Global Change and Public Health

Paul R. Epstein
Harvard School of Public Health
Cambridge, MA

Introduction and Background

The resurgence of infectious disease in the 1980s and 1990s reflects widespread changes in disease vectors and microbiological agents and in the environment that shapes their growth and distribution. The emergence of plague in India after a 30-year hiatus has brought this resurgence to center stage, but it has occurred in the context of the emergence, resurgence, and redistribution of infectious diseases on a global scale.

In addition to social vulnerabilities and unevenly distributed exposures, changes in biodiversity--particularly the decline in top predators and the selection of "generalist" species over "specialists" (associated with shrinking ecological niches)--provide the background for the emergence of new diseases. Losses in biodiversity reduce the resilience of ecosystems in the face of climatic factors, be they normal or anomalous. Additionally, long-term climatic trends in (a) temperature and precipitation means, (b) minimum to maximum temperature ratios, and in (c) variability are contributing to the redistribution of disease vectors and reservoirs into new latitudes and new altitudes. Against this background, El Niño anomalies generate new breeding sites for disease vectors and generate bursts in their abundance.

Given this interaction among complex systems, deriving simple underlying principles and simple outcomes is essential. Key species (e.g., rodents and insects on land, algae at sea) carry many of the diseases of plants and animals; thus, the trend towards selection and redistribution of these opportunistic species has major implications for agriculture, forestry, fisheries, and human health, as well as commerce, tourism, and allied industries.

Climate variability and extreme events (such as heat waves) directly affect human health (cardiovascular disease and heat stroke), and global changes in UV-B radiation influence the growth of skin cancers and cataracts, as well as depress the immune system (increasing susceptibility to infectious diseases). This review, however, focuses on the indirect effects of global change on health and agriculture, as mediated through the transport of pathogens and the emergence of pests.

Note that person-to-person infectious diseases (diphtheria, measles, TB, HIV) are primarily associated with social dislocation, as well as human population abundance, distribution, and inequities; infectious diseases involving three or more species in their life cycle more readily reflect ecological and meteorological factors. Additionally, unlike evaluating the direct impact of droughts (e.g., on agriculture), interpreting the impacts of climate on ecosystems interactions involves the filtration of climatic factors through the community assemblages of species. For example, the influence of warm events on the salmon of the US Northwest coast is not direct; during warm events, salmon move northwards, but it is the northern movement along the California coast of the mackerel--consumers of baby salmon exiting from rivers--that reduces the future stocks. Thus, warm sea-surface temperatures in one year may result in a decline in salmon stocks two years later, given their four-year growth cycle. Similarly, in terrestrial ecosystems, droughts may remove predators of small mammals (e.g., raptors and snakes), and heavy rains associated with an ENSO event may precipitate an explosion of rodents due to new food supplies and a lag in predation. The latter process may have been central to the 1993 emergence of Hantavirus in the US, and to the 1994 "plague of rodents" as agricultural pests in Southern Africa. In India, climate variability (floods accompanying an 80-day monsoon) left animals drowned in mud flats in Surat, providing food for the rodents and fleas involved in spreading the plague (Yersinia pestis).

Thus, the biological and health impacts of ENSO events must be interpreted against the background of other human activities, including the overuse of resources (biotic and abiotic), as well as the generation of wastes beyond the capacity of biogeochemical systems to recycle them. Moreover, climate variability (and long-term trends) may themselves decrease biodiversity and disturb landscapes, further reducing resilience in the face of climate anomalies. These synergies increase the vulnerability of animals and plants to the invasion of exotic species and to the emergence of new pests and pathogens.

The following is a synopsis of changing disease patterns related to climate variability and global environmental change:

Human Health -- Terrestrial Ecosystems

Dengue Fever (Aedes aegypti)

- redistribution of vector in the Americas, 1980 to 1994

- new areas of dengue epidemics in the 1990s--Costa Rica, Northeast Brazil, Australia, India, Argentina

- appearance of dengue at higher altitudes than historical records indicate (> 1,000 meters)--Costa Rica (1250 M), Colombia (2200 M), India (> 2121 M) (note temps in India 124°F this summer); plague occurred coincident with a dengue outbreak in India

- seasonality of dengue extended--six to nine months--in Argentina; early appearance in 1994 in Costa Rica related to spring rains

- large dengue outbreaks associated with precipitation--Costa Rica, NE Brazil, SE Brazil--with new outbreaks predictable where vector and viruses are established. (Dengue Hemorrhagic Fever results from the introduction of a second dengue strain, i.e., impact may be compounded over several years.)

