WORKSHOP ON THE SOCIAL AND ECONOMIC IMPACTS OF WEATHER

April 2-4 1997
Boulder, Colorado, USA

Roger A. Pielke, Jr., Editor

Sponsored By

U.S. Weather Research Program (USWRP)
American Meteorological Society (AMS)
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White House Subcommittee on Natural Disaster Reduction (SNDR)
Environmental and Societal Impacts Group (ESIG)
National Center for Atmospheric Research (NCAR)

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TABLE OF CONTENTS

Workshop on the Social and Economic Impacts of Weather

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EXECUTIVE SUMMARY
of the
Workshop on the Social and Economic Impacts of Weather

2-4 April 1997 ◆ Boulder, CO

Workshop Homepage Location: http://www.dir.ucar.edu/esig/socasp/weather1

Sponsors

U.S. Weather Research Program
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White House Subcommittee on Natural Disaster Reduction
Environmental and Societal Impacts Group (NCAR)

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Introduction

Significant potential exists for society to benefit in tangible ways from improvements in the specificity, reliability, verification, and usefulness of weather forecasts on time scales of minutes to days. Weather is important to society from the standpoint of responding to extreme events and also from the standpoint of improving decision making in the face of the more typical day-to-day vagaries of weather.

Why should society care about weather?

Extreme weather

The box to the right summarizes data presented at the meeting on the direct impacts of recent extreme events in the United States as measured by loss of life and current dollar losses. There was general agreement among participants that the relatively poor quality of available data on impacts limits conclusive findings.

Several points stand out. First, it may come as a surprise that the largest loss of life in recent years has been associated with extreme temperatures. Second, among the first four phenomena listed in the box, floods result in the most deaths, followed by winter storms and tornadoes, and finally hurricanes. Lightning has perennially been associated with a large loss of life.

Extreme Event Impacts in The United States

Event	Annual Mean Loss of Life (period)	Annual Mean Current $ Loss (period)	Recent extreme event, $ loss, deaths, (date)
floods	96 ('86-'95)	$2.4B ('84-'93)	$20B ('93) 156 ('76)
hurricanes	20 ('86-'95)	$6.2B ('89-'95)	$30B ('92) 256 ('69)
winter storms	47 ('88-'95)	>$1B (est.)	$6B ('93) 200+ ('93)
tornadoes	44 ('85-'95)	$2.9B ('91-'94)	$3.8B ('93) 94 ('85)
extreme heat	384 ('79-'92)	?	>$15B ('80) 522 ('95)
extreme cold	770 ('68-'85)	?	>$30B ('76-'77) ?
lightning	175 ('40-'81)	>$1B (est.)	?
hail	-	$2.3B (est.)	$650M ('90)
ANNUAL AVERAGES	**>1500**	**>$15.8B**	

In terms of the economic losses associated with extreme weather, a conservative estimate of national losses is on the order of $300 million per week. The number is conservative because it neglects the effects of inflation, covers only the direct impacts of extreme events, and leaves out the costs associated with extreme temperatures, which are certainly significant. The actual total

economic impacts associated with extreme weather events is likely to be several times that estimated here.

Trend data can mislead. Workshop participants pointed out that underlying the data on extreme event impacts are sub-trends in climate patterns and changes in society. For instance, hurricane damages have risen almost exponentially in recent decades during a period of decreased hurricane activity. The reason for the increase in damages is the enormous coastal growth, placing more people and their property in vulnerable locations. As a consequence of societal change, historical impacts data is likely to underestimate today's vulnerability to weather.

In recognition of our relatively poor understanding of trends in impacts and the underlying vulnerability to those impacts, participants at the Workshop put together a qualitative summary of trends in impacts, event frequency and intensity, and causes for the trends. This figure is shown to the right.

	OBSERVED FREQUENCY	OBSERVED INTENSITY	DOCUMENTED SOCIETAL IMPACTS	POSSIBLE CAUSES OF TRENDS IN IMPACTS
FLOODS	↑ Weak	~	↑ Deaths ↑ Damage	Land Use Population Shifts Changes in Climate(?)
TORNADOES	↔ Strong ↑ Weak	↔	↓ Deaths ↑ Damages	Warning Time Mobile Homes
HURRICANES	↓ Intense ↔ Weak	↔	↑ Deaths ↑ Damages	Coastal Development Population Growth
EXTREME TEMP	↔	~	↑ Deaths ? Damages	Aging Population Heat Island
WINTER STORMS	~	~	? Deaths ↑ Damages	?
LIGHTNING	↔	↔	↔ Deaths ↑ Damages	Infrastructure Recreation
HAIL	↔	↔	↑ Damages	Agriculture Urbanization

~ = variable with no discernable trend
? = unknown

The figure shows that impacts associated with all extreme events, on a roughly 20-year time scale, are perceived as increasing in terms of both deaths and dollars (with the single exception of tornado-related deaths). Additionally, the figure shows that participants perceived that the increase in impacts was largely due to societal factors with respect to each phenomenon, expect for perhaps floods. Participants identified a need to better understand the interrelationship of climatological and societal factors which underlie the trends in impacts.

Economic efficiency and competitiveness
Participants felt strongly that the cumulative impacts of more typical day-to-day weather were significant, and probably much larger than the attention-getting extreme events. Day-to-day weather associated with temperature, precipitation, winds, etc. has the potential to disrupt

decision making, thereby adding to the "cost of doing business." The impacts of weather on the day-to-day costs of business are thus a matter of economic efficiency and competitiveness.

Present at the meeting were experts from the following industries: oil and gas, electric power, surface transportation, agriculture, aviation, and insurance. They related numerous examples of the effects of weather that decision makers face in their day-to-day operations and the potential value of improved weather information and information use. Examples of impacts and their potential reduction include:

Oil and gas exploration:

◆ improved forecasts of tropical weather conditions (wind, waves, disturbances) can reduce delays in drilling operations at a cost of up to $250,000 per rig per day (several thousand rigs in the Gulf).

◆ improved hurricane track predictions could reduce days of production shutdown, each day of which costs the industry and the U.S. treasury a combined $15,000,000.

Vegetable processing:

◆ improved temperature and precipitation forecasts can lead to greater efficiency in chemical spraying (e.g., pesticides), which costs $10-$15 per acre per application for hundreds of thousands of acres.

◆ on a national scale the annual cost of lost production to the vegetable processing industry, primarily due to weather, is $42,500,000.

Insurance:

◆ a single hurricane could lead to more than $50,000,000,000 in damages.

◆ weather-related catastrophes have led to more than $48,000,000,000 in property insurance claims over the period 1989-1993.

Rail transportation:

◆ it costs $2,000 per hour to stop a train. A single tornado warning covering 15 miles of track for 15 minutes can lead to seven stopped trains.

◆ most weather-related derailments cost $1,000,000 to $5,000,000.

Electric power:

♦ using improved thunderstorm forecasts could save one utility $200,000 annually in reduced outage time.

♦ using "good QPF forecasts" could save one utility $2,000,000 over five years.

♦ using improved temperature forecasts could save "hundreds of millions annually nationwide for the utility sector".

Aviation:

♦ every avoided cancellation saves $40,000, every avoided diverted flight saves $150,000.

♦ for the 16 members of the Air Transport Association, delays and cancellations cost $269,000,000 annually.

Participants observed that while extreme events capture the attention of the public and policy makers, it is in the area of improved decision making in the face of routinely disruptive weather where the greatest economic savings to the nation can accrue. This is because typical decision making is more amenable to study and optimization as compared to the highly infrequent and uncertain environment that characterizes extreme events. With many trials, significant value can accrue.

How can we better understand the use/value of weather information to society?

The answer to this question is needed in at least three areas: (1) in the research prioritization process, (2) in order to inform policy makers and the public of the value of weather information, and (3) to contribute to more effective decision making utilizing weather information.

Available Tools
Social scientists utilize a range of methodologies to research the use and value of information to decision makers. Examples include:

♦ *prescriptive studies* assume that decision maker behave in a manner consistent with prescribed principles, such as maximization of expected utility. Such studies typically involve formal modeling of decision situations.

♦ *descriptive studies* focus on the context in which actual decision makers operate in order to describe their behavior. Such studies can use models, but also can rely on narrative techniques.

♦ *decision analysis* focuses on choosing among a set of alternative actions based on expected probabilities and values associated with various outcomes.

◆ *institutional analysis* focuses on the role that various institutional factors such as goals, rules, norms, authority, control play in creating circumstances for effective or less-than-effect decision making.

◆ *microeconomics* is the area of economics that focuses on the behavior of individuals and firms in a market setting.

◆ *macroeconomics* is the area of economics that focuses on the entire economy in an aggregate sense.

◆ *survey techniques* are used to assess the value of certain information or services to decision makers through, for example, assessing their willingness-to-pay.

Participants at the Workshop concluded that tools such as these are available to better understand the value to society of improved forecasts and to contribute to improved use of weather information by decision makers. The tools have been well developed, and thus do not need additional refinement to be applied in the context of weather and society.

Value to Society is a Function of Information Quality AND Information Use
It has long been recognized that information acquires value through influencing the behavior of decision makers. A perfect forecasts is of no value if it is unavailable to or unusable by a decision maker. Consequently, attention must be focused on the use and value of weather information in parallel to ongoing efforts to improve the quality of the information. Participants at the Workshop noted that typically, greater attention is paid to improving the *quality* of information than it is to improving the *use* of information. As a result, decision makers do not use existing information products to their full potential. This theme was reenforced by the representatives of the "user community" at the Workshop who felt strongly that existing weather information is not as well used as it could be.

Meeting Recommendations

I. Establish an ongoing user-based group to advise the USWRP (and others) on needed research and feedback information on research value.

II. Focus a complementary research effort, parallel to research focused on improving weather information, in the area of the use and value to society of weather information. Two areas are particularly important:

   A. Conduct a comprehensive assessment of the use and value of weather information in a particular community (population <100,000) in order to systematically identify opportunities for and constraints on improved use of information by various decision makers. Work with similar initiatives under way by the Federal Emergency Management Agency, Insurance Institute for Property Loss Reduction, and Center for Disease Control. Such an assessment could ultimately lead to the development of "tool kits" for decision makers to help guide use of

weather information. Such "tool kits" would be tested as prototypes prior to operational use.

B.   Support focused evaluations of the use and value of weather information in various decision contexts in particular public and private sectors in order to establish an understanding of "what works" and "what is needed." Such evaluations could be sponsored through a modest grants program.

Breakout group chairs -
Trends, Chris Adams
Users, Nick Keener
Methodology, Ken Heideman

Impacts of Temperature Extremes

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Introduction

Extremes of heat and cold have a broad and far-reaching set of impacts on the nation. These include significant loss of life and illness, economic costs in transportation, agriculture, production, energy and infrastructure. The 1976 - 1977 winter freeze and drought is estimated to have cost $36.6 billion in 1980 dollars. In 1980 the nation saw a devastating heat wave and drought that claimed at least 1700 lives and had estimated economic costs $15 - $19 billion in 1980 dollars. While these are atypical examples, in recent years on average there are about 1200 deaths due to extreme hot and cold weather.

While there are numerous case studies of particular events, little systematic knowledge exists on the impacts across various sectors of the nation. The most rigorously documented impacts are the health impacts, based to a large part on epidemiological studies conducted by the U.S. Centers for Disease Control and Prevention (CDC) and others in the public health arena.

Extreme Heat

On average over the last 30 years, excessive heat accounts for more reported deaths annually than hurricanes, floods, tornadoes, and lightning combined.

Much of the literature on extreme heat impacts combines heat and drought into one climatological event. This is especially true of the work assessing the economic impacts. It is often unclear if the effects are from a short duration heat wave or a longer term drought. In many cases the two hazards are inextricably linked. In the area of health impacts, the focus has been on the temperature as a causal agent of health impacts.

Health Impacts

The July 1995 Heat Wave killed 522 people in Chicago alone. Research by CDC found that on average 384 people were killed by excessive heat each year during the period 1979 - 1992 (NOAA, 1995). (This is significantly higher that the numbers reported in the National Weather Service's (NWS) Summary of Natural Hazards Deaths. This is due to the research methodology of local NWS offices relying on published accounts of events. They do not have access to the death certificates used by CDC.) Attributing excessive heat as a cause or contributing factor in mortality has varied considerable across jurisdictions. This has led to speculation that the actual, as opposed to reported, death toll is much higher. For example, one study suggests that the actual death toll of the 1980 heat wave may be 5,000, not the official number of 1700 (Kilbourne, 1997). Other studies indicate that diagnosis of heat-related deaths have been regularly underestimated by 22% to 100%. A recent National Oceanic and Atmospheric Administration(NOAA) sponsored Heat Wave Workshop focused on the health impacts of heat waves, better forecast techniques, and community preparedness. The health effects were viewed as preventable to a large extent with improved forecasts, warnings, community preparedness and appropriate community based response. Officials from CDC referred to heat waves as a known, preventable epidemic.

Those at greatest risk of death in heat waves are the urban-dwelling elderly without access to an air-conditioned environment for at least part of the day. Thus the issues of prevention and mitigation combine issues of the aging and of public health.

One area not well understood is the morbidity, or injury and illness, associated with heat waves and excessive heat. The research has focused on mortality, in part because mortality data was available. This is a critical area for research in understanding and preventing the deleterious effects of excessive heat. Scientists at the NOAA Heat Wave Workshop identified this as a high-priority research need.

Transportation Impacts

There are several impacts on transportation documented in case studies. Aircraft lose lift at high temperatures. Phoenix airport has been closed due to periods of extreme heat that made aircraft operations unsafe. Highways and roads are damaged by excessive heat. Asphalt roads soften. Concrete roads have been known to "explode" lifting 3 - 4 foot pieces of concrete. During the 1980 heat wave hundreds of miles of highways buckled (NOAA, 1980). Stress is placed on automobile cooling systems, diesel trucks and railroad locomotives. This leads to an increase in mechanical failures. Train rails develop sun kinks and distort. Refrigerated goods experience a significant greater rate of spoilage due to extreme heat.

Agriculture

Various sectors of the agriculture community are affected by extreme heat. Livestock, such as rabbits and poultry, are severely impacted by heat waves. Millions of birds have been lost during heat waves. Milk production and cattle reproduction also decreases during heat waves. Pigs are also adversely impacted by extreme heat. In terms of crop impacts in the summer of 1980, it is unclear that the impacts are of very high temperatures for a few days, versus the above average summer temperatures versus the drought. We do know that high temperatures at the wrong time inhibits a crop yields. Wheat, rice, maize, potato, and soybean crop yields can all be significantly reduced by extreme high temperatures at key development stages.

Energy

The electric transmission system is impacted when power lines sag in high temperatures. Last summer a major west coast power outage impacting 4 states was blamed in part on extreme high temperatures causing sagging transmission lines to short out. The combination of extreme heat and the added demand for electricity to run air conditioning causes transmission line temperatures to rise.

The demand for electric power during heat waves is well documented. In 1980, consumers paid $1.3 billion more for electric power during the summer than the previous year. The demand for electricity, 5.5% above normal, outstripped the supply, causing electric companies to have rolling black outs.

Water Resources

The demand for water increases during periods of hot weather. In extreme heat waves, water is used to cool bridges and other metal structures susceptible to heat failure. This causes a reduced water supply and pressure in many areas. This can significantly contribute to fire suppression problems for both urban and rural fire departments.

The rise in water temperature during heat waves contributes to the degradation of water quality and negatively impacts fish populations. It can also lead to the death of many other organism in the water

ecosystem. High temperatures are also linked to rampant algae growth, causing fish kills in rivers and lakes.

Extreme Cold

The average number of deaths attributed to cold is 770 yearly, substantially higher than the number attributed to heat (Kilbourne, 1997).

Health Impacts

The health impacts of extreme cold are greater in terms of mortality in humans. It appears that the causal mechanism for cold-related mortality is not so much a single cold snap as it is a longer term chronic exposure. Thus the deadly nature of heat waves *per se* appears to be greater than that of short periods of extreme cold. Research indicates that those at risk are primarily either engaged in outdoor activity, or are the elderly who are chronically exposed to colder indoor temperatures. This mechanism of injury causes a different set of problems for community mitigation than the heat problem.

Transportation

There are a variety of transportation impacts due to cold weather. Diesel engines are stressed and, often fuel gels in extreme cold weather impacting trucking and rail traffic. Rivers and lakes freeze, stopping barge and ship traffic. Subsequent ice jams threaten bridges and can close major highways. Cold temperatures take their toll on vehicle batteries. Shear cold temperatures stress metal bridge structures. Transportation losses for the winter of 1976 -77 came to $6.5 billion (in 1980 dollars) (NOAA, 1982).

Agriculture

Cold temperature impacts on agriculture are frequently discussed in terms of frost and freeze impacts early or late in growing seasons. Absolute temperature and duration of extreme cold can have devastating effects on trees and winter crops as well. Prolonged cold snaps can impact livestock not protected from the frigid temperatures. In the winter of 1983-84, a single cold snap around Christmas destroyed over $1 billion of the citrus crop in Florida. Louisiana lost 80% of its citrus crop. Tennessee estimated $15 million in agriculture losses. Texas experienced hundreds of millions of dollars in crop damage (NOAA, 1983).

Energy

Energy consumption rise significantly during extreme cold weather. In the winter of 1976-77 additional energy consumption cost $3.8 billion (1980 dollars). This includes increase costs of electricity, fuel oil, and coal.

Water Resources and Infrastructure

Extreme cold temperatures can cause significant ground freezing problems, especially if there is little snow cover. Buried water pipes can burst causing massive ice problems and loss of water pressure in metropolitan areas. This poses a variety of public health and public safety problems. On case of a broken water main in Denver, Colorado forced the entire evacuation in sub-zero temperatures of the medically fragile patients of the Veteran's Hospital. Other cases of broken water mains have shut down subway systems and financial centers.

Schools often close during extreme cold snaps to protect the safety of children who wait for school buses.

Summary

The total impacts of temperature extremes are not fully documented and known. Much of the documentation of temperature impacts combines other meteorological events and uses climatological scales of space and time. The nature of seasonal impacts is more cumulative and complex than the impacts of cold snaps and heat waves. Yet the impacts are measurable. Weather forecasting must take into account the hazards and impacts of temperature extremes to provide useful, understandable and timely information for the nation to reduce natural disasters.
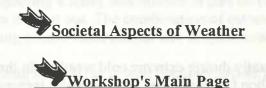
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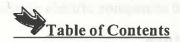
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Extreme Cold Impacts

- **Average 770 Deaths - About Double the Annual Loss of Life Due to Extreme Heat**

- **1976 - 1977 Winter Freeze and Drought - $36.6 Billion in Losses**

Chris Adams
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4/1/97

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Impacts of Weather on the Vegetable Processing Industry

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Overview

Weather plays an integral part of agriculture production in the U.S. The vegetable processing industry (canning and freezing) in the U.S. constitutes approximately 1.3 million acres, producing 6.1 to 6.8 million tons of raw product with a value of $750 million. This paper will focus on the use of weather information in the vegetable production portion of the processing industry. Del Monte Foods is one of the world's leading processors of fruits, vegetables and tomatoes. The company contracts approximately 100,000 acres of vegetables (asparagus to zucchini) which produces about 480,000 tons of raw product. The major bulk of production is in snap beans, sweet corn and green peas.

Weather information (historical, current and future) is more critical to the vegetable processing industry than other segments of agriculture. Commodity crops, grain corn, soybeans, etc., are for the most part planted in a relatively narrow period of time and harvested when the crops are physiologically mature. Vegetable crops on the other hand must be planted on a tight schedule to provide orderly harvest and delivery to a processing plant. Growing seasons, planting to harvest, for major vegetables are typically 60 to 90 days. The majority of vegetables must be harvested and processed within a 24 to 48 hour period to maintain peak of quality.

Weather information is, therefore, critical to all stages of planning, planting, pest control and harvest of vegetable production.

Planning

Processing facility capacity - tons per day - is a function of the physical limitations of facility equipment. Using historical weather data, planting and harvest schedules are developed to determine how many acres are to be planted to provide for processing facility daily tonnage requirements. At Del Monte, a raw product forecast system is used to aid in the planning, planting and harvesting stages of crop production. The system provides a model of planting and harvest dates as well as yield forecast. Historical data - daily high-low temperature averages, rainfall, frost and freeze dates are used to provide models for each crop each year.

Planting

Once the planting season starts, daily and near term 2 to 7 day forecasts are used to provide field personnel guidelines on what adjustments are required to the planting schedule during the following week. These schedules must reflect the impact of temperature (heat units) and moisture forecasts for the coming period. Daily adjustments are made, keeping in mind that plant capacity is fixed and that over and/or under supply affect operating costs. Satellite data transmission services are currently in use to provide current weather information, forecast information and satellite/radar information. Adjustments based on actual weather events and short range forecasts are used to ensure volumes meet production plant capacities.

Pest Control

Most pest problems (insects and diseases) of vegetable crops vary in intensity, depending upon weather conditions. Local "atmospheric" characteristics (hourly and daily) can influence the degree of pest pressure on the crop. Large scale weather patterns can also contribute to a large degree to the intensity of pest problems. Chemical spraying measures can be organized within 24 to 48 hours lead time to provide control. These control measures are costly and critical to maintaining quality and yield. A single spray application ranges from $10 to $15 per acre. Sweet corn, for example, can require up to several treatments for insect control. Accurate short-term and, to some extent, 30 -ay forecasts can play a major role in the formulating decisions on number and timing of applications.
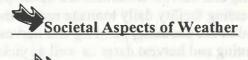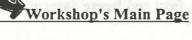
Harvest

Most vegetable crops have a very narrow harvest window to maintain optimum quality. In order to maintain reasonable plant production, 5 day tonnage forecasts are prepared and updated daily. The tonnage forecast must take into account short term (1 to 5 days) weather forecasts. Longer term forecasts (6 to 10 days) are used to "look ahead" to anticipate the impact weather will have on future volumes. This information, both short-term and long-term, is used to enable production personnel to adjust crewing on a shift-to-shift and or a day-to-day basis. The accuracy of forecasts is critical to production decisions on daily crewing and to maintaining quality of processed product throughout the season.
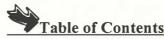
Financial Implications

The year-to-year variation from planned production targets is primarily the result of weather events. Sales are based on annual forecasts; target volumes can be missed (above or below) primarily due to seasonal weather variability. It is estimated that annually 6% of planted acreage is not harvested, primarily due to weather related events. On a national scale the lost production is estimated to be valued at $42.5 million.

Weather cannot be avoided, but accurate short-term and long-term forecasts can be instrumental in maintaining orderly flows of raw product to processing facilities, at optimum costs and at the peak of quality.

Trends in Hail in the United States

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Introduction

Hail causes considerable damage to U.S. crops and property, occasionally causes death to farm animals, but seldom causes loss of human life. The damaging aspects of hailfalls include the hailstone sizes (average and maximum), number of hailstones per unit area, and associated winds, and hail risk is a combination of these factors plus the frequency of hail at a point or over an area. Crop hail losses in recent years nationally are estimated at $1.3 billion annually, representing between 1 and 2 percent of the annual crop value. Hail losses vary considerably regionally, representing, for example, 1 to 2 percent of the crop value in the Midwest, 5 to 6 percent of the crops produced in the High Plains, and much less elsewhere in the nation. Property losses caused be hail have been increasing with time, now appearing to approximate crop-hail losses in recent years with crudely estimated annual losses of $1 billion.

The long-term trends in hail incidence and hail losses across the United States, and within states and discrete regions within the nation, were examined using readily available data and results. Data on hail sufficient to be used in multi-decadal analyses comes from two sources: the records of hail from the National Weather Service (NWS), and insurance records of hail loss. In preparing this analysis, I have drawn on the available data bases.

Data. Since the 1890s, the U.S. Weather Bureau (now NWS) has recorded days when thunder was heard (thunder days) and when hail fell, identified as "hail days." This was done at the 200+ first-order stations (FOS) across the nation, and these are manned by staff who make observations around the clock. At the 10,000+ cooperative substations of the NWS manned by volunteer weather observers, the incidence of hail *could be* recorded, and considerable research of these data has shown that weather observers at some stations have, over the years, accurately recorded the incidence of hail. Data on hail presented in the NWS's *Storm Data*, since its publication began in 1955, are unfortunately badly biased and are unsuitable for temporal analyses of hail or any form of severe local storms. Thus, the hail-day data of the NWS stations, all FOS and some cooperative stations, are one major data set suitable for temporal analysis.

The other long-term records of hail are from insurance records of hail-produced loss. These come from different sources. The *crop-hail insurance data* have been systematically collected since 1948 by companies acting through a central association which has compiled the data and archived it. These data have limitations including the fact that not all farmers have taken insurance coverage (hail insurance is estimated to cover 25 to 30 percent of all crop losses caused by hail). Second, records of loss occur only when crops are growing and susceptible to loss, and this susceptibility to hail damage changes during the growing season and varies between crops (e.g., tobacco and tea are more susceptible to hail damage than corn). Third, crop-hail losses for a state or the nation shift with time due to the amount of coverage (liability) and the crop value, as well as the temporal variations in hail occurrences (which are large). Fortunately, the industry devised an adjustment factor named "loss cost," which is the amount of loss per year ($) divided by the annual amount of liability ($) multiplied by $100. The loss cost values for 1948 to 1996 provide a useful measure of the temporal fluctuations of insured loss.

The *property insurance industry* has not kept loss records for hail alone (or for any other individual form

of severe damaging weather). However, since 1949, the industry, through its centralized Property Claim Services of the American Insurance Services Group, has recorded each catastrophe, defined as storm situation producing $5 million or more loss to property (not crops). For each catastrophe, an *estimated* amount of dollar loss is available along with the weather factors causing the damage and states where the losses occurred. The catastrophe data available since 1949 have several biases limiting their use in temporal analyses. Fortunately, one major insurance company systematically over time made major adjustments to the catastrophe data base (done each year) to adjust for the ever changing dollar value, for changes in property density-location, and changing of costs of construction. This "adjusted" catastrophe data base offers an opportunity to meaningfully examine the temporal trends in catastrophes related to hail.

Impacts of Hail

Data from the insurance industry were used to assess the trends in the impacts of hail. The crop-hail loss data began in 1948 and the property catastrophe data base began in 1949. The following analyses are based on the 1948(9)-1995 period.

Crop-Hail Losses. The national annual values of insured crop-hail losses appear in figure 1, along with amount of liability. This shows ever increasing losses ranging from $15 million in 1948 to $129 million in 1974, then jumping to $265 million in 1980, and approaching $400 million in the early 1990s. Liability also climbed steadily in this 48-year period.

Figure 1 also presents the adjusted loss cost values, seen as the best way to examine the climatological trends in crop-hail losses. This shows relatively high values in the 1950s, early 1960s, and again in the early 1990s. After the peak centered at 1962-63, values declined slowly until the recent 3-year high in 1992-1994. The long-term average loss cost for the U.S. is $2.55, and the highest 3-year loss costs since 1947 are $3.38 in 1961-63, $3.27 in 1954-56, and $3.25 in 1992-94. From a risk standpoint, the recent peak was preceded by an 11-year period with relatively low-loss cost values, as shown in table 1. This circumstance only acted to emphasize the recent losses, but when put in a 48-year time frame, the highs in the early 1990s rate third. No statistically significant long-term trend of decrease or increase in crop-hail losses is evident. This distribution also illustrates another key aspect of hail loss found at all scales -- the county, state, region, and national level -- the losses are skewed over time with 1 to 3 years of high losses often separated by many years (5 to 15) with low losses.

Regionally, one finds startling differences in crop-hail loss trends, a not unexpected outcome since hail is so notoriously variable in both space and time. As shown in figure 2, upward trends exist in recent years in the Northern High Plains and since about 1970 in certain East Coast states (VA, NC, SC, and GA). Conversely, trends in loss costs in the Midwest and Tennessee Valley states show continuing decreases over the past 30 years.

Property Catastrophes. The adjusted catastrophe data for 1949-1995 were examined to identify *only* those events when hail was part of the cause of loss. Hail, as one cause of damage, was further assessed for those catastrophes when the loss was due *only* to hail with wind. Figure 3 presented two curves based on the pentad values for these "hail-only" catastrophes during 1950-94. One curve shows the frequency of the hail-only catastrophes, revealing a peak in 1965-69 (30 storms) and a minimum of 5 storms in 1955-59. The frequency distribution does not indicate a long-term trend upwards or downwards, particularly since 1960. The other curve on figure 3 is based on the average hail-only catastrophe loss values per pentad. This shows peaks early, in 1950-54 and 1960-64, followed by low values until higher averages re-appeared in 1980-84 and 1990-94. The values of dollar loss per storm for these 177 hail-only catastrophes suggest a slight downward trend with time.

The top 20 most damaging hail-only catastrophes during 1949-1994 are listed in table 2. This reveals three important findings. First, the distribution over time is bi-modal with 13 of the 20 events in two pentads, 1960-64 with 7 top storms, and 1990-94 with 6 events. The 1949-54 period had 3 top storms and 1965-69 had 2 events. Thus, the distribution forms an early peak and a recent one. Second, the storm losses are confined to one or two states with 17 events causing damage in 1 or 2 states, a much smaller areal extent than found with most weather catastrophes. Third, the states where the top 20 events most frequently produced property-hail losses formed a SW-NE oriented area including Texas (8 occurrences), Oklahoma (5), Kansas (4), Missouri (4), and Illinois (5 occurrences). This distribution likely reflects a combination of large hailstorm incidence with the target at risk.

Many other weather catastrophes included hail damage along with damages due to two or more conditions like tornadoes, heavy rains-flooding, high winds, lightning, etc. These cases also were analyzed and their frequencies per pentad appear in figure 4 is the U.S. population distribution with time. This and other studies of the nation's weather catastrophe data reveal that the time-related increase in catastrophic events and their losses is largely a function of the increased target-at-risk, as indicated by population as a surrogate measure of the property at risk. The insurance company's adjustment is the catastrophe data for shifting property-at-risk obviously did not capture all the societal changes affecting at risk, such as to growth of property density by location and the changing value of property.

Furthermore, study of the catastrophe data for events causing >$100 million in losses revealed (figure 5) that the greatest relative increases in catastrophes have occurred in the southeast and south where population growth has been greatest since 1950. The annual losses produced by *all* weather catastrophes causing >$100 million in losses were divided by U.S. population (figure 6) to obtain a population normalized time distribution. This reveals an oscillating but generally unchanging distribution with time. The five peaks are a result of major hurricanes like Hugo and Andrew.

