I. Introduction

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The US Global Climate Change Research Program (USGCRP) and the Office of Science and Technology Policy (OSTP) are coordinating a series of workshops on vulnerabilities of various regions of the United States to climate variability and climate change. These workshops are expected to engage key regional stakeholders to identify and examine high priority regional environmental issues affected by current climate variation and climate change and to obtain information that can be aggregated across regions to support analyses of climate-related impacts and vulnerabilities at the national scale. The workshop on the Southeastern United States, which is being jointly sponsored by the National Aeronautics and Space Administration (NASA), the U.S. Geological Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA), will be held at the Vanderbilt University campus in Nashville, Tennessee on June 25-27, 1997.

The purpose of the Southeastern Regional Workshop is to examine the impacts of climate variability and potential vulnerability to future climate change on natural resources, with an emphasis on water resources, in the following southeastern states: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Tennessee. The initial basis for this workshop was to develop better long-term dialogue between federal agencies engaged in climate-related research and key regional stakeholders who are responsible for the operational decisions of natural resources management for the purpose of demonstrating the value of federal earth science research for practical applications. This workshop focus was later expanded in accordance with the USGCRP and OSTP themes mentioned above to include an examination of the regional vulnerability in a broader range of potential impact areas such as agriculture, forestry, and human health to current climate variations and climate change.

The emphasis on how climate variation and climate change will influence hydrology and water resources of the southeastern United States, and in turn, how these changes may affect interests such as agriculture, forestry, water resource management, etc., was selected for several reasons. First, there is a relatively strong El Nino-Southern Oscillation (ENSO) signal in the southeastern United States that can be related to interannual variations in precipitation and temperature. Thus, any improvements in these ENSO forecasts in the future can provide significant economic benefits to farmers, utilities, and other natural resource managers in this region depending on their ability to use these predictions effectively. Second, better forecasts of precipitation and temperature have enormous economic benefits to large power producers in the region including the Tennessee Valley Authority, Duke Power, and the Southern Company. For example, improved precipitation forecasts are estimated to save $2M over a five-year period for one southeastern utility. Also, better short-term (48-72 hours) temperature forecasts offer significant economic benefits to utility load management decisions. As the nation's utilities move toward a more competitive environment, such forecasts will become invaluable. These potential economic benefits, however, are related not only to better forecasts but also to improvements in how water and energy resources managers use these forecasts. Finally, the southeastern United States has suffered over the years from extreme climate events including hurricanes, tornadoes, lightning, and winter storms. A better understanding of climate and weather data, and the application of this information to private and public sector decisions on disaster prevention and mitigation could have significant benefits for society.

In addition to the economic implications of climate variability in the Southeast there are also scientific considerations for emphasizing hydrology and water resources, and their influence on various economic sectors. For example, beginning in 1998 the GEWEX Continental-scale International Project (GCIP), a study of the Mississippi River Basin intended to improve scientific understanding and to model on a continental scale the coupling between the atmosphere and land surface for climate prediction purposes, will focus its attention on the eastern part of the basin - namely the Tennessee-Cumberland and Ohio River Basins. One aim of these intensive studies is to generate inputs for operational hydrologic and water resources management models for use in local level decision making. Other major ongoing studies in the Southeast such as the EPA's Gulf of Mexico Program and USGS's National Water Quality Assessment Program also provide the scientific underpinnings for the workshop focus.

This white paper contains a summary of our current knowledge of global climate variability and observed climate-related trends in the Southeast as well as the regional stakeholders' perspectives on their vulnerability to current and future climate events. Additionally, eight potential impact areas including agriculture/forestry, parks and public lands, water resources, coastal/fisheries, human health, urban areas, extreme climate events, and air quality are briefly discussed in relation to current climate variability and potential future climate change. Finally, new technologies, data, and information expected over the next decade or so are mentioned, and actions needed to enhance our understanding of the relationship between climate and regional vulnerabilities are summarized. The purpose of this white paper is to provide a framework for the discussion at the workshop. One product resulting from the workshop will be a final report summarizing the vulnerabilities and possible consequences of climate variability and climate change on key regional sectors. In addition, the workshop summary will identify specific data and information needs of the regional stakeholders and research needs for improving future estimates of regional impacts.

II. Global Climate Variability

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Introduction

The Planet's earth, air, water, ice, biological system experiences climate variability over many time scales. As humans, we are acutely aware of the diurnal and seasonal time scales. Persons who are fortunate to travel discover the effect of latitude on the range of air temperature and precipitation on these daily and annual signals. Folks who talk to grandparents or live past 40 years' experience interannual variations, i.e., “last winter was the coldest, I have experienced; we never had a hurricane as long as I have lived in this town,” etc.

When the author was studying to be a chemist at Rutgers, all these interannual events were blamed on Soviet bomb tests in the upper atmosphere. As recent as the early 1960's, geophysicists predicted an ice age and people were talking about moving equator-ward. Now the tabloid presentations of Global Warming impacts have people considering moving inland and poleward.

Scholars have found that there are other potential short term variability events such as 5 - 10 year or 10 - 20 year natural variability events such as the dust bowl in Oklahoma in the 1950's, t he droughts in Texas in the 1950's, the lack of hurricanes in the 1970's, the drought in the Sahel in the 1980's, etc.

