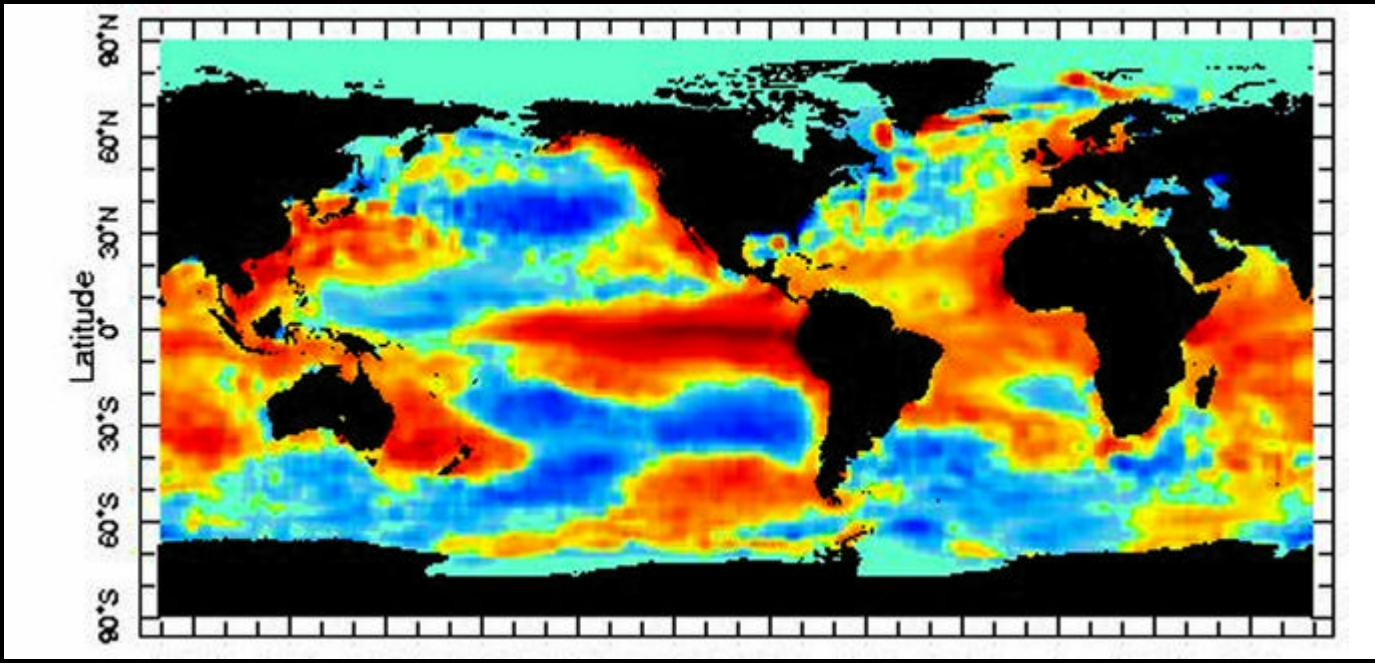
EXTREME WEATHER EVENTS: The Health and Economic Consequences of the 1997/98 El Niño and La Niña



Monthly Sea Surface Temperature Anomaly - February 1998

Harvard Medical School

EXTREME WEATHER EVENTS: The Health and Economic Consequences of the 1997/98 El Niño and La Niña

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Database available on website:
http://chge2.med.harvard.edu/enso/disease.html

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EXECUTIVE SUMMARY

Extreme weather events (EWEs) often create conditions conducive to outbreaks of infectious diseases. The upsurge of insect, rodent and water-borne diseases following Hurricane Mitch in Central America in October, 1998 highlights this connection. Heavy rains can produce new breeding sites for insects, drive rodents from burrows and contaminate clean water systems. Conversely, flooding followed by drought can spread fungal spores and spark fires.

The 1997/98 El Niño-related extreme weather events spawned "clusters" of disease outbreaks in many regions of the globe. In the Horn of Africa extensive flooding led to large outbreaks of malaria, Rift Valley fever and cholera. In Latin America, extreme weather was associated with outbreaks of malaria, dengue fever and cholera. In Indonesia and surrounding island nations, delayed monsoons - and the compounding effects of local farming practices - led to prolonged fires, widespread respiratory illness, and significant losses of wildlife.

Throughout the 1990s an area the size of Massachusetts has burned each year in the Amazon. During 1997/98 tropical rainforests in Brazil, Mexico and Central America - normally soaked and relatively immune to forest fires - raged out of control. Winds brought the smoke from tens of thousands of Mexican fires - the largest forest fire complex on record for Mexico - in a great gyre through the southern U.S.. 500,000 acres later erupted in Florida; 100,000 people were evacuated and 300 homes were lost (Pyne 1998). The losses to Florida in timber alone were over $400 million. Flooding in California spawned agricultural pests and brought large economic losses. In Europe and the U.S., 1998 summer heatwaves killed hundreds.

The 1998 La Niña event- beginning abruptly in the Spring of '98 - continued the pattern of extreme weather. The impacts have included:

(i) widespread flooding in Bangladesh and China - the latter displacing 230 million people;

(ii) flooding in Texas, following drought and a heatwave (with temperatures exceeding 100ºF for 60 days - 29 in a row - and a record-breaking string of warm nights over 80ºF), causing significant agricultural damage as well as human deaths;

(iii) Hurricane Mitch, swamping the Central American isthmus (with thousands of deaths and numerous epidemics);

(iv) a severe October cold wave across Europe; and

(v) a crippling December Ice Storm across the southern U.S..

All told 1998, the warmest year on record - and perhaps of the millenium (Warwick 1998) - proved to be the most costly year on record in weather-related impacts. In the first 11 months of 1998, $89 billion was lost due to weather-related events; more than all the combined losses of the 1980s. If climate change continues to be associated with more frequent and intense El Niño and La Niña events - and the accompanying volatile and severe weather patterns - we have begun to see the profound consequences climate change can have for public health and for the international economy. There are implications for monitoring, public health early warning systems and for environmental and energy policies.

I. BACKGROUND

The El Niño/Southern Oscillation

The Southern Oscillation is the difference in sea-level atmospheric pressure between the island of Tahiti and Darwin, Australia. A negative Southern Oscillation Index (SOI) is associated with slackening of easterly winds (westward-blowing), allowing the western warm pool (WWP) - centered east of Indonesia, the world's "hot spot" - to shift to the east. A negative SOI is thus associated with an El Niño event, in which anomalously warm water reaches the west coast of South America. This usually occurs around Christmas time, thus the event has been dubbed El Niño, or "The Christ Child".

El Niño events affect the jet stream and are statistically related to extreme weather events in specific areas of the globe (Kiladis and Diaz 1989; Glantz et al. 1991). As examples, Northeast Brazil usually experiences drought, while southeast Brazil and Peru experience heavy rains and often flooding. Southern Africa has a strong "signal," and usually experiences drought.

The opposite pattern is associated with a cold ENSO event ("La Niña"). In a La Niña event - often following an El Niño event - anomalously cold water appears near South America. Southern Africa usually experiences heavy rains and flooding during La Niña or cold ENSO events. The La Niña event that began in the Spring of 1998 was associated with flooding in Texas and Central America, following extended drought conditions that accompanied the previous El Niño event.

Both anomalous phases - with either warm (El Niño) or cold (La Niña) surface waters - bring weather extremes to many regions across the globe. With the La Niña phase of 1995-1996, many regions of the world that had lived with drought during the El Niño years were besieged with intense rains and flooding. Flooding in Colombia, South America, and in southern Africa were accompanied by upsurges of vector-borne diseases. Other areas experienced a switch of the opposite kind, with drought and wildfires replacing floods. A similar pattern of extreme weather events have accompanied the La Niña of 1998, with signals reciprocal to those of the 1997/98 El Niño.

Disease Clusters

Disease outbreaks in various regions of the globe have historically been correlated with unusual weather patterns, such as those associated with the El Niño/Southern Oscillation (ENSO) phenomena (Bouma et al. 1994; Epstein et al. 1995; McMichael et al. 1996; Patz et al. 1996; WHO 1996). In order to explore the associations among disease outbreaks and anomalous climatic conditions during the 1997/98 El Niño event, precipitation and temperature anomalies were mapped along with outbreaks of dengue fever, malaria, cholera, Hantavirus pulmonary syndrome and forest fires.

This study is based on correlations rather than time-series analyses. It is intended as a qualitative search for overlapping of events and as a guideline for a) further modeling and hypotheses testing, and b) pilot programs to evaluate the efficacy of health early warning systems. The sources for this work include primarily ProMED, the World Health Organization's Weekly Epidemiological Record, the Centers for Disease Control and Prevention's Morbidity and Mortality Weekly Review, Emerging Infectious Diseases Journal, and media reports. ProMED - the Program for Monitoring Emerging Diseases - is a communication listserv, established by the US Federation of American Scientists, Washington, D.C..

Please refer to the database available on the website: http://chge2.med.harvard.edu/enso/disease.html

El Niño events most often begin in the Fall, peak in April or May, and last for approximately one year. The 1997/98 El Niño came early, beginning in April of 1997, and ended unusually abruptly in May of 1998. In terms of sea surface temperatures in the Pacific Ocean it was the strongest El Niño event of the century. The El Niño was followed by the sudden appearance of a cold anomaly. This La Niña event, however, was accompanied by persistent warm water conditions in other regions of the Pacific Ocean.

Disease Transmission and Meteorological Conditions

The transmission of malaria and dengue fever (DF) depends upon the life cycle of the mosquito vector and the microorganisms they can carry. Unusually warm weather increases the infectivity of mosquitoes, and increased precipitation provides breeding sites for anopheline mosquitoes that can transmit malaria. (Note: heavy rains can also flush out standing pools and eliminate mosquito larvae.) In mountainous regions, dry periods may result in the pooling of rivers and streams and provide favorable conditions for mosquito breeding. For the periodomestic *Aedes aegypti* mosquito, which can carry the DF virus, anomalously warm and wet conditions may precipitate outbreaks, while container storage of water can lead to population explosions of mosquitoes during droughts. Where socioeconomic conditions are favorable, mosquito populations - and disease transmission - may occur only sporadically, under suitable conditions.

In Latin America in 1997/98 the outbreaks of malaria and DF occurred in regions that were anomalously warm, suggesting a significant role for warm temperatures in encouraging transmission. Specifically, increases in daily minimum (nighttime) temperatures (TMINs), a hallmark of climate change (see Section IX) (Easterling et al. 1996) - that is exaggerated during El Niño events - may enhance development of mosquitoes and the parasites or viruses they can carry. Increases in TMINs may also be important in permitting mosquitoes to extend their seasonality and their range to higher altitudes or latitudes, thus exposing new populations with little immunity to increased risk (Epstein et al. 1998).

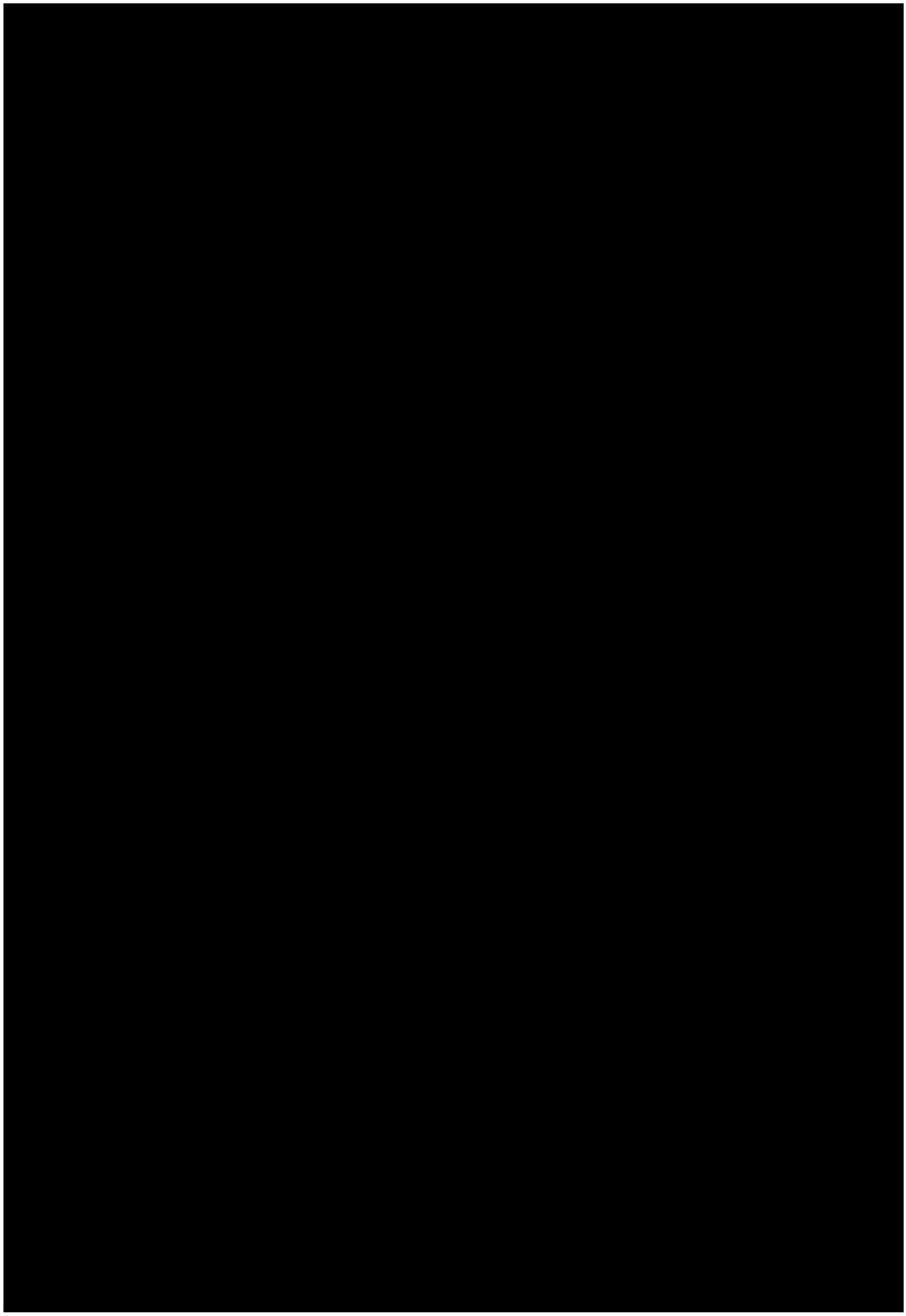
For rodents, droughts can decrease predation while heavy rains provide new sources of food. Flooding can also drive rodents from their burrows, increasing contact with humans, as demonstrated by outbreaks of rodent-borne **leptospirosis** in Central America following Hurricane Mitch.