In *summary*, the major insurance-based expressions of damaging hailstorms (crops and property catastrophes for hail-only events) do not suggest long-term trends up or down. They do show periods lasting from 1 to 5 years with extremely high losses, followed by longer periods of relatively low loss. upward trends in losses due to hail exist and these are largely a result of the changing dollar values, questionable construction practices and materials, and growth in the property at risk.

Hail-Day Data

The hail-day incidence values based on data collected by NWS stations offer an unbiased evaluation at the time distribution of hail since 1900. Data were available from three states, and the results for 4 stations (distributed west-east) in Nebraska appear in figure 7. Other than Omaha, these showed low early (1921-30) values. Then, all stations had high hail values during 1951-1980, followed by low values for 1981-1990. The values for Texas stations (figure 8) show two trends. Most stations in northwest Texas and the Panhandle show sizable increases (e.g., San Angelo and Wichita Falls) with time, whereas stations in east and south Texas showed declines in hail incidence with time (Dallas and Austin). The Illinois stations (figure 9) all display similar time distributions with their highest values in 1955-79 (when crop-hail loss values were highest), and slowly declining hail-day frequencies from 1970 to present. Illinois and all other Midwestern states have experienced continuing declines in crop-hail loss cost values from the mid 1960s to present.

A key finding revealed in the hail-day values for these three states, and in the state values of loss cost and in the regional shifts of catastrophe frequency, is that *trends in hail incidence and damages vary considerably across the nation, and even within large states like Texas*. Since hail is a product of thunderstorms, available temporal results on thunder-day incidences since 1900, being studied in an

on-going project, were examined. The 1901-95 data from 200 FOS across the U.S., when analyzed statistically to define regions of similar temporal behavior, defined five discrete regions, each with a different time distribution. Figure 10 presents the results for these five regions that comprise the 48 contiguous states. Basically, the distribution in the western mountains and the southeastern U.S. show marked downward trends in thunderstorms since the 1920s. The incidences of thunderstorms in High Plains and Midwest show an up-then-down distribution centered on a peak in the 1940s. This is similar to the hail-day distribution in Illinois and Nebraska. The West Coast stations suggest a slight upward trend with time, whereas the stations in and adjacent to Texas show a major increase in thunderstorm activity with time, also similar to the hail-day distributions. These thunder results reflect the findings from the hail data -- different long-term trends occur in different regions of the nation.

Limitations of the Data

The past text has defined many of the limitations of the existing data on hail to define long-term trends and measure loss. It is a case of good news/bad news. The crop-hail insurance data bases offer some useful quantitative measures of loss detrended for shifting practices and dollar values. However, the crop-hail insurance data base represents only about 25 percent of the actual crop-hail loss.

The property losses due to hail are not well defined and conflicting information exists. For example, in 1992 the Property Claims Service declared that "hailstorms across the country (in 1992) ran up a bill of $1.57 billion." yet, their data on all weather catastrophes shows that hail plus other conditions caused $3.9 billion in insured losses in 1992, and only one storm was a hail-only event, and it caused losses listed at $275 million. So, where did the $1.57 billion value come from? Other recent insurance publications have claimed that all losses from catastrophes listed as caused by 3, 4 or 5 weather conditions were *solely due to hail, an amazing overstatement*.

This points to *the lack of good data on the property losses due to hail*. In an economic study of hail losses done in 1975, it was shown that crop-hail losses over a 20-year period were about ten times greater than the property-hail losses. In recent years several major hail-caused property losses occurred in cities like Denver with $650 million in hail damage in July 1990, Orlando with $85 million in April 1992, Wichita with $215 million in June 1992, Oklahoma City with $200 million in April 1992, Dallas with $227 million in April 1995, and $300 million in Ft. Worth in May 1995. Recall that the insured crop-hail losses during these years were less than $400 million, and thus, these huge big-city property losses provide annual values in excess of the crop-hail losses in 1990, 1992, and 1995. This suggests that the ratio of crop to property losses has drastically shifted, at least in recent years. The results further suggest that property losses have been increasing with time due largely to the ever increasing property target. The good news is that the property insurance industry, through its Insurance Institute for Property Loss Reduction, has begun keeping records of weather-induced property losses.

Unfortunately the NWS hail data since 1900 is only for hail incidence with no other information. However, careful studies of the cooperative station data have found that some observers also reported hail sizes when storms occurred. A project will soon start to get the hail-day data for most of the nation complete for the 1901-196 period. Field studies of hail in Illinois and Colorado both agree -- most hailstones are windblown, but there is no data to analyze the temporal aspects of this condition. Inexpensive hail sensors, developed 35 years ago, could be used at many weather station locations to begin collecting data that would allow measurement of hailstone sizes, number of hailstones, and the windblown incidence of hail.
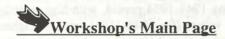
Causes of Trends

Several results presented reveal that the growth of population, or property at risk, with increased urban

targets, increased population in storm-prone areas, and higher property values per unit area have been the major factors behind the ever growing hail losses to both crops and property in the United States. When these data are normalized to area/density at risk, the time distributions do not reveal increases since 1950, but rather level 50-year distributions interspersed with occasional periods of high losses.

A recent study of very costly weather catastrophes, those causing >$100 million per event, revealed the time trends of these 189 storms (1949-94) were more closely associated with weather conditions, such as extra-tropical cyclone activity in the U.S. For example, figure 11 illustrates the time distribution of these costly catastrophes (many due to conditions other than hail) for 1949-94 along with the frequency of cyclones. A moderately good relationship exists and the constantly increasing population was not found to be an important factor affecting the fluctuations of these more damaging weather events. Recall, however, that only 19 of the 177 hail-only catastrophes since 1949 caused losses >$100,000. The more costly weather catastrophes are a result of hurricanes, massive outbreaks of tornadoes and associated thunderstorm conditions (including hail), major flooding events, or severe winter storms.

Societal Aspects of Weather

Workshop's Main Page

Table of Contents

Table 1. Assessment of National and State Annual Loss Cost Values during the 1980-1994 Period.

Period	National rank[1]	State values rated[2] No. 1	No. 2	Number states with top 20 values[3]	Where
1980	4	1	4	14	Midwest, N.Plains
1981	27	1	0	7	N.Plains
1982	38	1	0	7	S.Plains
1983	33	0	0	7	Southeast
1984	45	0	0	6	Isolated areas
1985	37	1	0	10	Southeast, Midwest
1986	24	0	1	10	Plains, Southeast
1987	10	0	1	11	High Plains
1988	47	0	0	4	Southeast
1989	42	0	0	5	South Plains
1990	20	0	0	10	Plains, Midwest
1991	41	0	1	6	Mountains
1992	1	1	3	15	Plains
1993	14	2	0	12	Southeast, Plains
1994	7	0	1	16	Plains, Southeast

[1] National rank of annual loss cost, based on 1948-1994 period, with highest value = 1, lowest = 47.
[2] Number of states having annual loss cost values (for 1948-1994) rated as highest (#1) or second highest (#2).
[3] Number of states (out of 25 analyzed) having annual loss cost values ranked in the upper 20 of the 47 values during 1948-1994.

Table 2. The Top Twenty Most Damaging Catastrophes Caused Only by Hail and Wind, 1949-1994.

Rank	Loss, $ millions[1]	Date	State/s
1	650	7/11/90	CO
2	317	6/21/53	KS
3	261	4/10-11/92	KS,MO,IA,OK
4	246	4/2/64	IL,MO
5	205	6/19/92	KS,OK
6	191	10/1/94	CO
7	185	9/19/94	IL,MO
8	172	8/13/87	IL
9	170	4/27/68	TX,AR
10	165	5/21/49	IL,MO,IN,KY
11	157	3/27/61	LA
12	144	6/17/69	OK,TX
13	140	7/16/61	OK
14	134	6/14/62	TX
15	125	3/25-26/93	TX
16	125	3/28/61	TX
17	114	6/10/51	TX
18	104	4/30/61	TX
19	103	6/18/80	CO,NE,KS,OK,TX
20	98	6/28/60	IL,IA

[1] Values normalized to 1991 conditions. For example, the $317 million loss on June 21, 1953 was listed as $14.3 million in 1953.

Figure 1. Annual values of loss, loss cost, and liability from crop-hail insurance in the United States, 1948-1995.

Figure 2. Pentad Values of Catastrophes that were due to Hail and Wind from 1950 to 1994. One curve shows the frequency of events, and the other is the average 5-year $ loss per event.

Hail Alone — Ave Loss

Figure 3. Pentad Values of all Catstrophes when Hail was listed as one of the Conditions causing Damage, 1950-1994, and U.S. population
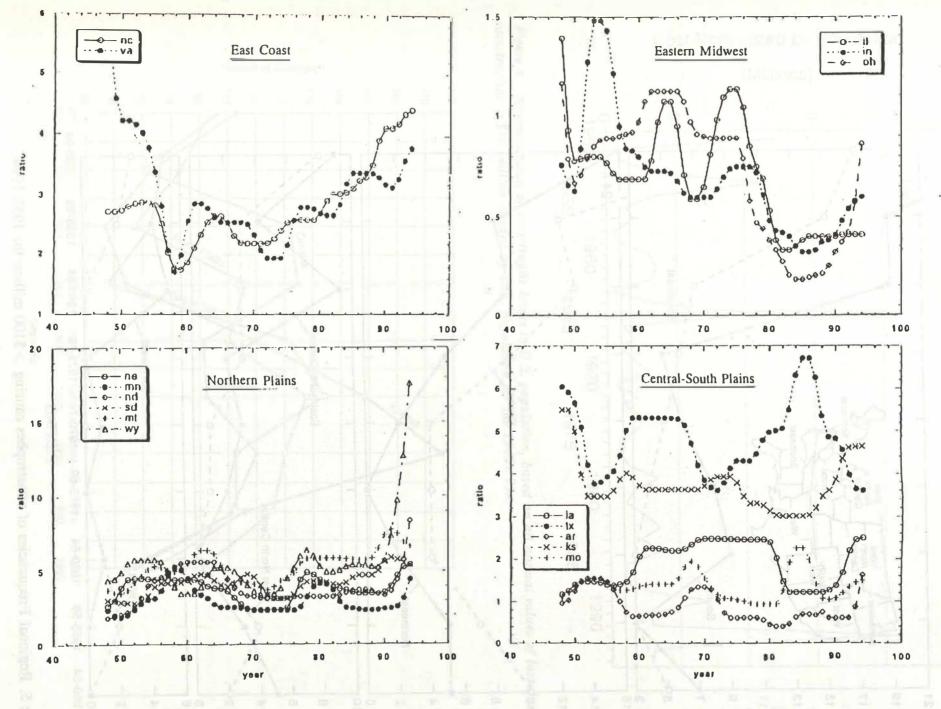
Figure 4. Median annual loss costs for crop-hail insurance for groups of states for 1948-1994.

28
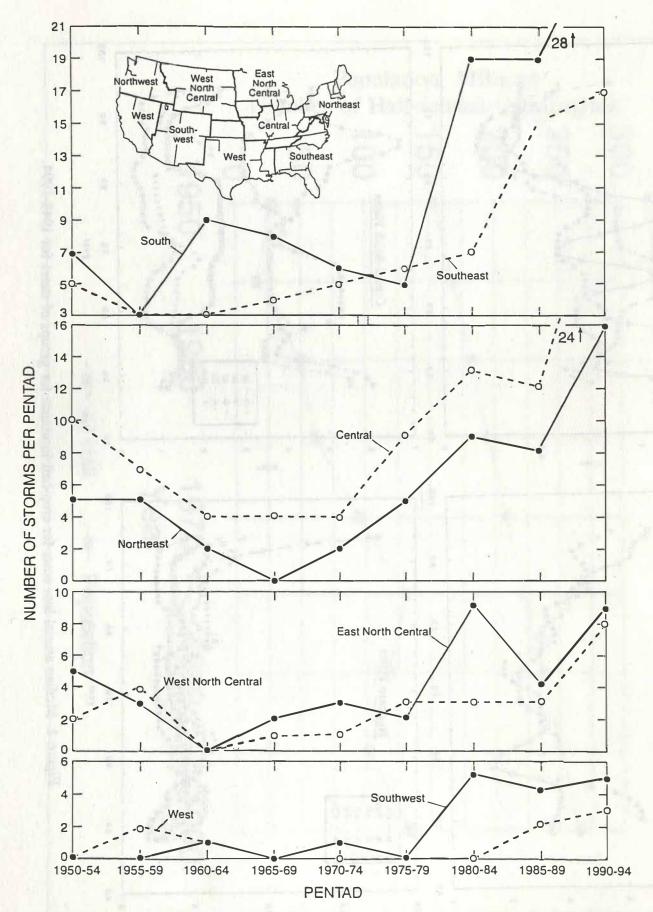
Figure 5. Regional Frequencies of catastrophes causing > $100 million for 1950-1994.
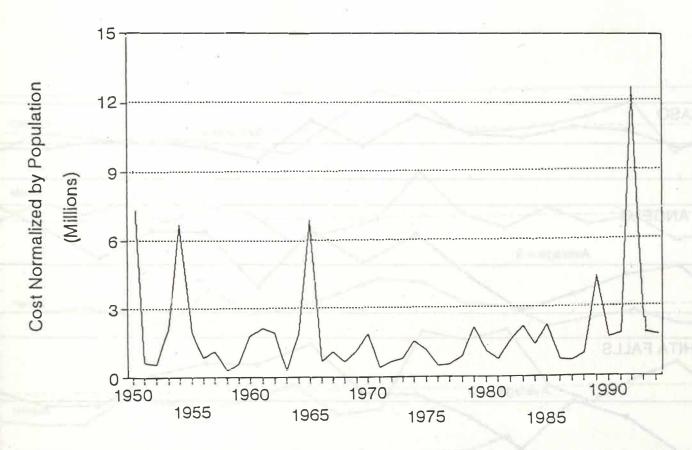
Figure 6. Normalization of catastrophe losses to U.S. population, based on all annual values of loss due to catastrophes >$10 million divided by U.S. population for the 1949-1994.
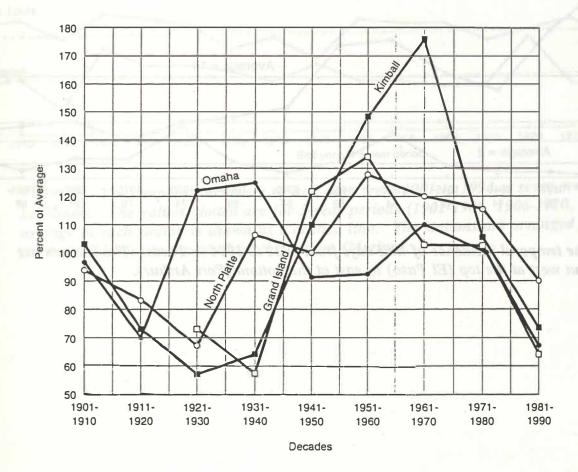
Figure 7. Decadal values of number of hail days, expressed as a percent of the long-term average, for four Nebraska stations distributed from the far west (Kimball) to the far east (Omaha).
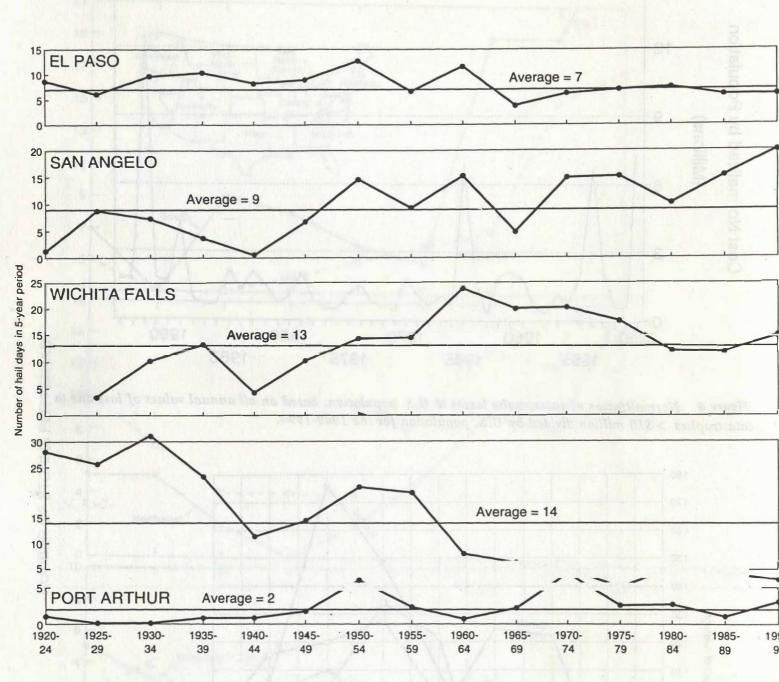
Figure 8. The temporal incidence of hail days from 1920 to 1994 in Texas. The stations are arranged from west at the top (El Paso) to east at the bottom (Port Arthur).
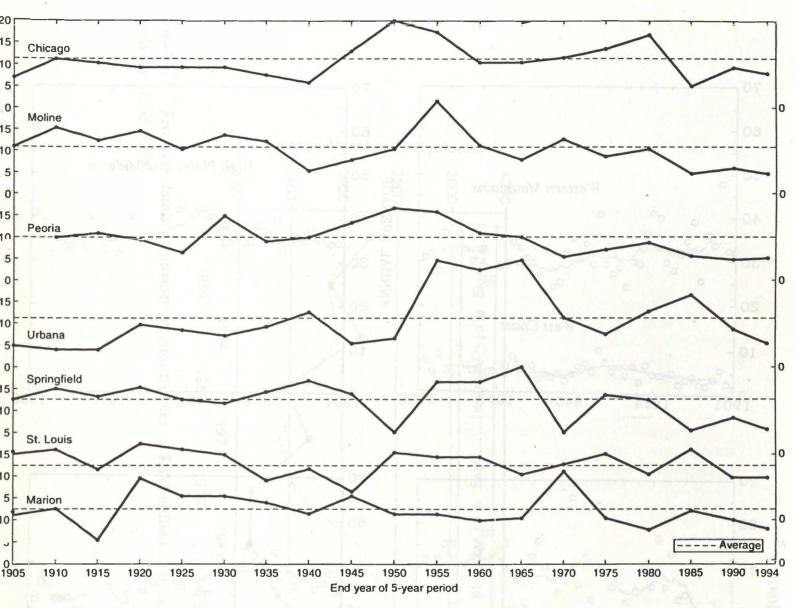
Figure 9. *The temporal incidence of hail days from 1901 to 1994 at seven weather stations in Illinois. The values plotted are for 5-year periods (1901-1905, 1906-1910, etc.), and the average at each station is shown as a dashed line. The stations are arranged from north at the top (Chicago) to the south at the bottom (Marion).*

32
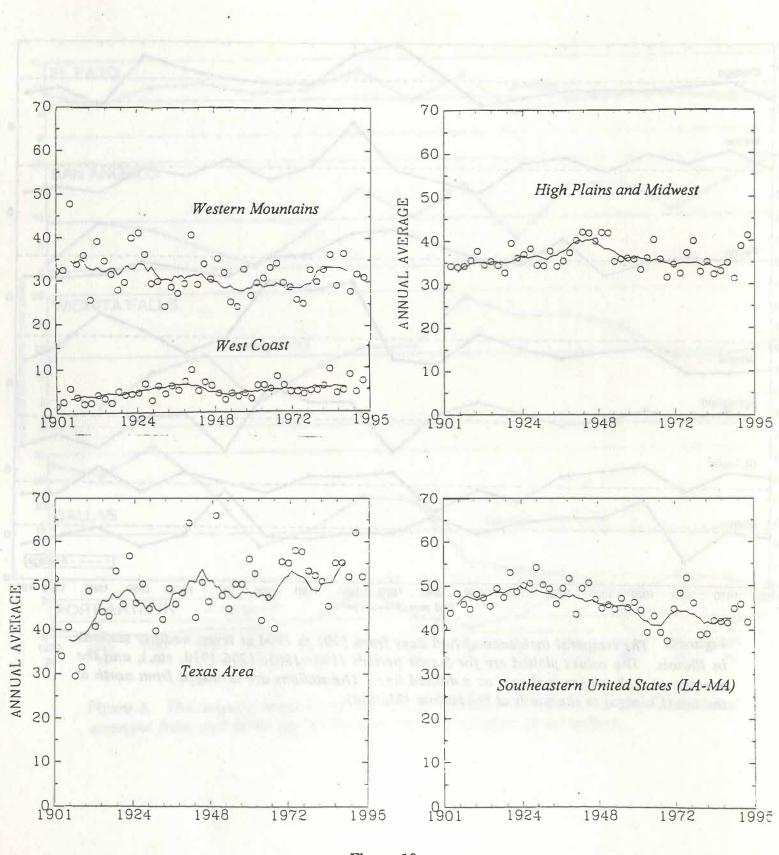
Figure 10.

**TRENDS IN THUNDER-DAY FREQUENCIES FROM 1901-1995
IN FIVE AREAS OF THE UNITED STATES.** *Curves are 9-year
moving averages*
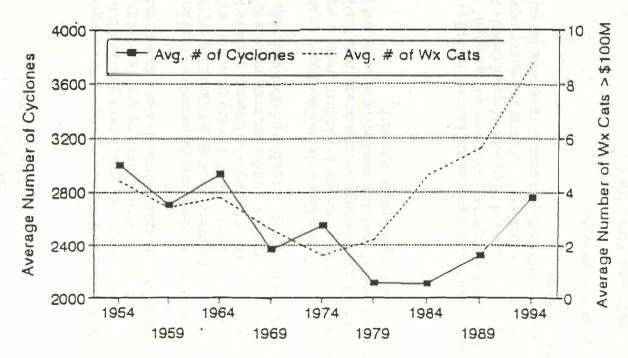
Figure 11. *Five-year totals of number of catastrophes > $100 million and the number of North America cyclones, 1950-1994.*

"What is a Good Weather Forecast?"
in the eyes of a forecaster

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Background

This question was presented to me as my discussion topic by the Workshop organizers. It initially seemed like a simple question with a simple answer, however, I quickly realized it is a multifaceted question with rather complicated answers. The intent of including this topic in the Workshop was to bring the perspective of the forecaster into the discussions of public and private sector decision making.

The core mission of the National Weather Service is the protection of life and property through its Watch and Warning program. This note will concentrate on public forecasts since these are integral to this program. The public is also one of the more difficult user groups to work with given their diverse character and needs. Forecasts for the public contrast sharply with forecasts prepared for specialized groups including agriculture, aviation, and commerce. In addition, many of these forecast responsibilities are being transferred to the private sector through the public-private partnership.

The Modernization of the National Weather Service is nearing completion at a price tag of over $4 billion. It has been an overwhelming technological success. In addition, dramatic improvements in several forecast categories have been documented, e.g., lead time for tornado warnings. On the other hand, it may be more debatable as to whether the promise of much improved public forecasts and warnings has been met. So, in the forecasters' opinion, what makes a good public forecast?

Methodology

A short survey was conducted as a means to gain insight into how a small group of forecasters viewed their public forecasts and what criteria they might use to measure the "goodness" of a forecast. All forecasters from the Seattle forecast office were surveyed. The group of approximately 20 includes both interns that are relatively inexperienced and senior forecasters with over 20 years of experience. Participants were asked not to discuss the questions with each other prior to completing the survey. The survey was very simple and included three questions:

1. What makes a good forecast? Please explain.

2. Give an example of a good forecast. Please explain.

3. Give an example of a bad forecast. Please explain.

Results

A great deal of work has already been done to evaluate or verify forecasts, both within the NWS and the academic community. Typically public forecasts, are verified against another forecast (e.g., MOS or climatology) to demonstrate some improvement over the other forecast, or skill. These are typically single point forecasts. It therefore seems logical that some of the forecasters would feel a good forecast was one

that showed skill over a competing scheme. A definition might include some specific ranges of tolerance for various parameters. For example, a 24 hour maximum temperature forecast that is within two degrees of what occurs might be considered a good forecast.

Of the group of forecasters surveyed, only four focused their answer on measures of skill. Since these are region specific and have been documented objectively in many rigorous objective studies, I will not present any details of these responses. Nonetheless, there is clearly some weight given to the accuracy of the forecast in measuring its goodness.

The remainder of the forecasters placed their measure of a "good" forecast in the accuracy of its perception by the public or its societal impact. Specific remarks given by the forecasters included:

- a forecast that is honest and gives some measure of confidence
- the bottom line is accuracy from our users perspective
- a forecast that conveys something that people can visualize
- a forecast that compels the public to react
- a forecast that is read by the radio disk jockey and maintains its meaning
- a forecast that creates a picture in the user's mind

Although these are not dramatic or earth shattering they do show that the forecasters are concerned about public perception and the action the forecast instills.

When the examples of good forecasts and bad forecasts were compared, there were a few surprises. For example, one forecaster felt that good forecasts were "very short forecasts." The argument was that detail is lost to most people and by keeping the forecast simple you minimize possible confusion. The forecaster's examples were:

GOOD FORECAST: "Scattered showers and sunbreaks."

BAD FORECAST: "Rain likely, turning to scattered showers, mainly near the foothills this afternoon with isolated thunderstorms. Possible small hail and gusty winds with the thunderstorms."

In the good forecast case, the forecaster suggested most people would experience benign weather so the forecast would be accurate short and sweet for them. It would only be the few individuals who experienced a thunderstorm who would think it was a bad forecast, and to include the additional material for those few was not worth the risk of confusion.

This set of forecasts contrasts sharply with another forecaster's examples. These were:

GOOD FORECAST: "Rain ending and becoming partly sunny during the afternoon. Except mostly cloudy with occasional showers continuing north of Seattle through early afternoon."

BAD FORECAST: "Mostly cloudy with scattered showers."

It seems this contrast in forecaster opinion might be linked to the Modernization, which promised highly detailed and accurate mesoscale forecasts. The technology is in place to make those forecasts but the means to communicate that information is still under development. At this time it seems the text product is a synoptic-scale forecast system and does not do as well at communicating mesoscale information to the general public.

Additional discussion from the forecasters included external factors determining whether a forecast was

considered a good forecast or a bad forecast. Two forecasters mentioned the role of credibility. If there have been a few bad forecasts then credibility goes down -- less and less attention is paid to the forecasts by the user. The forecasters also mentioned other external factors that play a role, including: several sources of forecasts resulting in confusion, paraphrasing by radio disk jockeys and/or the use of old forecasts, access to weather information, and a lack of attention by the news media and emergency managers.

I have attached statements from two windstorms that struck western Washington. The statement for each storm is the one that told of the issuance of a high wind warning. Although it is difficult to compare forecasts for an entire event (since literally dozens of products are issued) these seem as good as any. What is rather dramatic about these two storms is that even though both forecasts verified well and had about the same lead time, user perception and forecast impact were dramatically different. For case 1, the windstorm was perceived as a "surprise." Even an editorial in the Seattle Times chastised the forecasters for not getting the warning out. (The Times wrote a follow-on editorial after the time line of watches and warnings was brought to their attention acknowledging the forecasts had been good). For case 2, public reaction was dramatic. Schools were dismissed early, businesses closed early, and grocery stores were emptied. Why was one of these forecasts a good forecast and one a bad forecast?

Case 1 happened to be inauguration day and there was a lot of news. The forecast office had also issued several false-alarm forecasts during the previous month. It appears that these facts conspired against the forecast and the word never got out. For Case 2 it is a little difficult to pinpoint what made the people react. There was something that evidently was very compelling to the public and to the decision makers. One possibility is that in several statements issued prior to the storm references were made to the storm -- an historical event for the Pacific Northwest. Perhaps this personalized the storm for those who had been in Seattle for that storm and they chose to react.

Discussion

From this short analysis it is clear that several factors are viewed by forecasters as important measures of a forecast's goodness. Among these factors are accuracy and user perception, with user perception getting a greater emphasis. This is encouraging since the general public can't rely on cost benefit analyses. Rather the general public reacts only according to their individual perception of risk. To be effective the event must be personalized by the forecast, emergency managers, and news media. The forecast needs to be compelling enough to trigger the desired action.

This gets to a final point. If we assume a forecast is only good if it gets the general public to react according to the impending risk, then we need to protect against those things that might interfere with this process. There are probably many and these need to be explored. However, one that was discussed in this survey is an increasing trend for the issuance of warnings by more than one group. Contradictory statements and forecasts often result in a decrease in user confidence and thus little action. It is critical that a single voice have the sole responsibility to communicate watches and warnings to the general public. At this point it is the National Weather Service and this role needs to be protected.

Case 1

High wind warning
National Weather Service Seattle WA
1000 PM PST Tue Jan 19 1993

...A high wind warning is in effect for the Washington coast for late tonight and Wednesday...
...A high wind warning has been issued for the interior of western Washington for Wednesday...

South winds will increase along the Washington coast tonight with sustained winds to 40 MPH and gusts to 70 MPH by late tonight. The strong winds will continue through Wednesday morning...then shift to the southwest and decrease to 20 to 30 MPH by afternoon.

In the western Washington interior...south winds will begin increasing Wednesday morning. In the southwest interior and the Puget sound area...including Seattle...Tacoma and Everett...Sustained winds will reach 30 to 40 MPH with gusts to 50 MPH by late morning... then decrease by mid afternoon. South winds over the northwest interior of Washington will be slightly stronger...with sustained winds of 40 MPH and gusts to 70 MPH. The strongest winds will likely be felt on higher hills...headlands...and near terrain constricted areas.

If you live or are traveling in any of these areas...prepare for strong...possibly damaging winds. You may have downed tree limbs and power lines...flying debris...and power outages. Damage to structures is also a possibility.

A rapidly deepening storm system is developing several hundred miles offshore. It will track northeastward across the northern part of Washington late Wednesday morning.

KAM/ART

Case 2

High wind warning/watch
National Weather Service Seattle WA
330 AM PST Tue dec 12 1995

...A high wind warning is now in effect for all of western Washington today through this evening...
...A high wind watch is now in effect for all of eastern Washington for late this afternoon and evening...

The National Weather Service has issued a high wind warning for western Washington today with strong south winds of 50 to 60 MPH and gusts to 90 MPH developing along the coast by late morning. In the interior of western Washington strong south winds of 50 MPH and gust as high as 80 MPH are expected during the late afternoon and evening.