In the 1960's, El Nino was discovered but except for some oceanographers who worried about anchoveta stocks off Peru, the climate variability caused by El Nino in all the Pacific Rim countries and other far away places like southern Africa, India, etc., were not studied. El Nino means warm water (+1.0 degree) along the equator west of the Galapagos Islands in the Pacific which lasts for five or more months. El Nino occurs every 3 - 7 years. The climate variations created by El Nino over North America are substantial as will be discussed below.

Recently, climate scientists were investigating some 'new' phenomena, such as the 'North Atlantic Oscillation' as a creator of both 2 - 5 year and 18 - 25 year climate variability

All in all, upon reflection, we can identify time scales of climate variability from day, season, year, interannual, decadal, multi-decadal and longer. Unfortunately, we do not have the climate records to study longer time scales and we resort to the marvelous fingerprints of climate variability in trees, fossils, ice, mud, etc.

In fact, in the southeast, we are experiencing a slight cooling over the past tens of years. The main point is that climate variability occurs on many time scales. Our climate records are very short. In the southeast United States, we have very few stations more than 150 years long. This means that we have not experienced the outliers in a NORMAL stationary climate record. We must really expect to experience hotter, colder, wetter, dryer weather than ever measured before. A few years ago, everyone in Tallahassee was commenting on a drought near the end of the year because we had 15 inches less rainfall during that year. Some blamed the event on global warning or the new high magnetic fields produced at Florida State University which pushed the rain away. In fact, such a deficit should occur about every 12 -

14 years. An inspection of the climate record for Tallahassee indicated this was true, but everyone has too short a memory.

The economic impacts of climate variability are vast. The impacts on food production, energy, fisheries, recreation, etc., are enormous. We are gradually learning about climate variability and how to anticipate climate variability. We need to learn to forecast climate variability and bring these understandings and prediction to the stakeholder level.

Climate Change

There will certainly be global climate change and regional climate change. The increase in human population, the change of land use and many other man-created changes will affect climate change. Some will be permanent changes. The emission of radiatively-active gases such as carbon dioxide and methane have a radiation interaction with the atmosphere and increase the greenhouse effect. Whether we get warming from carbon dioxide or cooling from a coming ice age, is not as important as identification of the cause and magnitude of climate variabilities.

The existing record shows an increase of $0.5^{o}C$ in the globally-averaged surface air temperature more than 100 years. Is this signal a remnant of the difference between warming and cooling or is it a part of a 200-year long variability?

In the southeast United States, the largest cause of climate variability is El Nino and its counterpart (Mr. Hyde), or 'El Viejo,' the scientific term for a cold ocean along the Equator in the eastern Pacific Ocean. After one subtracts the diurnal and seasonal signal from the climate record, then floods and droughts, heat waves and ice storms, more or fewer hurricanes, more or fewer tornadoes, etc., in the southeast United States are directly linked to the occurrence of warmer or cold water in the Pacific Ocean west of the Galapagos Islands

Hurricanes and Things

The biggest single effect of the number of hurricanes to strike U.S. landfalls (almost all in the southeast) is El Nino. If there is warm water in the eastern equatorial Pacific, the probability of 2 or more hurricanes striking the southeast United States is one in every five-years. If the ocean water is not $0.5^{o}C$ warmer, the probability of two or more hurricanes striking the southeast United States is one in every two years. Hurricanes and tropical storms are a major source of fresh water foremost of the southeast. Unfortunately, they do lots of damage when striking
popular coastal regions. Recent studies have shown that the incredible increase in damage due to hurricanes is not due to global warming, but due to the fact that more people live in the coastal zone.

The increase in the number of Atlantic hurricanes in the 1995 season was due to El Nino going away. The large number was natural variability. The Insurance Industry asked the author to discover whether global warming would mean more Atlantic hurricanes. A study by the Max Planck Institute shows that warm ocean in a CO_2 doubling-experiment is similar to a semi-permanent El Nino and, thus fewer hurricanes in the Atlantic.

Unfortunately, there will be more intense Pacific hurricanes (the kind that strike Hawaii or Mexico) and more typhoons for Asia. (After all, the Planet general circulation must have hurricanes to transport the heat poleward to high latitudes and tropical storms are very efficient to accomplish this.)

The conclusion is, if we have more global warming, there will be fewer hurricanes for the southeast. We need to calculate how much loss of water for the Carolinas, Georgia and Florida. On the other hand, a recent study by Cane, et al. indicate that the 100-year SST record in the Pacific shows more El Viejo or cold events. This means more Atlantic hurricanes!

What is going on? The models are not good enough! Maybe! The coupled ocean-ice-atmosphere models show warming when one increases the CO_2, but the ocean in the- -Pacific shows cooling and the minimum temperatures in the southeast United States show cooling.

El Nino is a Good Dude

El Nino is a wonderful positive climate happening for the Southeast United States. El Nino suppresses hurricanes. El Nino gives winter rain to the coastal Carolinas, the State of Florida and the coasts of Alabama, Mississippi , Louisiana, and Texas. This greatly suppresses forest fires, helps winter vegetables, produces better oranges. And, nicely, it is only a 'bit of extra rain,' so it does not hurt tourism.