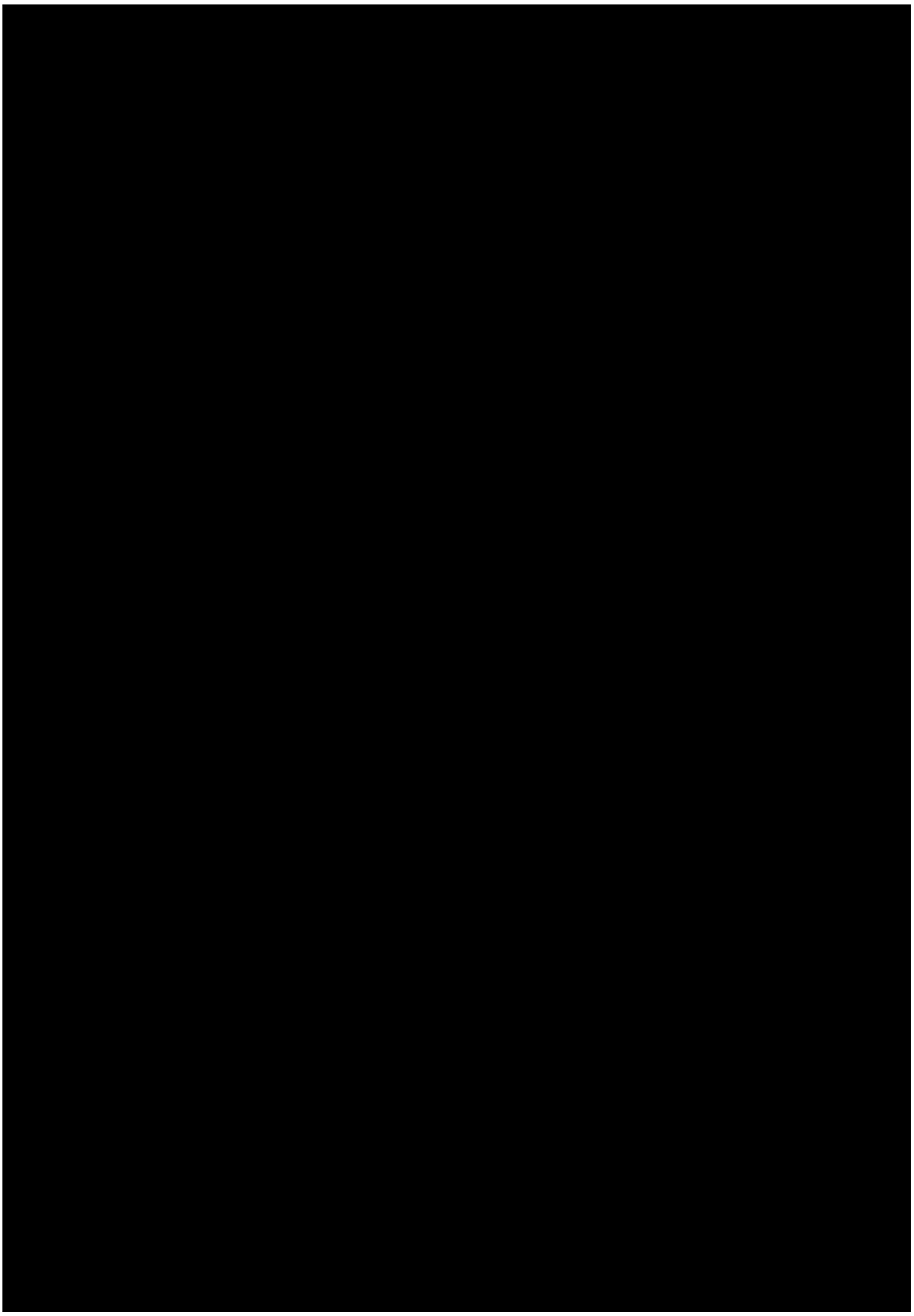
With cholera, heavy rains can flush organisms (and nutrients and chemicals) into clean water supplies, thus spreading the disease through the water system. In the marine environment, heavy rains may also provide pulses of nutrients that initiate cholera-harboring plankton blooms (Colwell 1996; HEED 1998).

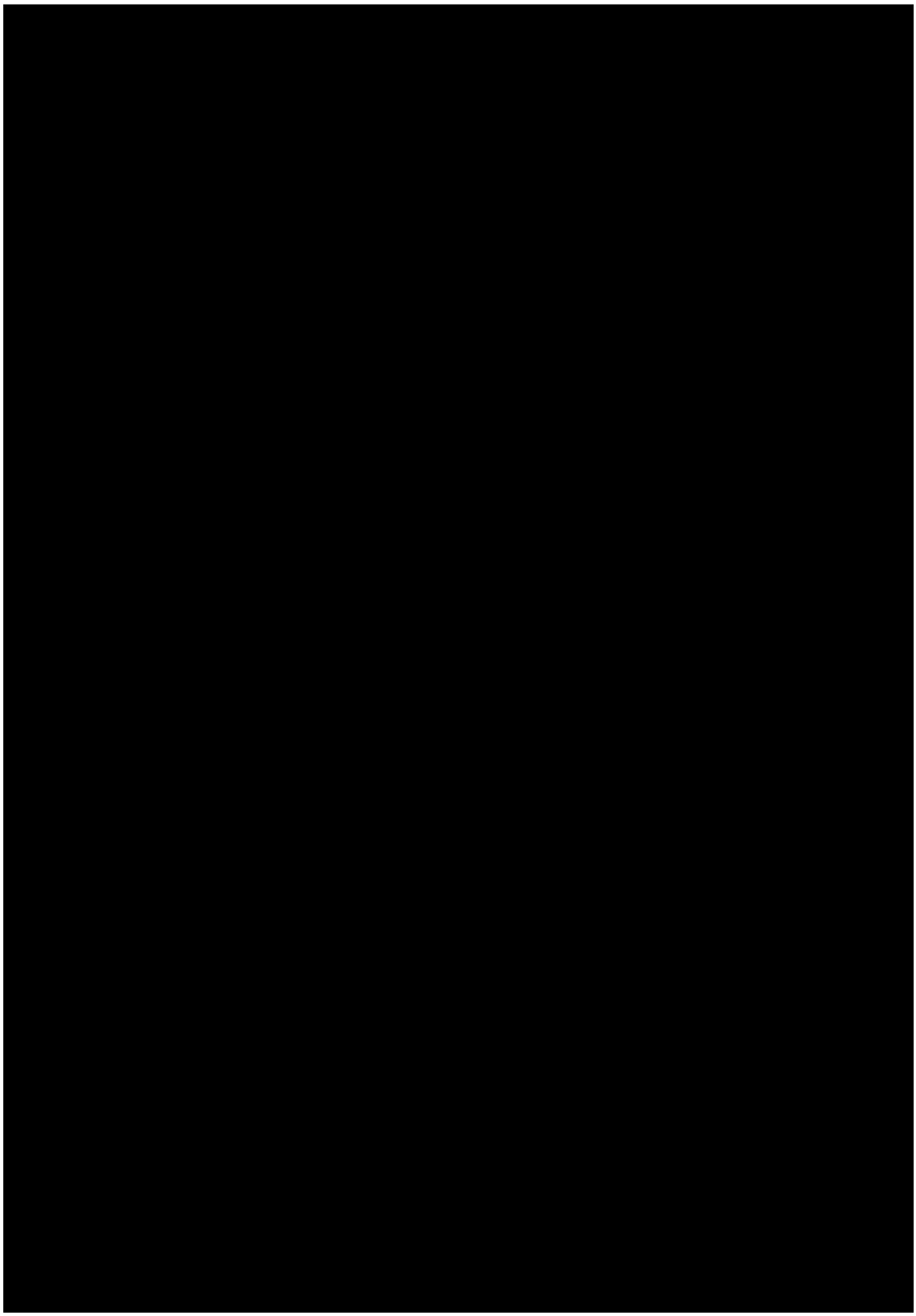
Dry extremes are also capable of fostering outbreaks of cholera and other water-borne diseases. Dry streambeds can concentrate microorganisms and impede hygiene. The lack of access to adequate water, in quantity and quality, can also hinder treatment and increase case fatality rates.

II. World Health Organization Report

The following report appeared in the World Health Organization's Weekly Epidemiological Record on May 15, 1998. It provides an excellent summary of the disease outbreaks associated with the El Niño of 1997/98.







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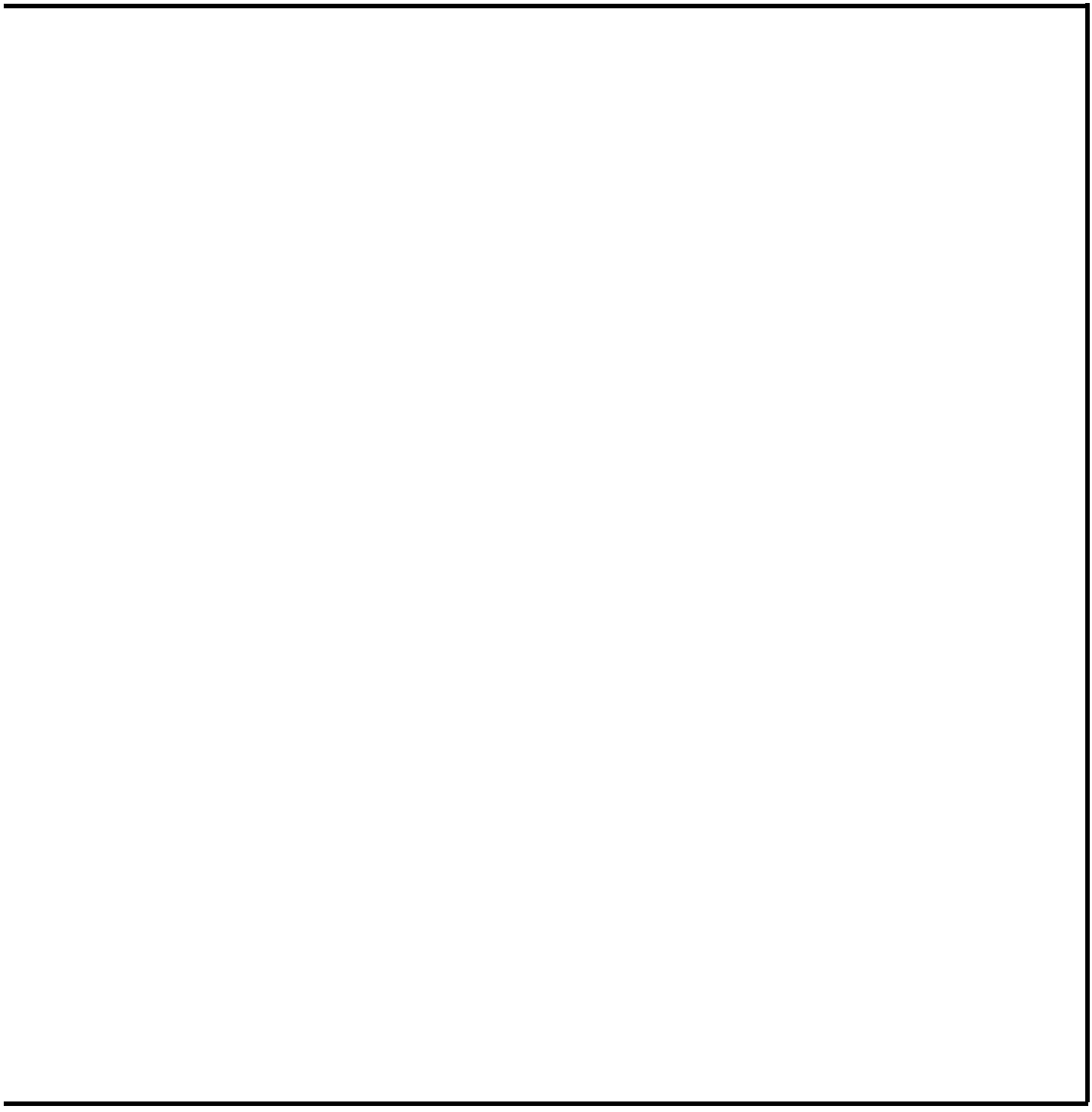


IV. REGIONAL STUDIES

A. LATIN AMERICA

Climatic Zones

South America experiences four major types of climate: tropical, temperate, arid and cold.

Tropical conditions: These include a high average temperature with low variability and heavy rain fall, characteristic the Pacific coast of Colombia, the Amazon basin, the Atlantic coast of Brazil, and Central America.

Temperate conditions: These involve a more moderate average temperature with higher variability, and moderate precipitation. They characterize regions south of the tropic of Capricorn, the lower regions of the Andes, and the mountainous regions along the west coast of Central America.

Arid conditions: These include a high average temperature but low average rainfall, and characterize the regions east of the Andes (the Rain Shadow Zone), the narrow coastal strip along the Pacific coast of Peru and northern Chile, the desert that extends from northeastern Colombia to Venezuela, and northeastern Brazil.

Cold conditions: Low average temperatures with high variability, and low average precipitation, characteristic of regions of the high Andes in southern Argentina and Chile.

ENSO and Latin America

The precipitation and temperature anomalies during El Niño events in Central and South America have been fairly consistent since records were begun in 1877 (Kiladis and Daiz 1989). Temperatures in the tropical regions of the continent are higher than normal, while Central America, Venezuela, the Guyanas, and northeastern Brazil tend to receive less rainfall than normal. The coasts of Ecuador and Peru, and the southeast region - from northeastern Argentina through Uruguay and southern Brazil - are subject to extraordinarily high rainfall.