- Aedes albopictus, a competent vector for dengue, yellow fever, and encephalitides, present in Southeastern and Central US

- Eastern Equine Encephalitis (involving Aedes vectors, birds, and horses); outbreaks since 1960s correlated with ENSOs in Northeast US.

Malaria

- resurgence in the 1980s worldwide with widespread vector and parasite resistance

- habitat fragmentation in the Amazon (by satellite imaging) associated with malaria resurgence (new breeding sites, non-immune laborers)

- outbreaks and quantitative leaps in incidence coincident with ENSO events in Pakistan, Costa Rica, Honduras

Rodent-borne viruses

- Sabia (Brazil), Junin (Argentina), Machupo (Bolivia), Guaranito (Venezuela), and Lassa in several South American nations;. emerging viral hemorrhagic fevers related to land-use changes (causing shifts in rodent populations from forest to field species, plus influx on non-immune laborers)

- hantavirus in North America, following six years of drought (removing predators) and one year of rain, nourishing rodents (with grasshoppers and piñon nuts), resulting in a ten-fold increase in rodent populations from May 1992 to May 1993

- plague in India following monsoon flooding, drowning animals, providing breeding ground for rodents and fleas

Marine Events ("red tides")

- global increase in coastal algal blooms (warming increasing photosynthesis and metabolism, and encouraging shifts to toxic species--cyanobacteria and dinoflagellates)

- "jumps" of toxic species into new areas highly correlated with ENSO events

- [underlying ecosystem changes include loss of wetlands, excess nutrients and overfishing]

- summer, 1994--one-third of Baltic covered with algal blooms coincident with temperatures 73°F

1987 ENSO
associated disease events across marine taxa, US Atlantic Coast

(a) *Caribbean coral bleaching*

(b) *Florida sea grass die-off*

(c) *agent of neurological shellfish poisoning (gymnodynium breve) - transferred from Gulf of Mexico to North Carolina*

(d) *large die-off of sea mammals in New England*

(e) *emergence of amnesic shellfish poisoning in Prince Edward Island (new diatom toxin--domoic acid--later appearing worldwide (see figures)*

1991 ENSO
Emergence of Pfeisteria piscicida, agent of large fish kills (10^3 to 10^9) off North Carolina; now "relatives" active in Delaware, Florida, and Gulf of Mexico

Cholera

- 7th pandemic of cholera introduced into the Americas in 1991 (the vibrios attach to algae are amplified in algal blooms, and are passed on to humans through the food chain, i.e., fish and shellfish)

- emergence of cholera "0139 Bengal" in Asia (1992/93), agent of 8th pandemic

Sea Mammals

- large sea mammal die-offs highly correlated with warm events (morbilliform viruses--relatives of measles viruses--also involved; same virus family found in Serengeti lions)

Agriculture and Timber

- locust outbreaks in China and in Southern Africa related to ENSO events

- herbivore rodents in Southern Africa associated with ENSOs and compounded impact of interannual climate variability

- spruce budworms in boreal forest of Northeast US and Canada associated with ENSO event of 1987 (and 50% decline of neo-tropical birds since 1950)

Plant Diseases

- fungi in Southeast Brazil, 1994, associated with early rains and flooding

- bean golden mosaic geminivirus (BGMV) carried by La mosca blanca (white fly), spreading in California and in Central America

Tourism and Commerce

- dengue affecting tourism in Costa Rica and Northeast Brazil

- cholera in Latin America--$250 million lost in Peruvian food trade in 1991

- Canadian fisheries losses in 1987/88 from disease events--$4.7 million

- Indian plague affecting tourism, air transport and food export (losses in tourism and trade estimated in the hundreds of millions of dollars).

Conclusions

Emerging diseases reflect changes in social and in environmental conditions. The redistribution of disease vectors and the emergence and resurgence of pathogens across a wide taxonomic range may be among the first biological signals of global change. Remote sensing is a tool for understanding terrestrial and marine ecosystems, and geographic information systems can help integrate this information with soil conditions, vegetation biomass, and with health and other social outcomes. A multidisciplinary approach is needed to understand the impacts of interannual climate variability.

Multisectoral application of multidisciplinary understanding is also possible. Breakthroughs in climate forecasting associated with better understanding of the ENSO signal--one highly correlated with regional weather patterns across the globe--give new hope for improving public health surveillance systems and disease control. Integrating the health sector in application centers is important for (1) developing early warning systems for public health interventions, (2) applying ecologically sound, environmentally friendly interventions, and (3) in developing anticipatory practices that reduce the vulnerability to disease emergence and spread. Whether the pace, intensity, and variability of ENSO events reflect long-term global trends is of utmost importance, for the primary forces driving the global climate system (i.e., fossil fuel and forest use) will have long-term significance for disease and society.