The opposite of El Nino is called 'La Nina' by some scientists, 'El Viejo,' by COAPS, and more properly, the cold phase of ENSO by the educated scientific community. El Viejo is very bad for
the United States. We have more hurricanes, winter droughts in the coastal regions of the southeast, and therefore, raging forest fires. But there is a newly discovered serious climate variability problem. When El Viejo is alive, '% 'near the Galapagos Islands, a new tornado belt exists from Mississippi to Indianapolis. In Tennessee, the probability of four or more tornadoes occurring in the spring (March, April, May) when El Viejo has occurred in the winter is 4 - 5 times more likely than other years. This recently discovered fact arose from studying climate variability and not secular trends.

The Future

There will be an alarming climate change in the southeast United States due to growth of population, and, accompanied land use changes. On the bright side, oceanographers and meteorologists are learning how the ocean controls the climate variability on daily, seasonal, interannual and decadal time scales. If we learn to educate the stock- holders on the new scientific knowledge and the new ability to forecast these events, a great economic benefit will be achieved.

III. Observed Climate Trends: Global Warming and the Southeastern U.S.

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The Overall Picture.

The Intergovernmental Panel on Climate Change has concluded that we humans may indeed have begun contributing to the Earth's process of climatic change (Houghton et al., 1996). Probably with help from an enhanced greenhouse effect, global average temperature has increased by about half a degree Celsius over the past century (Fig. 1). We should not be surprised by this tentative conclusion. After all, the greenhouse effect is real. Water vapor is the most potent greenhouse gas, and its resultant greenhouse effect, combined with that of other gases (notably carbon dioxide, see Fig. 2), warms the Earth to the point where life as we know it is possible. Without a greenhouse effect, the Earth would be a frozen world. Since there is a plausible physical mechanism and we are irrefutably increasing the greenhouse gas concentrations in the atmosphere (Fig 3), we should not be surprised to see the climate change somewhat. Furthermore, given the apparent and logical relationship between world population and carbon dioxide in the atmosphere (Fig. 3), and projections of global population through the 21st century (Fig. 4), it would probably be surprising if global climate did NOT respond in a measurable way. Combining the data from land surface temperature stations with the carbon dioxide data in the simplest statistical climate model ever devised, the results are a little unnerving (Fig. 5).

Regional Focus.

Global patterns of regional daily mean maximum, minimum, and daily temperature range are shown in Fig. 6, and annual and seasonal means are shown in Fig. 7. Note that the minimum is warming more than the maximum, with a resultant decrease in the temperature range. Also note that the southeastern U.S. is one of the handful of places on Earth showing a net cooling over the sampling period of these data, 1901-1996. Some climate model simulations show a tendency toward reduced warming in the eastern U.S. due to anthropogenic sulfate aerosols (IPCC, 1995). The contiguous 48 United States have warmed by an amount similar to the globe (Fig. 8a).

U.S. precipitation has also increased (Fig. 8b), in general agreement with model projections that as the globe warms, mid- to high-latitude precipitation will increase. Most of this increase has been in the more extreme events, and very little in the more moderate events, nationally (Fig. 9,10) and regionally (Fig. 11, 12). While moderate rains generally benefit agriculture and the water supply, heavy rains are less efficient (more water runs off into the sea), and are more likely to cause flooding. Although it is not possible to ascribe a cause like global climate change to any one event or even a few events, (there were many serious floods and droughts in the past that had nothing to do with global warming), we can say that severe weather and flooding have increased in recent years. Fig. 13 shows the losses in the U.S. from billion dollar climate catastrophes, adjusted for inflation, for 1980-1996. So far in 1997 (as of May 9th), there have been at least two billion dollar flooding events. And, we can also say that climate model predictions infer that floods, and in some scenarios, droughts, will likely be more frequent and severe in a greenhouse-enhanced atmosphere.

To further monitor our progression of climatic variation and change in the U.S., we have devised two simple indices (which are under continuing review for improvements) whose change tells us whether the U.S. climate is becoming more extreme, and/or more "greenhouse-like" (Karl et al., 1996). The U.S. Climate Extremes Index (CEI) is the annual arithmetic average of the following five indicators of the percent of the conterminous U.S. area:

(1) The sum of:
a) Percent of the U.S. with maximum temperatures much below normal.
b) Percent of the U.S. with maximum temperatures much above normal.

(2) The sum of:
a) Percent of the U.S. with minimum temperatures much below normal.
b) Percent of the U.S. with minimum temperatures much above normal.

(3) The sum of:
a) Percent of the U.S. in severe drought.
b) Percent of the U.S. with severe moisture surplus.

(4) Twice the value of:
the percent of the U.S. with a much above normal proportion of precipitation derived from extreme (more than 2 inches or 50.8 mm) 1-day precipitation events.

(5) The sum of:
a) Percent of the U.S. with a much above normal number of days with precipitation.
b) Percent of the U.S. with a much below normal number of days with precipitation.