In eastern Washington a high wind watch is in effect for late this afternoon and evening where south winds of 40 MPH and gusts to 55 MPH are possible.

Satellite pictures and ocean body reports indicate an intense low pressure center 300 miles off the south Oregon coast. The current track of the low moves it along the Washington coast early this afternoon and to just off the Tatoosh Island by late afternoon.

Because this low pressure system has a very low central pressure and is moving very close to the Washington coast this storm has the potential for being one of the strongest wind storms in recent history.

People in the warning and watch areas should be prepared for strong damaging winds with this storm...which could result in widespread power outages due to downed trees and power lines.

Stay tuned to NOAA weather radio or your favorite radio and television stations for more information about this storm.

Weather Impacts on Energy Activities in the U.S. Gulf Coast

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Introduction

Oil and natural gas exploration and production activities in the offshore sector of the Gulf of Mexico must address weather phenomenon in almost every phase of operations. Offshore, both fixed and floating facilities are designed for safe and efficient operation in weather events ranging from hurricanes, to winter cold and summer heat. Onshore, refineries are also impacted by tropical weather systems, and the flooding that often accompanies them.

Production Operations

Every day in the offshore Gulf of Mexico, production facilities extract, process, and transport approximately 3 million equivalent barrels of oil and natural gas. Companies that produce hydrocarbons from leases located in state or federal waters typically pay royalties to the government equal to at least 12.5% of the produced volumes. Assuming an oil price of $19 per barrel, each day $7 million dollars goes into public treasuries from royalty payments alone. Weather related production shut-downs defer millions of dollars annually in royalties paid for hydrocarbons produced from fields owned by the American public.

Undoubtedly, the biggest impact on production operations comes from tropical cyclones. Shut-downs impact operating companies more severely than royalty owners, since the operating companies incur the costs associated with deferral of production, transportation of crews to safety and back, downtime for damage assessment, and the costs of facility repairs prior to resuming safe operations. While fixed structures usually come back on-line within 48 to 72 hours of evacuation. Floating production systems, like those now operating in deep waters, may take up to one week to resume production. Most companies include 5 to 7 days of weather related production losses each year in their business plans. Improved storm track and landfall forecasts could potentially save 3 days of production shut-down for companies operating offshore. If one assumes producers have an after tax, net income margin of $5 per barrel, the cost of deferred production alone for a Gulf-wide production shut-down might be $15 million per day. The oil production is not lost, only deferred to the future with a reduced net present value.

Today most operating companies transport crews offshore in helicopters, rotating crews on a 14 day schedule. Unscheduled, weather-related evacuations add approximately $10,000 per production facility and $50,000 per drilling rig, over and above normal transportation costs. Dense fog is commonplace along the Gulf Coast, often preventing flight operations for days at a time during the winter months. Operating companies working the eastern and central Gulf have shore bases in the Mississippi delta that provide normal resupply via marine vessels known as crew boats or work boats. Once flights are grounded, boats make more trips through the already crowded Mississippi river navigation system. For facilities 50 miles offshore, travel time from the shore bases in good weather is 3 hours on a crew boat, 6 hours on a work boat. Foggy conditions in southern Louisiana can cause additional delays up to 24 hours.

Offshore platforms function primarily as the processing facility of hydrocarbon fluids which then enter

product pipelines. Pipeline operators set specific conditions which produced fluids must meet prior to entering the product pipelines, typically temperature, pressure, and water content. Producers whose products fail to meet pipeline specifications must take measures to reach compliance, or risk curtailment. Pipeline input temperature is a common specification for produced gas. In the high ambient surface temperatures of the summer months, many operators must route produced gases through heat exchangers to reduce temperatures to pipeline specifications. Although subsurface teams and facility designers attempt to characterize reservoir fluid properties before fabrication and installation of processing equipment, modifications are frequently required. A modification to add gas cooling on a facility can cost $300,000, allowing the operator to optimize both oil and gas production.

Drilling Operations

Exploration and appraisal drilling precedes production operations. Today, exploration drilling focuses on deep water opportunities, using semi-submersible rigs and dynamically positioned drill ships capable of operating in water depths up to 2500 meters. Current operating costs for these rigs may exceed $250,000 per day. Weather related events which effect drilling operations include tropical weather systems, high winds and wave heights, and abnormal currents. During the unusually active hurricane season of 1995, the arrival of a semi-submersible drilling rig from the North Sea in the Gulf of Mexico for BP was delayed by 2 weeks because of course changes required to dodge dying hurricanes in the Atlantic.

Presently, offshore drilling methods depend on highly specialized lengths of pipe, known as drilling risers, to connect the well head and blow-out preventer equipment at the sea floor to the drilling and fluid handling equipment located on the surface vessel. Tension loads on these drilling risers are carefully monitored via position indicators, and remotely operated vehicle (ROV) dives which monitor riser flex and measure current profiles. Loop currents and the eddies associated with them are common phenomena the warm waters of the Gulf, especially in the prospective deep water areas. These strong ocean currents can have velocities exceeding 3 knots in the upper 1000 meters of water, producing unsafe loads on risers due to rig offset. Another potential hazard is riser failure due to stress from vortex induced vibration. For the period from 1989 to 1995, excessive currents forced 126 days of delays in drilling operations, at an estimated cost to BP exceeding $6.5 million dollars. (Wheatley, 1995) Seismic acquisition projects are also impacted. Using ocean current data and forecasts obtained from public and private sources, the industry monitors loop currents and associated eddies, attempting to minimize their effects by avoiding operating in effected areas during the late summer and fall when these eddies tend to reach maximum extent and speeds.

Conventional structures are used in water depths up to about 400 meters. Drilling operations from fixed platforms also experience delays associated with wind velocity and wave heights exceeding safe operating conditions for supply vessels. Wave heights greater than 3 meters, and wind speeds over 25 knots create unsafe conditions for loading and unloading heavy equipment and fluids from shallow drafted supply vessels. Operators attempt to prevent delays associated with wind and waves by monitoring forecasts and transporting critical items in advance of adverse conditions. In December 1996, a single BP drilling operation incurred 10 days of delays from wind and waves, with a direct cost of $300,000. Additional costs for standby time for contract personnel and services accumulated while drilling operations waited for the essential items such as rig engine fuel, potable water, and drilling fluids.

Refining

BP's Alliance Refinery is located about 40 km. south of New Orleans in Plaquemine Parish, Louisiana, situated on the west bank the Mississippi River. The primary weather concern for Plaquemine Parish residents and businesses is hurricanes. Most of Plaquemine Parish is at or just below sea level, protected

from flooding and storm surge by massive levees. In the event of a hurricane evacuation order, Plaquemine Parish is supposed to be evacuated 3 days before predicted landfall, to allow time for subsequent evacuation of the greater New Orleans urban area. Therefore, landfall predictions significantly impact refinery shut-down timing, with a minimum of 4 days down time required after an official evacuation order. Pipelines supplying the refinery are shut-down, as are the producing platforms offshore which feed the pipelines. The economic impact of refinery shut-downs along the Gulf Coast during the hurricane season is well documented in the popular media by tracking gasoline prices.

Construction and Installation

In the deep water operating areas of the Gulf, the size of facilities necessary to process 100,000 equivalent barrels of oil and gas each day creates unique installation requirements. Operators plan offshore construction during the early summer, to take advantage of the normally calm seas during those months. During the launch of BP's Pompano platform, wave heights less than 2 meters were necessary to place the 32,600 metric ton platform jacket over an existing template on the sea bed 400 meters below. Next, a 4,350 metric ton, pre-fabricated topside was lifted, fitted, and welded to exacting specifications. With only one heavy lift crane barge in the world capable of the jacket lift, timing was critical. After transporting the jacket by barge from Corpus Christi, Texas, to the Louisiana coast, an early season tropical storm caused a 7 day delay in the jacket launch, at a cost of $1.5 million. Improved long range forecasts of tropical storm tracks and intensity can potentially save the industry millions of dollars annually in offshore construction costs.

Platforms for Research Network
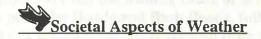
Platforms for Research (Rooney, 1993) is a cooperative effort between the oil industry, academia, and government agencies, principally NOAA, the Minerals Management Service, and EPA. As the industry develops offshore fields with 20 year life spans, the Platforms for Research sites have the potential to yield benefits for industry, academia, and the public. BP encouraged the use of its production facilities for research into marine life diversity, (Dokken, 1993) migratory bird movements, and hosted a National Geographic team investigating sperm whale migration in the central Gulf. Possibilities for future cooperation between the offshore industry and scientific research organizations include installation of remotely controlled weather stations on surface facilities, sub-sea instrumentation to permit monitoring of currents and water chemistry, and many other activities which benefit scientific research and discovery.

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Tornadoes

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Tornado Climatology

The tornado season tends to begin in the Gulf Coast states during the late winter and early spring, and migrates northward to the Great Lakes and Canadian border by late June and July. Many of the tornadoes that affect the central and eastern Gulf Coast during the late fall and early spring originate over the northern Gulf of Mexico as intense waterspouts. Bluestein and Golden (1993) noted that many of these do not have hook echoes or other classic, distinguishing characteristics on radar. Many of the increasing number of tornadoes being reported along the U.S. West Coast (Monteverdi, 1994), particularly the greater Los Angeles basin (Hales), since the deployment of NEXRAD Doppler radars originate offshore as waterspouts in the presence of an intense upper cold low.

The most definitive study of U.S. tornado climatology from 1680-1991 was published in a large volume by Grazulis (1991). Tornadoes are most likely over the southern and central Plains, southern Mississippi Valley and upper Midwest. It is apparent that the risk of tornadoes is considerably less west of the Rockies and into southern Canada. However, the U.S. averages about 100 tornadoes per year and is the world's capital (Fujita, 1974). Xu (1993) reported on an 11-year study of tornadoes in China, and found several over the plains of the middle and lower Yangtze River, with a peak frequency in July. Tornadoes are also found inland from both southwest and east coasts of Australia and over the plains of Argentina.

The U.S. is the world's tornado capital because of the unique juxtaposition of the north-south Rocky Mountain range and the moisture source from the Gulf of Mexico. Models show that the Rockies allow the inflow of warm, moist air from the Gulf of Mexico to be overlain by colder air flowing over it from the west. These jet stream disturbances are often associated with explosive cyclogenesis and attendant severe weather. Similar geography does not exist elsewhere; for example in China, the elevated Tibetian Plateau is oriented east-west, and there is no comparable moisture source to the south like the Gulf of Mexico.

The primary data source for all climatological records of severe storms, including hurricanes and tornadoes, is the monthly STORM DATA, published by NOAA/NESDIS. It tabulates daily occurrences of all *reported* severe storm phenomena, by state and date. Most of these reports are gathered at local NWS offices, from both official sources and storm spotters. However, Burgess and Doswell (1988) noted that with decreasing NWS staff and storm surveys by untrained individuals, the number and characteristics of tornadoes (intensity, path length and path width) are becoming increasingly suspect and unreliable. Grazulis (1992, 1993) examined not only tornadoes in STORM DATA, but also visited local NWS offices and libraries nationwide to clean up the U.S. tornado record; he found that about 2000 tornadoes reported out of about 10,000 were improperly designated tornadoes since the late 1880's.

The thirty-year average yearly deaths from flash floods/floods, lightning, tornadoes and hurricanes is shown in Fig. 1. We note that tornadoes **are not the leading cause of severe storm fatalities; indeed, the greatest average yearly threat is posed by floods and flash floods, followed by lightning and tornadoes**. It might be argued that this situation has partly resulted from the significant improvement in the accuracy and lead-times for tornado and hurricane warnings concomitant with the NWS Modernization (Sheets, 1990; Polger et al, 1995). The trends in U.S. annual tornado frequency since 1953, broken down

by intensity, are shown in Fig. 2, after Ostby (1993). The three intensity categories are weak (F0, F1), strong (F2, F3) and violent (F4, F5), as well as for all intensities combined. Most striking is the dramatic rise in reported tornado totals since the mid-1980's. We attribute this rapid rise primarily to the increased reports of weaker tornadoes that in turn have been the result of population increases, increased NWS emphasis on warning verification, and the NWS Modernization ("beating the bushes" by post-storm phone calls to spotters and local officials - see Hales, 1985, 1993), storm chaser reports and eyewitness videos. This figure also points to a major shift in the tornado intensity distribution: During the 1960's and 1970's, studies indicated that about two-thirds of all U.S. yearly tornadoes were weak, one-third strong, and only about 2% violent, these newer data suggest that *about 85% of reported tornadoes are weak, 15% strong and less than 1% violent (shown in Fig. 2)*. Most important, recent studies by Monteverdi et al. on California tornadoes suggest that there may still be significant *underreporting* of tornadoes west of the Continental Divide.

The recent year-to-year trends in tornado losses are shown in Table 1, which shows data compiled by the NWS/OM from STORM DATA from 1985-95.

Table 1 - U.S. Tornado Impact Statistics

	#Deaths	In mobile homes	#Injuries	Estimated damage
1985	94	30%		
1986	15	47%		
1987	59	41%		
1989	50	24%	2490	$1088M
1990	53	13%	1150	$668M
1991	39	51%	854	$798M
1992	39	51%	1300	$764M
1993	33	39%	3990	$368M
1994	69	38%	1067	$518M
1995	30		647	$408M

Source: NWS/OM

The columns show deaths, percentage of fatalities in mobile homes, injuries and dollars of estimated damage in millions. While tornado damage in 1989 was over one billion dollars, it has declined somewhat since that year. However, the Ft. Smith, AK tornado in the last year alone caused $300 million in damage, and the recent major outbreak again in Arkansas may well exceed that figure. Table 2 gives total insured property losses from 1986-1995, based on estimates from Property Claims Services for all wind, hail, snow and tornado losses combined.. These claims have risen from under one billion dollars in the late 1980's to slightly over five billion dollars in 1992, and nearly that amount in 1995 as well.

Table 2- 1986-1995 Wind, Hail, Snow and Tornado Losses

Note: Losses are based on estimates from the property claims Services (PCS) in New York. PCS losses account for property insured under fire and allied lines coverages, inland marine fixed property coverages, and comprehensive automobile coverages.

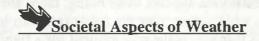| Year	Wind, Hail, Snow & Tornadoes
1986	$849,247,500
1987	$875,000,000
1988	$1,314,000,000
1989	$1,777,000,000
1990	$2,545,000,000
1991	$2,378,000,000
1992	$5,055,000,000
1993	$4,355,000,000
1994	$4,306,000,000
1995	$4,850,000,000
Total	**$28,304,247,500**

Most interesting by contrast in Table 1 is the fact that after 1985, the yearly tornado deaths were well below the 30-yr average shown in Fig. 2. There is no discernible trend in either tornado deaths or injuries, although 1989 was a bad year for both injuries and damages. Another interesting point is that there are generally 40-50% of yearly tornado deaths occurring for occupants of mobile homes. This comes at a time when the only affordable housing for a growing percentage of American disadvantaged and the elderly is manufactured housing (e.g., mobile homes). A striking example was the tornado outbreak across Florida and the Southeastern U.S. documented by the NOAA Survey Team Report on the March 13-14, 1993 Superstorm. We should stress that while the risks to occupants of manufactured housing from all types of severe windstorms appears to be rising, there are mitigation measures that can be taken. Most important among these, which arose after the many fatalities in the large mobile home park devastated by the 1991 Andover, KS tornado, is the requirement for a fixed, permanent shelter at every mobile home park in wind-prone areas. The wind engineering community has examined the manufactured home construction and recommended better windstorm protection through improved anchoring systems (Marshall, 1994). After detailed examination of the damage to permanent and mobile home construction in Miami after Hurricane Andrew, Marshall (1993) found that damage to manufactured homes ranged from loss of roofing to total destruction. In general, units that conformed to the HUD safety standards suffered less damage than did pre-HUD units. However, conventional residential construction adjacent to manufactured home parks performed better, in some instances significantly better, than did manufactured homes, including HUD-labeled units. Based on Marshall's (1993) windspeed assessments and damage to roof and wall coverings at fastest-mile speeds of up to 42.5 m/s and significant structural damage at wind speeds ranging 44.7 to 53.6 m/s. At wind speeds ranging from 53.6 m/s to 60.3 m/s, there were numerous instances of HUD-labeled units suffering total destruction. Marshall used these results to recommend some improvements to the HUD wind load requirements in its construction and safety standards for manufactured housing.
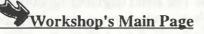
The trends in NWS warnings since the first deployment of NEXRAD Doppler radars have been gratifying. Lead-times for tornado warnings up to the early 1980's had been *negative, that is, the tornado had already touched down and been producing damage on the ground for several minutes by the time the first NWS warning was issued*. Beginning around 1990, and coincident with the first NEXRAD radar deployment at Melbourne, FL, the NWS warning lead-times have been positive and increasing steadily. The latest NWS warning statistics for 1996 are shown in the Table, and while these are preliminary figures, suggest tornado warning lead-times averaging over 18 minutes, a CSI of 0.46, a POD of 0.826, and false alarm ratio (FAR) of 0.489. The first three figures have all improved steadily since 1990. However, the FARs have slightly

increased over the past few years, after dropping during the early part of the decade. The reasons for more NWS false alarms are not clear, but may relate to newer forecasters replacing more experienced ones who have retired and being somewhat overzealous with the new technology.

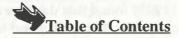The trends above in tornado climatology and warnings suggest that, overall, things seem to be improving. Indeed, the recent major tornado outbreak over Arkansas on March 1, 1997 was well-warned, lead-times ranging from 18-35 minutes. However, there are still significant tornado forecast and warning challenges, highlighted by the major tornadoes with 44 deaths in the Southeast during the 1994 Palm Sunday outbreak, the Tulsa, OK tornado, and the Ft. Smith, AK tornado last year. Another problem may be lurking with the recent rise in false-alarm rates. There are potential social response issues as well that the increased warning lead-times may cause: The AP reported that after being warned of the tornado that struck Arkadelphia, AK, 20 minutes later, young Katie Kolb did the once-unthinkable act: she traveled into its path to retrieve her sister. There are also increasing numbers of people putting themselves in harm's way by chasing tornadoes with video cameras or by watching and waiting too long after being warned at home. A new controversy has arisen in the literature lately by Schmidlin and King (1996, BAMS) who question current NWS recommendations to mobile home residents to seek permanent shelter or lie in a culvert when warned of an approaching tornado. These authors question such advice and suggest instead that it may be safer to outrun the tornado in an automobile. This needs rational thought and debate, and much more scrunity of the evidence, pro and con. The fact remains that a large fraction of the total deaths in the Wichita Fall, TX tornadoes of 1979 and Huntsville, AL in 1994 were people that were caught in their cars during rush hour trying to get home ahead of the tornado.

For references, please contact the author.

Societal Aspects of Weather

Workshop's Main Page

Table of Contents

TORNADOES BY FSCALE
BY PERCENT
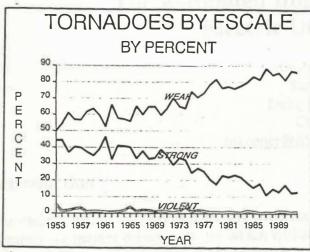
Figure 3. Tornado frequency by the percent of each F-Scale category.

Table 1. Fujita- Pearson Scale.

Category	F-Scale	Wind speed (mph)
Weak	0	<73
	1	73-112
Strong	2	113-157
	3	158-206
Violent	4	207-260
	5	261-318
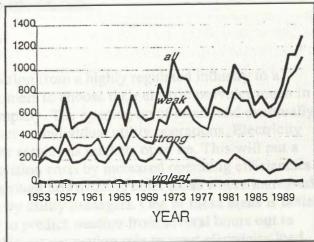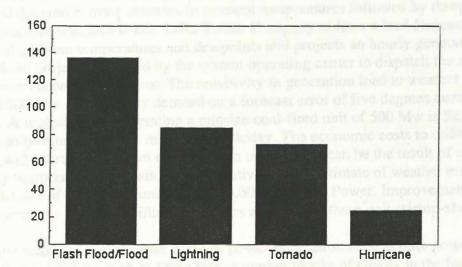
Figure 2. Tornado frequency by F-scale: weak (F0,F1), strong (F2,F3), violent (F4,F5).

Weather Fatalities
1966-1995 (30 year average)

The Estimated Impact of Weather on Daily Electric Utility Operations

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Introduction

The electric utility industry is currently undergoing a transition from a highly regulated industry to a competitive market driven industry which will allow customers to choose their electric provider much in the same way people choose their long distance phone company. The opening up of retail, and eventually residential markets, to allow choice will have a great impact on individual utility operations. Electricity providers will focus on lower cost generation and customer service as markets open up. This will put a premium on individual utility companies to decrease generation costs by increased operating efficiencies. While there will continue to be pressure to reduce costs through downsizing, other areas where increased operating efficiencies can reduce costs will be focused on by utility managers. One of these areas is better generation demand forecasting which relies on the ability to predict weather from several hours out to several weeks which determines the best and most cost efficient generation mix to meet electricity load demands. Another area where weather will play a role is customer service. The ability to predict severe weather that disrupts electric service to utility customers and act in a proactive manor will aid those companies that place excellence in customer service as part of their business market strategy.

This paper will discuss the way weather information plays in daily utility operations and attempt to provide some conservative economic estimates of the costs involved.

Weather Impact on Power Generation

The impact of weather forecast information on power generation can be substantial. Utilities base their daily generation on a load forecast of power demand for their perspective native load regions. This load forecast is a model of the relationship of power demand, time of day, season, and weather. Of weather variables, the load demand is most sensitive to ambient temperatures followed by dewpoint temperatures, cloud amounts, precipitation, and winds. Duke Power Company utilizes a load forecast model which takes hourly forecasts of ambient temperatures and dewpoints and projects an hourly generation load out through eight days. This load projection is used by the system operating center to dispatch the available generation resources in the most economical manor. The sensitivity in generation load to weather forecast can be as much as 600 to 1000 Mw of electricity demand on a forecast error of five degrees during peak winter and summer months. A typical cost of operating a midsize coal-fired unit of 500 Mw is $250k/day while 500 Mw of combustion turbines can be as much as $500k/day. The economic costs to utility operations are the costs associated with startup-shutdown of generation units which can be the result of error in the short-term hourly temperature forecasts. A conservative annual estimate of weather error costs associated with startup-shutdown of generation units is $8,000,000 for Duke Power. Improvements in short-term forecasts of temperatures can save millions of dollars annually in these unit startup-shutdown costs.

Daily weather forecasts also impact other areas of power generation such as bulk power marketing and hourly energy pricing. Utilities such as Duke Power market blocks of energy in the form of short term and long term contracts to other utilities or large industrial customers. The energy price must be competitive

with the market with some risk built into the price that reflects uncertainty in the available generation mix (i.e., fossil, nuclear, or hydroelectric) and the weather forecast. Therefore a significant error in the 1 - 8 day forecast could result in a substantial economic loss to the energy provider. Improvements in the medium range forecasts could reduce the risks associated with bulk power marketing and hourly energy pricing. Consequently, increased confidence in seasonal forecasts for departures from normal for temperatures will aid in the energy sector's ability to price energy and schedule operation and maintenance of large generation resources more efficiently between seasons.

Utilities with hydroelectric operations utilize precipitation forecasts to optimize the availability of their water resources. Duke Power utilizes QPF forecasts daily to route water through 25 hydroelectric stations (1007 Mw net) and two pump storage reservoirs (1675 Mw net). While hydroelectric power generation is less than 14% of the total Duke Power net system capability it provides an important and economically inexpensive means of power generation to meet peak demands. By utilizing good QPF forecasts and operating the hydroelectric system in a proactive manor, it has been estimated that Duke Power could conservatively save $2,000,000 over a five year period in wasted water (water not available for hydroelectric generation). An important side benefit to efficient utilization of good QPF forecasts is to minimize shoreline impacts of high water to property owners along Duke Power reservoirs. Improvements in QPF forecasts in the 0 - 48 hour forecast period and extending the QPF forecasts through the 48 - 72 hour forecast period can provide additional economical savings to water resource and hydroelectric managers.

Severe Weather Impact on Daily Utility Operations

The most obvious impact of weather on electric utility operations are power outages as a result of some weather phenomena. Electric power outages are the most noticeable result of severe weather. Severe weather can be classified as weather events that are life threatening. In the utility industry severe weather is classified as a weather event that directly causes widespread outages to a utility's distribution system, or in a worst case, causes extensive damage to a utility's transmission system. Over the years Duke Power Company has experienced several severe weather events that have caused extensive damage to Duke's electrical distribution system. The table below lists the dates of several big storm events, type of storm, total customer outages (out of a total 1.8 million customers served throughout the service area), and the total cost of restoration which includes material and labor.

Storm Date	Storm Type	Total Customer Outages	Cost
May - 89	Tornadoes	228,341	$ 15,189,671
Sep - 89	Hurricane Hugo	568,445	$ 64,671,150
1990*	ALL STORMS		$ 753,805
Mar - 93	Wind, Ice and Snow	146,436	$ 9,176,203
Oct - 95	Hurricane Opal	116,271	$ 1, 655,350
Jan - 96	Western NC Snow	88,076	$ 872,585
Feb - 96	Ice Storm	660,000	$ 22,905,627
Sep - 96	Hurricane Fran	409,935	$ 17,471,826

* 1990 is used as a typical year without any major storms. Dollar amounts are the total restoration costs in labor and materials for all weather related events throughout the year.
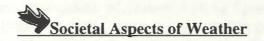
Utilities utilize severe weather forecasts to plan and mobilize resources to meet the anticipated challenges

of storm restoration. For example, prior to landfall of Hurricane Fran, Duke Power Company pre-staged materials and restoration crews in the northeastern portion of the service area. The result was that a concentration of available crews and materials were ready to begin restoration work immediately after Fran's passage through the region. This aided in reducing the total storm outage time for customers in the affected regions. Improvements in severe weather forecasts of major events such as Hurricanes, winter storms, and severe thunderstorms can aid utility managers in resource scheduling and materials management. Utilities that focus on excellence in customer service will retain customers as the electric utility industry moves into a more competitive market.
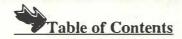
Finally, lightning related outages are estimated to cost the nation's utility industry over $100 million annually in materials and labor costs (from EPRI). For Duke Power alone, lightning causes nearly 90% of power outages during the summer months. Lightning and wind damage associated with severe thunderstorm activity can disrupt electrical service throughout the year. Forecasts of storms with high probability of intense electrical activity with just a few hours lead time would reduce customer outage time if decision makers were more proactive in utilizing a forecast of this type. The economic benefit to Duke Power has been conservatively estimated to be near $200k annually in reduced outage time. A much bigger savings to customers with large investments in standby power generation could be realized as well.

Summary

Improvements in weather forecasting from temperature forecasts to severe weather events can have a large economic impact to a utility's bottom line. The discussion above focuses on how weather impacts one southeast US utility. Extrapolating the estimated costs of unit startup - shutdown due to weather error in the temperature forecasts alone may well be in the hundreds of millions annually nationwide for the utility sector. Better QPF forecasts and improvements in how water resource managers utilize these forecasts can save millions annually nationwide and reduce shoreline impacts as a result of high water operations.

Societal Aspects of Weather

Workshop's Main Page

Table of Contents

An Overview of Lightning Safety

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Summary

Lightning is an underrated hazard. As a result, applied safety initiatives from its effects have been studied little and applied even less. On a continuing global scale, there are some 2000 thunderstorms producing 100 lightning strikes per second. Long term statistical averaging shows that lightning causes more deaths than floods, hurricanes, or tornadoes (Number of Deaths by Natural Hazards, 1940-1981). Yearly lightning costs can be shown to exceed $2 billion (Annual USA Lightning Losses).

Many USA lightning codes are incomplete and superficial, providing more benefit to commercial vendors than to those seeking relief from the strike event. Many devices are promoted that offer "no strike - absolute protection." Such unsubstantiated claims only serve to confuse specifying architects, engineers, and facilities managers.

Lightning cannot be "stopped" or "prevented" and in this sense absolute lightning protection is impossible. Preparedness can mitigate lightning consequences. A comprehensive risk management guideline can provide a rational and systematic approach towards lightning safety (Lightning Safety Guidelint).

Risk Management of the Lightning Hazard.

Preparedness for the lightning event is addressable by a mix of hardware and software. Hardware (equipment) is a combination, where appropriate, of devices such as lightning detectors and related warning equipment, air terminals (lightning rods), surge protectors, and grounding, bonding and shielding techniques. Hardware generally provides improved safety for facilities. Software (education, information and training - EIT) mainly benefits employee safety thresholds.

As a general minimum requirement, all personnel should have a general understanding of basic lightning safety terms such as:

FLASH-TO-BANG --- STEP VOLTAGE --- TOUCH VOLTAGE SIDEFLASH --- FARADAY SHIELD --- SAFE/NOT SAFE ZONES --- AVOID ALL WATER --- AVOID ALL METALLICS, INCLUDING TELEPHONES & HEADSETS --- LIGHTNING SAFE POSITION.

(Note: The USA lightning standard NFPA-780-1995, C-2.5.d descriptor for a lightning safe position is incorrect and should NOT be followed.) (NLSI Lightning Safety Tips)

For most employee situations a phased EIT program is suggested, consisting of the following elements:
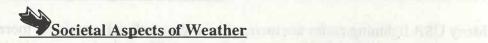
Category I: EIT Training-In-A-Box. This is intended for presentation of lightning safety information by designated trainers. The package consists of a video, an instructor tutorial, handouts, booklets, and posters which focus on the lightning safety theme. All employees should be exposed to this information, with annual repetition.
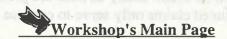
Category II: EIT Workshop. All supervisory personnel should attend a focused 3 hour Lightning Safety Seminar annually.

Category III: A designated Safety Officer within the organization should have a comprehensive understanding of lightning safety issues. Professional accredited training in this field is available.

Conclusion

The arbitrary nature of lightning makes absolute safety from its effects unlikely. Hazard levels, however, can be mitigated. Safety margins can be improved. Deployment of site-specific equipment is useful. Education, information, and training of employees is an effective investment towards confronting the lightning hazard.