Image courtesy of SeaWiFS Project
NASA/Goddard Space Flight Center and ORBIMAGE

The 1997/98 ENSO Event

From April 1997 to May 1998 many regions of the globe experienced precipitation and temperature anomalies. Extreme weather events in Latin America included:

a) severe flooding in Ecuador and northern Peru,
b) prolonged and severe drought in southern Bolivia, and central Brazil, and
c) heavy rainfall in Venezuela (as in Florida, U.S.), in the early part of 1997, was followed by drought later in the year.

Disease Outbreaks in Latin America, 1997/98:

Mosquito-borne diseases

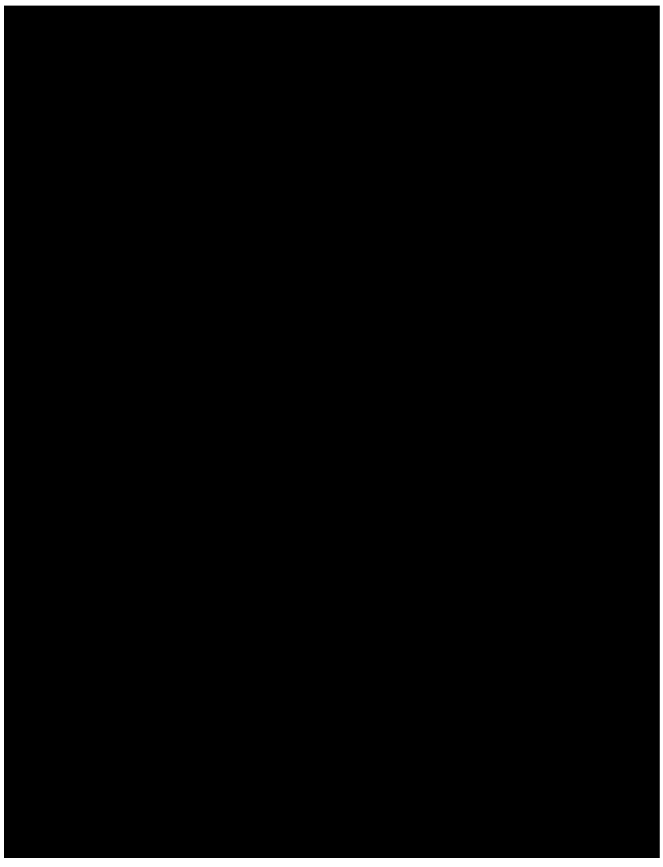
Multiple outbreaks and upsurges of malaria occurred in Latin America during this time period, with eleven South and Central American countries reporting unusual problems. Bolivia and Peru both experienced significant malaria upsurges. Malaria reappeared during this period in Rio de Janeiro, Brazil, having been eradicated in 1968. Continuing outbreaks occurred in the Amazon region in 1998. Resistant forms of the *plasmodium* parasite were reported in many regions of Brazil.

Significant outbreaks or upsurges of **dengue fever** (DF) were reported from twelve Latin American nations.

Dengue and **dengue hemorrhagic fever** (DHF) reemerged in Cuba in 1997, having been controlled after the large outbreak in 1981. In the summer of 1997 the Pacific coast of Costa Rica experienced an outbreak of DF in a region in which the disease was thought to have been eradicated. Northern Venezuela had especially high levels of DF and DHF in 1997, and Brazil experienced a major upsurge of both beginning in January, 1998 - especially in Rio de Janeiro and the southeast - in the wake of intense rains and flooding.

Cholera

Areas in South and Central America with heavier than average precipitation during the 1997/98 El Niño event experienced large upsurges of cholera, a water-borne disease. Outbreaks of cholera occurred in Ecuador, Bolivia, Honduras, Peru and Nicaragua in association with anomalous meteorological conditions. Although cholera has been a chronic problem in Peru and Ecuador since its reintroduction to South America in 1991, these nations reported significant increases in the number of cholera cases during the 1997/98 El Niño. In Venezuela and Chile, outbreaks occurred that were apparently not correlated with ENSO-related weather conditions. While there were 320,000 cases and 2,900 deaths due to cholera in Peru in 1991, 34,000 cases and 265 deaths were recorded during the 1997/98 period (Marston 1998).



Forest Fires

Regional anomalies in South America associated with the 1997/98 El Niño event - especially drastic fluctuations in precipitation - provided ideal conditions for extensive and prolonged forest fires in the Amazon. The ongoing clearing of forests for livestock production, agriculture, and timber were compounded by the most extreme drought in 50 years (D. Moura, IRI, personal communication, 1998), enhancing the intensity and geographic distribution of the fires. During this and other El Niño events tropical rainforests became net sources of carbon to the atmosphere, rather than acting as carbon sinks. Extensive fires provided large pulses of carbon to the atmosphere.

Whereas tropical rainforests usually serve as carbon sinks, under heat-stressed conditions brought on by El Niño events, millions of tons of carbon dioxide can be released into the atmosphere (Tian et al. 1998).

Fires led to significant acute respiratory illness in such cities as Manaus, central Amazon. Brazilian forest fires blazed out of control, invaded many towns and engulfed rural areas inhabited by Yanomami people. The chronic respiratory impacts from inhalation of soot (particulates) and hydrocarbons (chronic lung disease and cancer) have not been evaluated. Ecological impacts of the fires on animal and plant life in affected forests are significant. The economic impact on the region has not been tallied.

Hantavirus Pulmonary Syndrome

Since 1995 Hantavirus pulmonary syndrome (HPS), associated with increased rodent populations, have occurred in several Latin American nations. In 1997/98 HPS cases appeared in areas where land clearing affects population dynamics (e.g., species composition and predator/prey relations). Some outbreaks may have been exacerbated by extreme weather, particularly droughts were followed by heavy rain. The outbreaks impacted health as well as tourism and travel.

In Latin America, the 1997/98 El Niño event was associated with upsurges of malaria, dengue fever, cholera, and hantavirus pulmonary syndrome, and to respiratory disease accompanying forest fires in South and Central America. Public health measures can ameliorate the deleterious effects of El Niño-related extreme weather events, provided early warnings of meteorological conditions (see Conclusions and Recommendations).

B. THE ASIA-PACIFIC REGION

Climatic conditions during 1997/98

During the 1997/98 ENSO event, weather anomalies in the Asia-Pacific region varied monthly and regionally. From March through May, 1997, below normal temperatures prevailed over most of India and, in May and June, heavy rains fell in the northern region. Throughout the remainder of the summer and into the early fall India as a whole recorded normal to slightly above-normal rain. In China, Japan and South Korea typhoons caused flooding throughout the summer months. In contrast, northern and central Asia experienced summer drought that ended in August with typhoon Winnie. In Indonesia, Malaysia, and southern Thailand, heavy rains occurred in May of 1997, but monsoon rains were delayed. A period of dryness set in across Indonesia and much of the Philippines, leaving significant deficits of rain during the summer.

Extensive fires occurred in the region throughout the Fall, and were rekindled in the Spring of 1998. The burning was sustained by fires involving peat and deep coal seams. Heavy rain in May, 1997 provided growth and kindling that fueled the fires, while lightning sparked (and drought sustained) the extensive fires that subsequently had wide-ranging impacts on health and forest ecosystems.

Note that China again experienced heavy rains in the summer of 1998, accompanying the La Niña. Extensive flooding occurred along the Yangtze River. The damage was enormous: 3,700 people died, 223 million people were displaced and the losses were set at $ 30 billion. In the wake of this disaster, China openly examined it's vulnerability to flooding - the deforestation and drainage of wetlands (nature's "kidneys" and sponges) (see Costs Section).

The floods in China have had wide-ranging ecological impacts. For example, rare Siberian cranes migrating to the Jiangxi Province in December, 1998 were deprived of eelgrass and other essential foods.

While Indonesia received some rain in late April, 1998, Vietnam and the Philippines reported drought continuing into late April. In Australia, both dry and warm seasons began a month earlier than usual, the former beginning in May, the latter in October. The wet season progressed normally, but after December, 1997, rainfall increased in magnitude. The Cape York Peninsula, extremely hard hit by precipitation, continued to record rain surpluses well into 1998.

Image courtesy of SeaWiFS Project
NASA/Goddard Space Flight Center and ORBIMAGE

Vector-borne Diseases

Throughout the Asia-Pacific region numerous vector-borne disease outbreaks were associated with anomalies that accompanied the 1997/98 ENSO event. "Premature" rains were implicated in the early onset (in late May) of the epidemic season in the Philippines. Heavy rains were associated with an outbreak of encephalitis in India, in January, 1998.

In Thailand there were over twice as many cases of dengue fever in 1997 compared to 1996, as ENSO-related high temperatures apparently extended the dengue transmission season into the cooler months of the year. In Jakarta and the southern Sumatra region of Indonesia the worst upsurge of dengue fever in the five years occurred in the spring of 1998. Severe drought and famine in the region contributed to a widespread crisis.

The 1997/98 ENSO event was also accompanied by the spread of vector-borne diseases to new areas, especially in the Western Pacific. In January, 1998, Japanese encephalitis (JE) was identified for the first time in Papua New

Guinea; reports linked extreme drought and mosquito breeding sites in dried up stream beds to the spread of the disease from the south to the north. In early 1998, the first-ever case of JE on the Australian mainland was identified. Cyclones and prevailing winds brought mosquitoes to the western Cape York region, while rain surpluses and warm temperatures associated with the ENSO event may have facilitated mosquito breeding.

Malaria

During the 1997/98 ENSO event significant outbreaks of malaria were reported in Irian Jaya and Papua New Guinea, Indonesia's Bintan Islands, India, the demilitarized areas of South Korea, a Thai refugee camp, and the Philippines. Severe drought (with drying of stream beds) and prolonged hot weather in Indonesia apparently enabled mosquitoes to survive at high altitudes. Warm and wet conditions on the Bintan Islands provided ideal habitat for mosquitoes.

In India, malaria is tied to the monsoonal cycle. Although the endemicity of malaria in India makes it difficult to discern trends, there was a sharp rise in the number of cases reported in 1997.

Cholera

During the 1997/98 ENSO, significant outbreaks of cholera occurred in Indonesia, Malaysia, and the Philippines, linked primarily to the lack of clean drinking water associated with the severe ENSO-related drought. Drought-induced famine also heightened the vulnerability of populations in many of these areas to the complications of diarrhea. In Hong Kong, increased precipitation and contamination of food supplies were linked to large cholera outbreaks. Parts of India, Bangladesh, and Sri Lanka suffered extensive outbreaks of cholera, aggravated by social factors including poverty, poor sanitation, and overcrowding. North Korea reportedly experienced a severe outbreak of drought-associated cholera, the impact of which was compounded by unstable economic and political conditions. Thailand also experienced outbreaks of cholera though reporting was delayed.

During 1997/98 extreme weather events contributed to significant morbidity and mortality across the Asia-Pacific Region.

Image courtesy of SeaWiFS Project
NASA/Goddard Space Flight Center and ORBIMAGE

C. NORTH AMERICA

Despite varying predictions, North America was strongly affected by the 1997/98 El Niño. Extremely heavy rains pounded both coasts, affecting agriculture, causing massive flooding and mud slides, and led to billions of dollars in emergency relief. This section focuses on human health concerns in North America: rodent-borne diseases, mosquito-borne diseases, water-borne diseases, and harmful algal blooms. Outbreaks of several significant plant pets and pathogens are also examined.

Hantavirus Pulmonary Syndrome

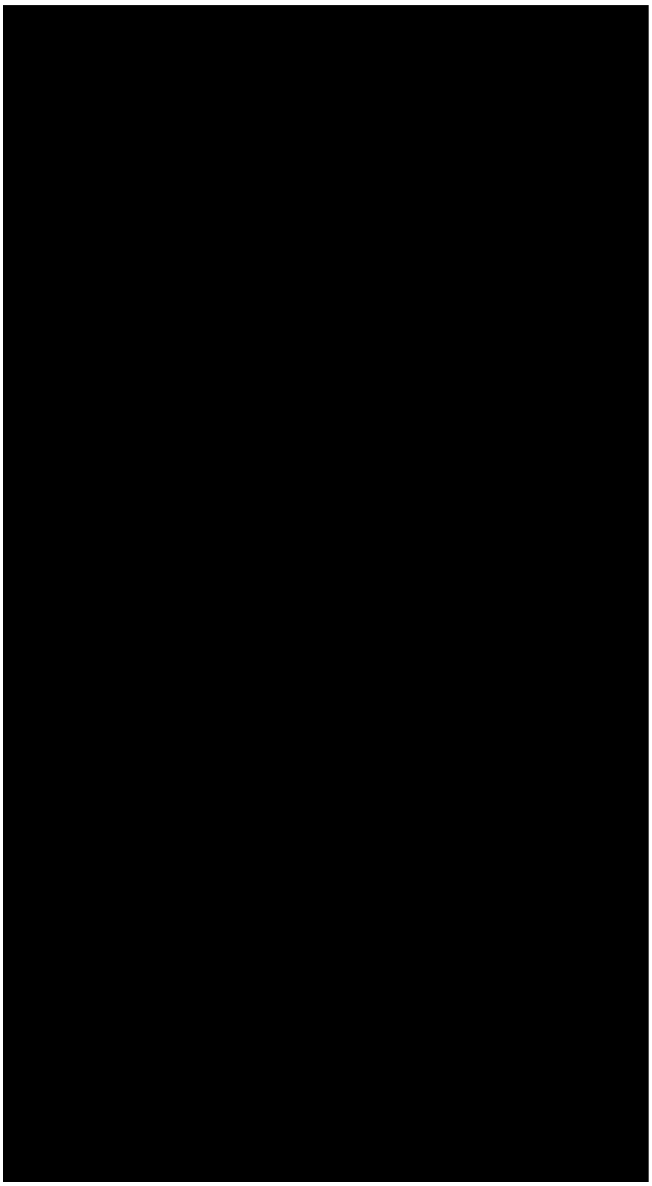
In January of 1998, rodent populations began exploding in the southwest as areas "greened-up" with unusually heavy rains. In 1998 there were seven new cases of hantavirus: 2 in New Mexico (one fatal), 2 in Arizona (1 fatal), 2 in Kansas, and 1 fatal case in Colorado. While rodent populations continued to be high in the U.S. southwest, early warnings by the Centers for Disease Control and Prevention were apparently successful in educating the

public and preventing greater disease transmission.