In each case much above or below normal or severe conditions are those falling in the upper or lower tenth percentile of the local, century-long record. In any given year each of the five indicators has an expected value of 20% in that 10% of all observed values should fall, in the long-term average, in each tenth percentile, and there are two such sets in each indicator. An extremely high value in any one of the five indicators does not exclude extremely high values for the others. The fourth indicator, related to extreme precipitation events, has an opposite phase that cannot be considered extreme: The fraction of the country with a much below normal percentage of annual precipitation derived from extreme (i.e., zero) 1-day precipitation amounts. Hence, the fourth indicator is multiplied by twice its value to give it an expected value of 20%, comparable to the other indicators. Overall, the CEI gives slightly more weight to precipitation extremes than to extremes of temperature. A value of 0%, for the CEI, the lower limit, indicates that no portion of the country was subject to any of the extremes of temperature or precipitation considered in the index. In contrast, a value of 100% (or more, considering the nature of indicator 4) would mean the entire country had extreme conditions throughout the year for each of the five indicators, a virtually impossible scenario. The long-term variation or change of this index represents the tendency for extremes of climate to either decrease, increase, or remain the same.

Like the CEI, the weighted U.S. Greenhouse Climate Response Index (GCRI) combines a number of climate indicators that relate to specific aspects of climate change. It has a clear meaning (the percent of the country exhibiting changes consistent with greenhouse warming theory; the direction of change of the GCRI tells us if we are moving toward (positive) or away (negative) from conditions consistent with a greenhouse-enhanced climate); a moderately long history; and expected continuity into the future. It does not smooth out potentially important aspects of climate change in the name of simplification. Non-greenhouse influences on climate, such as the cooling effects of sulfate aerosols and natural climate change mechanisms, will either enhance or reduce the GCRI. It is worth noting however, that in the U.S. there was little net change of anthropogenic emissions of sulfur dioxide (which can cause sulfate-induced smog) between 1950 and 1993. The U.S. GCRI is calculated from the weighted annual arithmetic average of the following five indicators of the percent of the conterminous U.S. area:

(1) The percent of the U.S. with much above normal minimum temperatures.
(2) The percent of the U.S. with much above normal precipitation during the months October through April (the cold season).
(3) The percent of the U.S. in severe drought during the months May through September (the warm season).
(4) The percent of the U.S. with a much above normal proportion of precipitation derived from extreme 1-day precipitation events (exceeding 2 inches or 50.8 mm).
(5) The percent of the U.S. with much below normal day-to-day temperature differences.

The weights are: a value of 5 for the first indicator (temperature); 4 for precipitation; and 3, 2, and 1 for indicators (3), (4), and (5) respectively. The progress of these indices from 1910 to 1995 is depicted in Figs. 14 and 15. Both show recent rises, with the GCRI being a statistically significant increase.

Not all indicator trends are bad. The number of land falling U.S. hurricanes shows a downward trend for all storms (Fig. 16a) and severe category 3,4, and 5 storms (Fig. 16b). But within this news there is an ominous threat. If hurricane frequencies rebound to historic levels, which is climatologically likely, increased coastal vulnerability guarantees that losses will increase dramatically over past experiences.

The Future.

Based on climate perspectives studies and computer models of climate, it now seems probable that changes in regional weather patterns will accompany global warming. Longer and more intense heat could likely result in public health threats and increased heat-related mortality, as well as infrastructure stress like to electrical power outages and structural damage.

Perversely, the trend over the southeastern U.S. has displayed a contrarian *cooling* (Fig.7). But this does not mean that the SE is immune from the global effects of climate variation and change. As global population and technology increase, the global average temperature is likely to rise an additional 1.0 to 3.5 degrees C by the year 2100. The resulting sea level rise could be devastating for coastal areas. Fig. 17 shows the current IPCC projections of global mean temperature warming and the resulting sea level rise between the years 1995 and 2500. The range of uncertainty is considerable, but the trend is clear. Heat waves such as the tragic 1995 episode in Chicago will likely be repeated with more frequency. Fig 18 shows the huge increase in mortality associated with the 1995 heatwave, as documented by the Chicago Public Health Dept. Earlier heatwaves in 1983, 1986, and 1988 are also reflected in the record.

Climate change will also affect the patterns of precipitation, with some areas getting more and others less, changing global patterns and occurrences of droughts and floods. Similarly, increased variability and extremes in precipitation can exacerbate existing problems in water quality and sewage treatment and in erosion and urban storm-water routing, among others. Such possibilities underscore the need to understand the consequences of humankind's effect on global climate (Karl et al., 1997). Fig. 19 shows regional model predictions of changes in precipitation intensity (specifically, the percentage change in the proportion of total annual precip from 1-day events of various intensities) for the 48 contiguous U.S. This experiment was run to estimate the likelihood that observed precipitation trends (generally toward more intense events) would continue. The experiment used two 20-year climate model ensemble outputs, one consisting of a control run with carbon dioxide concentrations close to today's levels, and the other simulation with twice that amount. The difference between today's precipitation climate and the climate with doubled carbon dioxide was calculated and mapped for nine U.S. regions and the contiguous U.S. as a whole. Maps of regional differences are shown in Fig. 18, with the overall mean of all nine areas plotted to the right off the SE coast.

It is clear that increased flooding, runoff, and erosion are likely in a greenhouse enriched atmosphere.