Some Thoughts on the Societal and Economic Impact of Winter Storms

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The National Weather Service produces summaries of the deaths, injuries and damages attributed to a variety of weather events. From the figures provided (Figure 1), (Figure 2), it would appear that winter storms, including both snowstorms and icestorms, have much less an impact on society than such phenomena as convective storms (tornadoes, severe thunderstorms, hail; 100 to 200 deaths annually and damages of 1 to 2 billion dollars), heat waves (1000 fatalities in 1995), tropical cyclones (20 to 30 billion dollars for Andrew, for example), floods (21 billion dollars estimated during the Mississippi floods of 1993), drought (4.5 billion dollars in 1988), and cold (1.9 billion dollars in 1989). During the period from 1988 thru 1995, the contribution from winter storms to the total damage estimate of $114 billion was a little over $3 billion, less than 3% of the total. In contrast, the damage estimates from just 2 events, 1992's Hurricane Andrew and the Mississippi River flooding of 1993 yielded about half the total. During this same 8-year period, 4101 deaths and 26,441 injuries were attributed to weather-related causes. Winter storms accounted for 372 of the deaths and 5690 of the injuries. These numbers work out to about 9% of all weather-related deaths and nearly 20% of the injuries, with the bulk of the injuries associated with icestorms. These figures would seem to indicate that winter storms, with emphasis on snowstorms, appear to have a relatively small effect on the economy and society, especially when compared to other weather threats such as hurricanes, floods and tornadoes.

However, events during recent years indicate that the impact of a major snowstorm on society could be more significant than the above figures imply. For example, the March 1993 Superstorm and the January 1996 Blizzard of 1996 were 2 events that impacted the daily routine of 50 to 100 million people over the course of several days, and in some instances, for more than a week. These 2 events were predicted with relative accuracy, and emergency managers, private industry, the media and the general population seemed to respond to the warnings in a multitude of ways. In the March 1993 Superstorm, newspaper "reports" showed damage from $1 billion to as much as $6 billion and some 200 to 300 deaths. In the January 1996 blizzard, the NWS disaster survey report just released cited insurance losses over $500 million and fatalities, primarily attributed to overexertion, at 60. The economic costs were provided by the American Insurance Association, primarily for wind and water damage. What wasn't included in these numbers were public cleanup costs and the economic impact of lost business. While these numbers were not included, the likelihood is that these numbers could be very high. According to the Liscio Report, a private financial newsletter that documents national economic trends, the impact of just 1 storm, such as the March 1993 Superstorm or the January 1996 blizzard, could be critical since payroll surveys, part of the Bureau and Labor statistics that reflect the state of the national economy, can be influenced significantly by snowstorms. According to the January 9, 1996 report, "Weather is a significant and all but neglected factor in economic performance". The newsletter cites the example that during the cold and snowy winter of 1977/1978, the GDP was moving at a 6% to 7% rate through the first 3 quarters of 1977 and the last 3 quarters of 1978. The index slowed to -1% in the last quarter of 1977 and less than 3% in the first quarter of 1978 during a winter that was characterized by several major snow events in heavily populated regions of the nation. The newsletter states that winter storms will impact retail sales and housing activity but the impact on payrolls may be particularly influential as many people are temporarily put out of work by a

major snow event. While it is not clear exactly what these impacts are, it is clear that there are significant impacts that are not consistently measured. These effects may have national and global economic implications.

Thus, the economic effects of winter storms may be more indirect than the damage-driven effects of weather phenomena such as hurricanes, flooding, tornadoes and hail. Perhaps, even the physical effects of snowstorms may also be somewhat minimized. Death tolls from other phenomena tend to be concentrated and obvious (for example, from physical trauma or drowning), such as in hurricanes and tornado outbreaks. Traffic accidents and deaths and injuries that result from attempts to clear snow, overexertion, the combination of cold temperatures and strong winds can be anecdotal and occur in many different areas, unlike the concentrated nature of other weather events. It also raises a number of other questions not only on the impacts of such storms and how we measure them, but how do forecasts alter the impact? What would have been the effects of the March Superstorm and the Blizzard of 1996 if there were no forewarning? What impact does a relatively accurate forecast several days in advance have over a forecast of say 1 day in advance. What would be the impact if there were no forecasts?
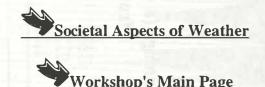
The meteorological community has seen tremendous improvements in recent years in its ability to predict cyclogenesis several days in advance with significant gains in numerical weather prediction techniques. In recent years, certain winter storms that had once been barely predictable a day in advance are now being forecast with some degree of accuracy as much as 5 to 7 days in advance and with confidence 1 to 2 days in advance. As a result, the March 1993 and January 1996 snowstorms, 2 of the most significant winter storm events to affect the most heavily populated region of the nation during the present decade, were predicted with a remarkable degree of success. Both storms resulted in loss of life and societal and economic impact that were very significant. How significant? How do we measure the societal and economic benefits such forecasts may have entailed? We know how warnings were issued to keep the population off the roads, retailers were able to provide some supplies that would otherwise be unavailable, and airlines moved their jets to locations where planes could fly. On the other side of the coin, not every storm is predicted with such a high degree of skill. For example, on 17 March 1997, weather forecast models provided information indicating that the New York City area could receive a major snowstorm in the following 48 hours, prompting the issuance of a "Winter Storm Watch". However, the later nighttime model simulations had a considerably different character, with New York to receive no snow, which subsequently verified. While it is humbling to see that such forecast dilemmas can still exist, it still raises questions about what kinds of costs are involved when forecasts are wrong, what savings occur when they're correct, and how society benefits from forecasts of winter storms. Given the wrenching budgetary times when it is probably critical to come up with hard numbers of how such improvements may have mitigated some of the impact of these storms seems to be of paramount importance.
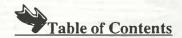
Given that winter storms may have more impact on the population than the Weather Service numbers indicate, there must be a more objective means of quntifying that impact. Therefore, it is not simple to address the issue of economic and societal trends directly, but winter storm trends in the Northeast United States can shed some light on the impact of winter storms on a part of the nation that is home to 1/4 to 1/3 of the nation's population. In Fig. 2, mean seasonal snowfall is depicted during the 20th century for an ensemble of approximately 30 sites shown in Fig. 3. This figure shows the widely varying seasonal nature of snowfall along the Northeast urban corridor. These figures can be viewed as a measure of the periodic nature of winter storm activity. To summarize some general findings, it appears that the 1990's represent a period of great fluctuations with some very snowfree seasons competing with some of the snowiest seasons of the 20th century, in particular, 1992-93, 1993-94 and 1995-96, which was the snowiest season of the 20th century. The 1990's are characterized by a significant number of extreme winter weather events that had considerable societal and economic impact. There may have been an increase in the number of intense coastal cyclones, including the Halloween Gale of 1991, the coastal storm of January 1992, the
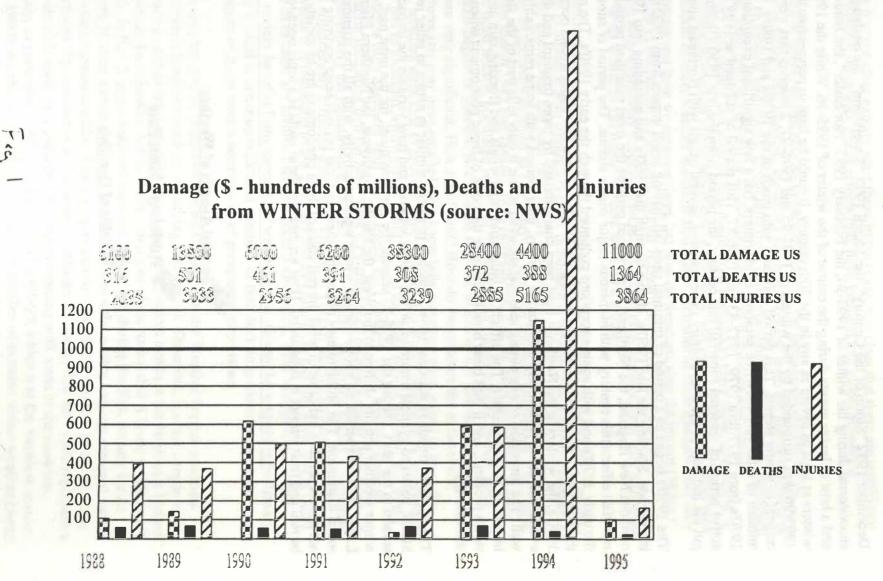
December 1992 "Storm of the Century", the March 1993 "Superstorm", the onslaught of numerous ice and snowstorms during the winter of 1993-94, the February 1995 "Nor'easter", the January 1996 Blizzard of 96 and a host of lesser events during the course of the winter of 1995-96. While the 1990's have produced 3 winters at least as severe as any in the 20th century, it could be kept in perspective that the snowy winter of 1995/96 was surrounded by the winters of 1994-95 and 1996-97, 2 seasons that were relatively gentle with respect to winter storms. This period contrasts with much of the 1970's and 1980's, which saw a large number of relatively snowfree seasons, mild winters, but a few significant exceptions, in particular, the late 1970's from 1977 thru 1979, 1982-83 and 1986-87. This period of subdued activity followed the most active period of seasonal snowfall this century, the period from the late 1950's through the late 1960's. To put the last half of the 20th century in perspective, several trends with Northeast snowfall become obvious:

The 1950's began as a period of minimal snowfall, having small impact from 1950 through the middle of the decade. Starting the late 1950's, lasting through the 1960's and extending into 1970-71 in portions of northern New England, the Northeast experienced perhaps the most extended period of winter storm and snowfall effects this century with numerous major winter storms. The period of snowy winters ended in the early 1970's and with some exceptions continued through the early 1990's. The major exceptions were the late 1970's and a couple winters during the 1980's, when a few major events occurred. Since the early 1990's, the winters in the Northeast have been characterized by more frequent and debilitating winter storm events and some particularly debilitating winters, interspersed with some remarkably quiet seasons, as well. The limitation of examining seasonal snowfall is that it only tells part of the story with respect to the impact of winter weather. The effects of bitter cold, high winds and freezing rain are also part of the winter storm problem, and it isn't clear how to measure the costs of these phenomena when comparing them to snowstorms.
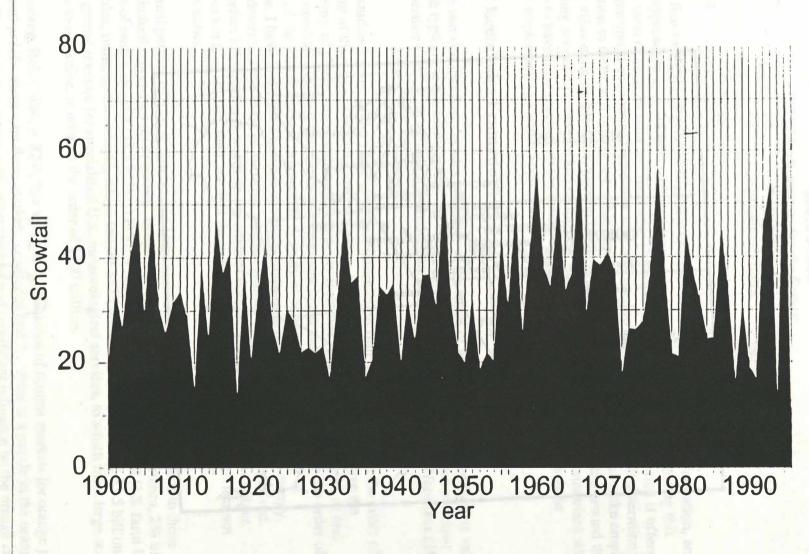
The apparent trends in seasonal snow, which is probably similar in nature to other regions of the United States, points to cyclical nature of severe winter weather and how variable the impact can be from one season to the next. During the 1996-97 season, the East was quiet, for the most part, and much of the winter weather activity shifted to the West, the Pacific Northwest, the Northern Plains and the Great Lakes, which experienced above-normal winter weather activity, with all the attendant economic and social disruption. The problem may not be that these cyclical periods keep occuring but more that we may not have a reliable indicator of what the real costs of these phenomena are to society. These costs appear to be real and their impact is substantial. How we measure these costs is a topic open to debate.

Societal Aspects of Weather

Workshop's Main Page

Table of Contents

Fig 1

Damage ($ - hundreds of millions), Deaths and Injuries from WINTER STORMS (source: NWS)

	1988	1989	1990	1991	1992	1993	1994	1995	
TOTAL DAMAGE US	6100	13800	6000	6200	38300	28400	4400	11000	
TOTAL DEATHS US	315	501	461	391	308	372	388	1364	
TOTAL INJURIES US	2835	3033	2956	3264	3239	2885	5165	3864	

DAMAGE   DEATHS   INJURIES

100 Year--Yearly Averaged Snowfall

Fig 2

Fig. 3

NORTHERN

Portland

Concord

Worcester
Albany
Boston
Hartford
Blue Hill
Providence

Scranton

Bridgeport
New Haven
Nantucket

Newark
Block Island

Allentown
New York
CENTRAL

Reading
Trenton
(JFK, LGA, City)

Harrisburg
Philadelphia
Wilmington

Baltimore
Atlantic City

Washington D.C.

SOUTHERN

Lynchburg
Richmond

Roanoke
Norfolk

Some Dimensions of the Value of Weather Information:
General Principles and a Taxonomy of Empirical Approaches

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I. Introduction

This paper seeks first to provide a general overview of issues associated with valuing information, and then to illustrate approaches taken largely, although not exclusively, by economists addressing this problem in the context of weather data and forecasts. The paper proceeds as follows. Section II offers an example of the conceptual economics framework typically used to depict how individuals determine the value of information to them, and briefly notes that nonappropriability of information can make empirical estimation of the value quite problematic. Section III illustrates several methods for getting around these problems, including revealed preference and contingent valuation studies. Section IV summarizes where consensus seems to have been reached on the concepts and methods and where gaps remain in understanding or implementing various approaches.

II. The Usual Economics Framework

It may come as a surprise that four decades of studies of the value of weather information find its value to be quite low. The typical measurement relates the contribution of information to the value of output -- say, the effect of a weather forecast on agricultural production. In a review of these studies, Nordhaus (1986, p. 130) notes that

> all of the studies I know of the value of perfect information find its value to be on the order of one percent of the value of output. For example, ... one study found that if you halve the standard error of precipitation and temperature, say from one percent to half percent, or one degree to one-half a degree, you get an improvement in the value of the output on the order of 2 percent of the value of wheat production. A study of cotton gave the same order of magnitude. I have looked at a number of studies in the area of nuclear power and energy, trying to determine the value of knowing whether nuclear power is ever going to pan out. Again, perfect information is worth on the order of one percent of the value of the output. From these kinds of studies, then, we find the value of information is not zero, but it is not enormous either.

To be sure, a small percent of a large number is a large number -- so the value of forecasts to these industries may indeed represent a lot of money. In the case of wheat production, for instance, 2% of the U.S. farm value of output in 1994 ($8.2 billion) is $164 million; the same percent of all U.S. farm income (grains, vegetables, fruits, and livestock), which totaled $175 billion in 1994, would be $3.5 billion. But estimated total annual revenue for specialized U.S. meteorological services, to which most large scale farms are likely to subscribe, is only on the order of $400 million.

By similar reasoning, Roll (1984, p. 879), in a study of the behavior of futures markets for orange juice and the effect of weather information on these markets, concludes that "... there is a puzzle in the orange juice futures market. Even though weather is the most obvious and significant influence on the orange crop,

weather surprises explain only a small fraction of the observed variability in futures prices." If Nordhaus's point is borne out, then compared to the value of final products, whether measured as the value of production or capitalized into futures prices, the incremental gain from information appears to be quite small.

This observation sharply contrasts with another view, illustrated in an editorial by the administrator of the National Oceanic and Atmospheric Administration, D. James Baker. Writing shortly after heavy rains had flooded many parts of California in the winter, 1995, he commented "If we'd been able to produce a forecast last spring that California would be deluged this winter, it would have been worth whatever research investment was involved, if only because of the human misery it would have relieved" (Baker, 1995). Such a conclusion might be easier after the fact ("If only I had known" about the weather, a stock market pick, a lottery number)[2]. It is much more difficult to arrive at such a conclusion before the fact, however. In general, it is only *ex ante* -- before the event -- that we are willing to pay for information, because afterwards it doesn't matter.

Indeed, the *ex ante*, or expected value, is what experts agree determines the value of information. If the probability of an event is either very unlikely or very likely, or if the actions that can be taken to avert its effects are minimal, then this value can be quite low. The value of a flood forecast is small if flooding is either highly unlikely or very likely in a geographic region, or if the effects of flooding are almost impossible to prepare for (for instance, in the case of Bangladesh due to factors such as the quality of the housing stock, other infrastructure, and population density).

IIa. The Canonical Model

The value of information, then, is essentially an outcome of choice in uncertain situations. Individuals may be willing to pay for information depending on how uncertain they are, and on what is at stake. They may be willing to pay for additional information as long as the expected gain exceeds the cost of the information -- inclusive of the distilling and processing of data to render it intelligible information. Moreover, an individual usually has subjective probabilities about the quality of the information, and will make use of additional information by using it to "update" his prior beliefs.

The mathematical formulation that underlies this framework is a state-preference approach. In such models individuals are assumed to form subjective opinions about the probabilities of two states of the world -- say, "rain" and "no rain." The value of information is in permitting the person to revise estimates of these probabilities.

Formally, the typical model is something like this:

maximize expected value: $$E(y/A) = p_1 y_{A1} + (1-p_1) y_{A2}$$

subject to a budget constraint: $$y = P_x X + P_I I$$

where y is income, A is the state of the world (say, A_1 is crop yield if it rains; A_2 is yield if it doesn't rain), p is the probability of rain; and in the budget constraint, P's are prices of information (I) and all other goods and services (X).

The result after deriving first order conditions is that the person should buy additional information until the expected marginal gain from another piece of information is equal to its cost. Usually expected value is represented by a utility function, about which different assumptions can be made as to its functional form,

which in turn can proxy the individual's attitude towards risk (he can be a risk lover, or be risk averse, or be risk neutral).

One of the best textbook examples of how this formulation operates is reproduced in table 1 and figure 1 (Quirk, 1976). Suppose a farmer can harvest his entire crop today at a cost of $10,000 or half today, half tomorrow at a cost of $2,500 per day. The harvested crop is worth $50,000. Table 1 indicates the "payoff" to the farmer in the event of heavy rain. In expected value terms, these payoffs are $40,000 to decision A and p ($22,500) + (1-p) ($45,000) to decision B. If p = 5/22.5, then the decisions give the same payoff[3].

Table 1 - The payoff matrix (see Quirk, 1976, p. 309)

Nature	Heavy rain tomorrow	No heavy rain tomorrow
Decisions: A. Harvest all today	$40,000	$40,000
B. Harvest over two days	$22,500	$45,000

If it is possible to forecast the weather, then p is the probability that the information the farmer receives is that there will be a heavy rain tomorrow with certainty (and 1-p is no rain, with certainty). Since it is a subjective probability, p can vary among different farmers. The expected payoff with information is then:

p ($40,000) + (1-p) ($45,000)

If $x is the most the farmer would pay for information, then $x is equal to the difference between the expected payoff with information, and the expected payoff without information. The value of information varies with p as in figure 1.
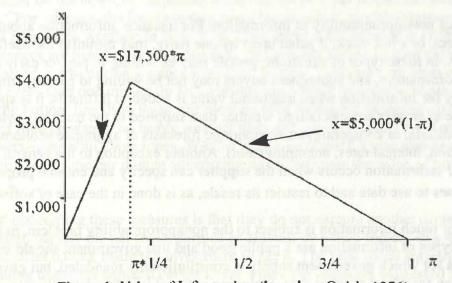

Figure 1. Value of Information (based on Quirk, 1976)

The value is maximized at p = 5/22.5 (where $x = $3,888); as from above, this is the p at which the farmer flips a coin. Information can thus make the biggest difference here. The value of information is zero at p = 0 and p = 1, since at these extremes, the farmer is already certain in his own mind whether it is going to

rain, and information is extraneous (even if the farmer is wrong).

Applications of the model can show the effects of changing the amount or quality of information as well as subsequent revisions that the individual may make of the probability (so-called Bayesian updating).

The implications for the value of information from this approach are:

    A. Information is without value
    --- when individual's subjective beliefs are at extremes (p=0 or p = 1)
    --- there are no costs associated with making the wrong decision
    --- there are no actions that can be taken in light of the information
    B. Information has less value
    --- when individual's subjective beliefs are close to extremes
    --- when the costs of making the wrong decision are low
    --- when actions to take are very limited
    C. Information has the most value
    --- the more indifferent is the decision maker among his alternatives (flips a coin)
    --- the larger are the costs of making the wrong decision
    --- the more responsive are the actions that can be taken

IIb. Nonappropriability and the Value of Information

In the context of the model above, the farmer might be willing to pay as much as $2,000 or more for information depending on the value of p. He could then resell the information for, say, $1,999, and other farmers would be willing to buy it from him since it is cheaper than buying it from the original supplier. This can pose a problem in the supply and pricing of information. Since every farmer can argue the same way, it may be impossible to sell the information for any positive price even though it is worth over $2,000 to each farmer. This characteristic of information -- nonappropriability -- results because one person's use of information doesn't diminish the usefulness of the information for someone else to use. A weather forecast, for example, can usually be shared by everybody within a geographic region.

There is a spectrum of nonappropriability of information. For instance, information about a mineral deposit, an oil prospect, or a hot stock, if acted upon by one party, may diminish the usefulness of the information to others. In these types of situations, people may be willing to pay for early and perhaps exclusive access to information, and subsequent buyers may not be willing to pay anything. Buyers may also be willing to pay for information when additional value is added to it (that is, it is specially interpreted and packaged). Some examples are specialized weather data supplied to the trucking, aviation, maritime, and construction industries, or competing macroeconomic forecasts of aggregate economic statistics (the money supply, inflation, interest rates, unemployment). Another exception to the general nonappropriability of information occurs when the supplier can specify and enforce property rights -- for example, issue licenses to use data and to restrict its resale, as is done in the case of software[4].

Because the supply of much information is subject to the nonappropriability problem, most experts conclude that many types of information are a public good and that government should supply it. Census data are the only data for which government supply is constitutionally mandated, but government has also come to be relied upon for a host of other data, including national weather data; climate, environmental, and space science data; and statistics on health, education, agricultural production, etc.[5] A recurrent problem in these cases, however, is that it is hard to know if the benefits of the data justify their cost. Most data are made available at the cost of reproduction (as required by Office of Management and Budget Circular A-130). Very little is known about the "true" value of the data. This gap in understanding the

value of the data haunts agencies and the Congress in annual budget deliberations.

The nonappropriability of public weather forecasts and other weather- and climate-related data has made it difficult to estimate empirically the value of these types of information. The next section describes some approaches; all of them are based on the general economics of information framework in the preceding discussion.

III. Empirical Approaches to Measuring the Value of Weather Information

The two general procedures that economists have used or could use to obtain estimates of the value of weather information are *revealed preference* approaches and *contingent valuation* studies. Revealed preference models attempt to identify instances where individuals actually demonstrate their willingness to pay for information. By far the bulk of empirical research on the value of weather information uses variations of this method. By contrast, contingent valuation (CV) uses a questionnaire format to construct a hypothetical market where the individual can express willingness to pay for alternative amounts or different types of information. To date, CV has not been applied to study the value of weather information.

IIIa. Revealed Preference

i. Brute force -- directly observed values

Explicit evidence of the value of weather data can be captured in some cases by direct measures of peoples' willingness to pay for it. The net revenues earned by the private weather forecasting industry are an example. From these can be gleaned, say, "annual expenditures by the major trucking companies for specialized weather forecasts." Other examples of willingness to pay to avoid the consequences of unfavorable weather are weather-related insurance premia paid in the event of rain during a sporting event or festival, or monetized values of the extra trouble people go to in carrying an umbrella, winter coat, etc.

Another measure associated with a daily forecast is the per- minute revenue and audience ratings associated with weather on the news, or "expected annual ad revenue per household associated with TV weather broadcasts." For instance, the local evening news broadcasts in the Washington, DC area allot between 2 and 3 1/2 minutes to weather; in New York City, about 1 1/2 minutes is allotted. Producers report that the differences are based on market research, presumably including data collected about how many viewers are gained or lost during weather segments. In New York, viewers want only the "bottom line," which can take less than one minute. In DC, viewers are willing to listen to explanations of the forecast as well as the bottom line. Bob Ryan, the most popular broadcast meteorologist in DC, gets "whatever amount of time he wants" on heavy weather days and averages about 3 1/2 minutes on normal weather days.(Conversations with Dave Jones, WRC-TV meteorologist). These minutes could be capitalized by multiplying by the per minute advertising rate to estimate the value of broadcast weather in different markets.[6] [7]

An important caveat concerning these measures is that they do not capture another dimension of the value of weather information, namely the net social surplus or amount by which society as a whole is better off with the information, after having made the investment to get it. The total social surplus would be estimated by integrating under the demand curves along which the measures suggested above are but single points. From this total measure could be subtracted the total cost of providing weather information to derive net social surplus. The information needed to make these calculations is difficult to obtain, but such net surplus measures would be useful in guiding public investment in weather instruments, spacecraft, and analysis and distribution facilitates.

The measures described above do, however, reveal actual choices made by people who are more or less free to choose the quantity of weather information they prefer. Indirectly observed measures, such as those described next, are also based on actual behavior but are inferred from some model of the relationship between the information and uses to which it is put.

ii. Other measures of capitalization -- indirectly observed prices

Other approaches to valuing weather information use indirectly observed prices. This is the gist of the majority of studies to date; the specific approach is to estimate productivity gains associated with weather forecasts and infer the value of weather information based on the monetized value of these gains. Johnson and Holt (1986) note twenty such studies dating from the 1960s on, including applications to bud damage and loss; haymaking; irrigation frequency; production of peas, grain, soybeans, grapes (raisin), fed beef, wool, and fruit; energy demand; and construction. More recently, Adams and co-authors (1995) observe changes in crop yields associated with phases of the El Nino- Southern Oscillation (ENSO), and use the market value of the yield differences to estimate the commercial value of the ENSO phenomenon.

Other studies use the time-series behavior of commodity prices in futures markets to infer weather-related values. Two examples are Roll (1984), who, as noted earlier, studies orange juice futures, and Bradford and Kelejian (1978), who study stock prices of wheat.

Another large literature dating from the 1970s uses wages and housing prices to infer the value of weather information, under the hypothesis that it is capitalized into the prices of such goods and services. These studies are premised on hedonic price theory, by which researchers model the equilibrium market for a commodity and then derive and estimate a function relating price to characteristics of the commodity. Coefficients on the characteristics are then interpreted as dollar estimates of the implicit value of the characteristics.

Rosen's (1979) study is among the seminal theoretical and empirical research that considers the extent to which interurban wage differences capture urban quality of life. He offers a conceptual framework that takes into account an important fact but one that can be difficult to disentangle empirically, namely, that wages, like prices, are the result of supply and demand. He then develops an econometric model derived from the wage equation often studied by labor economists but expanded to include additional explanatory variables.

Specifically, Rosen regresses an interurban cross-section of average wages on a set of explanatory variables which include not only personal characteristics influencing wages, such as education and age, but also measures of urban amenities and disamenities. These "quality of life" factors include pollution (water pollution, particulates, sulfur dioxide, inversion days); the crime rate; crowding (population density, population size, central city density); market conditions (the unemployment rate and population growth); and climate (number of rainy and sunny days and number of extremely hot days). Higher wages are expected in cities with disamenities compared with nicer cities, and this compensating differential is expected to work in the opposite direction for urban amenities -- a city with pleasant weather, for example, may not have to offer higher than average wages to attract workers and may even be able to offer lower wages. Rosen finds that climate variables are statistically significant in the expected directions; wage rates are higher, for instance, in cities where the weather is rainy or extremely hot.

In one of the most recent studies linking housing prices, Blomquist and co-authors (1988) estimate interurban "quality of life" indices using household's monthly housing expenditures (rent for tenants; imputed rent for homeowners) and measures of climate, environmental quality, crime, and other variables. The climate measures include precipitation, humidity, heating degree days, cooling degree days, wind

speed, and sunshine. All of the climate variables are found to be statistically significant determinants of housing expenditure, with an inverse correlation between expenditure and precipitation, humidity, and heating and cooling degree days and a positive correlation between expenditure, wind, and sunshine.

Blomquist and co-authors also include wages in their study, and combine the housing expenditure and wage data in a model that estimates the "full implicit price" of urban area quality of life variables. They find negative prices (that is, a marginal net *dis*amenity) for precipitation, humidity, heating and cooling degree days, and wind speed.

These hedonic approaches to valuing amenities are not without problems of data availability, modeling assumptions, and econometric issues. Freeman (1993) surveys and critiques the methodology of most of the studies to date linking wages and housing prices with environmental amenities. Nonetheless, the approaches could be useful in estimating the value of weather information; for instance, while neither the property value nor wage studies directly shed light on the value of a weather *forecast*, the approaches could be extended to include weather variability, say, and thus more closely proxy the value of *information* associated with weather. In addition, the hedonic approaches could be used to ascertain different values associated with different attributes of a forecast -- timeliness, frequency, accuracy[8].

IIIb. *Hypothetical Approaches -- Contingent Valuation*

Rather than draw data from observations of real-world choices, hypothetical approaches use people's responses to hypothetical questions. For example, people can be asked how much they are willing to pay for a specific change in environmental quality. The responses, if honest, are expressions of the value that respondents associate with the change. This approach has been called the survey method, the interview method, and other names, but is known most typically as contingent valuation (CV). CV has not yet be used for valuing weather information, although other dimensions of environmental quality have been a popular field for CV research.

CV methods have a long history, beginning in the 1960s with questionnaires used to estimate the benefits of outdoor recreation in Maine.[9] Other applications of CV have included assessing the value of visibility at the Grand Canyon; national water quality; information about natural hazards (earthquakes); and hunting, fishing, and other recreational permits. Most recently, CV studies were done by parties to the litigation over damages and penalties to land, water, habitat, and other resources as a result of the Exxon Valdez oil spill. The method was also the recent focus of an advisory panel convened by the National Oceanic and Atmospheric Administration to consider the general problem of how best to assess natural resource damages.