Vector-Borne Diseases

The most important vector-borne diseases for the U.S. are Lyme disease and insect-transmitted encephalitis. Lyme disease reports increased once again in 1998, as they have throughout the 1990s. Most concerning were reports of high densities of ticks in the summer of 1998, following the exceptionally warm winter.

While no widespread increase in insect-borne diseases occurred during 1997/98 in North America, specific cases were of significance. For example, a locally-transmitted case of malaria in Toronto suggests that the conditions for transmission at high latitudes may become increasingly prevalent during warmer, wetter years.



Water-borne Diseases and Harmful Algal Blooms

Despite the development and wealth of Canada and the United States, much of the continent has experienced a growing trend in water-borne diseases and harmful algal blooms over the last two decades.

Extreme weather events - especially heavy rains and flooding - are highly correlated with outbreaks of cryptosporidiosis (J. Rose, USF, personal communication, 1998). The 1993 outbreak of cryptosporidiosis - an intestinal illness caused by ingestion of the parasitic protozoan, *Cryptosporidium parvum* - in Milwaukee, followed heavy rains and extensive flooding along the Mississippi River. These conditions overwhelmed sanitation systems and non-point source runoffs into Lake Michigan, leading to the contamination of drinking water. This led to over 400,000 cases of cryptosporidiosis - and over 100 deaths in those with compromised immune systems.

Reviews of **Harmful Algal Blooms** (HABs) indicate an increase in the magnitude, extent, duration and varieties of HABs over the past several decades (Anderson 1995; Smayda 1990; Burkholder 1998). Since 1972, U.S. coastlines have been increasingly affected by HABs, resulting in episodes of paralytic shellfish poisoning, neurotoxic shellfish poisoning, amnesic shellfish poisoning, ciguatera fish poisoning, brown tide, and *Pfiesteria* poisoning (HEED 1998). *Pfiesteria piscicida* is a newly discovered dinoflagellate that, under certain conditions (including sufficient nutrients and warm sea surface temperatures), has produced fish lesions and fish-kills in North Carolina, Virginia and Maryland waters (Burkholder 1998). Outbreaks during the summer of 1997 were extensive, as heavy rains increased runoff of farm wastes and warm SSTs allowed proliferation of the toxic dinoflagellates. The costs - in terms of health, investigation, seafood industry, and tourism - were on the order of $60 million (HEED 1998).

In the summer of 1998, isolated *Pfiesteria* outbreaks occurred, perhaps dampened by large storms that flushed out semi-enclosed waters (J. Burkholder, UNC, personal communication 1998). A study of fishermen and others exposed directly to the toxins emitted during blooms indicate that neurological impacts - including memory loss and learning difficulties - can be substantial (Grattan et al. 1998). There is also the potential for immunosuppression from *Pfiesteria* and other dinoflagellate-related toxins.

D. AFRICA

During the 1997/98 El Niño precipitation in the Horn of Africa was five to ten time above average. The losses and costs were extensive throughout the region (see Costs section).

> *"Victims experienced severe vomiting and diarrhea and did not last more than six hours after contracting [Rift Valley fever]."*
>
> - local councilor, Nairobi.

> *"When I visited these villages I told the mothers not to feed their children the meat of dead and diseased animals. But they said they had nothing else, and I couldn't disagree."*
>
> - Louise Martin, WHO

> *"As the malaria outbreak in Wajir Town spread to areas surrounding the town, it claimed more than 43 lives in 48 hours... In the wards, up to three patients were sharing a bed. In one of the male wards, two elderly patients were in the same bed with the corpse of another patient who had been dead for several hours."*
>
> - district commissioner, Wajir, Kenya

Anecdotes of disease outbreaks such as these provide a haunting human face to the effects of 1997/98 El Niño on nations in the Horn of Africa. The effects of ENSO 1997/98 are personally tangible to individuals and communities that faced famine, homelessness, disease and - sometimes - immeasurable losses.

During this period 89,000 Somalians and Kenyans were sickened with Rift Valley fever (RVF), many dying from hemorrhage, and tens of thousands died from malaria and cholera.

Climate

Northeastern Kenya and southern Somalia form part of the plateau savanna region of Africa - part of the tropical wet-and-dry climate zone. Here, seasonal climate rhythms are chiefly controlled by the large-scale pressure systems of the western Indian Ocean. There are typically two rainy seasons: the first, and more important, runs from late March to May; the second, which does not always occur, spans September to December. In 1997/98 heavy rain fell from December to March - a period where the dominant air mass is usually comparatively dry. From June to August there is usually very little rainfall and stable weather conditions prevail. Total annual precipitation is usually 20-30 inches in northeastern Kenya and 13-20 inches in southern Somalia. Annual maximum mean temperatures range from 64-72 degrees Fahrenheit, and annual minimum mean temperatures range from 43-50 degrees for the region.

Africa - the Horn of Africa highlighted
Image courtesy of SeaWiFS Project
NASA/Goddard Space Flight Center and ORBIMAGE

ENSO and Precipitation in Africa

El Niño events do not always bring floods to the Horn of Africa. Indeed, the most severe floods between 1930 and 1990 occurred during La Niña years. While the 1997/98 El Niño event was accompanied by heavy rains in the Horn, the 1983 El Niño brought drought. The years with the most precipitation between 1930-1980 were 1947, 1962, and 1978 - all La Niña years. By plotting the precipitation and temperature anomalies in Nairobi, Kenya against the sea surface temperature anomalies of the niño3 index, one finds that, while the correlation is positive for both, the relationship is low. More accurate forecasting for this region will depend on combining information from the Pacific and Indian Oceans.

Indian Ocean temperatures are a major contributor to prevailing weather patterns for the Horn and Southern Africa. Along the east coast of southern Africa, weather anomalies accompanied the 1997/98 ENSO event. Severe drought, for example, was punctuated by bursts of rain. In southern Mozambique rains came early in September, several months prior to the usual rainy season.

In the Horn region, torrential rains fell for weeks at a time, and were accompanied by heavy and destructive flooding. The most intense spell of rain began in October; and "incessant rains" lasted for at least 6 weeks. Widespread flooding occurred in Kenya and Somalia. Similar periods of heavy rains occurred again throughout much of the region in January and early February of 1998.

Significantly, much of the rain that fell in the Greater Horn region - particularly in northeast Kenya and southern Somalia - occurred out of season. The January-February rainfall, in particular, was unexpected and unseasonal, not

only in severity but in duration.

As projected, there was little to no effect of El Niño in the northern, inland areas of the continent - namely the Sahara. Little effect was also observed in the Western Sahel regions and West Africa.

While the cluster of diseases in 1997/98 in the Horn of Africa was undoubtedly linked with the extreme rainfall and flooding that accompanied the 1997/98 El Niño Event, it is more difficult to correlate the outbreaks to the El Niño phenomenon over time.

Diseases:

Rift Valley Fever

Rift Valley fever is an acute, fever-causing illness that affects domestic animals and humans. RVF was first reported among livestock in Kenya in 1930, and continues to primarily affect livestock. While it generally occurs in eastern and southern Africa, RVF has also been found in most of the sub-Saharan nations and Madagascar. The largest outbreaks or epizootics occurred in 1950-51, resulting in the death of 100,000 sheep. In 1977 an outbreak in Egypt killed roughly 600 people. In 1987 RVF was first found in West Africa and was linked to severe flooding accompanying the Senegal River Project.

RVF is spread by mosquitoes - Eretmapodites spp., Aedes spp. and others - which hatch during periods of intense rainfall and flooding. The mosquitoes preferentially bite livestock, but will also bite humans. Humans can also contract the disease through handling infected animals or meat. While RVF is generally a mild illness, it sometimes progresses to hemorrhagic fever, encephalitis or ocular disease. The usual case fatality rate in humans is between 1% and 5%; in animals, it is higher. There is currently no treatment for RVF, though the U.S. military does have a vaccine in the experimental phase.

Distribution of RVF

In 1997/98 Kenya, Somalia and Tanzania experienced the largest outbreak of animal and human RVF in recorded history. Because it was concentrated in isolated, rural areas, and because of the intense flooding, it was difficult to obtain accurate counts of fatalities. It is believed, however, that 89,000 people were infected and that between 750 and 1,000 died. The outbreak was primarily concentrated in the Northeastern province of Kenya and the Jubbada and Gedo provinces of Southern Somalia. As was the case for malaria outbreaks, the districts of Wajir and Garissa in Kenya appeared to be the center of the outbreak. There were minor outbreaks in the Eastern, Rift Valley, Central and Coastal Provinces of Kenya. The northeastern Tanzanian districts of Arusha and Kilimanjaro also experienced large epizootics and thousands of domestic animals died throughout Somalia, Kenya and Tanzania.

There is a very clear connection between the anomalous weather and the emergence of RVF in the Horn of Africa. Heavy rains began in the Horn region on October 23, 1997 and continued for six weeks, causing rivers to flood throughout the region (see Timeline on following page). The floods created ideal conditions for mosquitoes to hatch.

The first cases of RVF apparently appeared in northeastern Kenya and southern Somalia in mid-November, three weeks after the rains began. In late December a mysterious hemorrhagic disease causing many deaths was reported. By January 1998, there were at least 300 confirmed human deaths; in addition to thousands of livestock deaths in northeastern Kenya and Southern Somalia. By mid-January, the epidemic was out of control, and was spreading. New cases were reported in other provinces of Kenya including the Eastern, Rift Valley, Central and Coastal provinces.

Health workers reported that they felt powerless in the face of this deadly disease, compounded with the fact that it was ravaging communities that were inaccessible due to flood-destroyed roads and infrastructure. Outbreaks in the other Kenyan provinces remained relatively small, and by early February, as the rains began to subside, so did the appearance of new RVF cases. By mid-March the epidemic ended in Kenya and Somalia.

In Tanzania, a large outbreak in livestock occurred in the northern Arusha and Kilimanjaro regions. While originally considered malaria, the diagnosis was eventually determined to be RVF. In April, there was confirmation of outbreaks in livestock in Zimbabwe, which were estimated to have begun in January.

Uncertainty in diagnosis: On January 6th, 1998 tests began to indicate that the mystery disease was Rift Valley fever. However, only two weeks after the disease was confirmed as RVF, health workers and scientists began to question the diagnosis because of the unusually high mortality rate. Some conjectured that there was another disease altogether, while others hypothesized that it might be a new "super" strain. The exact nature of the disease (or combination of diseases) has not yet been determined.

Timeline: The Story of Rift Valley Fever in Eastern Africa during the 1997/98 El Niño

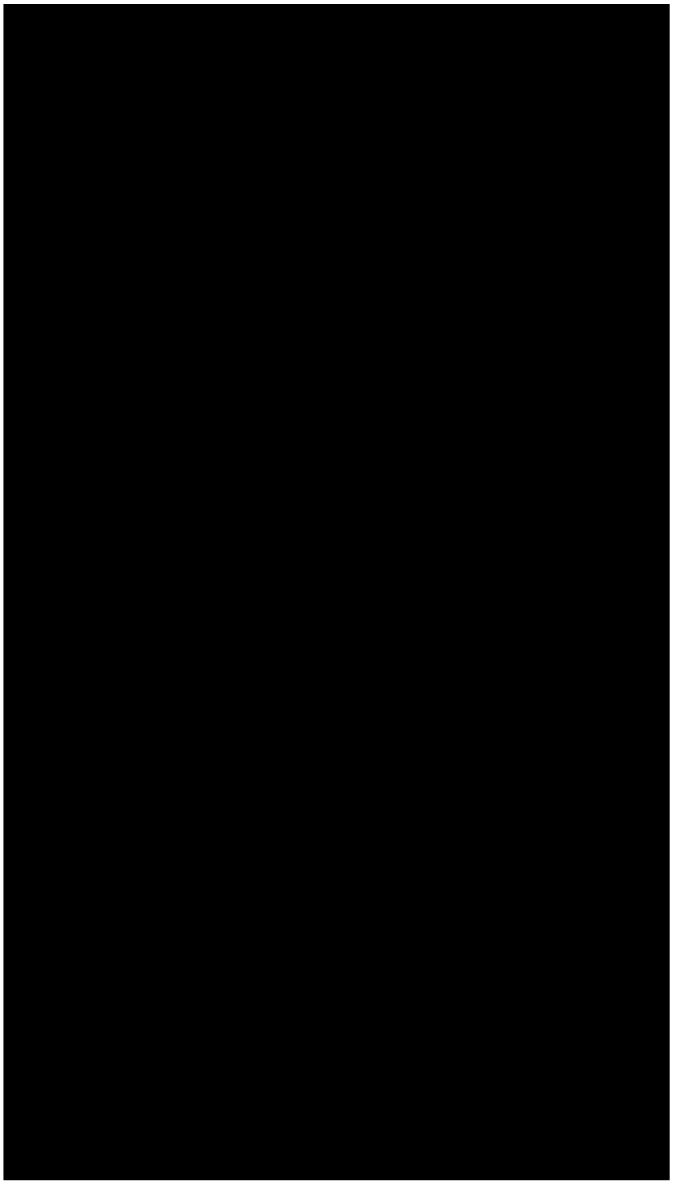
Oct. 23	heavy rains begin throughout the horn region
mid Nov.	virus appears in northeastern Kenya and southern Somalia
late Dec.	reports of mysterious hemorrhagic disease, many deaths in NE Kenya and S Somalia in humans and livestock
Jan. 1	thousands of livestock dead; at least 300 confirmed human deaths in Kenya and Somalia
Jan. 6	tests begin to show that mysterious disease is Rift Valley fever
Jan. 8	health officials begin to fear worst-ever outbreak, with potential to spread across the Red Sea
Jan. 13	unusually high mortality rate leads some scientists to suspect super-strain of RVF
Jan. 15	epidemic reported out of control
Jan. 16	new cases appearing in other Kenyan provinces - Eastern, Rift Valley, Central and Coastal
Feb. 10	as rains subside, number of RVF cases also drops
Feb. 26	RVF confirmed in Tanzania (northern regions); causing human and livestock mortalities since November (initially considered malaria)
Mar. 11	epidemic comes to an end in Kenya and Somalia

Fatalities: Inaccessability, isolation and difficulties with diagnosis make fatality estimates uncertain. 700 deaths were reported in the Kajera region, for example - some considered to be due to RVF - but these figures were not confirmed. The shortage of health workers and hospitals in the region meant that most people died at home, isolated from reporting mechanisms. In addition, the Kenyan and Somalian governments were slow to report the epidemic. By January 1, there were 300 deaths officially reported in the region, but this figure did not increase in January, while reports from health workers, the WHO and Red Cross surveys indicate that the epidemic continued and even reached its peak in January. Given the discrepancies, there were probably as many as 450 human deaths in southern Somalia and as many as 700 deaths in northeastern Kenya. The number of livestock deaths was certainly in the thousands. These estimates would make this the largest outbreak of RVF ever recorded.