Climate has changed many times in the past, but the current rate of change seems to be large and is consistent with increasing greenhouse gas concentrations. While there is still uncertainty, the primary concern has shifted from the question "Will climate change? to the question "What will be the nature of the impending climate change, and most important, what will be the consequences?"

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Fig. 11. Same as Fig. 10, but regionally for the contiguous U.S.

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Fig. 16. U.S. Atlantic landfalling hurricanes by decade, 1900-1996, for: a) all storms, and b) the most severe storms (cat. 3,4, and 5). The 1990-1996 data are adjusted to per decade units via multiplication by 1.43.

Fig. 17. IPCC 1995 projections of a) global warming and b) sea level rise (after Houghton et al., 1996). The shaded area represents spread between the smallest projected warming & sea level rise (dashed line, assuming stabilization at 450 ppmv carbon dioxide in 2100), and the largest warming & sea level rise (solid line, assuming stabilization at 650 ppmv carbon dioxide in 2200).

Fig. 18. The daily death rate per 100,000 people during 17 consecutive summers in Chicago, as recorded by the Chicago Dept. of Public Health. The excessive mortality related to the 1995 heatwave is a strikingly tragic feature of the time series, as are lesser heatwaves in 1983, 86 and 88.

Fig. 19. Goddard Institute for Space Studies (GISS SI95) global climate model predictions of changes in the percentage change in the proportion of total annual precipitation from 1-day events of various intensities. This experiment used two 20-year simulations, one consisting of a control run with today's carbon dioxide, and the other a series of runs with doubled carbon dioxide near today's level, and the other with twice that amount. The difference between today's precipitation climate and the climate with doubled carbon dioxide was calculated and mapped for nine U.S. regions and the contiguous U.S. as a whole, with the overall mean of all nine areas plotted to the right off the SE coast. For most areas an increase in precipitation intensity is evident.

IV. Trends in Extreme Weather Impacts

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I. Introduction

> "We do not know. . . for sure that the warming of the Earth is responsible for what seems to be a substantial increase in highly disruptive weather events, but many people believe that it is, and that we have to keep looking into it. . . If there is a larger cause which can be eased into the future, we ought to go after that solution as well"
>
> President Bill Clinton, April 22, 1997 (quoted in Baker 1997)

The recent statement by Present Clinton reflects two common perceptions. First, it reflects a sense that the economic impacts associated with extreme weather events have increased in recent years. Second, a perception exists that the recent increase in weather-related events is due to changes in climate related to global warming. In recent years, these perceptions have resulted in almost every extreme event being attributed, by someone, to global warming (Figure 1).

The perceptions are more than simply idle speculations -- they underlie policy decisions with important social, economic, and political ramifications. For instance, in December of this year representatives from nations around the world will meet in Kyoto, Japan to discuss and debate implementation of the Framework Convention on Climate Change. Because policy is based on the perceptions that policy makers hold about climate, it is worth determining the validity of the two perceptions.

In the case of economic losses associated with extreme weather events (specifically hurricanes, floods, and tornadoes), there is a trend of increasing losses in recent decades in the United States. Thus, the first perception is demonstrably valid. There is, however, no reliable evidence to date to support the perception that recent trends in economic losses in the United States are attributable to changes in climate -- *regardless of the hypothesized cause*. Clearly, climate has varied regionally with respect to particular phenomena, however, this variation is difficult to discern in the historical record of societal impacts (e.g., dollar losses). Instead, the strongest signal present in the historical record is that increased societal vulnerability is the primary cause of recent increases in documented economic losses. Note that this finding in no way refutes the global warming hypothesis. Rather, it refutes the claim that past losses can be attributed to the increased frequency or magnitude of extreme weather events. This is consistent with the findings of the Intergovernmental Panel on Climate Change, published in 1996.

This short report discusses trend data on hurricane, flood, and tornado impacts in the United States. Arguably, hurricanes and floods are the two phenomena that societal impacts researchers best understand from the standpoint of trends and causes of impacts. It also presents a brief discussion of other weather-related impacts.

II. Impacts Trend Data

The impacts of weather on society have been defined according to a three-tiered sequence (Changnon 1996): "Direct impacts" are those most closely related to the event, such as property losses associated with wind damage. "Secondary impacts" are those related to the direct impacts. For example, an increase in medical problems or disease following a hurricane would be a secondary impact. "Tertiary impacts" are those which follow long after the storm has passed. A change in property tax revenues collected in the years following a storm is an example of a tertiary impact.   The impacts discussed in this paper are direct impacts.

A. Hurricanes

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 (WMO, various sources). 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 3 shows the dollar losses year-by-year and Figure 4 shows the dollar losses and casualties by decade. (Figure 2 shows the insured losses related to hurricanes 1949-1995, data courtesy of Property Claims Services, Inc.). Figure 5 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).