CV is fraught with significant controversy. A substantial amount of research and testing of how best to design surveys to elicit honest expressions of valuation has taken place, and where possible, the results of CV studies have been compared with results from direct valuation studies such as those described above. The jury is still out on the acceptability of the approach, although its proponents rightly note that in many cases, there is no alternative means of eliciting values about some types of public goods, including natural resources and other environmental amenities. In addition, design and administration of a high quality CV survey can be quite expensive.

Subject, then, to these advantages and disadvantages of CV studies (and of course, the direct valuation studies have their own limitations), it may be interesting to apply CV to peoples' valuation of weather information. In addition, just as the direct valuation studies use a hedonic approach to understand differences in values associated with different attributes of a good or service, so, too, can CV. In other words, different attributes of a weather forecast -- timeliness, accuracy, frequency -- could be the subject of

a CV survey. Its results could be compared with those obtained from the direct valuation studies.

IV. Conclusions

The state-of-the-art in understanding the value of information reflects general agreement on how to model an individual's decision calculus and some useful implications about the value of information: when it is most valuable, least valuable, and its relationship to an individual's subjective priors and the individual's ability to take action in light of the information. Most estimates of the value of information suggest that it is not large as a percentage of final output (in agriculture, trucking, and other markets). This result seems inconsistent with some perspectives of the value of information, such as those offered in the context of natural disasters and loss of life. But in these cases, the ex ante and ex post values of information need to be distinguished; in some instances, people's prior beliefs about the low probability of the hazards figure prominently in reducing the perceived value of the information. Finally, consideration must be given to the costs of actions that were able to be taken, or not taken, in anticipation of and in response to the information.

There is less state-of-the-art agreement about how best to estimate empirically the value of information. Obtaining from individuals their actual willingness to pay is problematic, although the news media through viewer ratings may have a brute force approach appropriate for their purposes. Among other approaches, both revealed preference and CV tools have strengths and weaknesses. The revealed preference approach -- which has dominated research to date -- has the advantage of being based on actual decisions. However, the researcher is limited to using data on market situations that may not precisely isolate the value of information from other factors. Examples are other determinants of productivity gains, in studies of the role of weather data in changes in agricultural output; or determinants of property values or wage rates, in studies of the effect of weather on quality of life. The CV approach, yet to be applied to weather information, can be tailored to address the specific question of interest. For instance, it can be administered to a general population sample or to a sub-sample, and it can address changes in the amount and nature of information (e.g., frequency, accuracy). The principal disadvantage is that the CV approach is based on what people say rather than what they do, and CV can be very expensive to design, administer, and evaluate. As the case with applications of CV to other goods, if CV is applied to weather information, the results might be usefully compared with results from revealed preference approaches and the media's ratings scheme.

Finally, the brief overview presented here of approaches to modeling and measuring the value of information has not addressed how individuals "process" information and incorporate it into their expected value calculations. The lack of this so-called transfer function is a gap in most models of information economics. There is a growing literature on adaptive responses by consumers to risk, and new investigations of ways to increase public interest in and understanding of science and weather.[10] These lines of research are generally interdisciplinary, and, taken together, are important extensions of the framework outlined here.

Foot Notes

1 - It is far from clear that the "misery" would justify research investment in climate and weather forecasting alone. We may also want to invest in research on other activities affecting quality of life, such as health care or education. (In addition, just as the empirical estimates of the value of infomation appear small, so, too, are there limits on the estimated value of life. Numerous studies suggest that the value of a statistical life ids around $8 million - which may not justify unlimited funding of *any* type or research.

2 - Although archived data frequently have research value.

3 - This assumes the farmer is "risk neutral." If he is risk averse, he would want a lower value of p before he would wait to harvest. The expected utility model described here is a usual point of departure for studies of individuals' responses to risk in a host of contexts, not just weather forecasts. For example, see Brookshire and coauthors.

4 - Legal protection is not an unequivocal good, however, as it limits the fullest use of information.. Because it would be costless to share the information, imposing costs leads to some losses to society. Legal protection thus requires a trade-off in the supply of and maximum use of data.

5 - The supply of weather data by government was dramatized in the early 1980s when the Communications Satellite Corporation proposed to buy the government's land remote sensing and weather satellites in order to obtain economics of scale and scope in their joint operation. Cartoonists lampooned the proposal with sketches of a citizen scarching franatically for a dollar to buy a vending machine forecast as a mean-looking hurricane bore down on him.

6 - Another measure now discussed in the broadcast industry is the number of accesses to media station's Internet sites. According to NBC/WRC meteorologist Dave Jones (interviewed in Conton, 1996), web hits after the heavy snows in January, 1996 went from 5,000 per day to 50,000 per day at the Washington DC affiliate of NBC (http://wxnet4.nbc4.com). Web hits are highly imperfect measure of the public's value of weather information for several reasons: web hits may be made accidentally or in passing rather than deliberately made on the basis of true interest and information value; a variety of information is poted on the site, not just weather data; and web hits through Internet access are priced at close to zero marginal cost, encouraging people to over-consume. Nonetheless, much of the huge increase during the January 1996 snows is probably indicative of sicere interest in the forecast!

7 - The British Meteorological Office has considered selling weather data to companies which sell commodities such as pet food and tissue paper, having observed correlations between weather and consumer spending patterns. See "Raining Cat and Dog Food," *The Economist*, 15 March 1997, p. 68.

8 - Ausubel (1986), for example, shows the significant variation associated with the value of weather forecast given its standard deviation; Nelson and Winter (1964) use an expected value approach (described above) to show which attributes of a forecast matter most to the trucking industry.

9 - Mitchell and Carson (1989) reline the history of CV and offer an excellent overview of the literature and approach. Cummings and coauthors (1986) and more recently, Freeman (1993) are also excellent references.

10 - See, for instance, Viscusi and O'Conner (1984), and the NASA/NOAA/NBC project on public use of remote sensing data and the internet (in Conton, 1996, and at http://wxnet4.nbc4.com).

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Societal Aspects of Weather

Decision Analysis Applied to Weather-Related Warning Systems

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Methodology

Decision analysis is a well-developed tool for aiding decision making in uncertain environments. The familiar 2x2 decision table summarizes the decisions and outcomes for warnings about hazardous events. The decision maker has two choices - warn or not warn - and the hazardous event either occurs or not. This leads to four possible outcomes - two correct decisions (correct warning and correct quiet) and two errors (false alarm and miss). If the goal is to minimize the costs due to errors, then the optimal decision is the one that minimizes the probability-weighted average of the costs of the two kinds of errors. Key technical difficulties in implementing the method for warning systems is modeling the event probabilities conditional on information such as forecasts and measuring the costs (which may involve difficult to measure and even difficult to discuss costs such as the value of a life).

	Event Occurs	No Event Occurs
Warning Issued	Correct Warning	False Alarm
No Warning	Miss	Correctly Quiet

Illustrative Case Study

Telemetered system of rain gauges for early warning of possible dam failure.
Original Problem: There are several hundred earthen dams in the western United States. An earthen dam, unlike a concrete dam, is likely to fail catastrophically if it is overtopped. Many people live downstream from many of these dams, but the dams themselves are often in remote locations which are difficult to monitor. Most of these dams are highly unlikely to be at risk in "100-year" storm events, but might be at risk for, say, a "500-year" storm event.
Engineering Solution: Place a system of rain guages above the dams, using telemetry to send data to a central site.
New Problem: After how much rain is on the ground should an evacuation warning be issued?

Decision Analysis Solution

We algebraically rearranged the standard decision analysis equation to answer the question: At what probability of dam failure should an evacuation warning be issued? Using reasonable assumptions, the optimal threshold probability can be expressed in this equation, where TPF is the time prior to [dam] failure that the warning is issued. This expression effectively separates the problem into a value or policy component - the right-hand side of this equation - and an expert or scientific estimate component - determining the actual values of P as a function of environmental conditions and rain gauge information. If the scientifically estimated value P exceeds the threshold value calculated above, then a warning should be issued.

$$P_T = \frac{Evacuation\ Costs\ (FA)}{\begin{array}{l} Value\ Lives\ Saved\ (TPF) \\ +Value\ Property\ Saved\ (TPF) \\ -Evacuation\ Costs\ (TPF) \\ +Evacuation\ Costs\ (FA) \end{array}}$$

On the right-hand side of the equation for the threshold probability, the difficult to measure costs were, of course, the value of life and the expected number of lives saved as a function of warning time prior to failure. The latter turned out to be reasonably simple to estimate by building a statistical model of deaths resulting from actual dam failures throughout the United States and Europe (see DeKay & McClelland, 1993). Valuing lives is more controversial but the results were not especially sensitive to differences in the standard values commonly used in such analyses. Also, for decision makers we reversed the calculations to show them the value of life implied by various threshold probabilities. For example, for one of our study dams, waiting until one is 50% certain the dam will fail before issuing a warning implies a value of life of ranging only from about $300 to $3000, clearly unreasonable values.

Across several dams studied, the optimal threshold probability for evacuation ranged from .01 to .0001, depending on dam characteristics, especially how many people live various distances in canyons below the dam.

The scientific estimation problem involves predicting reservoir hydrographs with standard errors, on the basis of initial reservoir level, degree of ground saturation, and amount of rain in the basin. Developing this model was not our task, but was instead the responsibility of the agency implementing the rain gauge system. Sensitivity analysis indicated that the accuracy of this system was a much more important determinant of overall system performance than was the accuracy of the cost estimates.

Implementation Difficulties

Evacuation Authority: The agency responsible for operating the dams has no authority to order evacuations. Instead, the agency can only recommend to the local sheriff that he or she order an evacuation. Given that warnings will be very rare (even a false alarm is expected to occur no more than once every 30 years at any given dam), it will be difficult to have in a place a system for contacting the sheriff and providing credible information that an evacuation is needed.

Policy Maker Conservatism: Policy makers and engineers developing systems such as the rain gauges prefer conservative strategies for dealing with risk. For example, engineers "overbuild" so that structures can withstand several times more than the greatest anticipated stress. However, when there are two kinds of errors, as in the case of warning systems, such conservatism is impossible because conservatism with respect to one kind of error necessarily increases the risk of the other kind of error. Policy makers do not like confronting such tradeoffs.

Fear of False Alarms: Extremely rare events, such as dam failures, are inherently difficult to predict. Even the best warning system will necessarily have far more false alarms than correct warnings. Public officials often receive severe criticism for false alarms (cf., swine flu inoculation decision) and they often fear that false alarms will diminish subsequent response when the threat is real. In this case, the probability of a false alarm at a given dam is very low (probably less than one false alarm in 50 years) and the probability of a false alarm at a given dam followed soon by a real threat is even lower. So even if there is a diminishing effect caused a false alarm, it is unlikely to have negative consequences because there will be little memory of the prior false alarm when the true warning occurs. However, system-wide across many dams, there is a good chance of making a false alarm every couple of years. Thus, the policy maker's

experience with false alarms may be different than someone living below a dam. If the policy maker becomes more conservative in issuing warnings in order to avoid false alarms, then residents below dams will be at greater risk.
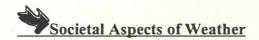
Conclusion
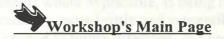
Decision analysis is an effective tool for informing decisions to issue weather-related warnings and evacuations. However, its successful implementation requires an undestanding of the social and political environment in which the warning system will be used.

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Societal Aspects of Weather

Workshop's Main Page

Table of Contents

Description of the Project
"Assessment of Research and Applications on Natural Hazards"

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Introduction

The project is designed to summarize, assess and evaluate knowledge in all fields of the physical, natural, social, and behavioral sciences and engineering regarding natural and related technological hazards and disasters. The assessment is divided into three parts: review the past, take stock of and integrate the present, and create a future. Currently, over 100 experts have been recruited from varied fields, universities, and agencies and are working on specialized project parts, nine experts have taken on subgroup leadership roles, and five graduate students are employed and plan project-related dissertations. Experts are still being added.

The Past

The last 20 years, and its historical context where applicable, is being reviewed to explore the thesis that our nation and its communities are becoming more brittle and susceptible to disaster losses, to explain why, and to document the basis for a change in future direction. We are reviewing significant disaster events, synthesizing and analyzing loss data, exploring data on expenditures for mitigation, pointing out data gaps to fill for a national baseline needed to track change, and updating the disaster scenarios posed in the 1975 assessment. We are addressing the reasons for increased susceptibility, e.g., population and climate change, globalization of economic and social systems, and others. We are also reviewing the last 20 years to trace the evolution of hazards policy, institutional, and organizational arrangements.
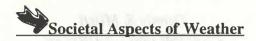
The Present

Subgroups of experts have been organized to integrate and synthesize knowledge across applicable hazards and disciplines regarding individual mitigations, e.g., land use and planning; emergency planning and response; engineering, codes, standards, and practices, and so on. Subgroups will also create a research agenda for the future, and estimate the applicability of each mitigation to foster long-term sustainability in terms of resiliency from disaster losses, maintaining a local economy and ecosystem, and so on. Eventually, these mitigation-specific integrations will themselves be integrated to create integrated mitigation management as a tool useful for local decision making. Subgroups are now in different stages of development and work.
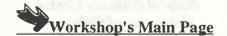
The Future
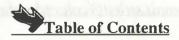
We are currently cataloguing and evaluating new tools and approache that have emerged over the last 20 years and estimating their place in the future, for example, risk analysis, computer-assisted decision information systems, and many others. We will eventually bring all research recommendations together into a catalogue of needed future research. We will also develop a vehicle for measuring and defining local acceptable risk, and we will investigate and make recommendations about how to interest and then involve

local stakeholders in using integrated mitigation management based on those local definitions.

Societal Aspects of Weather

Workshop's Main Page

Table of Contents

Trends in Floods

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Introduction

It has been reported that floods account for more losses than any other natural disaster in the United States both in terms of loss of lives and damage to property and crops (FIFMTF, NHC). Trying to characterize what these losses mean in terms of impacts over time, in terms of the magnitude and frequency of events, and in terms of future socio-economic problems for the nation is difficult at best. This brief paper addresses the questions raised by the workshop organizers by presenting a review of some of the existing data that shed some light on the issues. I rely mainly on the sources available from the Natural Hazards Center's (NHC) careful review of the last 20 years of NOAA's Storm Data set (the analysis is one part of the Center's development of a loss data base for the "Second Assessment of Research and Applications for Natural Hazards" project), other analyses done on data available from the National Weather Service (Yen and Yen, Nishenko, Pielke), and data from the U.S. Army Corps of Engineers' annual flood damage reports to Congress.

Trends in Flood Impacts

Economic Impacts Using data compiled by the National Weather Service from 1903 to 1993, Yen and Yen conclude that average annual flood damages in the U.S. are $2.41 billion. They report that 10-year moving averages of the data show an increase in losses over time in constant dollars. Their linear regression of the damage data shows a 1.17% annual increase in damage value (pg. 559). Pielke's analysis of the same data over a 25-year moving average reveals a similar, steadily increasing trend in losses due to floods. (pg. 77).

The NHC review of Storm Data records on damage due to floods indicates between $19.5 and $195 billion (in 1994 dollars) of property was lost to floods during the 20 year review (Figure 1). Seven of those years had property damages exceeding $1 to $10 billion. The most costly year was 1993 when floods damaged between $3.3 and $33 billion of property. Not surprisingly, 1988, the most costly year for droughts, was the least costly year for floods. During 1988, property damages ranged from $30 to $300 million dollars.

In addition to these property losses, between $8.1 and $81 billion damage was done to crops. The trend line indicates this is an escalating figure (Figure 2). Again, 1988 had the fewest crop losses due to flooding. By adding property and crop losses together, a total of some $27.6 billion to $276 billion dollars in 1994 dollars were lost to floods (Figure 3).

Loss of life and injuries Figure 4 shows the number of deaths per year due to floods from 1975-1994 as reported in Storm Data. The trend indicates a slight reduction in the number of deaths. Pielke draws the same conclusion though also points out that a review of a longer record of data over a moving 25-year period beginning in 1927 suggests that the number of deaths due to floods have been increasing in the second half of the century (Pielke, pg. 74). The Corps of Engineers reported an average of 94 deaths per year due to floods from Fiscal Year 1986-95 (U.S. Army Corps of Engineers, pg 13). Nishenko's review of cumulative flood fatalities since the beginning of the century indicates a similar average (personal communication).

An important point to note is that many flood deaths and injuries occur in single catastrophic events. For example, the number of deaths in 1976 is largely due to the Big Thompson Canyon, CO flash flood that killed 156 people and the 1985 peak is chiefly due to a flood in Puerto Rico that killed 180 people. In contrast, the 1993 Midwest floods that affected millions of more people over a much longer time killed far fewer people than these flash floods.

Figure 5 shows that injuries due to floods have also declined slightly in the past two decades. Injuries were highest in 1982 and lowest in 1988 and 1989. The lowest number of injuries coincides with the lowest death totals.

Environmental Impacts Floods are naturally occurring phenomena that are part of the physical and biological processes which have shaped our nation's landscapes. Smith claims "More than any other environmental hazard, floods bring benefits as well as losses." He points especially to the importance of floods in maintaining ecosystem habitats and soil fertility. (Smith, pg 257). Consideration of the negative impacts of floods on the environment more often appraise the detrimental aspects of human attempts to manage flood prone areas which, in turn, disrupt the natural flood cycle. For example, the Federal Interagency Floodplain Management Task Force reports that human activities have deeply affected floodplains and the nature of flooding. Activities such as drainage of wetlands and land clearance for farming; upstream development that replaces natural vegetation with paved asphalt; and construction of channels, levees, reservoirs change the flood cycle and often result in increased runoff, destruction of riparian habitat, and increased water pollution--all of which can be considered destructive to the natural environment (FIFMTF, pp. 19-21). However, systematic assessment of the environmental benefits and costs of flooding and the environmental benefits and costs of floodplain management programs has not been done.

Indirect Impacts In addition to the impacts described above, floods also have indirect impacts that disrupt society. As is the case for all disasters, these impacts and their costs (or value) are not well documented. However, they include such things as business disruption and loss of income, loss in tax revenues, transportation delays, and spread of illness--both physical and mental. There is also the indirect impact on other government-funded programs. Each tax dollar spent on flood response, relief, and recovery is a dollar not spent on other publicly funded programs such as education.

Trends in Frequency and Magnitude

Are floods occurring more often and are they bigger? From a social perspective, it appears that because flood damages are increasing, one might conclude intuitively that the answer is yes. The NHC review of Storm Data over the last 20 years shows a steady increase in the number of events that have caused at least $50,000 in damages (Figure 6).

However, these numbers must be viewed with caution. They may be on the rise due to something as simple as better reporting. More important, though, damage resulting from floods depends on a variety of factors ranging from the specific characteristics of the flood itself (e.g., velocity and duration) to the specific characteristics of the area inundated (e.g., land use, mitigation measures in place, etc.) to the time at which a flood occurs (e.g., agricultural flood damages can vary greatly based on the stage of crop maturation). Without taking all these kinds of factors into consideration, it is not possible comment on the trends in flood frequency and magnitude.

Limitations of Data

Gilbert White, in an invited comment on the "Floodplain Management in the United States: An Assessment

Report" summed the problem, "The report candidly recognizes the severe handicaps of incomplete and inconsistent collection of data on which policy judgments must be based." (FIFMTF, pg. 67). This view is shared by many; each of the sources referenced in this paper include a similar caution about the data being discussed. Staff at the NHC working on the Second Assessment of Hazards Research and Applications project found that the nation has no systematic method of accounting for direct losses much less for indirect losses, has no single repository for loss statistics, and data that is collected by various agencies use different criteria making it impossible to accurately compare loss figures between agencies. Further, the data that is gathered is open to criticism because of the scales involved and the subjectivity with which collection criteria are applied.

An example is the Storm Data which form the basis for some of the material presented above. The categories used to classify damage lump all events between $50,000 and $500,000; between $500,000 and $5 million; between $5 million and $500 million; between $500 million and $5 billion! By using powers of ten, it is obvious that actual damages in any category could vary considerably. Other limitations inherent in Storm Data involve the naming and subsequent coding of events. It appears that in some instances, there was no consistent naming of meteorological events. Further, much of the information in the Storm Data set is gathered by volunteers and is, therefore, subjective in nature.

Based on the analysis of Storm Data and several other loss data bases (e.g., insurance claims, FEMA data) the NHC believes that the reliability of the existing data is questionable at best and is filled with gaps and inconsistencies. Data sets from different agencies cannot be compared much less combined. As a result, losses due to natural hazards, including floods, may be greatly underestimated. Unfortunately, we cannot assess how serious the situation is because losses have never been consistently reported or compiled.

For Better, For Worse?

Are things getting better or worse in regard to the flood hazard? In terms of dollar losses, despite the steady increase in damages described above, there is evidence that in a broader context the picture is not so bleak. The Federal Interagency Floodplain Management Task Force reported over a 70 year period (1916-1985) "Property losses from floods appear to have been fairly constant in relation to the overall national economy." (FIFMTF, pg. 18). Yen and Yen's analysis is similar: "The result shows clearly that the damage as a percentage of the GNP decreases slightly despite the fact that the damage in terms of constant-value dollars keeps increasing.." This led them to conclude that flood mitigation measures put in place over the same time have been effective (Yen and Yen, pg. 560).

One must be careful about such conclusions. First, the reliability of the data on which they are made is very questionable. Second, it is important to note that the conclusions are backward looking. They measure what has happened in the past and do not take into consideration the myriad of factors which may contribute to increasing flood losses in both the short- and long-term future. Some of these factors include an increase in the population and built environment at risk, aging infrastructure which becomes more vulnerable to damage from flood, changing climate patterns which may increase the frequency of flood events, and changing development patterns that increase runoff.

Without careful scrutiny of these types of factors, along with several of the "fallacies of floods" noted by Pielke (pp 13-29) one could be lulled into complacently thinking that things are not getting worse, that we are "holding our own", and that things might be improving slightly. I would argue that is not the case. Rather, we do not know if things are getting better or worse.

Socio/Economic Problems

What, then, are the socio-economic issues for the nation in regard to floods? I believe that this complex

question can only be answered if several other questions are answered first. Briefly, these are:

- What are the benefits of floods and floodplain occupancy? We have no reliable data on which to weigh the losses described above against the benefits which are reaped by use of areas subject to flood damage during non-flood periods.

- Who are the winners and losers? For every flood disaster that occurs, there are victims (those who lose their property and possibly lives) and there are victors (those who benefit from economic gains in recovery and reconstruction, for example). Does this inequity create a socio-economic problem?

- What are the indirect, potentially catastrophic, impacts of future floods? Can they be anticipated? For example, does the location of hazardous materials facilities adjacent to populated areas mean there is a growing likelihood of disasters with very serious ramifications, beyond that which has been experienced in the past?

- What are the social implications of technological advances? For example, does increased technological sophistication imply that weather forecasting of flood events will improve? Further, does more accurate forecasting mean that flood losses will be reduced?

- What is the effect of current federal policy on future flood losses. Just as an example, do the nation's disaster relief programs encourage or discourage mitigation programs?

Until such questions can be satisfactorily answered, the jury will remain out on the issue of how serious a threat floods are to the nation.

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FIGURE 1

Property Losses due to Flooding in the US from 1975-1994 in 1994 Dollars (Information from Storm Data)

FIGURE 2

Crop Losses due to Flooding in the US from 1975-1994 in 1994 Dollars (Information from Storm Data)

FIGURE 3

Property and Crop Losses due to Flooding in the US from 1975-1994 in 1994 Dollars.
(Information from Storm Data)

FIGURE 4

Deaths due to Floods from 1975-1994 (Storm Data)

FIGURE 5

Injuries due to Floods from 1975-1994 (Storm Data)

FIGURE 6

Total Number of Flood Events that Caused at Least $50,000 in Damages to Property and Crops from 1975-1994. (Information from Storm Data)

Impact of Weather on Health

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Introduction

The adverse impact (mortality and morbidity) of certain types of weather events on health is significant, and considerable effort is directed at reducing this impact. In these efforts, it is important to have a good understanding of the number of people affected by each weather event and the ways in which each event produces its adverse effects. Such understanding is crucial to the implementation of measures to prevent adverse effects from similar weather events in the future. Table 1 shows deaths from weather events and earth movements in the U.S. 1979-94.

Lack of Common Definitions

To determine the number of people affected by a weather event, one must decide which deaths, injuries, and illnesses should be counted and be aware of good sources of information on health affects. At present, there is no generally accepted definition of what constitutes a weather-related death, injury, or illness. Furthermore, those attempting to assess the impact of weather events may use different sources of information. As a result, it may be difficult to compare the impacts of different weather events on mortality and morbidity, and different groups may report dissimilar numbers of persons affected by the same weather event.

Scenarios

Each of the following scenarios presents a death that occurred at the time of or shortly after a weather event. Even among medical examiners, who are usually responsible for investigating and determining the cause of deaths due to injuries and violence and who were asked to review these scenarios at a recent meeting, there is often disagreement on what constitutes a "disaster-related" death. Mortality data from several eastern U.S. cities affected by the 1993 heat wave reinforce this point.

1. Roof trusses from a neighbor's home were blown off during a hurricane, penetrating the roof of the decedent's home, striking her in the head. She died from blunt head injury.

2. During a hurricane, a 72 year old man with a history of heart disease was in his garage lifting a piece of plywood to repair a storm-damaged window, when he collapsed and died immediately. Cause of death was cardiac dysrhythmia.

3. Two days after a flood, a family was still without power. Because the decedent was afraid of the dark, her mother left a candle burning in her bedroom. During the night, the candle fell over and started a fire. The decedent died from carbon monoxide poisoning.

4. 15 days after a tornado occurred, a workman was asphyxiated when a storm-felled tree trunk toppled back over, trapping him beneath its roots.

5. The decedent - armed and apparently intent on looting a storm-damaged home - approached, shot at,

88

but missed a homeowner; but the homeowner, defending his property, and himself, shot the would-be robber in the head.

6. A husband shot and killed his wife and then himself 6 months after a hurricane; they were still living in temporary housing and their marriage had become unstable.

7. The decedent was from another state. He was in the area providing relief efforts to victims who were displaced by a flood when he was stung by a hornet and died from anaphylactic shock. The decedent had no known history of allergies or previous exposure to stinging insects.

Relationship of death to disaster in seven scenarios, as judged by medical examiners at the annual meeting of the National Association of Medical Examiners, Charleston, South Carolina, 1994.

Death related to disaster? If yes, directly or indirectly?

Scenario	Yes-Directly	Yes-Indirectly	Possibly	No	Total
1	63	0	0	0	63
2	4	43	4	12	63
3	5	41	9	8	63
4	27	30	4	2	63
5	2	13	6	41	62
6	0	10	15	37	62
7	1	9	7	46	63

Proposed Definition

To determine whether a death, injury, or illness is related to a weather event, the health effect must be temporally and geographically related to the weather event, and make causal and biological sense. Thus, in counting people affected by weather, one must establish reasonable geographic and time frames, and assess the nature of the circumstances and health effects:

- *Time Frame* - One should establish an explicit starting and ending date for counting health effects. For example, for a weather event such as a hurricane in which preparations, including evacuation, can be made and for which physical destruction of the natural and built environment is extensive and, therefore, clean-up after the event is often prolonged, the time period could extend from one or more days prior to the event to two or more months after the event. For an event with little or no advanced warning and little clean-up, for example, a severe hail storm, the time frame may start with the event and end the same day.

- *Geographic Frame* - One should establish the geographic area in which people may be affected by the weather event. For example, an affected person must have been present in the county or counties affected by a tornado to be counted.

- *Circumstances* - A death, injury, or illness is directly related to a weather event if it is caused by the *direct* environmental effect(s) of the weather. A death, injury, or illness is *indirectly* related to a

weather event if it is caused by unsafe or unhealthy conditions that occurred because of the anticipation or occurrence of the weather event. These conditions include the loss or disruption of usual services, personal loss, and disruption of an individual's lifestyle. We divide these *indirect* effects into those caused by (1) unsafe or unhealthy conditions that caused a loss or disruption of usual services (including medical care services) or (2) temporary or permanent displacement, property damage, or other personal loss or stress.

- *Biological Sense* - For a death, injury, or illness to be related to a weather event, the circumstances leading to the health effect and the reported health effect must make causal and biological sense. For example, a lung cancer which results in someone's death two days after a hurricane could not be causally related to the weather event. It is possible, however, that the death of someone whose medical care for lung cancer was disrupted by the hurricane could be attributed to the hurricane.
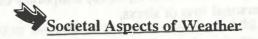
Source of Information

Mortality

- Death certificates are completed by physicians, medical examiners, coroners, and funeral directors for each death in the United States and filed with state or local registrars. The selected data from the filed certificates are compiled at the state and national level and form the basis of state and national mortality statistics. Causes of death are classified and coded using the International Classification of Diseases. See listing of weather related categories below.

- Medical examiners or coroners are responsible for investigating and certifying the cause of most deaths that are sudden, unexplained, or caused by injuries, including those related to weather events. Their records usually contain more detailed and complete information on the cause and circumstances of weather related deaths than do death certificates, and their records are usually available more quickly than are data from death certificates.

- Newspapers often provide reports of weather related deaths.

- Red Cross workers who respond to disasters usually compile information on persons affected by the disaster.

- The National Weather Service gathers information on weather related morbidity and mortality, which is published monthly.
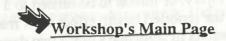
  A **Rapid Epidemiologic Assessment (Noji 1997,** p. 48) following a disaster may be used to estimate
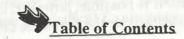
  o overall magnitude of the impact of the disaster (geographic extent, number of affected persons, and estimated duration)
  o impact on health (e.g., number of casualties)
  o integrity of health services delivery systems
  o specific health care needs of survivors
  o disruption of other service sectors (power, water, sanitation) that contribute to public health
  o extent of response to the disaster by local authorities

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Year	U.S. Population	Heat	Cold	Lightning	Cataclysmic storms	Other or unspecified weather event	Total weather	Cataclysmic earth movement
1979	224,635,000	133	356	87	144	233	953	14
1980	226,624,371	1,678	302	94	75	249	2,398	43
1981	229,488,000	305	289	87	87	169	937	21
1982	231,702,000	173	402	100	117	180	972	53
1983	233,781,000	536	510	93	101	131	1,371	21
1984	235,922,000	214	359	91	173	94	931	24
1985	238,005,000	212	519	85	198	96	1,110	23
1986	240,190,000	342	301	78	58	93	872	12
1987	242,395,000	318	326	99	91	74	908	25
1988	244,651,000	439	431	82	59	104	1,115	7
1989	247,002,000	179	524	75	94	92	964	72
1990	248,922,111	276	320	89	138	54	877	13
1991	252,275,000	186	295	75	70	80	706	10
1992	255,142,528	135	267	53	81	71	607	24
1993	257,866,383	286	327	57	96	106	872	17
1994	260,423,572	190	349	84	107	94	824	46
Total		5,602	5,877	1,329	1,689	1,920	16,417	425
Average		350	367	83	106	120	1,026	27

*ICD9 codes specifying the underlying cause of death were used for selecting deaths to include in each weather category as follows: heat (E900.0 & E900.9); cold (E901.0); lightning (907); cataclysmic storms (908); earth movement (909); other or unspecified (904.3).

