullen, Naval Research Laboratory, Monterey, Calif.; Aniello Russo, University of Ancona, Italy; Christopher Sherwood and Richard P. Signell, U.S. Geological Survey, Woods Hole, Mass.; and Dietmar Thaler, Austrian Military Weather Service, Aigen/E, Austria

For additional information, contact C. M. Lee; Email: craig@spl.washington.edu.

The Earth Sciences, Human Well-Being, and the Reduction of Global Poverty

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Poverty is not solely a social or political matter, nor is it caused simply by population pressures as Thomas Malthus postulated in 1798. A new understanding of poverty is emerging in which natural and environmental drivers, together with social, political, and demographic causes, underpin livelihoods. The Earth sciences, therefore, play a critical role in identifying the deep causes of human suffering and in identifying solutions.

The State of the Planet: Why Are So Many So Poor?

For far too many the state of human well-being is bleak. Around one in six human beings—1 billion people—are in extreme poverty, struggling to survive on less than $1 a day; another one sixth of humanity ekes out existence on $2 per day (U.N. Development Programme (UNDP) Human Development Report, 2004; http://hdr.undp.org/2004/). The extreme poor lack all normal attributes of a decent, dignified life: adequate food, housing, sanitation, health care, education, and employment. Some 800 million people lack sufficient nourishment almost every day. It stunts their mental and physical development and shortens their lives, making them susceptible to common illnesses that attack their hunger-weakened bodies. Poor nutrition in mothers and infants is the leading cause of reduced disability-adjusted life years in poor countries [Economist, 2004].

Poverty worldwide claims 30,000 lives every day—one life lost about every 3 seconds—and in places like Sub-Saharan Africa, the situation worsens daily.

How can our world be this way? Population pressures, as Malthus described, surely make a difference. In areas of high rural population density, farm households tend to be extremely poor, and landless rural peasants are even poorer. Yet some places, like Japan, also have low land areas per person and are rich, while other places, like Bolivia, have large land areas per rural household and are extremely poor.

Goverance and political institutions matter a lot, as seen in the striking differences between North and South Korea, but countries in extreme poverty lack the resources to combat basic causes of hunger and illness and cannot simply “govern” themselves out of poverty.

The root causes of poverty are complex, involving a suite of time-variable determinants, contingent influences, and internal feedbacks, many of which are location-specific. Economists and other social scientists have sought to understand the basic causes of, and solutions

Fig. 1. Average annual death toll for all hazards against the death toll relative to population, 1980–2000. Highly impacted countries are in the upper right where many deaths occur, and those deaths are in high proportion to population. Countries are colored with the Human Development Index (HDI) that combines indexes of per capita income with health status (longevity) plus a measure of educational opportunities. A simple average is included. While there is a great deal of spread indicating that a variety of influences are important, there is a clear relationship between human development and mortality risk from natural hazards.
Fig. 2. Malaria incidence anomalies in Botswana related to climate anomalies. Anomalies in sea surface temperatures (Nino 3.4, December–February (DJF), a quadratic rainfall model (measured using Climate Prediction Center Merged Analysis of Precipitation (CMAP)) for the same months are overlaid on standardized malaria cases per 1000 population (incidence) anomalies (for the period 1982–2003; main transmission period January–May). The malaria data have been standardized to remove non-climate-related trends and the impact of a major policy intervention in 1997. There are many factors that can cause changes in malaria incidence data, including changes in reporting, drug resistance, and control initiatives. However, in the semi-arid areas of Africa, rainfall is a major driving force of inter-annual variability in malaria. Where sea surface temperatures are significantly related to these changes, it may be possible for health services to use seasonal climate forecasts to predict malaria anomalies, before rains have fallen.

Earth’s Extremes and Human Well-Being

As seen from the tragedy of the SumatraAndaman tsunami of 26 December 2004, the poorest suffer disproportionately at the hands of nature. That tsunami followed the catastrophe in Haiti caused by storms in 2004. Beyond the immediate death toll, poor countries affected by disasters have the least capacity to recover, and few resources available for programs that stimulate long-term economic growth.