A new framework for scientific work and for determining policy directions must involve an integration of (1) the socio/political/economic system (the anthropogenic forces, exposures, and vulnerabilities), (2) ecological systems, and (3) the climate system. Climatic variability and the pattern of variability (i.e., sharp changes rather than gradual wave-like oscillations) will have profound effects on the Earth's biota; and alterations in the incidence, duration, onset, and intensity of storms, hurricanes, floods, and droughts associated with ENSO phenomena will greatly impact societies, productivity, and development through changes in the diseases of humans, animals, and plants. In past eras pandemics have motivated dramatic changes in societal practices; will our society read these signals before we exceed the resilience of our systems?

Examples of Weather-Related Concerns in Agriculture and Grazing Systems in Northern Australia

Roger C. Stone
Agricultural Production Systems Research Unit
Queensland, Australia

Extremes in climate variability in Australia impact strongly on rural industry and, subsequently, the national economy. Queensland is current losing $1 billion dollars (AUS) annually in production lost in this current three- to four-year, extended El Niño event. Impacts of extremes in climate variability are particularly evident in an examination of past grazing practices (cattle and sheep) and associated problems of ecosystem sustainability in Queensland.

Additionally, the large variability in rainfall in northern and western Queensland associated with extreme phases of the Southern Oscillation has been associated with large changes in pasture composition. These changes have included invasion of woody weeds and pasture degradation associated with the build-up of stock numbers during La Niña periods and invasion of spear-grass pastures by Indian Couch due to overgrazing in northern Queensland during an extended period of below-average rainfall (1982-87). One of the major causes of degradation is over-grazing during drought. Ideally, graziers should be able to match stocking rates to seasonal conditions so that animal production is maximized and damage to pasture and land production is minimized.

Three to four million tons of wheat are produced in north-east Australia. In this region, rainfall is summer dominant, its variability is great, and the most likely timing of frost coincides with the preferred flowering time. These climatic influences and their associated risks impact heavily on quantity, quality, and likely losses of harvested yield. To maintain farm profitability, analyses incorporating crop simulation models indicate substantial improvements in gross margins are possible through changes in management in wheat farming. Crop simulation models have established that 80% of the profits in a wheat-producing enterprise are made in just 30% of the years. In 40% of years, the producer may just break even, and in the remaining 30% of years, he/she will run at a substantial loss. If appropriate management techniques involving seasonal forecasting can be applied, then there may be some chance of avoiding unnecessary losses in the "bad years," and maximizing returns in the "good years."

Problems with Seasonal Forecasts

In Australia and Queensland we have developed a probability-based seasonal forecast system. This system is largely based on a fairly thorough analysis of lag relationships between the Southern Oscillation Index (SOI) and rainfall. Use of the SOI has progressed beyond mere correlation analysis of SOI and rainfall to development of use of SOI categories of "phases." "Forecasting" implicitly relies on the well-known "phase-locking" of the SOI into the annual cycle. This means SOI patterns established by about the end of May allow lagged rainfall probability distributions to be generated for three to six months into the future on an ongoing basis until about the end of January. This sort of system works quite well.

The word "forecast" may not be appropriate here. We do not rely (that much) on forecasts of an El Niño likelihood. We know, anyway (for example) that once we have deeply negative SOI values by the end of the austral fall (May), then there is a **high probability** of below-average rainfall for the coming winter/spring season, at least. So the interesting issue is not so much what a "forecaster" says is going to happen, but how a wheat producer can handle probabilistic information in his enterprise from the end of May onwards.

It was not much use, for example, knowing this year that the warm event (El Niño) was "over" back in February/March when we knew, historically, that the Pacific could remain volatile for some months to come. As it turned out, the experimental "forecast" information generated by the General Circulation Models (GCMs) was publicized widely in Australia, and it proved to be "wrong." Reaction against this "forecast" has been strong in the rural community. It appears that an error of the worst kind is to "forecast" an end to a drought that does not subsequently occur. So far, we are still happier with the probabilistic information provided by the less sophisticated SOI (and SOI phases).

YET WE COULD STILL DO WITH SOME MORE SKILL IN SEASONAL FORECASTING SYSTEMS.

Use of the SOI and SOI phases certainly does not solve all "forecasting" problems. Although SOI phases known at the end of May provide significant splits in rainfall (and frost) distributions for many months into the future, there is still scope for obtaining more skill from the system. Not all droughts in eastern Australia are related to the El Niño/Southern Oscillation (ENSO) system. Use of sea-surface temperature information from other regions than the central equatorial Pacific may help extract more skill in the future.