Malaria

Unlike diseases such as Rift Valley fever, which tends to occur only in distinct outbreaks, malaria transmission is ongoing in many regions of Africa. Each year, sub-Saharan Africa accounts for 90% of 300 - 500 million malaria cases reported worldwide, and most of the estimated 2 - 3 millions deaths.

There are four species of the *Plasmodium* parasite. *P. falciparum* is associated with the majority of fatalities. People may live for years with other types of malaria, never completely recovering, or may contract several types at the same time. Fatalities may occur from other forms of the *Plasmodium* parasite when patients are immunocompromised. Malaria deaths frequently occur in children (with low levels of immunity), and in areas where food, clean water and sanitation are inadequate. There is widespread - and growing - resistance of *P. falciparum* to most of the available drugs. Combination therapies are being studied to retard the emergence of drug resistance; but the combinations are expensive. Currently, there is no vaccine available against this complex parasite.



Geographical Anomalies: Highland Malaria -

During the season of June-July 1997, coinciding with a surge in precipitation, instances of highland malaria was reported in Uganda and western Kenya. Occurring at high altitudes where cases of malaria are infrequent (in areas outside of those considered endemic), highland malaria often indicates a spread of the disease beyond its normal borders. During July of 1997, the West Pokok and Uasin Gishu districts of western Kenya, along with the Kapchorwa district of eastern Uganda (among others) were severely hit with an outbreak that affected tens of thousands. Extremes in precipitation were reported along with famine. The severity of the outbreak warranted the transfer of mobile units of medical personnel and equipment to remote areas. Significantly, the highland cases of malaria were associated with the Rift Valley Province cases in June, thought to have spread from malaria-endemic areas to more remote regions. A recent report did not find and association between temperature changes and the highland outbreaks of 1997 (Malakooti et al. 1998).

During the 1997/98 ENSO season, incidents of anomalous malaria events reported as unusual in timing or altitude were also roughly concurrent with high precipitation and flooding, consistent with previous associations between weather extremes and malaria outbreaks.

Cholera

During the 1997/98 El Niño, tens of thousands of cholera cases occurred in eastern and central Africa. Sufferers of this intestinal infection, caused by the bacterium *Vibrio cholerae*, experience diarrhea, dehydration, vomiting, and sometimes death. Often, the disease is contracted from contaminated water and food. Many of cases can be prevented with adequate waste disposal, safe drinking water sources, improved food hygiene and rapid treatment.

Cases of cholera were primarily concentrated around the population centers of Pointe-Noire, Congo; Kinshasa and Kisangani, Democratic Republic of Congo; Mbale, Uganda; Nyanza and Nairobi, Kenya; Mogadishu, Somalia; Zanzibar, Tanzania; Djibouti; Comoros Islands; Maputo City, Xai Xai, and Beira, Mozambique.

V. Hurricane Mitch and Health

Hurricane Mitch - which dropped four to six feet of rain over three days (two feet in one six-hour period) - tragically demonstrates the multiple impacts of extreme weather events on health, infrastructure and development.

A. NEWS ARTICLE

After Mitch, Honduras reels from deadly disease spread

By Richard Chacon, Boston Globe Staff, 12/08/98, p.A1

TEGUCIGALPA, Honduras - Six weeks ago, it was the violent winds and torrential rains of Hurricane Mitch that sent millions in this country running for shelter. Then came the grisly task of digging out bodies and the counting of displaced families. Now, this small, impoverished Central American country is battling an array of deadly diseases and infections that could kill as many people, officials say, as the storm itself.

The Honduran government issued a national state of alert Friday because of epidemics following the hurricane. As many as 20,000 cases of cholera have been confirmed, the government says. More than 30,000 people have contracted malaria and 208,000 more have serious cases of diarrhea, which can be fatal for infants and small children. "This is when the real pain begins," said Douglas Ryan, Honduran director for Catholic Relief Services, a private volunteer organization. "From the level of destruction we've seen to water systems and their infrastructure, these kinds of numbers don't surprise me at all."

The government's estimates are dramatically higher than those previously given by health workers and aid agencies. Two weeks ago, for example, the Pan American Health Organization, the leading medical assistance group working in Central America, confirmed a total of about 560 cases of cholera in Honduras, Nicaragua, Belize, El Salvador, and Guatemala, the countries hardest hit by Mitch.

The Honduran Health Ministry also said in its alert that 62 people had been diagnosed with leptospirosis, a disease spread by rats that can cause liver or kidney failure. Four people so far have died from the disease. In addition, health workers said that 1,080 cases of dengue, a mosquito-borne illness that can cause chills, joint pains, and hemorrhaging, have been confirmed in Honduras. Although some international health and aid workers yesterday raised questions about the accuracy of the government's figures, no one doubts that this country, roughly the size of Ohio, has become an incubator for life-threatening diseases.

"Public health conditions here were vulnerable even before the hurricane," said Leopoldo Narvaez, a doctor who practices out of his home in a Tegucigalpa neighborhood. "We've been dealing with AIDS and high rates of cancer. But now we're talking about national epidemics to have to fight and with few resources."

Most of the worst cases of cholera, an intestinal disease that can kill through severe dehydration, and malaria have been found along the country's numerous rivers, in rural villages, and along the northern coastal communities, health workers said. But some cases have been reported in the capital city of Tegucigalpa, mostly in people who live or work near the Choluteca River, which since the storm has become a putrid collection of human waste, animal remains, and rotten food. Near the city's central market, one of the most popular shopping areas for everything from vegetables to fresh chickens, some residents have begun scavenging the river to collect items that can be washed and resold on the street. Government officials closed the market for health reasons immediately after the storm hit, but the hundreds of vendors simply have relocated their booths across the street.

Unless health workers can control the spread of diseases, the death toll from illnesses could double the 9,000 Central Americans who have been killed by Mitch, the most destructive hurricane to hit the area this century.

In Honduras, the country hit hardest by the storm, the official death toll stands at 5,657. On Friday, however, the country's Justice Ministry said it had suspended the governor of the state of Santa Barbara for overstating the number of dead there. Rather than the 1,159 dead initially reported, the government said, the actual number was 282.

The spread of so many diseases has stretched the country's medical institutions beyond capacity. Even before the threat of diseases appeared, hospitals and clinics were busy treating many of the 12,000 people who were injured by the storm.

Many water systems, most of which were built only recently, were severely damaged by heavy rains or by rivers that in some instances swelled up to 45 feet above their normal level. "More than 60,000 homes have been completely destroyed," said Scott Solberg, deputy director in Honduras for the relief organization CARE. "So much of the basic water infrastructure is still clogged with debris. The magnitude of destruction is astounding."

Officials in other Central American countries also are trying to fight the spread of diseases. In Nicaragua, more than 400 cases of suspected cholera and six of leptospirosis have been reported. Guatemalan officials have confirmed 26 cholera cases, and two have been found in Belize. Many of those who are not ill are being urged to take precautions. Aid organizations have distributed thousands of water purification tablets. Children are being vaccinated for hepatitis and tetanus. Rescue shelters are being checked regularly for infestations of rodents and mosquitoes. And government agencies are warning families to beware contaminated meats and produce.

Amid such grim precautions, many Hondurans are trying to resume their daily life. Along streets once covered with leather-colored water and outside many of the hillside homes that ring the city, Christmas lights and ornaments hang in anticipation of a more peaceful, joyful time. "It's important that people feel a sense of restoring their livelihoods," said Ryan, of Catholic Relief Services. "This has been like waking up from a nightmare."

B. ProMED POSTING

Following is a report, posted by ProMED, on the epidemiological situation in countries affected by Hurricane Mitch. This and other information is also available on Pan American Health Organization's (PAHO) Web site:

http://www.paho.org/english/ped/pedhome.htm

OUTBREAKS, POST-HURRICANE - CENTRAL AMERICA

Date: Fri, 27 Nov 1998 15:59:12 -0500
From: Pan American Health Organization (PAHO)
http://www.healthnet.org/programs/promed.html
A Report of the PAHO Emergency Task Force on Hurricane Mitch - November 25, 1998

EL SALVADOR:

Cholera: On 25 November, the Ministry of Public Health reported two new cases of cholera in the department of Santa Ana. These cases had come in contact with a person from Guatemala, previously confirmed with cholera, who was staying with the two recently confirmed cases. Both cases were bacteriologically confirmed (01 Ogawa). Through 25 November, there have been eight cases and one death.

With respect to the outbreak reported on 19 November of 15 suspected cases that were hospitalized, the Ministry of Health reports that they continue under observation, but the test results have been negative. In addition, the Ministry of Health has taken prevention measures in all cases, and emphasizes the execution of an intensive Communication and Health Education Plan.

GUATEMALA:

Cholera: No new information has been reported after 24 November. During the first weeks following Hurricane Mitch, the number of cases of cholera rose to 736, of which 170 were confirmed. There were three deaths, a case-fatality rate of 0.4%.

Leptospirosis: The Ministry of Health continues to report a total of six cases to date, of which five have been confirmed.

Dengue: No new information has been reported; however the country has been asked to update available information, given the fact that in Week 45 (8-14 November), an increase of more than 200 cases was reported over the previous week.

Malaria: The country has been requested to provide additional information on this disease and its behavior since Hurricane Mitch struck, given the fact that prior to Mitch, Guatemala was registering a rising trend when compared to 1997.

NICARAGUA:

Cholera: The Ministry of Health has reported 19 new cases of cholera, 10 of which occurred in Managua; four in Matagalpa, two in Masaya; and one in Jinotega. 50% of the reported incidence of cholera is in Managua.

Through Week 45, 25 deaths from cholera were reported, the majority of which occurred along the Atlantic Coast and the Rio San Juan.

The Ministry of Health continues to strengthen basic sanitation measures, health education, and early diagnosis and attention to cases. It continues to note that daily reporting can vary because of late case reporting.

Leptospirosis: From 22 to 25 November, 70 new suspected cases were reported: 22 on November 23; 12 on November 24; and 36 on November 25. Chinandega with 38 cases and Esteli with 18 continue to be the most affected areas. To date, 298 suspected cases have been reported. The laboratory has processed 202 of these samples, and 48 resulted positive (23.8%). Seven people have died from leptospirosis, a case fatality rate of 2.4%.

Dengue: The Ministry of Health reports that dengue has been at an epidemic level during all of 1998, and an increase in reported cases has occurred in the last three weeks. Cases of hemorrhagic dengue have been principally reported in Leon (54 cases) and Chinandega (9 cases). Three people have died: two in Leon and one in Matagalpa.

Malaria: According to information from the Ministry of Health, the situation remains stable.

HONDURAS:

Cholera: There is no change in the situation previously reported. The Ministry of Health had reported 3 confirmed cases of cholera and several suspected cases in Regions 1, 3 and 4. The Ministry has strengthened health education among the population and has stepped up training of health personnel. The plan includes laboratories, epidemiological surveillance, health promotion, sanitation, and case management.

Malaria: Since the emergency began and through 24 November, daily reports based on information collected in shelters indicates 1649 cases of malaria. 54% of the cases

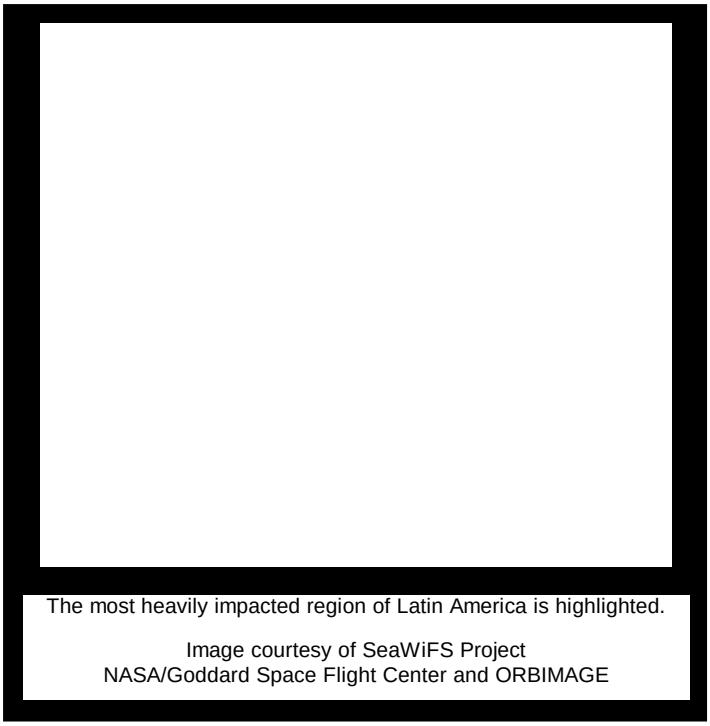
are in Regions 3 and 4. No deaths have been reported. The Ministry of Health has re-established the Weekly Epidemiological Surveillance Reporting System.

Leptospirosis: No new information is available since 24 November. The Ministry of Health reports five cases of leptospirosis. Four people have died. The epidemiological team made up of national and international specialists is strengthening surveillance and early detection of this disease.

Dengue: Up to 24 November, the Ministry of Health had reported 1,080 cases of classic dengue, 440 of which are in Region 3. To date, 17 suspected cases of hemorrhagic dengue have been reported, of which 8 are under study.

BELIZE:

There is no change in the situation reported on 24 November. To date, five cases of cholera have been confirmed, resulting in one death.



The most heavily impacted region of Latin America is highlighted.