Fig. 3. (a) HDI against latitude (north positive) shows the great prevalence of low HDI countries in the equatorial regions. Countries with lowest HDI are generally located near the equator. The color division is the same as in Figure 1 and is used in the subsequent figures. Figures 3(b), (c), (d), and (e) show vulnerability (defined as the number of people killed per million exposed to a particular hazard) for earthquakes, floods, droughts and cyclones using data presented by the UNDP (2004; http://www.undp.org/bcpr/). For flood vulnerability (3c) there is a clear separation between high HDI countries (blue) and low HDI countries (red), with the lower countries generally being much more at risk. These plots do not account for the relative severity of the natural events. Rainfall, and hence floods, are more intense in the tropics, but low HDI countries are one or even two orders of magnitude more at risk than high HDI countries; a difference that greatly exceeds the relative severity of natural hazards in these regions. Droughts that cause mortality (3d) are almost exclusively a poor world phenomenon. Earthquake vulnerability (3b) should have no natural latitude dependence and the results are more scattered, but a tendency for the richest to be least vulnerable remains. Note that these compilations do not include recent earthquakes in Gujarat, India and Iran, flood deaths in Haiti, or the Asian tsunami disaster that would serve to enlarge the differences between rich and poor.

Whether reconstruction aid from outside comes as loans to be repaid, which diverts funds from development programs, or as a donation, productivity losses and the disruption of lives that follow major disasters can impede growth and even destabilize governments. A 2004 UNDP report (http://www.undp.org/bcpr/) details how disaster risk reduction could be a key factor in achieving the UN’s Millennium Development Goals (http://www.un.org/millenniumgoals/).

Figure 1 depicts a clear relationship between human development and mortality risk from natural hazards. The causes that underlie the relationship are numerous. The urban poor have little choice but to live in high-risk, informal settlements around major cities close to work opportunities—in riverbanks subject to flooding, on the slump scars of landslides on denuded slopes, or in crowded coastal regions such as those where so many died around the Indian Ocean from the recent tsunami.

In Haiti, rural poor denude the land of trees to raise crops at low yields and to produce charcoal to sell cheaply. Cleared land promotes flash flooding and the disasters that took about 6000 lives there in 2004 compared with about 100 in the U.S. Gulf Coast from the very same storms.

Earthquakes, too, exact the greatest toll on the poorest people. Zoback [2004] points out that the 1989 Loma Prieta earthquake in Cali-
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The poorest often have few choices available to adapt to variations in natural conditions: they may not be able to harvest water, plant different crops, move to less stressed regions, or provide disaster-resilient infrastructure. Scarcity often means more time spent foraging for food and fuel. Haiti’s deforestation is one example of a feedback loop in which attempts to cope with poverty themselves amplify the conditions that produce further poverty [Mutter, 2004].

Countries caught in or near this feedback amplification have a suite of characteristics that Sachs et al. [2004] identify as an ecology of the human condition. They point out that most of the world’s poorest people live in tropical or arid countries, due neither to historic accident nor the fault of government (Figure 3A). These people are vulnerable to tropical climate extremes, diseases, pests, soil nutrient depletion, land degradation, and, in some regions (mountainous sites of high population density and the interior of sub-Saharan Africa), very high transport costs of needed goods and products to market. Vulnerability to natural variations in Earth’s behavior preferentially affects the lives of the poorest concentrated in equatorial regions (Figure 3), and suggests that Earth’s natural processes contribute to an ecology of poverty. Many consequences of ENSO, for instance, have their greatest impact in tropical countries. In Central America, multiple hazards suppress growth opportunities.

A Role for Earth Science in Improving Human Well-Being

Human well-being and Earth’s natural systems share a relationship that is complexity codependent, regionally diverse, often indirect, subtle, and nonlinear. Although clear correlations exist, they do not establish to what extent the correlations describe outcomes or causes of poverty. A basic research question is: How does the condition of the Earth govern and limit human well-being? This research domain lies on the boundary between natural Earth sciences and the social sciences, including economics. The research demands skills well known to Earth scientists, including spatial data analysis, time series analysis, inverse methods, observation and monitoring, and statistical analysis applied across data sets from both the natural sciences parameterizing Earth systems, and social science data that describe human systems.

The research, which is most pertinent to the world’s poorest societies, is unlikely to occur there, where science of any sort is virtually absent. What is needed is an effort like that of the Commission on Macroeconomics and Health, launched by the World Health Organization in 2000. The commission produced a 2001 report, with Jeffrey Sachs as lead author, that established the dual nature (both cause and consequence) of disease burden on poor people.

Participation by stakeholders from poor countries is essential to building their capacity to conduct research. The U.S. National Science Foundation and other granting agencies must develop programs targeted toward issues of the poor world. The AGU and other scholarly societies can also take up the challenge (e.g., J.C. Mutter et al., Earth science, human well-being and the alleviation of global poverty, session presented on 14 December at the 2004 AGU Fall Meeting, San Francisco, Calif.). In addition, individual scientists in this rich society must develop research programs that will help to improve the condition of so many who have so little and need so much.

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References


Author Information

John C. Mutter, The Earth Institute at Columbia University, N.Y.

For additional information, contact J.C. Mutter, Email:jmutter@ei.columbia.edu