A study underway is seeking to “normalize” hurricane loss values to 1995 levels through adjusting for growth in inflation, wealth, and population (Pielke and Landsea 1997). The results of this study will suggest what the economic would be had each season’s hurricane landfalls (1925-1995) occurred in 1995. Figure 6 shows some of the preliminary findings of this project. It shows that of the 71 years used in the study, In aggregate, hurricanes caused >$346 billion in losses over 71 years, or an annual average of about $5 billion, with a maximum of >$74 billion in 1926 and numerous years with no reported damage. Of the 71 years, 35 years (about 50%) had less than $1 billion in damages. There were 19 years (about 25%) with at least $5 billion and 12 years (about 17%) with at least $10 billion. Using such loss normalization methods, it might be possible to better understand the relationship of climate and societal factors which underlie the loss record.

Conclusion
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.

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 and 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.

B. Floods

Flood events in recent years provide vivid evidence that people and property in the United States remain extremely vulnerable to floods. However, data is lacking (or unavailable) that would allow accurate and useful determination of the trends in and current level of societal vulnerability to floods. The 1992 assessment of floodplain management in the United States found that "the actual amount of United States land in flood plains has not been clearly determined, nor has the amount of property and other economic investments at risk to flooding been firmly established" (FIFMTF 1992, 3-1). A review of various estimates of flood prone regions in the United States shows considerable disagreement as to the areal extent of flood prone regions, the number of people who inhabit those areas, and the amount of property at risk to flooding. In 1942, Gilbert White estimated that 35 million acres of U.S. land was subject to flooding (White 1945). In 1955, Hoyt and Langbein (1955) estimated that 10 million people live or work within the nation's 50 million acres of flood prone land. The 1955 estimate equates to 7% of the population living on flood prone regions which comprise about 3% of the United States land area. A 1978 study estimated that 4.5 million households were in flood hazard areas. A 1987 study classified about 94 million acres of land as U.S. floodplains containing 9.6 million households with $390 billion in property (FIFMTF 1992, 3-2).

A consequence of the lack of data on the areal extent of floodplains in the United States is that a difficulty exists in assessing trends in and current levels of population at risk to floods. Trends in population at risk to flood events are an important factor in any determination as to whether societal vulnerability to floods in decreasing, increasing, or remaining relatively constant. One can easily hypothesize that increasing population and urbanization in the United States has led to a commensurate increase in population at risk. Yet, one can also hypothesize that the various societal responses to floods may have more than compensated for population growth and in fact fewer people are today at risk to flood events. Currently, data is lacking to reliably assess trends in population at risk to floods events.

Accurate determination of property at risk to flooding faces many of the same obstacles facing accurate determination of people at risk to flooding. Pielke (1996) summarizes the findings of the various finding that there is relatively little systematic data collected on property at risk to flooding. Again, the lack of data limits what can be said about trends in vulnerability to flooding. It is likely that the Federal Insurance Administration, which operates the National Flood Insurance Program, has in its records data on property at risk to floods for the communities which it has worked with since the early 1970s. However, this data has seen only limited use, e.g., in determination of repetitive losses and substantial damages over 50%, and has yet to be systematically assessed from the standpoint of trends in societal vulnerability to floods.

Differences in the estimates of people and property at risk to floods are attributable to actual demographic changes, but also to differences in floodplain definitions, and simply that the data has not been collected and systematically analyzed. The data that does exist allows for only gross generalizations. The data limitation is one of the factors which limits what can be authoritatively concluded about trends in societal vulnerability to floods (cf. Changnon et al. 1983).

Floods and a Changing Climate

Current knowledge is limited as to the potential impacts of a changing climate on the number and intensity of flood events (IPCC 1995, OTA 1993, Dracup and Kendall 1990). It is almost certain that for particular regions and communities the climate will change in some way or another. There will likely be some communities that experience more flood events and others that experience less. It will almost certainly be more straightforward to document these changes than to attribute them to specific causes, such as anthropogenically caused global warming. For example, several regions in the Upper Mississippi River Basin have seen trends (at 80% and 90% confidence for different regions) of increasing precipitation since 1965 (Bhowmik et al. 1994, 132-146, cf. Changnon and Kunkel 1995). Meanwhile, the Colorado river basin has seen a decrease in streamflow over the latter two thirds of the twentieth century (Frederick and Kneese 1990). Such "winners and losers" have been documented in regions around the world (e.g., Rao 1995, Karl et al. 1995). In the United States (about 6% of the Earth's land surface) recent decades have seen an increasing trend (at various levels of confidence) in precipitation and consequently streamflow (Karl et al. 1996, Lins and Michaels 1994).

Flood Damages

As in the case of trends in people at risk to floods, analysts have sought to use trends in flood damages as a proxy for trends in property at risk to floods. However, it is at least as difficult to form definitive conclusions about vulnerability from the damage data as it is from the casualty data. Flood damages occur every year in various places around the United States. Such damages, per se, are not sufficient evidence of a policy problem. As the Task Force on Federal Flood Control Policy noted in 1966 (p. 13), "it may well be that the advantages of flood plain location outweigh the intermittent costs of damages from floods. Further, there are some kinds of activity which can only be conducted near a watercourse."

Flood damages (or losses) have been defined as the "destruction or impairment, partial or complete, of the value of goods or services, or of health, resulting from the action of flood waters and the silt and debris they carry. Easy to define, flood losses are difficult to set down in dollar figures" (Hoyt and Langbein 1955, 77). Because of the methodological difficulties in assessing flood damages, as well as the limited data available, "taking all in all, it is evident that any evaluation of flood damage is only a rough approximation" (Hoyt and Langbein 1955, 79). Nevertheless, the historical record of flood damages provides some insight as to trends in flood impacts on society (cf. Ye and Ye 1996).