A major problem in Australia is trying to provide seasonal climate forecast information through what has been called "the predictability gap." For some enterprises, such as winter wheat farming, the current system works fairly well. This is because the ENSO pattern has either just settled down or is well established at the time major farming decisions are being made. However, for many enterprises (e.g., cattle or wool production), knowledge of the climate outlook for the coming seasons needs to be made by mid-February to mid-May, a period when very little skill is currently available in seasonal forecasting.

The period of the "predictability-gap" is one in which most "bad press" and poor media coverage occurs regarding seasonal forecasting in Australia. Generally, rural producers who may have developed faith in seasonal forecasting methods over the previous nine months have difficulty coming to terms with conflicting media statements about the climate outlook, and an unsatisfactory image of climate forecasting can result.

Climate forecasting also appears to attract the charlatans in the scientific or semi-scientific community. Detractors of the ENSO system appear spontaneously when high media attention is focused on drought and climate forecasting. A major problem has emerged in Australia of managing the media "hype" over seasonal forecasting, as the media appear to actively seek out any opposing view on the climate outlook--perhaps just to create controversy.

However, as we in eastern Australia may be fortunate to be in a region where some skill can already be extracted from ENSO-based seasonal forecast systems, we have now focused on needs to better extend climate forecasting information. In Queensland, we have conducted some 100 workshops in country areas in which we explain ENSO, the SOI, and SOI phases and what these systems mean for the local area. More importantly, perhaps, we have run crop and pasture simulation models that incorporate the rainfall probability distributions of rainfall and frost likelihood to help answer the "so what?" questions in seasonal forecasting. The problem we face now is providing enough resources to more widely extend this information and to produce models appropriate for all rural (and other) enterprises and systems. In this regard, we are a little worried that developments in seasonal forecasting, such as coupled GCMs, may not be able to be easily integrated into crop and pasture simulation and farming decision systems.

What We Need from ENSO Forecasting

1. Provide forecast skill through the 'predictability-gap" (February-May). It's not much use having a GCM that can predict well after about June--the SOI can already do that.

2. Provide forecast skill for those periods (10%-20%) when, in eastern Australia, use of ENSO-based forecast systems *may* not work.

3. Have greater realization of the need to integrate research with the user community from the outset. Running our wheat systems models with *perfect* knowledge of El Niño and La Niña years for the past 40 years showed that this information was less valuable than the current skill we have from just the SOI! This partly because highest yields are obtained following the *break-down* of an El Niño pattern in the austral fall, and this information was obtained from our current knowledge of effects of recent rises in SOI. So, this example serves to illustrate that, while we need to forecast the onset of El Niños with as much skill and notice as possible, there may be other needs in seasonal forecasting that warrant as much attention (e.g., 1 and 2 above).

4. There is an overwhelming need for the research community to remain in close contact with the user community. A warning from the US CAC this September that we were

in the developing stage of another warm event was too late for us. We've missed out on our winter growing season already due to drought. Please realize that the user community stretches far and wide.

5. Of course, there is a need to provide as much lead time in climate outlooks as possible to aid policy and financial management.

6. Provide easily accessible information using user-friendly means. Examples (that we are using) include recorded information via telephone of the latest SOI and sea-surface temperature anomalies and a general outlook statement for the State.

7. Investigate "forecasting" other variables besides rainfall. Frost, number of "cool" days, prolonged heat, cloud cover, stream-flow, hail, wind strength, and tropical cyclone activity are some examples of forecast products that would have relevance to (rural) industry.

8. Continually provide explanation to the (farming) user of terms such as "median rain," "average rain," and any other scientific terms as they come into general use.

9. Do not be afraid to explain just how the forecast information was derived--give the user some ownership in the process. I might suggest that users mostly need ownership of the "forecast" information before they'll act on it.

10. Provide forecast information in regions not strongly influenced by ENSO.

11. Indicate when we are likely to run into prolonged, extended ENSO events.

12. Indicate how ENSO will behave under enhanced greenhouse conditions.

Scientific Response on Future of ENSO-Based Forecasting

The statistically based forecast systems have served us (in Australia) quite well. However, the future may lie in better understanding and better mathematical modeling of the climate system. Until now, most of our modelling efforts have been concerned with modelling the different components of the climate system. However, use of coupled ocean-atmosphere models will aid a more comprehensive understanding of the complete system.

In the meantime, a combination of GCM output and statistical output may work well, provided the system is managed properly.

Further development of supercomputers should aid the resolution of the climate models (2° latitude/longitude).