Image courtesy of SeaWiFS Project
NASA/Goddard Space Flight Center and ORBIMAGE

EPIDEMIOLOGICAL ANALYSIS
NOVEMBER 26, 1998

The epidemiological situation remains as reported on 24 November. Epidemic activity of cholera remains in the five affected countries. Epidemic activity of leptospirosis remains primarily in Nicaragua, with low reporting in Honduras and Guatemala. Epidemic activity of dengue is in Guatemala, Honduras, Nicaragua and El Salvador. Honduras reports cases and death from hemorrhagic dengue.

PAHO continues to recognize the efforts made by the affected countries to control the occurrence of epidemics. The Organization also reiterates the need to improve the efficiency of epidemiological surveillance systems with regard to early detection, not only in the general population, but particularly in shelters where conditions that favor the transmission and outbreak of infectious diseases that have a potential to cause epidemics, remain present.

PAHO considers that the recommendations put forth in the report of 23 November remain valid, and consequently reiterates the need to set them in motion.

Cholera:

1) Strengthen health control measures, including basic hygiene measures, provision of safe water, and handling and consumption of food from street vendors, among the at-risk population, particularly in shelters.
2) Intensify local epidemiological surveillance measures of cholera (active identification of cases) in the affected population.
3) Implement social communication campaigns particularly in shelters and among the displaced population and native communities.

Leptospirosis:

1) Strengthen the local capacity to diagnose and quickly treat cases.
2) Stimulate community participation in expanding the application of preventive measures and the early detection of suspected cases.
3) Step up health surveillance measures, including rodent control.

Hemorrhagic Dengue:

1) Ensure that health authorities have prompt access to suspected cases.
2) Intensify health measures to control vectors.
3) Strengthen local community participation in the control of breeding sites of mosquitos.

The Boston Globe boston.com Online

MITCH TRAGEDY MAY OPEN DOOR TO AWARENESS

Author: Paul R. Epstein
Date: SATURDAY, November 28, 1998
Page: A23
Section: Op-Ed Page

The Hurricane Mitch tragedy in Central America is immeasurable. But it does present an opportunity to launch clean development in that devastated part of the world.

The hurricane's early November shock waves rippled down the Andes to the vast convention halls of the recent United Nations-sponsored climate meeting in Buenos Aires. Delegates from more than 150 nations held a moment of silence for the victims, and discussed the consequences. Now leaders from Europe, the United States and Central America are urging debt-forgiveness and a Marshall Plan to rehabilitate the region.

Not lost on representatives at the Buenos Aires conference were reports that - over the span of three days - Mitch had deposited four to five feet of rain across the thin Central American isthmus; two feet in one six-hour interval. One reason may be that sea surface warming is fueling hurricances, and heat, from burning coal and oil, may be accumulating in the deep ocean and around both poles.

Deforestation worsened the impact of the deluge. Again fossil fuel combustion and the felling of forests emerge as chief perpetrators of man's swollen ecological footprint, remolding Earth's landscape.

This year extreme weather events - from Texas to the Horn of Africa - have spawned major problems for agriculture and for human health. Honduras and Nicaragua are now plagued with cholera, malaria, dengue fever, respiratory diseases and rodent-borne leptospirosis.

Emergency needs are enormous. But aid must lay a foundation for appropriate future development and for enviromental protection.

Energy is the key. It underlies every aspect of society. Progress in Central America, based on clean energy sources, could thus underpin development that rationalizes the use of resources and minimizes the generation of wastes.

A clean energy initative could also jump-start infant industries in the US and elsewhere that produce nonpolluting, climate-friendly technologies - such as wind, solar and fuel cells - and help propel these products into the global marketplace.

Two Massachusetts companies, Enersol and Soluz, are already shipping solar panels to Honduras to purify water and provide power to medical clinics. They already have local capacity to install and maintain clean energy devices. A regionwide initiative for clean development could provide the necessary push and pull to start a global energy transition, and the new enterprises and trade could prove beneficial to the world economy.

Hurricane Mitch, with its endless mud and irretrievable losses, may become a turning point for public awareness of the enormous potency of climate disruption. Debt-forgiveness would remove old barriers to development, while significant funding for clean energy could catapult new efforts over the enormous hurdles facing the poor people of Central America.

Clean development would also provide a measure of justice as one day we may look back on the victims of Hurricane Mitch as the first explicit victims of climate change.

VI. The Ice Storm of 1998

A Vertical Anomaly?

In December, 1998 an Ice Storm crippled crops and transport across a large swath of the southern U.S.. "Freezing rain glazed Birmingham, Alabama [on Dec 23] as air temperatures near the ground hovered at 31 degrees. Yet 5,000 feet aloft, temperatures were close to 50 degrees," read the New York Times weather page on December 24. "Such a vertical variance indicates the shallowness of the Arctic air mass that invaded the Deep South this week. The caricature of the Arctic air mass resembles a wedge of cheese… ". In January a new record low temperatures were set in Illinois - 36 below zero.

Can we expect more such invasions of Arctic air driving under a warmed mid-troposphere, as model projections might suggest? (See section on ENSO and Climate Change.) Will we experience more winter rains - instead of snow - due to the mid-tropospheric warming combined with the enhanced hydrological cycle; with ice storms following sudden cold snaps? The New York Times article below captures many of the social costs of such extreme weather events.

4-DAY COLD SPELL SLAMS CALIFORNIA; CROPS DEVASTATED
By Todd S. Purdum
The New York Times, December 25, 1998, p.1

A brutal four-day freeze has destroyed more than a third of California's annual citrus crop, inflicting upwards of a half-billion dollars in damage and raising the prospect of tripled orange prices in supermarkets by next week.

Throughout the Golden State, cold, dry air from the Gulf of Alaska sent temperatures below freezing beginning Monday, with readings in the high teens and low 20's in the agriculturally rich Central Valley early today - the worst cold spell since a 10-day freeze in 1990. Farmers frantically ran wind and irrigation machines overnight in an effort to keep trees warm, but officials pronounced the lemon crop a near total loss in the valley, and said perhaps half of the state's orange crop was lost as well.

"This should be a time of joy, but it's been a bitter disappointment," Bob Krauter, a spokesman for the California Farm Bureau in Sacramento, the state's largest agricultural organization, said of the Christmas-week freeze. "We've had more than our share of challenges from Mother Nature this year, with El Niño early on bringing excessive moisture and cold weather that delayed planting and increased pest infestation and disease problems."

Indeed, agriculture officials said, the late planting meant that more of the state's navel orange crop remained on trees than usual this week and thus susceptible to freezing. California grows about 80 percent of the nation's oranges eaten as fruit, and 90 percent of the lemons, and wholesalers said the retail prices of oranges could triple in the next few days. The price of lemons was certain to rise as well, but the price of orange juice should be less affected because most juice oranges are grown in Florida.

In some California markets, wholesalers reported that the price of navel oranges had increased to 90 cents a pound on Wednesday from 35 cents a pound on Tuesday.

The citrus industry accounts for well over $1 billion of the state's $27-billion agricultural output. But from the Central Coast to the inland desert Imperial Valley, the cold also threatened crops from avocados to strawberries and celery.

The freeze hit especially hard in the towns up and down the San Joaquin Valley, which took years to recover from the last big freeze and where some counties already have unemployment rates of upwards of 15 percent, three times the national average. Officials are preparing to seek state and Federal disaster aid.

"In a nutshell, it was way too cold for way too long," said Gary Kunkel, assistant agriculture commissioner in Tulare County, which has 100,000 acres of orange groves - about half the state's production - and estimated today that 85 percent of the citrus crop remaining on trees was already lost, about $370 million of its $500 million annual total. "We've had some places below 25 degrees for 13 or 14 hours at a time," Mr. Kunkel added. "Imagine watching somebody just tear up your annual paycheck right in front of your eyes."

When oranges suffer a hard freeze, the juice sacs inside crystallize and burst through the membranes. When the flesh thaws, the juice seeps out and evaporates through the skin, leaving the insides dry and inedible.

Because of El Niño-related planting delays and poor pollination caused by excess moisture, the California citrus crop was already expected to be about 20 percent below last year's, said Keith Collins, chief economist for the United States Department of Agriculture. "We were already on track to have a much reduced crop," Mr. Collins said.

Today's weather, meanwhile, wreaked havoc elsewhere in the country, especially in the South, where ice-laden tree limbs snapped power lines, The Association Press reported. About 315,000 customers were reported without power in Virginia, along with 106,000 in North Carolina, 128,000 in Louisiana,112,000 in Tennessee, 125,200 in Mississippi, and 11,000 in Arkansas.

The freeze capped a year of weather-related calamities in the nation that produced mixed results for the agriculture industry. The moist El Niño conditions led to record yields on winter wheat in Texas and the Plains states and record summer heat and drought caused declines in cotton, cattle and other crops and commodities from California to Texas, New Mexico and Louisiana.

In Florida, continued warm weather and drought have resulted in sharply lower citrus crop forecasts. State officials said more rain and cold weather were needed for a larger crop. The Florida Department of Citrus estimates that this year's harvest will produce 190 million boxes of oranges, down from last year's record harvest of 244 million boxes.

Last summer, fires and drought in Central Florida caused an estimated $150 million in damage to crops and destroyed $400 million in timber.

"What's particularly curious, even stunning, about this year, is that for all the weather turmoil we still wound up with many near-record crop yields," in corn and soybeans in states like Illinois, Indiana and Iowa, Mr. Collins said.

But the high yields also produced low prices for many crops and, together with the weather-related damage in selected areas, led to passage of the biggest agricultural relief measure in the nation's history, $5.7 billion, Mr. Collins said.

Darwin Smith, an orange-grower in Orland, 90 miles north of Sacramento, knows that stress first-hand. He expects to lose his entire 75-acre crop this year, which would have brought him $50,000. He and other farmers who formed a packing plant will have to lay off about 40 workers.

"I think at this point right now, the chances of anything being harvestable are just about nil," Mr. Smith said. "We'll know better when we go in next week and start cutting fruit, but at this point, if there was anything salvageable, I'd be shocked."

This is the second time Mr. Smith has lost his entire crop to a freeze in his 13 years of farming, and the Federal crop insurance he buys will cover only about half his expected loss. His family will have to rely on income from his wife's job and a part-time job he works in the summers, but he dismissed any suggestion of leaving farming.

"You've got to realize that growing oranges is always going to be a risk," Mr. Smith said.

In Lindsay, the LoBue Bros. packing plant, Tulare County's largest employer, laid off 450 of its 500 employees on Wednesday, and company officials said it could be two weeks before they know whether they would need their usual crew of pickers and packers for oranges.

"Four hundred and fifty people are not going to show up on Monday, they're not going to get paid, they're not coming to work," said Joe LoBue, the company's marketing director. "And we don't know when they will come back. If in fact these people don't go back to work for a long period of time, it starts to affect the whole economy of the county here. In 1990, you had a lot of people that showed up at food banks, a lot of people who ended up on welfare, a lot of people who couldn't get jobs."

Robert Ward, a citrus farmer in Exeter, about halfway between Los Angeles and San Francisco in the San Joaquin Valley, was up at 4 A.M. today, checking water pumps and wind machines designed to raise the temperature on his 250 acres. Damp soil is less susceptible to freezing and wind machines circulate any warmer air currents that may be aloft. Despite the efforts, Mr. Ward said the damage was severe.

"It's the only way of life I know," he said. "I'm 60 years old and it's too late to start over. I don't know what else I'd do." He added: "We'll make it. It's going to get tight around here. We're not going to upgrade any new equipment. We're just going to get by as best we can, and see what happens next season."

VII. Marine mammal strandings and mortalities, 1997/98

Cetacean (whale, porpoise, and dolphin) and pinniped (seal, sea lion and walrus) populations have been impacted, often severely, by algal toxins and viral epizootics (Heide-Jorgensen et al. 1992; Aguillar and Raga 1993). Morbilli (or measles-like) viruses have played a prominent role (Ferrar and Pumarola 1990). The West Indian or Florida manatee, one of four extant species in the order Sirenia, have been increasingly impacted by brevetoxins.

Research and the data for this section suggest that adverse events involving marine mammals can serve as another sentinel indicator of ecosystem health. Among seal populations, for example, research in the North Sea has established that increasing morbidity and reproductive failure are related to man-made environmental contaminants (Kinne 1983). Many marine mammal species are top predators, predisposing them to the bioaccumulation of contaminants over time. How this chronic exposure translates into strandings and mortalities is as yet unclear (Sindermann 1996).

Environmental pollutants - like biotoxins - can depress the immune (defense) system of mammals, allowing infections to penetrate (Lahvis, 1995). There is also evidence that anomalous warm (and cold) SSTs may depress the immune systems of mammals (Lavigne 1994). Records of marine mammal mortalities since 1918 suggest an association with warm and cold events (Trillmich et al. 1991). Globally a highly unusual series of mortality events occurred during 1997 and 1998 - the warmest years of this century. Several climate-related mechanisms have been implicated in the increasing number and extent of reported events.

During the 1997-98 El Niño event, a large number of major marine mammal mortalities occurred worldwide. Some of the winter (Austral summer) events listed below may be considered commonplace; others constitute more unusual mortalities.

The high level of marine mammal morbidity and mortality reported during the 1997/98 El Niño event may be a significant indicator of more widespread changes in the marine environment.

The data gathered for the HEED Global Change project indicate event clusters in 1979, 1982-83, 1987, 1994, and 1997-98. Throughout the 1980s and '90s, events peak during El Niño events. Geographically, marine mammal mortalities within this study area (Labrador to Venezuela) have clustered in the Northeast, in southern Florida, and around Galveston Texas - areas particularly affected by harmful algal blooms (HABs).

Recent occurrences in the HEED study area are presented in the graph below. This data was collected using the Lexis-Nexis mass media search tool. All occurrences were reported in mass media (primarily newspaper) pieces.

Anomalous sea surface temperatures, HABs, and viral agents may be linked to marine mammal mortalities in previously undocumented ways. The significance of monthly and seasonal pulses seen here, and in historical data, need greater exploration. Linking information from numerous sources can permit testing of hypotheses involving multiple factors and stresses.

VIII. COSTS

A. Worldwatch and Munich Re Report

The following report on the costs of weather-related events in the first 11 months of 1998 was compiled by the Worldwatch Institute and Munich Re, the latter representing reinsurance industries that insure other insurance companies for losses exceeding $1 million.