Figure 7 shows annual flood damages for the period 1903-1994 as tabulated by the National Weather Service. Figure 8 shows the same data from the standpoint of a 25-year moving average. The data show that flood damages have been increasing steadily at this time scale (using constant dollars). Table 4 presents the annual record of flood losses and deaths as kept by the National Weather Service.

Flood Casualties
Due to the lack of systematic data on the number of people at risk to floods, trends in flood casualties, for which relatively systematic data is available, are sometimes used as a proxy for trends in population at risk. An assumption underlying many such analyses is that a rise in flood-related casualties is indicative of a rise in the number of people at risk to flood events. Unfortunately, at least three confounding factors limit the use of trends in flood casualties as a proxy for trends in the gross number of people who are vulnerable to floods.

First, many flood-related deaths are concentrated in single extreme events, like a hurricane or a severe flash flood. Second, society has taken many steps to reduce its level of exposure, with mixed results. This means that a moving baseline of exposure underlies any record of flood-related casualties. Consequently, there may be a number of trends within a trend record of flood casualties (e.g., level of exposure, success and failures of mitigation efforts, etc.). Finally, the data on flood casualties is generally not perceived to be accurate enough to lead to definitive conclusions (F. Richards, NWS, personal communication). The longest, continuous record of flood casualty data is that of the National Weather Service (1903-present). However, there are different sources of data which have different numbers (e.g., Red Cross data in FIFMTF 1992, Wood 1994, Ye and Ye 1996). For these reasons, trend data on flood-related casualties does not lend much insight into broader questions of trends on vulnerability to floods.

Figure 9 shows the data kept by the National Weather Service on flood-related fatalities in the United States from 1903-1994.[1] The data shows a downward trend in flood-related deaths since the early 1970s, but also an increased frequency of years with high deaths. Figure 10 shows the trend of flood-related deaths over a moving 25-year period beginning with 1927 (i.e., sum of 1903-1927) and ending in 1994 (i.e., sum of 1970-1994). At this time scale, the more recent period contains more deaths (Wood 1993, using a different dataset finds a similar trend). However, this data must be viewed with caution, as it may be possible that the trend is due to better accounting in the more recent years. Of the annual deaths related to floods, 80-90 percent are caused by flash floods and 40 percent of these "are related to stream crossing or highway fatalities" (Zevin 1994, 1267).

In sum, available data indicates that flood-related deaths have increased in recent decades. However, because of the nature of the data, little can be said with authority about what the trend of increased deaths means from the standpoint of people at risk to floods.

C. Tornadoes

Tornadoes provide an interesting comparison to hurricanes and floods. While the impacts data is not as readily available as in the other areas, several tentative conclusions can be reached. First, deaths related to tornadoes have decreased in recent decades, due primarily to improved detection and warning systems (Hales 1990, Golden 1997). Second, the *observed* number of tornadoes has increased in recent years, with weak tornadoes increasing and strong tornadoes remaining constant. This trend has been attributed to better reporting and detection of tornadoes, rather than to a change in tornado climatology (Otsby 1993). Third,

[1] Data is kept by "water year" which runs from October 1 through September 30 the following year. Hence, Water Year 1996 started on October 1, 1995 and ended September 30, 1996.

damages related to tornadoes are perceived as increasing, however the data record is suspect.[2] For instance, records kept by the National Weather Service indicate that tornado-related damages totaled $1 billion for the period 1991-1993. At the same time, Roth (1996) reports that during the same period *insured losses alone* totaled $9.5 billion. The order of magnitude difference calls into question the validity of the impacts data kept by the National Weather Service. Consequently, the ability to detect trends in impacts, much less attribute them to climate or societal factors remains a topic of continued research.

D. Other weather extremes

Table 3 summarizes data presented at a recent workshop on the direct impacts of recent extreme events in the United States as measured by loss of life and current dollar losses.[3] Scholars agree that relatively poor quality of available data on impacts limits conclusive findings. Several points do 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 Table, 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.

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.
Participants at the workshop concluded that, on a roughly 20-year time scale, societal impacts associated with extreme events as increasing in terms of both deaths and dollars (with the single exception of tornado-related deaths). Additionally, participants agreed that the increase in impacts was largely due to societal factors with respect to each phenomenon (expect for perhaps floods). Our poor understanding of past impacts limits what can be concluded about the future, strongly suggesting a need to better understand the interrelationship of climatological and societal factors which underlie the trends in impacts. These findings are consistent with other data sources from insurance and emergency management.

Insurance (Data source: Property Claims Services, Inc., U.S. Congress 1995)
From that late 1970s up to 1988 the insurance industry had a steady rate of weather-related losses generally on the order of $1-2 billion annually, with peaks totaling less than $4 billion in the hurricane years of 1979, 1983, and 1985 (dollars are inflation adjusted to 1995). (Prior to the late 1970s annual losses were on the order of a few hundred million, see U.S. Congress 1995, 28). Then, in 1989 a change occurred. Losses from 1989-1993 were as follows: $9.1 billion, 3.2 billion, 5.2 billion, 24.6 billion, and 5.9 billion. The first quarter of

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[2] The Storm Prediction Center has a record of tornado losses from 1950-1995 at http://www.nssl.uoknor.edu/~spc/archive/tornadoes/index.html.