Source: National Center for Health Statistics' mortality data obtained through CDC Wonder (http://www.cdc.gov).

Trends in Hurricane Impacts in the United States

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Introduction

Hurricane-related damages have risen dramatically in recent years. The 1990s have already seen as much damage as the combined total of the 1970s and 1980s (even after adjusting for inflation). From the 1950s through the 1980s hurricane-related deaths decreased each decade, however midway through the 1990s it appears that this downward trend has stalled.

The Challenge of Impact Assessment: Assessing Damages

In the aftermath of any extreme event there is a demand for a bottom-line measure of damages in dollars. There are many valid ways to measure the costs of a hurricane. Any assessment of impacts resulting in a estimate of total damages associated with a disaster must pay explicit attention to assumptions guiding the analysis in order to facilitate interpretation of the estimate. The analyst needs to pay attention to five factors that can undermine damage assessment: Contingency, Quantification, Attribution, Aggregation, and Comparison.

Contingency: The Problem of Multiple-Order Impacts

When a hurricane strikes a community, it leaves an obvious path of destruction. As a result of high winds and water from a storm surge, homes, businesses, and crops may be destroyed or damaged, public infrastructure may also be compromised, and people may suffer injuries or loss of life. Such obvious impacts can be called "direct impacts" because of the close connection between event and damages. The costs associated with direct impacts are generally easiest to assess because they come in discrete quantities. Federal insurance payouts are one measure of direct impacts, as are federal aid, public infrastructure reconstruction, and debris removal. Table 1 shows the direct impacts associated with Andrew's landfall in south Florida in August 1992.

Secondary impacts are those that are related to the direct impacts of a hurricane. Generally, secondary impacts result in the days and weeks following a hurricane's passage. For example, a hurricane may destroy a water treatment plant (Changnon 1996). The direct impact is the cost associated with rebuilding the plant; secondary impacts might include the costs associated with providing fresh water for local citizens. In general, such secondary impacts are more difficult to assess because they require estimation and are part of an existing social process; e.g., estimating the costs of providing fresh water in lieu of that which would have been provided by the plant requires some sense of what would have occurred without the hurricane's impact.

Further order impacts on time scales of months and years occur and can easily be imagined. For example, a hurricane may destroy a number of businesses in a community resulting in a decrease in tourist visits, which in turn leads to a shortfall in sales tax collection. As a result, community services that had been funded from sales tax revenues may suffer, leading to further social disruption and thus additional costs. Estimation of the costs associated with such impacts is difficult to accomplish with much certainty because

of numerous confounding factors. In short, a hurricane serves as a shock to a community that leaves various impacts which reverberate through the social system for short and long periods. Pulling the signal of the reverberations from the noise of ongoing social processes becomes increasingly difficult, as the impact becomes further removed in time and in causation from the event's direct impacts.

Attribution: The Problem of Causation

Related to contingency is attribution. In the aftermath of a natural disaster people are quick to place blame on nature: "The hurricane caused billions of dollars in damages." However, it is often the case that "natural" disasters are a consequence of human failures. Damage is often a result of poor decisions of the past and inadequate preparation rather than simply the overwhelming forces of nature. It is often at the intersection of extreme events and poor preparation that a disaster occurs. An important aspect of learning from a hurricane is to understand what damages and casualties might have been preventable and which were not. Gross tabulations of damages neglect the question of why damage occurred, and often implicitly place blame on nature rather that ourselves.

Quantification: The Problem of Measurement

How much is a life worth? Or put in practical terms, How much public money are people willing to pay to save one more life in the face of an environmental hazard? According to a review by Fischer et al. (1989) the public assigns between $2.0 million and $10.9 million as the value of a human life. The difficulties associated with assigning an economic value to a human life is representative of the more general problem of assessing many of the costs associated with a hurricane's impact. Similar questions might include: What is the value of a lost ecosystem, park, or unrecoverable time in school, etc.? What are the costs associated with psychological trauma? The difficulties in quantifying the cost of a life are representative of the more general problem of placing a dollar value on damages that are not directly economic in nature.

A hurricane impacts many aspects of society that are not explicitly associated with an economic measure (e.g., well-being). As a consequence, any comprehensive economic measurement of a hurricane's impact necessitates the quantification of costs associated with subjective losses. Therefore, the assumptions that one brings to assessment of value can affect the bottom line. Care must be taken to make such assumptions explicit in the analysis.

Aggregation: The Problem of Benefits and Spatial Scale

Hurricanes are not all costs; however estimates of impacts rarely consider benefits. Consider the following example: Following a hurricane that severely damages agricultural productivity in a region, commodity prices rise nationwide. Thus, while farmers in the affect region see losses, farmers outside of the region may actually see significant benefits due to the hurricane. At a national level the hurricane may thus have net economic benefits.

The example of farmers seeing gains or losses, depending upon where they farm, points to two sorts of issues: benefits and spatial scale. Arguably, following every disaster some individuals and groups realize benefits in some way from the event. Should such benefits be subtracted from a hurricane's total impact? Further, the picture of damages depends upon the scale of the analysis. For the same event a county may experience complete devastation, the state moderate impacts, and the nation positive benefits. Transfers of wealth through disaster aid further complicate the picture. Because there are multiple valid spatial scales from which to view a hurricane's impacts careful attention must be paid to the purposes of loss estimates. Furthermore, it is important to remember that impacts go beyond those things that can be expressed in dollars -- Suffering and hardship are losses independent of scale.

Comparison: The Problem of Demographic Change

As a consequence of the challenges facing meaningful impact assessment, comparing hurricane impacts across time and space is problematic. Past intense hurricanes of the past would certainly leave a greater legacy had they occurred in more recent years. Yet, damage statistics often go into the historical record noting only the event and economic damage (usually adjusted only for inflation). Such statistics can lead to mistaken conclusions about the significance of trends in hurricane damage. Because population and property at risk to hurricanes has changed dramatically this century, such statistics may grossly underestimate our vulnerability. Therefore, care must be taken in the use of bottom line damage estimates to reach policy conclusions.

The Bottom Line: Apples with Apples, Oranges with Oranges

There are many ways in which to measure the costs associated with a hurricane. There is no one "right" way. The method chosen for measurement of the costs of damages depends upon the purposes for which the measurement is made, and therefore must be determined on a case by case basis. No matter what method is employed when assessing or using the costs associated with a hurricane's impact, the analyst need to ensure at least two things. First, the analyst needs to make explicit the assumptions which guide the assessment: What is being measured, how, and why. Second, compare apples with apples and oranges with oranges. If the purpose is to compare the impacts of a recent hurricane with a historical hurricane or a hurricane to an earthquake, the methods employed ought to result in conclusions which are meaningful in a comparative setting.

Trends: Economic Losses, Casualties, and Hurricane Frequencies

In the United States alone, after adjusting for inflation, hurricanes were responsible for an annual average of $1.6 billion for the period 1950-1989, $2.2 billion over 1950-1995, and $6.2 billion over 1989-1995 (Hebert et al. 1996). For comparison, China suffered an average of $1.3 billion (unadjusted) in damages related to typhoons over the period 1986-1994. Significant tropical cyclone damages are also experienced by other countries including those in southeast Asia, along the Indian ocean (including Australia), islands of the Caribbean and Pacific, and in Central America (including Mexico). While a full accounting of these damages has yet to be documented and made accessible, it is surely in the billions of dollars, with a reasonable estimate of about $10 billion annually (1995 $). Other estimates range to $15 billion annually (Southern 1992).

In the United States, 196 people lost there lives related to hurricanes over the period 1986-1995 (Hebert et al. 1996). Experts have estimated that world wide, tropical cyclones result in approximately 12,000 to 23,000 deaths (IPCC 1996). Tropical cyclones have been responsible for a number of the largest losses of life due to a natural disaster. For instance, in April 1991, a cyclone made landfall in Bangladesh resulting in the loss of more than 140,000 lives and disrupting more than 10 million people (and leading to $2 billion in damages). A similar storm resulted in the loss of more than 250,000 lives in November 1970. China, India, Thailand, and the Philippines have also seen loss of life in the thousands in recent years (Southern 1992).

Table 2 reproduces the trend data published in Hebert et al. (1996). Figure 1 shows the dollar losses year-by-year and Figure 2 shows the dollar losses and casualties by decade. Figure 3 shows the insured losses related to hurricanes 1949-1995 (data courtesy of Property Claims Services, Inc.). Figure 4 shows annual hurricane damage as a fraction of the U.S. Gross Domestic Product. According to this method of normalization, the 1938 New England Hurricane is roughly on par with Andrew (1992). The period of the

early 1950s through the early 1970s saw the most frequent period of large impacts. This is more consistent with the historical record of intense hurricane frequencies, which decreased over the period 1944-1994 (Landsea et al. 1996).

The increase in hurricane damages over recent decades has almost entirely taken place during an extended period of decreasing hurricane frequencies and intensities (Landsea et al. 1996). This means that fewer storms are responsible for the increased damages, and these storms are, on average, no stronger than those of past years. Rather than the number of and strength of storms being the primary factor responsible for the increase in damages, it is the rapid population growth and development in vulnerable coastal locations.

Conclusion

Society has become more vulnerable to hurricane impacts. The trend of increasing losses during a relatively quiet period of hurricane frequencies should be taken as an important warning. When hurricane frequencies and intensities return to levels observed earlier this century, then losses are sure to increase to record levels unless actions are taken to reduce vulnerability.

Inhabitants along the U.S. Atlantic and Gulf Coasts are fortunate in that hurricane watches and warnings are readily available as are shelters and well-conceived evacuation routes. However, this should not give reason for complacency -- the hurricane problem cannot be said to be solved (Pielke 1997). Disaster planners have developed a number of scenarios that result in a large loss of life here in the United States. For instance, imagine a situation of gridlock as evacuees seek to flee the Florida Keys on the only available road. Or imagine New Orleans, with much of the city below sea level, suffering the brunt of a powerful storm, resulting in tremendous flooding to that low lying city. Scenarios such as these require constant attention to saving lives. Because the nature of the hurricane problem is constantly changing as society changes, the hurricane problem can never be said to be solved.

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Table 1. Current dollar estimates of $30 billion in damages directly related to Hurricane Andrew in south Florida. Based on Rappaport (1993), updated and extended where possible.
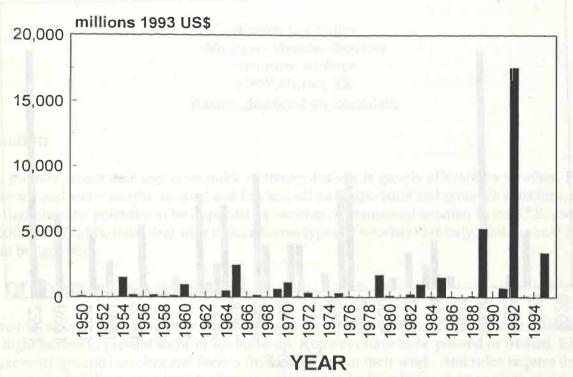
Damage Estimates in South Florida Associated with Hurricane Andrew		
Type of Loss	Amount ($billions)	Source(s)/Notes
Common insured private property	16.5	Sheets (1994), includes homes, mobile homes, commercial and industrial properties and their contents, boats, autos, farm equipment and structures, etc.
Uninsured homes	0.35	*The Miami Herald*, 16 February 1993, reported in Rappaport (1993).
Federal Disaster Package	6.5	Anderson et al. (1992); represents 90% of $7.2 billion package (the rest went to Louisiana).
Public infrastructure State County City Schools	0.050 0.287 0.060 1.0	Filkins (1994), tax revenue shortfall. Rappaport (1993). Tanfani (1992), Miami only. Rappaport (1993).
Agriculture Damages Lost Sales	1.04 0.48	McNair (1992a,b). Fatsis (1992).
Environment	2.124	Rappaport (1993); includes state request for clean-up and repair of parks, marinas, beaches, and reefs.
Aircraft	0.02	Rappaport (1993)
Flood Claims	0.096	FEMA Flood Insurance Administration, reported in Rappaport (1993).
Red Cross	0.070	Swenson (1993).
Defense Department	1.412	GAO (1993), for DOD and US Army Corps of Engineers expenses during recovery.

Table 2. Estimated annual deaths and damages (unadjusted and inflation adjusted to constant 1994 dollars) in the mainland United States from landfalling Atlantic or Gulf tropical cyclones 1990-1995. Source: (Herbert et al. 1996, Table 12).
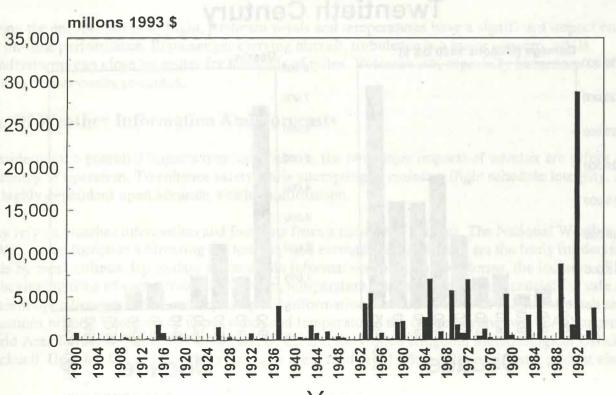
YEAR	DEATHS	DAMAGE ($Millions) Unadjusted	DAMAGE ($Millions) Adjusted	YEAR	DEATHS	DAMAGE ($Millions) Unadjusted	DAMAGE ($Millions) Adjusted
1900	8000	30	790	1948	3	18	113
1901	10	1	26	1949	4	59	370
1902	0	Minor	Minor	1950	19	36	222
1903	15	1	26	1951	0	2	11
1904	5	2	53	1952	3	16	16
1905	0	Minor	Minor	1953	2	6	33
1906	298	3	79	1954	193	756	4180
1907	0	0	0	1955	218	985	5348
1908	0	0	0	1956	19	27	139
1909	406	8	211	1957	400	152	758
1910	30	1	26	1958	2	11	55
1911	17	1	26	1959	24	23	116
1912	1	Minor	Minor	1960	65	396	2006
1913	5	3	79	1961	46	414	2102
1914	0	0	0	1962	3	2	10
1915	550	63	1660	1963	10	12	59
1916	107	33	723	1964	49	515	2564
1917	5	Minor	Minor	1965	75	1445	6996
1918	34	5	71	1966	54	15	70
1919	287	22	278	1967	18	200	900
1920	2	3	30	1968	9	10	43
1921	6	3	38	1969	256	1421	5647
1922	0	0	0	1970	11	434	1699
1923	0	Minor	Minor	1971	8	213	747
1924	2	Minor	Minor	1972	122	2100	6924
1925	6	Minor	Minor	1973	5	3	9
1926	269	112	1415	1974	1	150	396
1927	0	0	0	1975	21	490	1191
1928	1836	25	315	1976	9	100	233
1929	3	1	12	1977	0	10	22
1930	0	Minor	Minor	1978	36	20	38
1931	0	0	0	1979	22	3045	5210
1932	0	0	0	1980	2	300	463
1933	63	47	701	1981	0	25	36
1934	17	5	68	1982	0	Minor	Minor
1935	414	12	163	1983	22	2000	2751
1936	9	2	28	1984	30	66	88
1937	0	Minor	Minor	1985	30	4000	5197
1938	600	306	3884	1986	9	17	21
1939	3	Minor	Minor	1987	0	8	10
1940	51	5	66	1988	6	9	11
1941	10	8	98	1989	56	7670	8640
1942	8	27	286	1990	13	57	63
1943	16	17	169	1991	16	1500	1637
1944	64	165	1641	1992	24	26500	28687
1945	7	80	773	1993	4	57	59
1946	0	5	41	1994	38	973	973
1947	53	136	935	1995	29	3723	3582

U.S. Insured Losses to Hurricanes: 1950-1995

millions 1993 US$

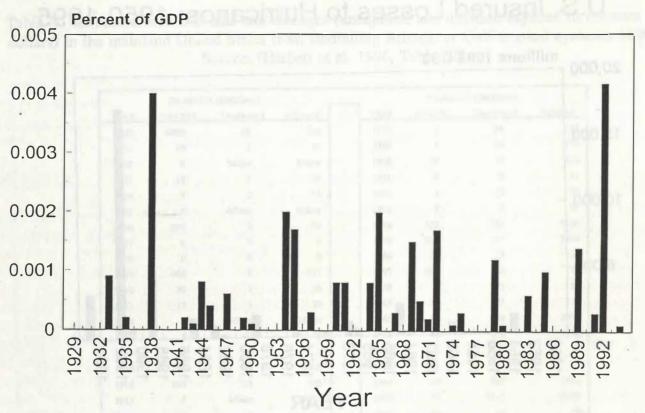Source: Property Claims Services, Inc.
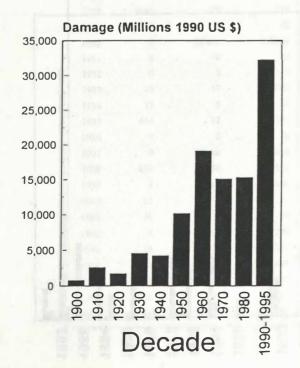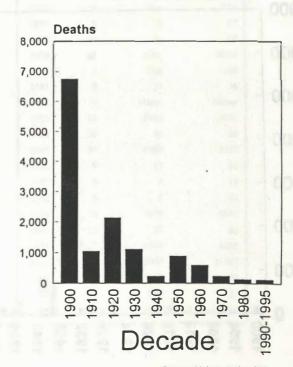
Annual Hurricane Damage 1900-1995

millons 1993 $

Year

Source: Hebert et al. (1996)

Annual Hurricane Damage 1929-1995
as a percentage of U.S. Gross Domestic Product (GDP)

Percent of GDP

Year

Hurricane Damage and Deaths in the Twentieth Century

Damage (Millions 1990 US $)

Decade

Deaths

Decade

Source: Hebert et al. (1996)

Impact of Weather on and use of
Weather Information by Commercial Airline Operations

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Introduction

Aviation, probably more than any other mode of transportation, is greatly affected by weather. From thunderstorms and snow storms, to wind and fog as well as temperature and pressure extremes, every phase of flight has the potential to be impacted by weather. Commercial aviation in the U.S. , with its more than 16,000 daily flights, must deal with these adverse types of weather regularly, and the cost is a significant budget item.

Effects Of Weather On Aviation

On the ground, aircraft may have to be deiced prior to departure, sometimes having to be coated with a fluid the night before to prevent snow or ice build-up. Runways have to be plowed or treated. Lightning in the area prevents ground handlers and fuelers from carrying out their work. And rules require that when temperatures/ wind chills are too low, workers are allowed outside only for short periods of time.

Departing and arriving aircraft are slowed by Air Traffic Control (ATC) when cloud ceilings or visibilities are reduced, with aircraft acceptance rates lowered to 75-50% of normal. Surface winds which produce too much cross factor similarly force reduced acceptance rates, and lower level winds (below 15,000 feet) often dictate greater aircraft spacing, resulting in reduced acceptance rates. Low-level wind shear conditions can cause the cessation of takeoffs and landings.

During the enroute phase of flight, jetstream winds and temperatures have a significant impact on fuel burn and on-time performance. In passenger-carrying aircraft, turbulence is a major concern, while thunderstorms can close air routes for hundreds of miles. Volcanic ash, especially hazardous to aircraft engines, forces costly re-routes.

Use Of Weather Information And Forecasts

Considering the potential impacts mentioned above, the two major impacts of weather are safety and efficiency of operation. To enhance safety while attempting to maintain flight schedule integrity, airlines are highly dependent upon accurate weather information.

They rely on weather information and forecasts from a number of sources. The National Weather Service (NWS) issues forecasts addressing the terminal and enroute area, and these are the basis for decisions made by most airlines. Up-to-date and accurate information about thunderstorms, the location of lightning, the beginning time of snow or ice at an airport, temperature and pressure data are crucial for safe and efficient operations. NWS charts depicting this information are displayed in all Flight Dispatch and airport operations offices. Forecasts of upper winds and temperatures are created by the two ICAO-approved World Area Forecast Centers, Washington, D. C., and the United Kingdom Meteorological Office at Bracknell. Updated twice daily, these forecasts are issued in a 1.25¡ x 1.25¡ horizontal grid, at nine vertical

levels and for five 6-hour forecast periods. The grid spacing was proven by both the U.S. and U.K. to be the optimum for a combination of accuracy, timeliness of delivery and airline computer time. Data and forecasts for airports are communicated from government sources to the airlines. Both upper air and surface weather data are sent via land-line and satellite to airlinesÕ mainframe computers.

Reports of actual conditions from airports increasingly rely upon Automated Observing Systems (ASOS). ItÕs imperative that reports from these systems are accurate and representative of the weather conditions at an airport. Any loss of the credibility of the ASOS reports by users could lead to increased fuel loads and flight delays.

After ensuring a safe weather environment, it is incumbent upon airlines to meet their schedules as frequently as possible. This underscores the need for timely and accurate weather information.

Costs Associated With Weather

Before addressing the costs which weather has on the airlines' operations, it's worth noting the cost of acquiring weather data and forecasts. Monthly fees for the communication of upper air and surface data alone, per airline, are approximately $6,000. Add to that the cost of acquiring graphical weather data, NWS DIFAX charts, lightning data, and radar and satellite imagery: approximately $7,000. There are four passenger and two cargo airlines which have their own staff of meteorologists. Salaries alone range from $750,000 to more than $1 million annually. Many airlines without meteorologists contract with a weather data and forecast vendor. Costs, though lower than a paid staff, can run well over $100,000 per year.

Direct costs due to weather on airline operations can be separated into several categories: diversion, cancellation, delay and insurance. The cost of a diverted flight can be as high as $150,000 and a cancellation close to $40,000 (Irrgang and McKinney, 1992). A report from the Air Transport Association (ATA) states that the direct annual costs to sixteen member airlines of the first two categories listed above are $47 million and $222 million, respectively (Air Traffic Management in the Future Air Navigation System, 1994). Delay costs vary greatly depending upon the type of aircraft and airport affected so are a bit more elusive to pin down. However, they are not insignificant. Annual insurance payouts for encounters with turbulence are well into the millions of dollars across the industry, while lost time due to employee injury (e.g. flight attendants) is similarly high.

The direct costs sometimes are eclipsed by the cost of ruboff factors. For example, one diverted flight can cause anywhere from 2 to 50 flight delays, while one canceled flight can result in 15 to 20 flight delays. The costs listed are from a variety of areas, some fixed and than others not: fuel, crew time, aircraft operating costs, lost passenger and cargo revenue, hotels and meals, ground-based employee overtime pay, insurance. Though the costs associated with delays and cancellations vary, airlines taking such actions risk eroding passenger goodwill and that results in lost future revenue.

To help mitigate the disruption to airline operations caused by weather, some airlines have developed intricate computer programs. The payback on the development cost, though difficult to quantify, is significant. These systems are capable of displaying the downline effects of off-schedule operations, assisting the airline planners in determining the optimum solution to achieve an on-schedule airline as quickly as possible after an adverse weather event.
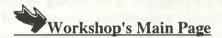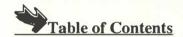
Future Direction

The airlines have a very real need for accurate forecasts of the parameters listed above. Information about the arrival of thunderstorms at a given hub airport, especially those which contain damaging winds or hail,

is required at least four hours ahead of time to allow airline planners to re-schedule flights. When addressing a snowstorm, extremely low temperatures, abnormally high pressure or high surface winds, the lead time extends to eight hours, to allow time for personnel staffing. Timing of the arrival of a tropical storm is needed nearly a day in advance in order to protect company resources, e.g. staging aircraft at an airport safely distant from such a storm. Accurate information about upper air conditions, necessary for flight planning, is required as much as eighteen hours in advance of a flight's departure. An anecdotal example for the latter follows. Consider an international flight from Chicago to Tokyo. If upper wind forecasts are such that the aircraft must have additional fuel, the number of passengers may have to be reduced. In order to "protect" these passengers on other flights to the same destination, they have to be re-routed to a different departure airport, say San Francisco. Since passengers planning to fly from Chicago to Tokyo begin their trips by first flying from, say, Detroit to Chicago, they must be notified in time to get them from Detroit to San Francisco to catch that flight. In order for this scenario to be successful, planning must begin at least eighteen hours prior to the start of the Chicago to Tokyo flight.

With the above comments in mind, it's not difficult to understand the need for a range of highly accurate forecasts, from storm-scale to mesoscale to synoptic-scale.

Societal Aspects of Weather

Workshop's Main Page

Table of Contents

Reducing Natural Disaster Losses:
A Blueprint for Achievement

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Introduction

Each year natural disasters take a huge toll on our nation - a toll that is measured in deaths, injuries, property damage and economic loss. The member insurance companies of the Insurance Institute for Property Loss Reduction (IIPLR) believe that this toll can be reduced. They envision a nation that builds the safest and most damage-resistant structures possible to protect its citizens. To enable that vision to become a reality, IIPLR's members have directed the organization to fulfill a critically important mission: *to reduce injuries, human suffering, deaths, property damage and economic loss caused by natural disasters.*

In implementing its mission, IIPLR will be guided by a "blueprint for achievement" - our new Strategic Plan. The organization will dedicate its resources to addressing five natural hazards: earthquake, flood, wildfire, hail and windstorms. Each of these will be addressed in the context of the following Key Result Areas (KRAs):

- Public Outreach

- Community Land Use

- New Building Construction

- Retrofit of Existing Structures

- Information Management

This paper will provide a brief overview of these Key Result Areas and the goals and objectives of each. These, in conjunction with associated strategies and projects, have been developed to establish IIPLR as the nationally recognized, credible resource on natural hazard mitigation.

Understanding and Addressing Risk

The first half of this decade has seen a regular occurrence of what might be described as "high profile" disaster events: Oakland, California wildfires (1991); Hurricane Andrew (1992); Hurricane Iniki (1992); Midwest floods (1993); Malibu, California wildfires (1993); Northridge Earthquake (1994); Hurricane Opal (1995), Hurricane Fran (1996) and this winter's Northwest floods and snowstorms are among the events that have made national headlines. This list does not reflect the *thousands* of tornadoes, windstorms, snowstorms, floods and the like that occurred in the same time frame but were not given the same scope of attention. While this latter group might not meet our national measurement for "big" disasters, people and structures are negatively impacted by them. On a local scale and in the realm of

personal experience they are, indeed, significant events.

In spite of all of that Mother Nature has thrown our way it is amazing to discover that, on the whole, we still remain under-educated about and even unaware of the natural hazards that can completely alter lives in a matter of minutes. Therefore, the first Key Result Area of IIPLR's Strategic Plan is **Public Outreach**. Its objective is to ensure that all stakeholders (policy and decision makers, the insurance industry, businesses, emergency managers, the media, planners, lenders, designers, builders and the general public) are aware of natural hazards and understand the associated risks. They will know how to reduce these risks and protect themselves, their families, their homes and their businesses.

It is our hope that through greater understanding people will truly want to reduce the level of risk to which they are exposed. They will only build, buy and use structures that are disaster safe. In addition, all of the stakeholders will understand incentives for mitigation and the associated benefits of such action. An initial project in this area will be to develop a pilot program designed to prove and demonstrate the benefits of a community-wide natural disaster mitigation program.

We live in a society where other types of risk have moved into the realm of public values: fire safety, auto safety, smoking and other issues related to our personal well-being to name a few. It is IIPLR's plan to conduct an information and education program designed to instill a new public value - natural disaster mitigation.

Where We Build

As a nation founded on principles of individual freedom, the right to acquire land and build on it with minimal restrictions is an integral part of our culture. Since virtually all areas of our nation are at risk from some type of natural hazard it would be unrealistic to think that all structures could be placed in locales that are completely "risk free."

We can, however, do a better job of evaluating potential risks as they relate to where structures are sited and the manner in which communities are developed. IIPLR's second Key Result Area is **Community Land Use**. Its objective is to promote locating structures out of high risk areas that are subject to floods, hailstorms, wildland fires, earthquakes and windstorms.

Land use policy and decision makers need to understand the vulnerability of individual properties to natural hazards, and consider that vulnerability in their land use, development and construction decisions. Consumers (owners and developers) have to be educated about the natural hazards associated with building sites and utilize this information when selecting such sites. IIPLR will work with other partners to develop incentives for not building in high risk areas or for using special mitigation techniques. An initial project in this area will be to promote the adoption of procedures by state and local governments requiring consideration of natural hazards vulnerability in making land use decisions.

How We Build

Efforts in KRAs one and two will be of diminished value without attention being given to the structures in which we live and work. The "blueprint's" third Key Result Area focuses on the **Construction of New Buildings**. Its objective is to ensure that all new structures will be designed, engineered and constructed using up-to-date techniques and materials that mitigate natural disaster risks. Property owners, developers and contractors must be encouraged to apply these techniques and materials. The benefits of such application must be made clear. Further, it is essential that we continue to develop new hazard resistant construction materials, testing and certification capabilities, and structural design and engineering techniques.

Another item which must be given consideration in this area is building codes. IIPLR is an active participant in the model code organizations. It is our belief that one of the best means for reducing potential harm to life and property is the adoption of statewide building codes. Proper adherence to and enforcement of building codes, both residential and commercial, is essential to a more resilient built environment.

As an initial project in this Key Result Area, IIPLR will establish a "Seal of Approval" program. It will be designed to provide recognition and incentives for incorporating mitigation features in new construction.