The climbing costs from extreme weather for the insurance industry and the rise in US Federal Emergency Management Agency assistance - may be the best aggregate economic indicators of the growing costs of "business-as-usual".

RECORD YEAR FOR WEATHER-RELATED DISASTERS - ***by Janet N. Abramovitz and Seth Dunn***
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With one month remaining, 1998 has already set a new record for economic losses from weather-related disasters. According to preliminary estimates by the Worldwatch Institute and Munich Re (Reinsurance), storms, floods, droughts, and fires caused at least $89 billion in economic losses during the first eleven months of the year.

Economic Losses from Weather-Related Natural Disaster Worldwide, 1980-98

Note: 1998 is preliminary, based on the first 11 months

The 1998 preliminary total represents a 48 percent increase over the previous record of $60 billion in 1996-and far exceeds the $55 billion in losses for the entire decade of the 1980s. During the first three quarters of 1998, the U.S. insurance industry alone had weather-related claims of more than $8 billion-three times the claims in 1997.

The direct human impact of this year's weather-related disasters has also been staggering. An estimated 32,000 people have been killed, and another 300 million-more than the population of the United States-have been displaced from their homes or forced to resettle because of extreme weather events in 1998.

Weather-Related Losses by Year

From China to Central America, the evidence is now clear that some of the most damaging weather-related events of 1998 were "unnatural" disasters. Deforestation has left many steep hillsides bare, causing rainfall to run quickly into rivers rather than being absorbed, and often leading to devastating landslides and floods. At the same time, growing population pressures have led many people to settle on vulnerable flood plains and hillsides. While meteorologists connect some of the 1998 disasters to El Niño and its aftermath, no previous El Niño has resulted in such devastating consequences.

Among the most severe 1998 disasters:

· Hurricane Mitch, the deadliest Atlantic storm in 200 years, caused an estimated 11,000 deaths in Honduras, Nicaragua, Guatemala, and El Salvador. Preliminary damage estimates are $4 billion in Honduras (equal to one-third of its GDP) and $1 billion in Nicaragua. As of late November, about half the population of Honduras had been evacuated, 70 percent were without clean water, and the risk of disease is growing. Nearly 100 bridges were wiped out as well as many of the roads that are needed to supply relief to the victims. About 95 percent of the crops were destroyed in a nation where nearly two-thirds of the workers are employed in agriculture.

Mitch hit a region that was ecologically vulnerable. Central American nations have experienced some of the highest rates of deforestation in the world - losing some 2-4 percent of their remaining forest cover each year. Honduras alone had already lost half of its forests. Just a few months ago, fires burned about 11,000 square km in the region. Then came Mitch. Denuded hillsides washed away, taking homes, farms, roads, and bridges with them.

· The costliest disaster of 1998 was the flooding of China's Yangtze River, which resulted in 3,700 deaths, dislocated 223 million people, inundated 25 million hectares of cropland, and cost $30 billion. Heavy summer rains are common in southern and central China, but the Yangtze Basin has lost 85 percent of its forest cover to logging and agriculture in recent decades, and the river is heavily dammed, greatly increasing the speed and severity of the resulting runoff. Historical records show that in earlier centuries flooding was a once every 20 year event, now floods happen 9 out of 10 years.

· Bangladesh suffered its most extensive flood of the century in the summer of 1998. Two-thirds of this low-lying nation at the mouth of the Ganges and Brahmaputra rivers was inundated for months, 30 million were left temporarily homeless, 10,000 miles of roads were heavily damaged, and the rice harvest was reduced by two million tons. Damage estimates exceed $3.4 billion. Logging upriver in the Himalayas of north India and Nepal exacerbated the disaster, as did the fact that the region's rivers and floodplains have been filled with silt and constricted by development. Climate change and rising sea levels are projected to make Bangladesh even more vulnerable to flooding in the future.

· Other parts of the world were also struck by devastating weather-related disasters in 1998. An ice storm in Canada and New England cost $2.5 billion in January, bringing down thousands of miles of power lines and wiping out the sugar maple industry in some areas. Floods in Turkey in June caused $2 billion in damages, and floods in Argentina and Paraguay cost $2.5 billion. Some 10,000 people were killed by a cyclone in India in June, while vast fires in Siberia burned over 3 million acres of forest.

The "hand of man" can be seen in many of these disasters. The loss of forests and wetlands, which normally intercept rainfall and allow it to be absorbed by the soil, permits water to rush across the land, carrying valuable topsoil with it. As the runoff races across deforested land, it causes floods and landslides with the strength to wipe out roads, farms, and fisheries far downstream.

Paradoxically, the lack of trees also exacerbates drought in dry years by allowing the soil to dry out more quickly. The record-breaking fires in Indonesia and Brazil in 1997 and 1998 occurred in tropical forests that are normally too moist to burn. But when fragmented by logging and agricultural clearing, these forests dried out to the point where deliberately set fires were able to spread quickly out of control. Fire claimed over 52,000 square km in Brazil and 20,000 sq. km in Indonesia. The economic toll in Indonesia was estimated at $4.4 billion.

As 1998 comes to a close, governments are beginning to recognize the role of human activities in worsening "natural" disasters. In China, where government officials initially denied that the Yangtze floods were anything but natural, the State Council has now recognized the human factor. It has banned logging in the upper Yangtze watershed, prohibited additional land reclamation projects in the river's flood plain, and earmarked $2 billion to reforest the watershed.

Unless ravaged nations rebuild along a path of sustainable development that emphasizes restoring and maintaining healthy ecosystems, they risk even greater exposure to the devastation of unnatural disasters in the future. The pressures of population growth and economic instability complicate efforts to control harmful development. Brazil, for example, is under heavy pressure to reduce its budget deficit and has cut back on its already minimal efforts to control logging and mining in the Amazon.

The need for healthy ecosystems is further underscored by the accelerated climate change projected by scientists in the coming decades, due to the failure to reduce greenhouse gas emissions. This is likely to lead to more severe storms, floods, and droughts in many regions. Munich Re, one of the world's leading insurance companies, issued a report in late 1998 suggesting that in the years ahead, large areas of the world, including the southeastern United States and Indonesia, may become virtually uninsurable.

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B. Africa: The direct, infrastructure and economic toll

In Africa, the 1997/98 ENSO event was associated with scores of regional catastrophes in addition to disease outbreaks. These included drownings, displacements, famine, disruption of production and trade, and destruction of infrastructure.

Flooding/Drownings: The heavy rains from mid-October to January in the Horn of Africa region caused the worst floods in three decades. In Somalia - the worst hit - over 2000 people died from floodwater drownings. In Uganda 100 people drowned when the Nile River overflowed.

Evacuations: Over 15 million people were displaced from their homes in the Horn region. To the south, Zambia called for aid to help 25,000 people who were driven from their flooded homes and shelters.

Famine: Crop failures and food shortages threatened at least 17 nations along an arc stretching from Somalia to South Africa, placing over 27 million people at risk of acute malnutrition. With rainfall over 500% of average this year, many farmers' planting seasons were aborted, preventing the cultivation of tens of thousands of acres of crops. As much as 20% of cultivated area was rendered useless; the destruction concentrated in Somalia, Ethiopia, Kenya, Tanzania, Rwanda, Burundi, and the Democratic Republic of Congo.

Kenya's sugar, rice, and wheat yields were halved. Some parts of South Africa reported up to 40% decreases in agricultural production. The United Nations Food and Agricultural Organization (FAO) called for emergency aid for over 10 million due to the floods.

Infrastructure: Damaged roads, bridges, railway lines, airports and telephone lines hindered internal transportation, communication and trade. **Trucks were marooned in mud-laden roads, and tons of rice, maize, beans, sugar and oil were lost.** Coffee and cotton exports could not be taken to port and hundreds of tons of cargo urgently being transshipped to or from land-locked Uganda and Rwanda were held up, due to closure of the main railway. Exporters lost tens of millions of dollars worth of orders for products ranging from flowers to furniture.

Production: Production of manufactured goods was hindered as energy sources were cut in flooded areas in the Horn. In drought-affected areas of southern Africa - where low water levels in dams led to severe electricity crises - only 50% of demand was provided at times.

Disruption of Production and Trade: Export of agricultural products was severely disrupted in East Africa, due to both a decrease in supply of exportable goods and destruction of transportation modes. Kenya, a long-time exporter of tea and coffee, did not produce sufficient tea and coffee for export and was forced to import these products to meet domestic demand. For the first time in many years southern Africa did produce sufficient grain for export. The number of animals exported dropped dramatically.

Many European nations were also reluctant to import food goods from disease-laden Africa. **The Saudi government banned import of live animals from the Horn of Africa for fear of livestock Rift Valley fever.** This turned Somalian businessmen to export of charcoal resulting in a wave of deforestation.

The European Community banned imports of seafood from east Africa for fear of cholera, resulting in the loss of millions of dollars in trade.

Tourism: The tourism industry was also severely compromised. Many roads leading to game parks were reduced to seas of mud, leaving hotels and lodges throughout Tanzania and Kenya without customers.

IX. ENSO and Climate Change: Are Human Activities Changing El Niño?

A. Climate change

There are three primary studies indicative of climate change known as "fingerprint" studies - i.e., the data coincides with model projections forced with rising greenhouse gas (GHG) concentrations. They are: 1) the warming pattern in the mid-troposphere in the southern hemisphere (Santer et al. 1996); 2) the disproportionate rise in nighttime and winter temperatures (Easterling et al. 1997); and 3) the statistical increase in extreme weather events in many nations (Karl et al. 1995a,b). All three aspects of climate change and climate variability have biological implications.

In particular, the disproportionate rise in TMINs (Karl et al. 1993) accompanying climate change favors insect overwintering of insects. Easterling et al. (1997) report that since 1950, maximum temperatures have risen at a rate of 0.88°C per 100 years, while TMINs increased at a rate of 1.86°C per 100 years. In both hemispheres TMINs increased abruptly in the late 1970s. A warmer atmosphere holds more moisture (6% more for every 1°C). These changes may, in part, be attributable to the intensified hydrological cycle (Graham 1995; IPCC 1996), and the increasing cloudiness that reduces daytime warming and retards nighttime cooling (Karl et al. 1997).

Records from the National Climatic Data Center - this nation's main repository for meteorological data - also indicate that extreme weather events have increased in the continental U.S. Droughts have become longer and sudden bursts of precipitation more intense (>2 inches over 24 hours). As a warmer atmosphere holds more moisture, it may release it in more tropical-like downpours.

Additionally data from the physical and biological sciences indicate a significant warming trend this century (IPCC 1996; Epstein et al. 1998). Moreover, Diaz and Graham (1996) report that, since 1970, the elevation of the freezing level (0°C isotherm) in the mountains (30°N to 30°S latitudes) has shifted upward approximately 150 meters, equivalent to a 1°C warming. As tropospheric temperatures rise, most of the glaciers and ice caps from the tropics to mid-latitudes [South American Andes, African highlands, European Alps, Asian Highlands, Indonesia and New Zealand] are retreating, many at rates that continue to accelerate (Kaser and Noggler 1991; Hastenrath and Kruss 1992; Thompson et al. 1993; Haeberli 1995; IPCC 1996).

Climate regimes can also change surprisingly fast. Recent analyses of Greenland ice cores indicate that significant shifts, called rapid climate change events (RCCEs), have taken place in the past in the span of but several years - not centuries, as was previously believed (Meyewski et al. 1993; Dansgaard 1993). While the oceans may serve as a buffer against sudden climate change, this mechanism may be limited, for some of the RCCEs seem to be associated with abrupt changes in ocean circulation.

In addition, shifts in the ocean "conveyor belt" - that includes the Gulf Stream - may have been associated with rapid climate change events, according to ice-core records (Broecker 1987; Meyewski et al. 1993; Dansgaard 1993; GRIP 1993; Pearce 1997; Tziperman 1997). Shifts in the Atlantic ocean temperatures and circulation patterns are now being reported (Chang et al., 1997).

The climate system exhibits equilibrium states, of which three may have been most common: when the poles of the Earth were covered with small, medium, or large ice caps. The present, Holocene period of the last 10,000 years - with medium-size caps and an average global temperature of 15°C (about 60°F) - has been associated with the development of modern agriculture and advancing civilization. But our present climate regime may be becoming less stable. Increased variance - that is, more extreme swings-in natural systems is inversely related to how stable and balanced the systems are, and how sensitive they are to perturbations. Wider and wider variations can occur as a system moves away from its equilibrium state.

B. Is the ENSO pattern changing?

Data: Since 1877, El Niño events have occurred every two to seven years (average 4.2 years). Since the mid 1970s, ENSO events have come more often and persisted longer than any previous period (Trenberth and Hoar 1996). For five years and eight months, from 1990 to 1995, the Pacific Ocean persisted in the warm El Niño phase. This was most unusual, for, since 1877, no previous warming period had lasted more than three years (Trenberth and Hoar 1996). Indeed since 1976, El Niño conditions have prevailed roughly half the time and the two largest El Niño events of the century occurred in 1982/83 and 1997/98. In addition the 1997/98 El Niño began unusually early and ended abruptly.

While statistical "proofs" of long-term shifts are difficult to establish, it does appear that the baseline of sea surface pressures - related to SSTs - may have shifted in a stepwise manner in 1976 (CLIVAR 1992). Pattern recognition is key to evaluating long-term change; ice core and coral records, and SST changes in the past quarter century are consistent with the "fingerprint" studies indicating an overall pattern of greenhouse gas-induced warming (Guilderson and Schrag 1998).

Models: Several models suggest that El Niño events will increase with global warming (Zebiak and Cane 1991; Manabe and Stouffer 1993; Meehl and Washington 1993; Bengtsson et al. 1993). The events of the past two decades are consistent with these projections.

Weather always varies; but increased variability and rapid temperature fluctuations may be a chief characteristic of our changing climate system. And increased variability and weather volatility can have significant consequences for health and for society.

C. Trends in the 20th century

The gradual warming that characterized the climate during the first four decades of the present century was accompanied by substantial temperature variability, as borne out in the record of heating-degree days in the U.S. grain belt. The ensuing cooling trend from 1940 to the mid 1970s showed less variability. From 1976 to the present day, the variability-apparent in hot and cold spells, drought, and floods-has again increased. Greenland ice core records suggest that the last time the Earth warmed abruptly, ending the last Ice Age, there was also a pattern of increased variability.

The cumulative meteorological and ecological impacts of the prolonged El Niño of the early 1990s have yet to be fully evaluated. In 1995, warming in the Caribbean produced coral bleaching for the first time in Belize, as sea surface temperatures surpassed the 29°C (84°F) threshold that may damage the animal and plant tissues that make up a coral reef. In 1997, Caribbean sea surface temperatures reached 34°C (93°F) off southern Belize, and coral bleaching was accompanied by large mortalities in starfish and other sea life. Coral diseases are now sweeping through the Caribbean, and diseases that perturb marine habitat, such as coral or sea grasses, can also affect the fish stocks for which these areas serve as nurseries.

D. Underlying ocean warming?

Is atmospheric and ocean warming changing the pattern of ENSO? Is the change in factors forcing the climate system (accumulating GHGs) altering the "natural" ENSO mode of climate oscillations?

Sea surface temperatures of the ocean have warmed this century (IPCC 1996), and a gradual warming of the deep ocean has been found in recent years in oceanographic surveys. Deep ocean warming has been reported from subtropical transects in the Atlantic (Parrilla et al. 1994), Pacific (Thwaites 1994) and Indian Oceans (Bindoff and Church 1992), and near the poles (Travis 1994; Regaldo 1995). Indian Ocean waters tested down to 900 meters warmed up to 0.5°C between 1962 and 1987, and the Indian Ocean has risen by 3.5 centimeters in those 25 years from thermal expansion. Also, the Indian Ocean - between 500 and 1,500 meters deep - contains more fresh water than in the past.

More basin-wide data are needed to fully evaluate these trends, but these findings could be indicative of a long-term trend. Corresponding temperature measurements of the sub-surface earth, in cores drilled deep into the Arctic tundra, show a similar warming trend.

Ocean warming may have contributed to the northward shift in marine flora and fauna reported along the California coast (Barry et al. 1995; McGowan et al. 1998), and to the drop in zooplankton in the same region (Roemmich and McGowan 1995). Ocean warming - along with increased terrestrial evapotranspiration - contributes to the enhanced hydrological cycle that, in turn, increases temperatures throughout most of the tropics (Graham 1995), and alters precipitation patterns that affect the timing of VBD outbreaks.

Warm seas are also the engines that drive tropical storms and fuel the intensity of hurricanes. Increased residence time of atmospheric water vapor also reinforces the greenhouse effect.

Warming sea surface temperatures appear related to the isotherm shift (Diaz and Graham 1996). The ocean may indeed be the main repository (capacitor) for the past century's global warming; and changes in El Niño patterns may signal instability in the dynamics of the climate system as a whole.

X. CONCLUSIONS AND RECOMMENDATIONS

Disease outbreaks are of course multifactoral. Poverty is directly correlated with the incidence of disease, and the vicious cycle between disease, environmental degradation and underdevelopment underlies the steep rise in infectious disease in the past quarter of a century (WHO 1996). But the events of 1997/98 clearly demonstrate that heavy precipitation and drought can significantly impact public health and well-being. Many analyses of ENSO conditions and disease time-series have found significant correlations. This review of events during a strong El Niño demonstrates the correlations between the associated extreme weather events and disease outbreaks.

An increase in extreme and volatile weather patterns is projected for the future with climate change. Thus, the precautionary principle - a central concept for the health professions - calls for adjusting programs, practices and policies based on these emerging trends.

There are multiple levels of interventions. All are important. Some of the direct public health issues are addressed first, followed by recommendations for: A) mapping, monitoring and modeling; B) early warning systems; and C) environmental and energy policies.

Public health recommendations:

- *Reporting:* There is a need for a uniform reporting system of disease occurrences, so that information can be channeled into centers and analyzed for rapid feedback and the formulation of appropriate responses. Training is needed at all levels, from laboratory and administrative to the field. Strong communication channels can permit distressed areas to communicate supply needs to key distribution centers, so that needs may be met in a timely fashion. Better communication can also allow for early warning to halt the spread of diseases.

- *Education:* Widespread awareness of origins of diseases and the simple measures one can take to prevent and treat them, can lead to significant decreases in the severity and spread of illness. Even with adequate knowledge, however - e.g., that RVF may be transmitted through infected meat - extreme conditions and food shortages can overwhelm the warnings.

- *Transportation:* Transport must be secure so that villages are not isolated during extreme weather events. Good roads are necessary for food and supply lines. Better methods for food storage are needed.

- *Infrastructure:* Sewage/sanitation and clean water systems must be strengthened. These are essential for health and the first lines of defense in preventing the spread of disease.

A. Monitoring, mapping and modeling

There is the need for coordination of reports of new events through a network of individual researchers, laboratories and agencies. ProMED, CDC and WHO provide the foundation for such a network.

Building historical databases and mapping events, integrated with environmental and social conditions, can help connect conditions with consequences. GISs provide the technological bases for such integrated assessments.

Programmatically, monitoring of disease epidemiology can be integrated into ongoing and planned projects for monitoring terrestrial ecosystems, watersheds and coastal zones. Developing ECOLOGICAL EPIDEMIOLOGY will require interagency cooperation. Surveillance for key biological indicators (insect, rodent and plankton populations) and related disease outcomes - in the context of environmental monitoring can:

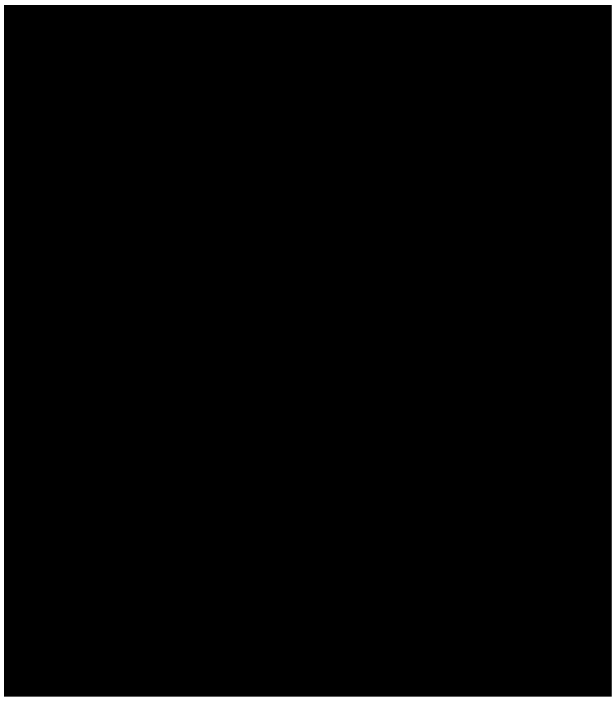
(i) enhance the work of epidemiologists and ecologists;
(ii) improve cost evaluation of environmental change; and
(iii) better inform environmental policies for prediction and prevention.

B. Public Health Early Warning Systems

At the outset of the 1997/98 El Niño event many nations exported food early on, only to spend hundreds of millions of dollars for imports later on. Advances in ENSO forecasting provide the opportunity for societies to better anticipate and prepare for conditions that may affect health, agriculture, water and hydroelectricity, and industry (see reports of the International Research Institute for Climate Prediction (IRI)). Advanced warning of ENSO conditions - and understanding of the associated weather patterns once ENSO events have begun - can also allow for preparations and early interventions.

Marine: Remotely sensed (RS) data with targeted sea sampling for HABs and associated pathogens can also help generate public health advisories marine-related illness. The Sea Wide Field Sensor (SeaWiFS) ocean color images have increased the accuracy of detecting algal blooms. This provides an important opportunity to improve and implement public health early warning systems for HABs and cholera.

Terrestrial: Epidemiological monitoring on land can be complemented by the use of RS/GIS, and advances in climate forecasting. Early warning systems can generate preventive, timely, and environmentally-friendly public health interventions. Close cooperation between health agencies (NIH, CDC, WHO and PAHO) and NOAA, NASA, EPA and NSF will be needed to develop, pilot and evaluate the utility of HEALTH EARLY WARNING SYSTEMS.



C. Environmental and Energy Policies

1. Ecosystem vulnerability

While identification of all the causes for specific events is rarely possible, it is possible to identify environmental conditions that increase vulnerability to, and are conducive to, the emergence and spread of disease. The underlying structural causes of vulnerability to disease must be addressed. Specific **infrastructure measures** include: improved sanitation systems, chlorinated water supplies, environmental management planning, and land-use strategies to reduce flooding and limit fires. Deforestation and "development" over wetlands remove necessary environmental buffers. These land-use changes severely compounded the impacts of extreme rains in China, Bangladesh and Central America in 1998.

By focusing on environmental systems that provide "generalized defenses," **general principles** emerge that may prevent the emergence, transmission and spread of disease. Thus primary prevention rests upon improved understanding of "nature's services" (Daily 1998) - the functions performed by the various ecosystem components. Watershed and coastal vegetation buffer marine systems, while the local fauna and flora all play functional roles as predators, prey (food), filterers, scavengers, competitors, recyclers, nitrogen fixers, and habitat. Better farming practices and surrounding vegetation, along with improved city disposal systems to capture and treat wastes, could reduce the runoff of nutrients, toxic chemicals, trace elements and microorganisms that flow rapidly into aquatic systems, estuaries and coastal zones during extreme rains and flooding.

In terrestrial systems, preservation of genetic, species, population, and functional group diversity all provide defenses against disease emergence and spread. These levels of biodiversity depend upon maintaining a diversity and mosaic of habitats. All the habitats and functions must be present in healthy ecosystems to preserve its vigor, productivity and resilience, and to prevent the proliferation of pests and pathogens.

2. Energy policies

The 1997/98 ENSO events and the ENSO events of the preceding two decades suggest that we have entered a period with increasingly intense and volatile weather patterns. The anomalous clusters of diseases associated with the extreme weather events raise the concern for how an increasingly uncertain future may affect the interactions among disease agents, hosts and the environment. The Precautionary Principle - based upon the accumulating signs and symptoms of climate instability - suggests the need to advance the numerous "no-regrets" options for reducing the rate of change by employing non-polluting and energy-saving technologies. Governments and international bodies must create incentives for research, development and transfer of clean technologies. Greater international governance over the "commons" - and significant **financial instruments** to propel the agreements - will be needed to ensure climatic as well as economic stability. Development of renewable energy sources can be the engine for clean development in the 21st Century.

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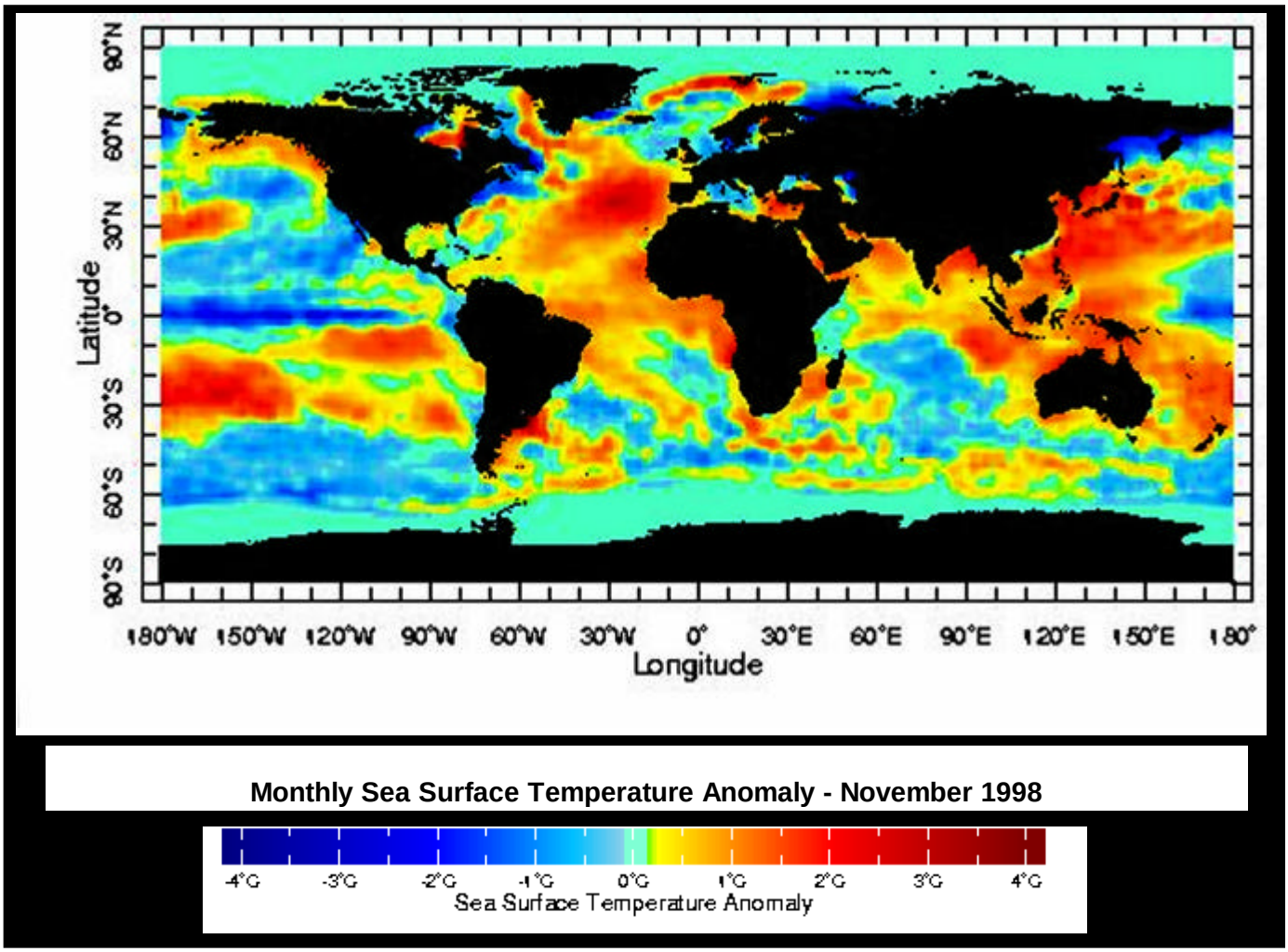

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