Since the vast percentage of our nation's building stock exists already, what steps can be taken to improve its resistance to natural disasters? This is the fourth Key Result Area, **Retrofit Existing Structures**. Its objective is to promote the strengthening of existing structures to mitigate natural disaster risks. Working with our partners, cost-effective techniques for retrofitting existing structures will be developed and incentives will be established that will encourage all stakeholders to apply these techniques.

Given the scope of this nation's retrofit needs, IIPLR has established an initial prioritization of its efforts in this area. Our first steps will be to promote retrofitting high "people risk" structures, public safety structures, life line structures, and structures located in high-risk zones. As such, our inaugural project will be to work with partners to retrofit every public and non-profit day care center in the country.

Making our entire built environment more resilient to natural hazards is only common sense. The immediate post-event loss of life and property will be diminished and the long term socio-economic health of our communities will be preserved.

Assimilating and Disseminating Information

The final element needed to achieve this "blueprint" is our fifth Key Result Area, **Information Management**. Its objective is to provide for the collection, analysis, and dissemination of natural disaster loss and mitigation information. This will support the development of a credible, accurate and comprehensive natural disaster risk, loss data and mitigation information system. IIPLR will be able to utilize this information system in identifying mitigation opportunities and as a guide in determining future IIPLR mitigation activities. It will also serve as a resource for IIPLR members and others.

Although we exist in the "information age" and in a culture that is very data intensive, the absence of organized and uniform data pertaining to natural disaster losses is quite surprising. This is why we are developing a database of insurance industry paid losses from such events. We will also look for opportunities to coordinate with partners in the collection and analysis of other types of post-event data.

An interactive World Wide Web site is under development that will provide links not only to IIPLR but to other information sources as well. It will serve as one information management tool designed to provide rapid and efficient access to mitigation related data.
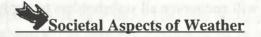
Conclusion

IIPLR cannot implement this "blueprint" by itself. The participation of partners representing all sectors is vital to achieving our cause. Mitigating natural hazard losses is too big a task for a single group, industry, or sector to take on alone. We will work with federal, state and municipal agencies as well as with other organizations and stakeholders, i.e., utilities, banks and lenders, realtors, builders, developers, contractors, code organizations, property owners and renters. As part of our commitment to making natural disaster
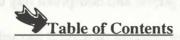
loss reduction a cooperative success story, IIPLR is developing Memorandums of Understanding with the Department of Energy, Department of Agriculture, the United States Geological Survey, the Federal Emergency Management Agency, and others.

When will we know that this "blueprint" has been achieved? When people ask if their homes and businesses are as safe as possible from natural catastrophes and press for action to make that a reality. Our vision is nothing less than ensuring that the planning and construction of the nation's homes, businesses and public buildings will incorporate loss reduction initiatives that enable people and commerce to live and prosper in an atmosphere of personal safety and financial security.

Harvey G. Ryland was named President of the Insurance Institute for Property Loss Reduction in October 1996; formerly he served as the Deputy Director of the Federal Emergency Management Agency.

Societal Aspects of Weather

Workshop's Main Page

Table of Contents

The Meteorology of Surface Transportation

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Surface transportation in the United States is viewed by many as a low technology, almost "smokestack" industry.

The reality is that America's railroads are growing (for the first time in 40 years) and the trucking industry benefits from stunningly high technology. There is a strong, competitive rivalry between America's railroads and truckers for market share. This battle is literally changing the face of the economy of the United States. And, increasingly, trucking and railroading depend on weather information tailored to their specific needs.

The Economic Setting

Railroads

In the last two years, railroad "Mega Mergers" have frequently been front page news in the business press. With the Stagger's Act of 1980 (which deregulated the railroad industry), there has been a revitalization of what had been an industry in decline for 40 years.

Beginning about 1940, truckers began capturing market share from the railroads. The improved passenger aircraft of the 1950's (such as the Lockheed "Constellation"), along with jet aircraft in the 1960's, caused the passenger traffic carried by railroads to rapidly decline, especially for interstate travel. The advent of the interstate highway system accelerated the decline in the amount of freight moved by rail as trucks were perceived to be less expensive, more versatile and more reliable. The bankruptcy of the Penn Central and other Northeast Railroads led many observers to conclude that railroads would go into a permanent state of decline, evolving, at best, to mere haulers of bulk commodities, such as coal and grain. "In the late seventies it seemed inevitable in Washington that the industry would have to be nationalized," according to James McClellan, then of the U.S. Railroad Administration, quoted in *Trains* magazine.

The Stagger's Rail Act allowed railroads to set their own rates (previously regulated by the now defunct Interstate Commerce Commission), terms of service and service standards. To fully capitalize on this opportunity, it became essential for railroads to lengthen their route systems (so that inefficient car interchanges could be minimized) and streamline their operations in other ways, both internal and external. This occurred in the early to mid-1980's when financially weak railroads were taken over by stronger railroads. For example, the Union Pacific of 1995 was a combination of the original Union Pacific combined with Western Pacific, Missouri Pacific, Kansas Pacific, Kansas-Oklahoma-Texas ("Katy"), and Chicago and Northwestern.

The mergers of the 1980's gave way to the "Mega Mergers" of the 1990's. For example, Union Pacific merged with Southern Pacific (the original Southern Pacific, plus the Central Pacific, St. Louis Southwestern [Cotton Belt], and Denver and Rio Grande Western); the Burlington Northern merged with the Santa Fe; and currently, the CSX is purchasing Conrail, which will then sell some of Conrail's routes to Norfolk Southern.

There is, however, no transcontinental railroad in the United States. It is believed by some that the rail mergers of the next decade will merge the eastern and western railroads. Some believe that the United States could have as few as three long line railroads in ten years.

Until the mid-1980's, railroads were controlled through an antiquated system of "train sheets" and "track warrants." This changed when Union Pacific built its Harriman and CSX built its Dufford control center. With this innovation, vast railroads were controlled from a single room, which made it possible, for the first time, to use weather information efficiently and effectively. All of the Class One railroads except Norfolk Southern control their systems from a single location. It is fortuitous that the advent of the national control centers came on the scene when they did, because railroads were developing new types of business and railcars that made them more vulnerable to weather than at any other time in their history.

Between 1978 and 1982, the Southern Pacific teamed with railcar builder ACF Industries and the steamship company American President Lines to create the "double stack" container car. The double stack made it more timely and economical to cross the United States by rail with containers than for ships to go through the Panama Canal. It takes 20 people to take a train of 25 five-platform articulated cars that hold 250 containers (within which everything from chemicals to VCR's are shipped) from Los Angeles to Chicago. It would take truckers 500 drivers (working in tandem) to haul the same quantity of goods in the same amount of time. However, the double stacks, especially when empty, are highly vulnerable to being blown over in crosswinds.

In 1989, the first joint service between trucks and railroads was launched. Known as "Quantum," the Santa Fe Railroad began shipping trailers for the J. B. Hunt Transport Company on flat cars. This service, now common to most major trucking companies and all major railroads, has been economically beneficial to both industries (see Trucking section of this paper). But again, the trailer mounted on a flat car, is highly vulnerable to blowovers.

Finally, railroads have captured a greater share of the long haul automobile shipping market by developing railcars that can carry 15 automobiles at a time while providing outstanding protection against damage in transit. These railcars, known as "autoracks," are vulnerable to overturning in high winds because of their high profile.

While railroads were regaining their economic health, they were becoming more vulnerable to weather and its effects.

Trucking

The interstate trucking industry was also deregulated in 1980, which allowed greater freedom in pricing and in determining which markets to serve. But, like the railroads, the advent of deregulation brought challenges -- especially since the Interstate Commerce Commission would phase out the "floor" under trucker's rates -- which, when combined with the challenge posed by more efficient railroads and by overnight delivery services such as Federal Express, meant the trucking industry had to become more efficient.

The "reengineering" of the late 1980's and early 1990's created an enormous opportunity for truckers, in the form of "just-in-time inventories." This is explained by Mary Walton in *The Deming Management Method*: "Having been perfected in Japan, 'just-in-time' production is enjoying a surge of popularity in this country. In this system, supplies arrive as they are needed, so that money and storage are not tied up in inventory."

Given the demands of just-in-time production processes, truckers needed to better anticipate and deal with

weather-related delays and problems. No longer is a flood a local event. For example, according to Kevin Williams of the American Trucking Association, the Saturn division of General Motors keeps only two days worth of parts on site. If there are delays or interruptions of more than two days in truck (and, to a lesser extent, rail) deliveries, the plant begins shutting down. A major flood event that closes interstate highways (such as the 1993 Midwest flood), can literally cause factories to shut down and layoffs to occur in businesses 1,000 miles from the nearest high water!

Surprising to many is the fact that the major trucking companies know the location of their trucks while they are on the road to a higher degree of precision than railroads or even airlines. For example, the trucks operated by J. B. Hunt are tracked by GPS and are in continuous communication with Hunt's central facility in Bentonville, AR. If immediate communications are needed with a given truck, it is only a few keystrokes away and, for urgent information, an alarm tone sounds in the cab.

Today's interstate truckers handle deliveries of up to 600 miles (eight hours) entirely on the road. Longer deliveries involve putting the trailer on a rail car, shipping it to the distant railyard that is closest to the truck line's customer, then mating the trailer with a truck cab for final delivery to the customer.

Weather Information Requirements

It goes without saying that train crew and driver safety are paramount. Besides safety, the following table summarizes the effect of various weather phenomena on surface transportation:

Phenomena	Rail	Trucking
Tornado	Derailment	Blowover
Hail	Little or none	Dented autos in transit
High winds	Derailment, crossing gate damage	Blowover
High Temperatures	Spoilage, sun kinks, locomotive problems	Spoilage, animal mortality
Low Temperatures	Broken rails, locomotive problems	Engine problems
Lightning	Signal irregularities	Little or none
Flash floods	Derailments, reroutes	Reroutes
Floods	Reroutes, performance penalties	Reroutes, penalties
Snow	Delays due to track clearing	Closed roads
Ice	Locomotive traction, signal lines	Closed roads, traction

With derailments and blowovers, there is the related problem of hazardous material spills.

Meteorological Responses

There have been various responses to the operational problems that adverse weather causes. These can be broken down into three groups: Specialized meteorological instrumentation, specialized weather forecasts and specialized weather warnings.

Instrumentation

According to materials presented at a December 1995 seminar sponsored by the Minnesota Department of Transportation (MnDOT), the first "Roadway Weather Instrumentation System" (RWIS) was installed in

the late 1960's on an interstate highway bridge. The RWIS was connected to a sign that flashed "Ice on Bridge" when ice was detected on the roadway. There are more than 300 RWIS systems currently operating in the United States. It is estimated that the benefit to cost ratio of RWIS systems is 2.5 to 1 for the DOT's that use them with a 20 to 1 ratio for society as a whole (i.e., fewer accidents, on time deliveries, etc.). Truckers and motorists derive considerable benefit from these systems.

The Union Pacific has an extensive network of trackside weather sensors which have been installed primarily in areas especially vulnerable to nonconvective high winds. In addition, a number of railroads have installed high water detectors at critical locations as well as rockslide detectors (slides are often indirectly related to weather).

It is interesting to note that the railroads often contend that truckers are unfairly subsi- dized as state and federal governments build and maintain roads and highways while the railroads have to build and maintain their rights of way. Regardless of the merits of this argument, this same pattern has emerged in weather instrumentation for surface transportation. For example, the Kansas Department of Transportation has installed more than 60 weather sensors along state highways but *none* along railroad rights of way. The KDOT even declines to share its weather information with railroad and aviation interests, in spite of the fact that the Kansas legislature, which established the KDOT, explicitly stated that KDOT's mission was to promote "railways, highways and airways" (in that order) in the legislation creating KDOT. This same pattern exists in at least several other states in the central U.S.

Weather Forecasts

For this purpose, weather forecasts are defined as routine, non-urgent information that can be used to plan day-to-day operations.

Railroads use weather forecasts to plan day-to-day operations, including outdoor maintenance. When extreme temperatures are forecast, "slow orders" will be issued in the morning to reduce the maximum speed of trains where temperature-caused track irregularities are suspected. The lead time for these forecasts is 24 hours. With the advent of the Mega Railroads, it has become possible to route trains around major storms (i.e., the Union Pacific now has three routes from Kansas City to San Francisco). However, reliable forecasts of blizzards, major floods and other synoptic scale storms are needed in the 48- to 72-hour time frame in order for this potential to be fully realized.

Interstate truckers desire lead time in the eight-hour range, because most all of their long hauls are done by rail. Snow and ice are their most serious problems, but high winds (50 m.p.h. or greater) and floods interfere with trucking operations. The shipment of livestock by truck can be affected by high temperatures and high humidity. Most (but not all) perishable goods are shipped by refrigerated truck.

Storm Warnings

For this purpose, storm warnings are defined as non-routine, urgent information that affects safety. *An unexpected temperature of 105¡ (if, say, 95° was forecast) is treated as a "storm" by the railroad industry since a sun kink affects safety in the same way as a flash flood or other traditional "storm."*

The trucking industry has not yet begun to use storm warnings except in the most general sense. J. B. Hunt, for example, has a monitor tuned to The Weather Channel at all times, which is then used in discussions with drivers and with their safety personnel in the field.

The railroad industry has become extremely active in using storm warnings to improve safety. However,

the needs of the railroad industry are quite different than the public's needs. As already mentioned, rapidly changing temperatures can be a "storm." Railroads are not affected by large hail. The railroads only care about a storm if it affects their right of way. If, for example, a tornado parallels a track eight miles away, the railroads will continue operating.

WeatherData has created a "track specific" storm warning service for its rail clients. Warnings are created only for the criteria which affect rail operations and they are "track specific" -- meaning the warnings are defined by track points known to the dispatchers, train crews and supervisors. The warnings are created on a proprietary workstation called SmartWARN which instantly flashes them to the railroad in the exact format requested. For some of WeatherData's rail clients, the warnings are displayed on the SmartRAD system (WeatherData's proprietary weather information display) and routed by computer to the specific dispatcher(s) handling an affected stretch of track through their DigiCon workstations, while bypassing dispatchers handling territory unaffected by the storm.

For example, if a tornado warning is issued for a given section of track, the dispatchers stop trains from entering the warning area. If a train is already in the warning area, it is allowed to exit if there is sufficient lead time prior to the start of the warning (i.e., a warning issued at 6:15 p.m. effective from 6:25 until 6:45). If the warning goes into effect immediately, the train is stopped. If a siding is nearby, the train pulls into the siding. If a blowover occurs on a stopped train, the damage is far less than if the train is moving at 70 mph.

The economics are huge. It costs $2,000 per hour to stop a single train. Because of the density of trains on some of the major rail lines (60-100 trains per day, operating at 70 mph), a tornado warning that covers 15 miles of track for 40 minutes can cause as many as seven trains to be stopped. However, most weather-related derailments cost at least one million dollars with the cost ranging up to six million dollars. Typically, the rail companies are self insured up to $5 million per occurrence, so a weather-related derailment causes a major negative impact on the bottom line, not to mention safety.

The economic payback of this service has been enormous. A proprietary 1995 study for the Santa Fe Railroad comparing a weather provider that merely relayed National Weather Service warnings versus WeatherData's track-specific warnings indicated that for every dollar spent on the NWS service, the payback was $1. For every dollar spent on the tailored service, the payback is more than $35, *even though the cost is three times as great*. This is due to the accuracy of the warnings (CSI of .89) and their specificity. For example, the number of "false alarms" caused simply by the hail component of NWS' severe thunderstorm warnings is excessive from a rail perspective, so much so, that railroads using severe thunderstorm warnings would typically begin to ignore them after a few months. Note: This is not a criticism of the NWS. Their role is to serve the public, not to create products for a particular company or industry.

This high degree of accuracy and customization is possible because of proprietary technology developed by WeatherData along with the high degree of training provided to its meteorologists. The SmartWARN system is a workstation used to integrate and evaluate numerous meteorological datastreams in real time (similar to AWIPS but tailored to WeatherData's needs and the needs of its clients). While WeatherData's meteorologists can generate fax, telephone or pager-based warnings with SmartWARN, clients that desire an even higher level of monitoring can receive their weather information through the SmartRAD Weather Information System. The people aspect of these services cannot be overemphasized. Meteorologists are carefully recruited and trained, not just in applied meteorology, but in client needs. WeatherData annually takes it meteorologists on "field trips" which allow them to meet clients, see the geography of particularly weather-sensitive locations (i.e., Donner Pass in California), and learn how the forecasts and warnings they create are actually used. WeatherData's storm warning services for railroads have attracted national

attention (see the April, 1997, issue of the magazine *Rail* News).

The "Public - Private" Partnership

In 1991, NOAA's National Weather Service announced its policy regarding the Public Private Partnership. This successful policy, in part, stated that the NWS would not seek to provide services that are already or could be provided by the private sector and that, in general, site-specific and industry-specific weather services were considered to be in the purview of the private sector. With this assurance, companies like WeatherData Incorporated could make the investments needed to create the state of the art services their clients require.

In this era of tight federal expenditures, the Public Private Partnership has proven to be an effective way of insuring that American industry receives the tailored services it needs while the National Weather Service concentrates on providing weather forecast and storm warning services to the public. Commercial weather companies are in an ideal position to become intimately familiar with their clientele and to design services specific to their needs.

Nevertheless, there is a role for government to play, which can help leverage the taxpayer's investment and assist commercial meteorologists and their client companies. These include:

- Data-sharing. The Federal Department of Transportation has paid for many of the RWIS sensors in the field. It should require that data acquired with Federal dollars be available to all. Perhaps the NWS could serve as a facilitator in this regard.

- Data enhancement. While the WSR-88D has been a major technological step forward, there are additional ways to enhance its value. For example, the -88D "holds" the NIDS base velocity and base reflectivity until the entire volume scan is completed (a process that takes four to five minutes). These products should be transmitted immediately. We also suggest that the volume scan strategy be changed to allow additional low level scans with fewer complete volume scans when meteorologically appropriate. It would seem that in a tornado situation reducing the "storm total" precipitation product to ten-minute intervals (rather than the current five-minute intervals in severe weather mode) in return for doubling base velocity and base reflectivity scans (to 2-3 minute intervals) would be an excellent trade off.

- Further strengthen the "Public Private Partnership." The success of this partnership should inspire it to be adopted by all elements of NOAA and by the research community.

- Research. The rift between the research community in meteorology and weather forecasters appears to be as wide as ever. For example, the preprint volume from the most recent conference on Weather Analysis and Forecasting (Norfolk, August, 1996) does not contain a single paper on temperature forecasting (there is one paper about an experiment in MOS temperatures using ensemble guidance)! There is little in the way of real world *verification* with regard to new models and techniques. The current paradigm seems to be to create a new model and "put it out there." Non-model-based forecast techniques are rarely discussed.

- When discussing the role of human beings in the forecast cycle, Brooks, Fritsch and Doswell (same preprint volume, page 524) state, "It is important to note, though, that although the number of large MOS errors is small, errors larger than 30°F occasionally do occur. Thus, one primary role of human forecasters will be ... rescuing the numerical models on days of extremely large errors." The question posed by this author is **how?** Today's forecasters are taught to rely on the models. If one relies on the

models, how will one know 24 to 48 hours in advance, that they are going to be in error by more than ten degrees? What is the technique?

- Stop "adjusting" the models. While this comment often brands one as a Luddite (generally with a remark along the lines of, "If we did that, we'd still use the barotropic."), the amount of continual "tinkering" (word chosen carefully) does not have a favorable benefit to cost. Experience at WeatherData, Incorporated confirmed by recent personal conversations with personnel at the NCEP in Washington and the NWS Central Region in Kansas City indicates that the MRF guidance has had significant biases in the Plains this past winter that are of the opposite sign as during the winter of 1995-96. Edward Deming, perhaps the world's advocates the following (from *Dr. Deming. The American Who Taught the Japanese About Quality*):

"One important ingredient of quality is uniformity. It seems almost too simple and insignificant." (p. 39)

An entire chapter (pp. 67-82) is devoted to the *necessity* for stable systems in order to improve quality. The current practice where models have a (for example) warm bias one season, are changed, and then have unknown (warm or cold) biases the next season is a formula for deteriorating quality. A minor improvement in RMS error at 500 mb is not necessarily an improvement in the forecast of sensible weather.

The author appreciates this opportunity to discuss current state of meteorology and weather research affecting surface transportation.

Societal Aspects of Weather

Workshop's Main Page

Table of Contents

Descriptive Decision Studies of the Societal Impact of Weather and Climate Information

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Introduction

This paper addresses methods for studying one important aspect of the impact of weather on society--the impacts of weather and climate information. This topic is important because much atmospheric research and, in particular, the U.S. Weather Research Program, is intended to improve the quality of such information. It is reasonable to expect that such improvement in the quality of information will result in the mitigation of some of the adverse impacts of weather. It is also reasonable to expect that improved information will help people take better advantage of the positive impacts of weather. These expectations have not been adequately examined, however. More research is needed on how people use weather information in order a) to determine whether the expected benefits of improved information are realized, and b) to discover how best to formulate and disseminate information for maximum benefit.

Two related topics are not directly addressed in this paper. One is the direct effect of weather on behavior and on physical and mental health (e.g., Rotton and Frey, 1985). Another is research on risk communication (e.g., Renn, 1992), which is clearly relevant to the communication of weather related risks to the public.

Descriptive and prescriptive studies

Studies of the societal impact of weather and climate information must consider -- either explicitly or implicitly -- the decisions made by users of the information. Most such studies involve both description (how users actually decide) and prescription (how they should decide). Both descriptive and prescriptive approaches are based on the belief that the impact of weather and climate information stems primarily from its effects on the decisions of individuals engaged in weather-sensitive activities (McQuigg, 1971), and both approaches require decision making models to estimate those effects. The critical differences between the two approaches are the methods used to develop the decision making models and the criteria employed for evaluating them. Descriptive models are evaluated according to their ability to reproduce the behavior of the decision maker. Prescriptive models are evaluated according to their ability to produce decisions that are optimal according to some normative theory of decision making.

Descriptive and prescriptive studies differ in how the user's decision rules (which comprise a decision model) are obtained. In a prescriptive study, the decision model is based on a normative theory (e.g., decision theory) that specifies an "optimal" set of decision rules (e.g., maximize subjective expected utility). In a descriptive study, the decision model is determined by the user's behavior, and the goal is to obtain an accurate model of the user's actual decision process. As a result, a prescriptive study will yield an estimate of the impact of information for an idealized decision maker who optimizes according to a decision criterion derived from the normative theory, while a descriptive study will yield an estimate of the actual impact of the information on a real decision maker who may or may not use information in an

optimal fashion.

In practice, descriptive and prescriptive modelers may bring quite different perspectives, and usually different types of training and experience, to their work. Those perspectives might guide their research in different directions and produce even greater differences in results than the formal differences between their purposes and methods would suggest.

For example, descriptive and prescriptive studies will require different amounts and types of involvement of decision makers. It is possible to do a prescriptive study with no direct decision maker involvement by using secondary data (Sonka et al., 1988). In a typical prescriptive study, one or more decision makers might be interviewed to determine what information is available and to ascertain decision alternatives, constraints, subjective probabilities and utilities and other parameters required by the prescriptive model. A descriptive study requires extensive involvement of several decision makers focusing on the subjective model that they use to process information and make choices.

Differences in the results obtained by the two approaches can be illustrated by comparing the descriptive study of the fruit-frost problem by Stewart, Katz, and Murphy (1984, hereafter referred to as SKM), based on interviews with fruit growers, the local NWS forecast office, and various experts in crop protection, with the prescriptive study of Katz, Murphy, and Winkler (1982, hereafter referred to as KMW), based on a dynamic decision theoretic model.

The 300 million-dollar apple crop in the Yakima Valley of Washington State is at risk every year in the early spring. Cold weather can freeze the blossoms and kill them. In order to survive, growers have to install crop protection systems to guard against frost. For years, they placed rows of oil burning heaters around the edges of their fields.

If anyone could use a good weather forecast to help them cope with uncertainty, these growers could. If they knew the night was going to be warm, they could let their help go home and sleep peacefully. If they knew the night was going to be cold, they could get their heaters fired up early (a process that might take a couple of hours) and be sure they would still have a crop in the morning. But if the forecast was bad, they could burn a lot of fuel and lose a lot of sleep unnecessarily, or they could lose their crop as their trees froze while they slept. In the early 1980's Bud Graves, the chief meteorologist at the National Weather Service Forecast Office in Yakima was preparing detailed frost forecasts every night during the season. The growers were avid listeners and strong supporters of his work.

Following are some of the differences between the KMW prescriptive analysis of this problem and the SKM descriptive study.

First, the fruit growers' alternatives were defined in different ways. KMW considered two alternatives for each night during the frost season: "protect" or "do not protect." SKM found that the important nightly decision was when to initiate protection and, of less importance, when to stop protection. KMW's choice was limited somewhat by modeling restrictions. Since they were developing a model that was dynamic over the frost season, their model would have become unmanageably complex if dynamic processes during each night were also included.

Both models recognized that crop protection and minimization of heating costs were the primary goals, but SKM identified another goal often mentioned by the growers -- psychological comfort. Since they faced substantial financial risk during the frost season, growers wanted to have confidence that they could anticipate frost hazard and would be ready to react. Thus, a frost forecast might provide psychological comfort to fruit growers even though their decision to protect their crops might be based on other

information. It would be difficult or impossible to assign a monetary value to such a psychological benefit, but that does not make it any less important to the grower. In a prescriptive modeling approach, such psychological benefits could be reflected in the utility function.

The KMW model omitted an item of information that growers use to decide when to protect their crops. Almost all large growers have temperature sensors located in their orchards and frost alarms by their beds that are set to wake them when temperatures approach the critical range. SKM found that the frost alarms initiated a period of vigilance that would result in protective measures (usually wind machines, which had replaced the heaters) being turned on if temperatures dropped close to the critical level. Consequently, the evening frost forecast was not the trigger for protective action, as assumed in the KMW model.

KMW were able to develop a dynamic decision theory model that produced a quantitative estimate of frost forecast value. SKM had to be content with a qualitative description of the process and were unable to estimate a monetary value for the frost forecast. While, in principle, a descriptive model could be used to estimate a monetary value, it has rarely been accomplished. If the objective of a study is to estimate the value of a forecast in monetary units, a combination of prescriptive and descriptive approaches should prove quite valuable, as SKM observe.

Finally, it is important to note that most prescriptive studies necessarily involve descriptive elements. For example, both KMW and Mjelde et al. (1989) developed dynamic prescriptive models because they recognize that these better describe the actual decision processes under study.

Examples of descriptive studies

Previous descriptive studies of impact of weather and climate information can be classified into the following four types:

1. Case studies

Case studies of the impact of weather and climate information are usually conducted after decisions have been made. For example, Glantz (1982) studied the case of a seasonal water supply forecast for the Yakima Valley that turned out to be inaccurate. Based on a forecast of water availability during the irrigation season of less than half of normal, the Bureau of Reclamation allocated 6% of the normal water allocation to holders of junior water rights and 98% of normal to holders of senior rights. In preparation for the predicted water shortage, some farmers had wells dug, leased water rights from other farmers (at high prices), and even physically moved their crops to the Columbia River basin where water was more plentiful. Cloud seeding activities were carried out in the Cascade mountains in an attempt to increase snowpack. Actual water availability turned out to be much greater than forecast, and many farmers filed legal actions. Claims for forecast-related losses totaled approximately $20 million.

2. User surveys

One approach to studying the impact of information is simply to ask (by interview, mail, or telephone survey) a representative sample of users how they use the information and how it affects them. Some surveys have included questions about whether users are aware of weather services, whether they use them, whether they value them, and how to make the services more valuable. These are essentially marketing studies and may yield useful information for providers of information, such as suggestions for improving services.

3. Interviews and protocol analysis

In these studies, descriptions of users' decision making strategies, or "protocols," are developed from verbal reports obtained from interviews or from analysis of other written materials. The Stewart et al. (1984) study of fruit growers described above is an example of this category.

4. Decision experiments

Sonka et al. (1988) have proposed the use of "decision experiments" to assess the use of climate information and provide a study illustrating this approach. They interviewed two key managers responsible for production planning in a major seed corn producing firm. The participants were given eight climate prediction scenarios (representative of actual growing season climate conditions) and asked what actions they would have taken if they had received this information when planning decisions had been made for the current season. They used the results to develop a decision model.

Most previous descriptive studies have been either case studies or surveys. Although such studies are useful, they cannot produce adequate models for assessing or predicting the impacts of weather information. Studies involving the detailed interviews, protocol analysis, and decision experiments that are required to develop descriptive models of decision making adequate for assessing the impacts of information are rare.

Although descriptive studies have rarely produced adequate descriptive decision models, they do suggest that decision makers often do not obtain the maximum possible value of information because of a) constraints that deny users the flexibility to respond to the information, b) lack of awareness of the information or ability to obtain it, c) misunderstanding or misinterpretation of information, or d) non-use or non-optimal-use of information.

Descriptive studies also suggest that, in some situations, the impact of information may be less than expected because of a) availability and use of locally tailored information more appropriate to a specific decision than a weather forecast, or b) low importance of weather information because other non-weather factors are more important.

Descriptive studies also indicate that there are important individual differences in the use of information. Those individual differences translate into differences in the impact of information on different decision makers.

Brief overview of descriptive modeling methods

Any descriptive modeling method requires a detailed and thorough understanding of the task that faces the decision maker. It is as important to understand the decision maker's task, or "environment," as it is to understand how she mentally processes information. After all, the environment defines the problem the person is trying to cope with, and it is where she learned to make judgments and decisions in the first place (Brunswik, 1956; Hammond, 1996; Stewart et al., in press).

Approaches to descriptive modeling of decision processes can be classified into two broad groups: 1) protocol analysis (or process tracing), and 2) judgment analysis. These approaches will be briefly summarized.

Protocol analysis relies on decision makers' verbal descriptions of their reasoning. Protocols are best obtained by asking individuals to "think aloud" while they work through a series of decisions. The protocols are analyzed to develop a model which consists of a number of "if ... then ..." relations that can

be diagrammed in the form of a flow chart. Protocol analysis has been used extensively by "knowledge engineers" to develop computer-based expert systems, and it has a long history in psychology as well (Kleinmuntz, 1968; Ericsson and Simon, 1984). Recently, the use of verbal reports to derive an "influence diagram," which could be considered a form of protocol, has become popular in decision analysis (Oliver and Smith, 1990).

Other researchers have used methods for analyzing judgment that do not depend on a person's ability to provide accurate verbal descriptions of decision processes. Judgment analysis refers to a class of methods for deriving models of decision making by analyzing a sample of actual judgments or decisions. The decision maker is required to do only what he or she does naturally, that is, to make decisions using familiar materials. The analyst develops a model to describe the inference process that produced the decisions. Descriptions of a theoretical foundation for judgment analysis and descriptions of the method itself can be found in Hammond et al. (1975), Brehmer and Joyce (1988), and Cooksey (1996).

The data required for the development of such a model are a number of cases of a particular type of decision. Each case includes the information used to make the decision and the resulting decision itself. Cases may be obtained in a natural setting (e.g., a fruit grower's decisions to protect crops each night during the frost season) or in controlled settings. In a controlled setting, the information decision maker would be asked to make judgments based on a sample of real situations or hypothetical scenarios designed to represent real situations.

The items of information that are available to the decision maker, called "cues," are considered independent variables in an analysis, and the decision is the dependent variable. Multiple regression analysis is one statistical technique that has been used with considerable success to fit a model to the data (Stewart, 1988), but a number of other methods have been used as well, including analysis of variance and conjoint measurement. The analysis yields a model of the decision maker that expresses the decision as a mathematical function of the cues and an index of how well the model fits the judgments (e.g., the squared multiple correlation coefficient).

Judgment analysis offers one major advantage as a tool for developing descriptive models of the use of weather and climate information: It provides a modeling method that does not rely on the decision maker's ability to describe his or her thinking process. This is important because the ability to make decisions is not always accompanied by the ability to describe accurately the process that produced the decisions, particularly when the process contains intuitive elements. Verbal descriptions of reasoning can be incomplete, inaccurate or misleading. Some important aspects of the decision process may not be readily accessible and may be difficult to translate into words. The description obtained may be unduly influenced by the method used to elicit it. Questions posed by the investigator impose a "frame" on the problem. Seemingly irrelevant and inconsequential aspects of problem framing can have a powerful effect on judgment (Tversky and Kahneman, 1981). For these reasons, it is desirable to have a modeling tool that does not depend on the expert's ability to describe the inference process.

Judgment analysis can be used in combination with verbal protocols (Einhorn et al., 1979), so that the investigator can take advantage of the insights provided by both while avoiding some of their pitfalls. If the investigator relies solely on the decision maker's verbal statements, then both the efficiency of model development and the ultimate accuracy of the model will be limited by the decision maker's ability to verbally describe his or her decision process. If, on the other hand, the investigator relies solely on judgment analysis, important characteristics of the decision problem that are not represented in the judgment task may be ignored or misunderstood. Although the two techniques complement each other well, few studies have combined them.

Conclusion

In order to understand fully the social impacts of weather and climate information, both prescriptive and descriptive studies will be necessary. Prescriptive studies provide estimates of the potential impact of information under the assumption that the decision maker follows an optimal strategy. They do not necessarily provide accurate assessments of the actual impact under current decision practices. Descriptive studies estimate the impact of information given current decision making practices but may overlook the possibility of additional benefits resulting from improvement in those practices.

Despite the potential for improved understanding of the impacts of weather information from combined prescriptive/descriptive studies, no such studies have been conducted. A major reason for this is the lack of descriptive studies that have produced decision models that are sufficiently well-developed to be used assess the impacts of weather information. Methods for developing such descriptive models exist and their application to the study of the impact of weather and climate information should be encouraged. Such application should prove useful to the meteorological community by providing a more complete understanding of the factors that determine the impact of information. This understanding could, in turn be used to help improve the formulation and dissemination of information and to help set priorities for research designed to improve information.

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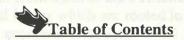
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Societal Aspects of Weather

Workshop's Main Page

Table of Contents

Weather Impacts in Canada

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Introduction

Canada is subject to a variety of hydrometeorological hazards and disasters. An inventory is being assembled and is summarized in <u>figure 1.</u> This chart shows the number of identified events by hazard for which cost estimates could and could not be made. The total of known costs are identified in 1995 dollars at the end of each bar. Tornadoes are not included, since there have been over 2,300 known Canadian tornadoes during the period 1961-1996. I would also note that a precise criteria was not used to include or exclude particular events but rather events were included if the information source suggested a "significant" impact of some sort (meteorological, social or economic).

Droughts, by far, are the most costly hazard, although they rank fourth in terms of frequency. It is worth noting that for hurricanes, only economic costs associated with Hazel (1954) have been included.

An historical survey of Canadian disasters shows that 44% of them are weather or climate related, that almost 1/3 of all disaster have occurred at sea, and that 80% of those were weather related.

Natural disasters are the extreme of natural hazards and occur when social vulnerability is triggered by an extreme event. The costs Canadians incur from hazards are a function of our adaptive decisions. Unsafe conditions result from a number of social forces which are rooted in limited access to power, economic resources and the nature of political and economic decisions.

These costs of natural hazards can be broken down into social costs and economic costs.

Social Costs

In terms of social costs the following statistics give some indication of the overall magnitude:

- Transportation

    o Decreasing trend of weather-related aircraft accidents from approximately 60/year in 1985 to

less than 20/year since 1992.

- o Although there have been few fatalities, there has been a significant number of weather-related railway accidents averaging between 20-40 per yea; however, 100-120 occurred in 1990 and 1991.
- o Historically, many of Canada's worst disasters have been ocean based with typically 300-400 weather-related marine accidents each year (note 1990 worst year in the past 10 years with slightly less than 500 weather related marine incidents).
- o Major road accidents result mainly from wet conditions, followed by ice, snow, slush and mud. In 1992 weather-related road accidents resulted in 298 fatalities, over 23,000 personal injuries and over 72,500 property damage incidents.

- Deaths

  - o Canadians occasionally die as a result of atmospheric hazards. Most deaths occur as a result of cold. In the past decade, however, the number of deaths from cold has shown a gradual decrease, while those resulting from other atmospheric causes have remained fairly constant (note: some concern as to how attribution of cause has been assigned).

Economic Costs

There are two fundamental economic costs associated with natural hazards - adaptive costs and impacts, response and recovery costs. Adaptive costs are those associated with protection, reduction of vulnerability or risk, education and research. These costs are difficult to estimate and little research has been devoted to increasing our understanding of these costs. One preliminary estimation of Canadian adaptation costs suggests that $13.7 billion is spent annually; however, this is likely underestimated by some unknown amount.

Impacts, response and recovery costs are those incurred when protection fails or no adaptive response is taken. Some examples for Canada include:

- Forest Fires

  - o Can have a direct impact due to the loss of natural resource, though it is unclear how to account for these losses as fires are now considered an essential part of the natural ecological cycle.
  - o The annual area burnt suggests an upward trend with 1995 being by far the worst year with over 7 million hectares burned, followed by 1989. This statistic is related to climate, but is also related to decisions made regarding fire management.
  - o All provinces incur costs related to fire management. Over the last decade, Ontario spent over $800 million, more than any other province.
  - o Annual fire management costs are shown on figure 2 with costs peaking in 1995 at over $450 million.

- Hydro Companies

  - o Weather-related costs are highly variable as indicated by those for Ontario Hydro which has annual weather-related costs ranging from zero to $3 million and averaging $1.4 million/year.
  - o The most costly hazard was "wet snow + high winds" the total cost which occurred due to one event at Vegreville and Lloydminster, Alberta. This two-day storm destroyed 108 steel transmission towers, 300 wood transmission structures, and more than 3000 wood distribution

poles. In addition more than 400 km of conductor had to be replaced.
  o Tornadoes (numbering 8) come second in terms of costs, though they were all from one utility company.

- Federal Payments

  o Floods have cost the most, by far, with audited totals over $300 million and federal payments of $150 million (does not include the 1996 Saguenay flood).
  o Storms and fire rank second and third with about 11% each.

- Provincial Costs

  o Provinces incur costs due to crop damage from hail, flood, drought and a variety of other hazards.
  o The largest annual expenditure occurred in Saskatchewan, with payments totally over $500 million (1988 and 1989).
  o Drought is the major hazard resulting in crop insurance payments on the Prairies (e.g., Manitoba paid out $400 million from 1966-1994 in response to drought-related crop losses, followed by excess moisture, hail, heat and frost).

- Insured Costs

  o Figure 3 shows the costs of multiple major payments from 1983-1994 (does not include the costs of events less than about $4 million, and therefore the true costs are much greater than those shown in this figure).
  o Hail has caused the most damage (over $450 million), followed by tornadoes, flood, storms and wind.
  o There appear to have been 9 events in 1995 which include significant damage from flood, hail, thunderstorms, wind and Hurricane Hortense.
  o the largest single disaster in Canada was the Calgary hailstorm of 1991, which cost insurance companies around $400 million. The insured costs of the Saguenay floods are currently estimated at $350-400 million.

Canadian Weather-Related Disasters in 1996

In 1996, Canadians suffered through some of the most extreme and destructive weather ever to have hit the country. For most of the year, the weather either froze, buried, soaked, buffeted or frightened Canadians. No part of the nation seemed to escape the wrath of the weather in 1996.

Total property damage will likely exceed $2.5 billion when the final figures are tallied. Indirect costs and losses from revenue shortfalls, canceled events, missed opportunities, and slowed business will probably be in excess of a $3 billion hit to the Canadian economy. Remarkably though, the number of personal injuries and fatalities linked to weather incidents could have been much higher. Unofficial numbers point to fewer than 25 weather-related deaths (excluding deaths from road accidents and hypothermia) - 10 from the storm in the Saguenay and six from lightning in separate incidents. The top weather stories of 1996 are:

The Saguenay Flood

By far the worst catastrophe of the year, and Canada's first billion dollar plus natural disaster, was the flooding and mud slides in Quebec's Saguenay River valley in mid-July. The storm

produced the largest ever overland deluge in Canada this century - an amount equivalent to a two-month flow over Niagara Falls - triggering a surge of water, rocks, trees and mud that killed ten people and forced 12,000 residents to flee their homes. It was the deadliest flood since Hurricane Hazel in Toronto in 1954.

The scale of the tragedy was staggering. Many of the region's roads and bridges and delivery systems for power and water simply disappeared. To the insurance industry it was Canada's worst-ever weather disaster in economic losses. By including insured and uninsured losses and indirect costs to the economy, total losses are sure to exceed $2 billion.

The Pacific Storm of 1996

During the period December 22 to January 3, 1997 a series of brutal winter storms blasted Vancouver Island, the Lower B.C. mainland and the Fraser Valley with up to 85 cm of snow paralyzing infrastructure and commerce. The accumulation of snow for this series of storms was unprecedented in historical records of Vancouver Island and the lower south coast of British Columbia. The recorded 64.5 cm snow that fell in a 24 hour period, at the Victoria airport, gave Victoria the distinction of having the 3rd highest snowfall, in a major city, in Canadian history. During the same period, Downtown Victoria received 85 cm.

The environmental impact was severe in that massive releases of untreated of partly treated effluent were released into rivers and the ocean.

Although estimates of the economic losses range in the area of $200 million, the true impact of the storm will probably never be known. The following list suggests the overall impact

- over $200 million in total losses estimated
- largest search and rescue team in the history of B.C. dispatched
- 170 motorists stranded and later rescued
- 1700 people received emergency food and shelter
- Trans Canada highway closed for two days - stranding thousands
- secondary arteries closed for up to 10 days
- police and fire departments unable to respond to emergency calls
- 150,000 homes without power
- roofs and buildings collapsed under the weight of heavy snows
- over 500 avalanches reported
- 65 reports of pollution spills
- hundreds of flights canceled
- ski resorts closed
- theaters and sporting events canceled
- food shortage

High Energy Costs

In much of Canada, 1996 featured one of the longest and most vicious winters in recent memory. Three straight weeks of frigid weather gripped almost the entire country in January making it colder in most cities in western and central Canada than it was at the North Pole. To keep up with the cold, utility companies pumped out power in record amounts from British Columbia to New Brunswick. Canadians paid an additional $500 million to keep their dwellings as comfortable as in the previous winter.

Costly Prairie Hailstorms

In July, hailstones the size of fists bombarded Winnipeg and Calgary, racking up close to $300 million in property losses. In Manitoba, more than half the losses were for auto damage, making it the worst single disaster claim against the Manitoba Public Insurance Corporation in its 25-year history. At least a third of the cars damaged had to be written off. In Calgary, hail and flooding rains knocked out the city's 911 service and swept away cars.

Wet and Cold Weather Reducing Crop Yields

Unfortunately for western farmers, prospects in early September for one of the most bountiful grain crops in Canadian history didn't exactly materialize. Fall temperatures across the west were much below normal (the Prairies had their second coldest fall in half a century) and precipitation was much above normal (the 7th wettest fall in half a century). Cool wet weather during the harvest of western red spring wheat led to a severe drop in its grade distribution, denying farmers an additional $180 million.

In southern Ontario, winter wheat production was severely affected by the wet cool weather throughout the growing season. Record rainfalls resulted in the worst outbreak of blight fungus ever seen in Ontario. According to Agriculture Canada, the excessive moisture and disease not only reduced yields, but it also reduced the quality of most of the crop to feed, since affected grain cannot be used for human consumption. The loss was estimated to be about $90 million.

Deep Winter Snows

So much snow fell early in the winter that before 1996 even started, many cities in western and central Canada had all but exhausted their snow removal budgets. Hardest hit was the central Ontario snowbelt from Barrie to Sault Ste. Marie, where on several occasions, cars disappeared in snow drifts, service centers became refugee camps, roofs collapsed and schools closed.

Insurance claims paid in the first three months of 1996 were 11% higher than in the previous year when the weather was much less severe. Total insured losses owing to the weather estimated at $165 million.

Slow Spring Affecting Retail Sales

For most of Canada, the winter season gave way to the monsoon season. Unrelenting rains and dreary weather plagued the country from April to June. Garden centers and golf courses were virtually empty during the spring. Retailers blamed the persistent cool and rainy weather for a 30% drop in the sales of weather sensitive goods and services, such as pools, air conditioners and warm season apparel. Sales of general merchandise in April and June were down by $100 million over the previous year's sales.

Flash Flooding in Ottawa and Montreal

The third major storm in less than two weeks, and the worst on record, hit Ottawa-Hull in early August with a deluge of 100 to 150 mm of rain in 90 minutes. Total insured property

damage exceeded $20 million, not including the costs of repairs to damaged sewers and roads. Between November 7 and 9, thirty hours of steady rains drenched parts of Montreal and southwestern Quebec. The rains washed out sections of highways, collapsed bridges, derailed trains and undermined road and rail beds. Damage estimates put the event at over $60 million.

Severe Thunderstorms and Tornadoes

The snow had hardly melted in southern Ontario when the season's first tornadoes tore through regions east of Lake Huron in April. The twisters injured two people and caused property losses, much of it uninsured, approaching $8 million.

Severe thunderstorms on July 4 spawned at least eight tornadoes in Saskatchewan. Winds of 140 km/h and hail the size of golf balls produced $15 million in property damage. Two weeks later seven tornadoes touched down in Alberta, trashing trailers and flattening granaries to the tune of $10 million. Near Stoney Plain, more than 100 mm of rain fell in severe thunderstorms backing up sewers and flooding basements for another $10 million in losses. Tornado-related damage in Canada easily exceeded $50 million.

Spring Flooding

Significant flooding occurred in several communities across Canada during much of the spring and early summer. The Okanagan experienced its worst flooding in six years, The Red River inundated farm fields, roads and major highways leading authorities to declare a provincial flood disaster for the first time since 1979. In Winnipeg, the costs of filling 336,000 sandbags and protecting pumping stations alone cost $1.2 million. In Timmins, Ontario the Mattagami River overflowed its banks in the worst flooding across Canada and losses are still being tallied, with final figures are expected to range between $20 and $50 million.

Hurricanes and Weather Bombs

Four hurricane-force storms struck Eastern Canada in 1996: Bertha, Edouard, Fran and Hortense. It was the second consecutive season with above average hurricane formation in the North Atlantic. In 1996 there were 13 named storms of which 9 were hurricanes, including six intense ones, compared to a normal of 9 storms, 6 hurricanes and 2 intense ones.

Hortense, which swept east of Halifax and traversed western Newfoundland on September 14, was the first hurricane to achieve landfall in Canada in 21 years. Winds topped 161 km/h on cape Breton Island, felling trees, lifting roofs and blowing out windows. Total property losses approached $5 million.

Described as the worst storm since Typhoon Freda in 1962, a "weather bomb" struck Vancouver Island on October 17 causing massive power outages while felling trees, setting adrift 50 pleasure boats and ripping apart docks. A "weather bomb" is a storm which intensifies very quickly and moves faster than a hurricane. This storm packed winds as strong as 161 km/h and produced waves as high as 30 meters.

Conclusions

Are the number of weather-related disasters in Canada increasing? According to the Insurance Bureau of Canada, ever since the Edmonton Tornado of 1987, the number of multi-million dollar losses from

weather disasters has been on the rise in Canada (note: before 1987 there was no single natural disaster with damages exceeding $1 billion anywhere in the world, let alone in Canada).

While the outburst of extreme weather was interesting, climatologists were not generally surprised by them. Climatologist are, however, becoming increasingly concerned that the volatile weather in 1996 might be a dry run of extreme conditions we might expect from a warming climate.

With this in mind, planners and decision-makers should note that natural hazards and disasters are expensive but not inevitable. With appropriate planning to reduce vulnerability, their social and economic impacts on Canadians can be reduced.
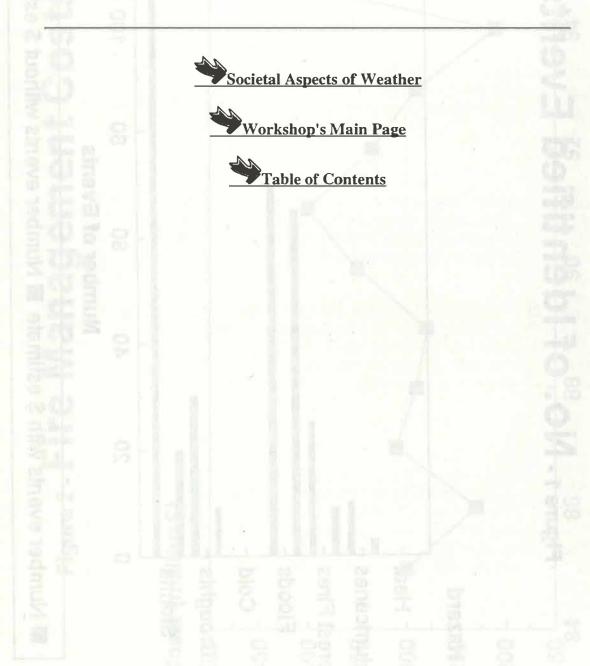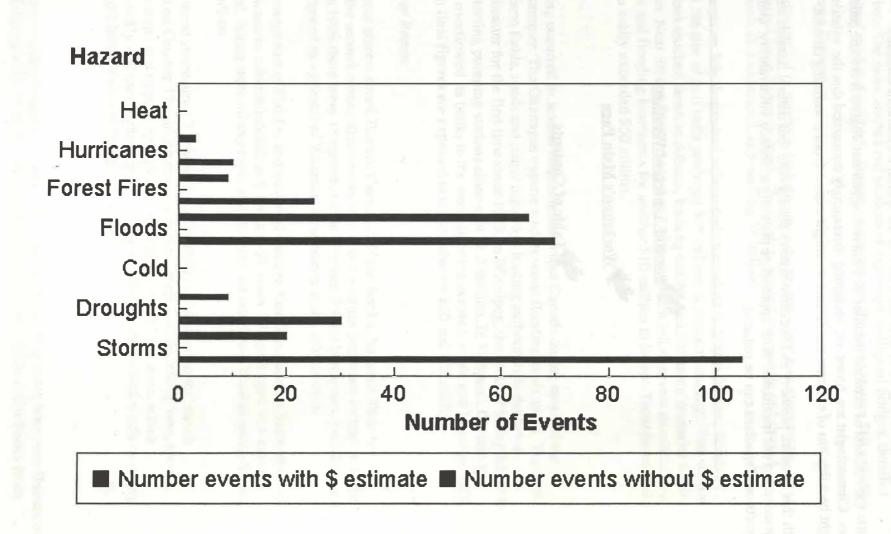
Societal Aspects of Weather

Workshop's Main Page

Table of Contents

Figure 1 - No. of Identified Events

Hazard

- Heat
- Hurricanes
- Forest Fires
- Floods
- Cold
- Droughts
- Storms

Number of Events

■ Number events with $ estimate ■ Number events without $ estimate

Figure 2 - Fire Management Costs
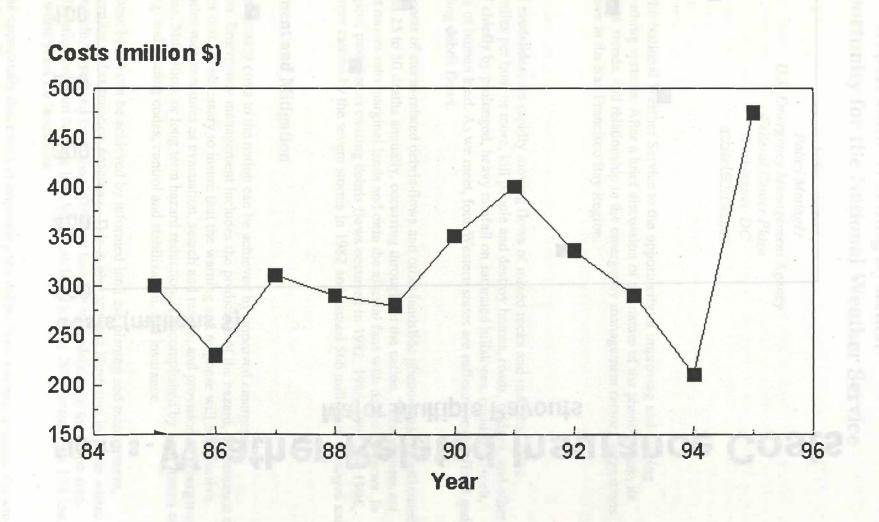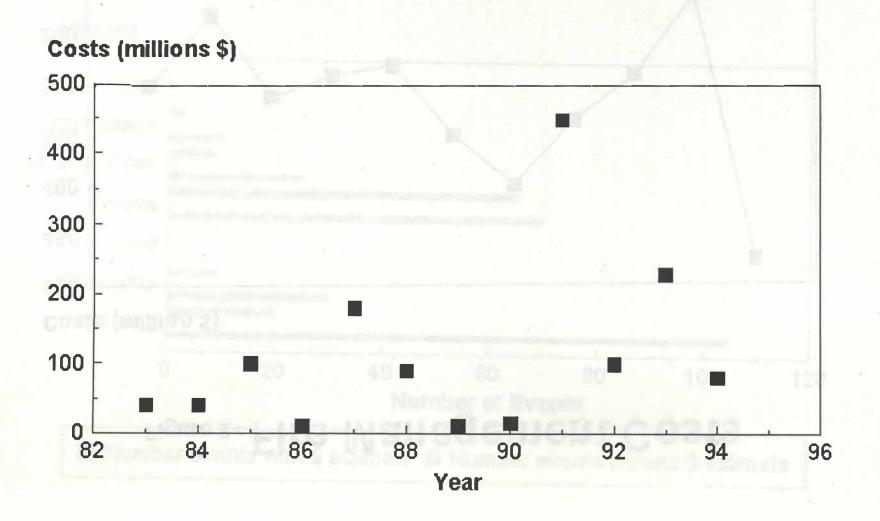
Figure 3 - Weather Related Insurance Costs
Major Multiple Payouts

Costs (millions $)

Year

Debris Flow Warning Systems:
an Opportunity for the National Weather Service

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Introduction

This paper seeks to alert the National Weather Service to the opportunity of improving and making operational debris flow warning systems. After a brief discussion of the nature of the phenomenon, its economic and social impacts, trends, and relationship to the emergency management sector, suggestions are made on how to improve in the San Francisco Bay Region.

Phenomenon

Debris flows, often called mudslides, are rapidly moving flows of mixed rocks and mud that move downhill at speeds of 35 miles per hour or more, kill people and destroy homes, roads, bridges, and other property. They are caused chiefly by prolonged, heavy rainfall on saturated hillslopes, rapid snowmelt, earthquakes and the works of human kind. As we meet, four Western states are suffering major flood and landslide disasters, including debris flows.

The economic and social costs of storm-related debris flows and other landslide phenomena are estimated to be about $2.0 billion and 25 to 50 deaths annually, occurring throughout the nation. These figures are increasing as development moves into marginal lands and onto the alluvial fans with desirable views. In the San Francisco Bay region, past storms causing debris flows occurred in 1982, 1986, 1995 and 1996, thousands of such flows were caused by the severe storms in 1982 and caused $66 million in damages and the deaths of 25 people.

Emergency Management and Mitigation

The reduction of these unnecessary costs to the nation can be achieved by improved emergency management and mitigation. Emergency management includes the prediction of the hazard, the issuance of warnings, and the measures that are necessary to insure that the warning and response will be effective. Emergency response includes such measures as evacuation, search and rescue, and provision of emergency food, shelter and health care. Mitigation, or long term hazard reduction, is accomplished by such means as avoidance, design, building, and grading codes, control and stabilization, and insurance.

Successful mitigation of these losses can be achieved by informed land use planing and management, engineering works, and warning and evacuation programs. This is perhaps best illustrated in Japan where in 1938 130,000 homes were destroyed and more than 500 lives lost due to landslides in the Kobe area. After a strong Japanese mitigation program became law, losses declined to only 2000 homes and 125 lost lives in 1976, one of their worst years for landslides.

This paper focuses upon the opportunity that exists in improving the debris flow warning systems drawing upon the experience of the Real-Time Warning System, a pilot program, that was put into place in the San

Francisco Bay region by the National Weather Service and the U.S. Geological Survey from 1985 to 1995. Many valuable insights into how similar debris flow warning systems should be established could be gained from a review of the history and demise of the Bay Region warning system.

Debris Flow Warning System in San Francisco Bay Region

The warning system was established in 1985, issued its first warnings during the severe storms of 1986 and gave its last warnings in January, 1995. Then it died. The warning system was developed by the U.S. Geological Survey and the National Weather Service and operated in cooperation with the State of California Office of Emergency Services and local governments agencies. The warnings issued by the system accurately predicted the times of actual debris flow events during storms and were used by several local governments as a basis for planning emergency response and for recommending temporary evacuation of hazardous areas.

The warning system was based upon empirical and analytical relations between rainfall and debris flow generation, real time regional monitoring of rainfall data from telemeter rain gauges, NWS precipitation forecasts, and delineation of debris flow hazard areas. It was developed by research geologists and weather forecasters and operated on a shoestring budget.

From most perspectives, the warning system was a successful demonstration of applied interdisciplinary science conducted on an interagency basis, and constituted a prototype system that could be adopted for use in other high-risk areas in the nation. But what went wrong? Why did such a promising warning system fail? Especially since similar warning systems in the Los Angeles area are working.

It would be presumptuous to say that anyone, particularly this author, could definitively figure out what went wrong and how to avoid making similar mistakes in the future. But certain insights were gained from long conversations with many of the scientists involved. These observations are offered in the hope that they may prove helpful in any future efforts to establish and maintain an effective debris flow, or any other hazard, warning system.

Insights

Enough science had been done to establish the relationship between actual and predicted rainfall, ground saturation, and geological parameters to set threshold levels for the occurrence of debris flows and to provide the basis for accurate warning. The San Francisco Bay Region Debris Flow Warning System moved through the research and demonstration phase during the ten years of its existence and was at a point where it could have become operational on a continuing basis. It was at this critical juncture that it was shut down, primarily because of the lack of support by the Federal agencies involved. Why weren't the minimal staff and dollar resources needed to continue a proven debris flow warning system provided by anyone? Why didn't the U.S. Geological Survey that identified the warning system as an exemplary project in their budget documents or the National Weather Service step forward with the necessary resources?

A scientist involved with the system cited the severe budgetary constraints in 1995 and the reorganization and reduction in force of the U.S. Geological Survey as contributing factors. The lack of a formal agreement between the two Federal agencies that resolved the issue of who would fund and staff continued operation was mentioned. Also, the absence of a "broker" to let the state and local governments know in time that new support had to be provided to continue the warning system was suggested as another contributing factor.

Important as these factors may have been, it seems that a critical element needed for success was missing.

The users and beneficiaries of the warning system, the state and local governments, were not able or willing to step forward in time to assume a major responsibility for its continued operation. Even if their support was sought at the time when the system was being dismantled, by then it was too late. Experience has shown that the use of scientific and technical information can best, and perhaps only, be assured if the user community is involved early and continuously in the process. In the similar debris flow warning system in operation in Los Angeles County, the county fire department has the main responsibility for operation of much of the warning system and for emergency response, in cooperation with the National Weather Service.

Opportunity

The Debris Flow Warning System experience in the San Francisco Bay region shows that the scientific knowledge exists to put similar systems into place in other high risk areas in the nation. With the advent of NEXRAD and GIS capability and of models for predicting the probabilities of debris flows and processing spatial, temporal and socio-economic variables, the probabilities of debris flow occurrence and their impacts now can be predicted spatially in great detail for any given hour. Such a real-time model for predicting debris flow occurrence would provide local emergency management officials with the ability to prioritize evacuations and to take other emergency response and mitigation measures during severe storms.

An administrative mechanism is in place to conduct the necessary scientific and technical studies in the geologic, hydrologic, and atmospheric sciences to improve the capability for public warning of potential hazards from debris flows and other landslides that result from severe weather conditions. A formal Memorandum of Understanding agreeing to the joint conduct of such research was signed in 1995 by the U.S. Geological Survey and the National Weather Service. Progress has been slow and no joint research project has been started.

What remains to be done is for these agencies to begin to conduct the joint research and development called for in their formal agreement and to help formulate the necessary emergency management and mitigation tools required to deal with the debris flow hazard. If the cooperative effort moves forward as it should, the emergency management community at all levels of government and other key users of this information should be fully involved in the process, early and continuously. Their substantial involvement is particularly critical as projects under the cooperation move from research and demonstration to becoming operational.

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