[3] Workshop on the Social and Economic Impacts of Weather, 2-4 April 1997, National Center for Atmospheric Research (NCAR), Boulder, CO, sponsored by U.S. Weather Research Program, American Meteorological Society, Electric Power Research Institute, University Corporation for Atmospheric Research, White House Subcommittee on Natural Disaster Reduction, Environmental and Societal Impacts Group (NCAR). Workshop report available at http://www.dir.ucar.edu/esig/socasp/weather1.

1996 saw $2.5 billion in weather-related damages. The increase is in part related to extreme hurricane impacts, but is also due to winter storms, etc. There has been a clear change in impact on the insurance industry and thus their recent interest in climate should come as no surprise. Figure 11 shows weather-related losses to the insurance industry during the first quarter of each year (January-March) 1976-1996.

Federal Emergency Management (Data source: FEMA, U.S. Congress 1995)
From 1985 through March 1996 FEMA declared 492 disasters, of which 396, or 80% were weather-related (fires excluded). During that period FEMA obligated $15.8 billion for disasters of which $10.9 billion, or 69%, was for weather-related events. Like the insurance industry, FEMA has also seen a marked increase in the number of and costs of disasters since 1989. The Red Cross disaster fund shows a similar trend (U.S. Congress 1995, 48). In the first three months of 1996 FEMA had already declared more weather disasters, with 42, than in any previous *year* except 1992 (43) and 1993 (56). Further, the first three months of 1996 put FEMA on a pace to be the third most costly disaster year. Figure 12 shows FEMA weather-related disaster declarations in terms of the number declared and dollars obligated.

III. Conclusions

The information presented in this short report is consistent with the findings of the recent IPCC report. At the regional level scientists have documented various increasing and decreasing trends in the frequency or magnitude of extreme events, but are not able to associate those changes to global warming. On a global scale it is difficult for scientists discern trends in extreme events. As the IPCC (1996a, 173) notes:

Overall, there is no evidence that extreme weather events, or climate variability, has increased, in a global sense, through the 20th century, although data and analyses are poor and not comprehensive. On regional scales there is clear evidence of changes in some extremes and climate variability indicators. Some of these changes have been toward greater variability; some have been toward lower variability.

A pattern of climate underlies the trends in weather-related casualties and losses. For many years decision makers in many contexts assumed that climate remained constant, at least over the relevant period of record. In recent years, scientists and policy makers have come to realize that we live in a climate that is changing in ways that are difficult to assess and predict. In other words, both the distribution of events and the central tendency may be changing. A consequence is that climate change or variability may be responsible for some of the variance in weather-related deaths and damages.

However, it is difficult to attribute the documented increases in economic impacts in the United States that have occurred in recent years to fluctuations in climate. This is primarily due to the fact that the strongest signal in the impacts record is increased societal vulnerability. Normalization methods hold the potential for identification of the climate signal in the impacts record.

Bibliography

V. Stakeholder Perspectives on Regional Vulnerabilities to Global Climate Change

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The Setting

The concept of global climate change is not in the minds of most people concerned with making a living, raising a family, drugs, crime, education, social obligations, and a finding a few moments of recreation. Some people are intrigued by the spectre of global climate change. Some have learned enough about the issues to know the distinction between greenhouse gasses and ozone-depleting pollutants, but most are unaware of the basic science of climate change and unable to assess the relative importance of global climate change effects in comparison with other environmental or health problems. Some few are well informed on climate-change issues and are leading educational, research, and responsive efforts in what they see as a controversial and high-stakes arena.

Stakeholder perspectives on environmental issues are generally complex and difficult to lay out simply and clearly. With issues as wide ranging and uncertain as those associated with global climate change, stakeholder perspectives range from uninformed/undeveloped through apathetic through various levels of knowledge of the situation, with or without significant concern for the implications of the situation.

The success or usefulness of an assessment of regional effects of climate change is dependent on incorporation of relevant stakeholder perspectives and their dynamics into the assessment process. First-hand, interactive stakeholder participation in and ownership of the assessment process is required. The workshop and subsequent planning, research, and assessment efforts need to address questions such as the following.

- Who are the stakeholders? There are perhaps two major groups of stakeholders in this setting (1) greenhouse gas emitters, stationary and mobile sources who are multinational corporations to households, and who are central to abatement strategies; and (2) those who are subject to the effects of climate change, including just about everybody. Both of these groups may be delineated geographically and/or by sector or other category and may have some measure of vulnerability or sensitivity ascribed to them.

- What is their level of awareness with respect to their contribution to climate change or their vulnerability to its effects? What are their concerns? What level of assessment have they already done? These range widely -- those with little awareness or concern may require special effort to be drawn into the process or to have their interests represented.

- What is their ability to respond to climate change? How vulnerable are they? How well organized are they? What information and financial or other resources do they have access to?

- How well can they play in the public or private policy-setting arenas? What organizations represent their views? What are their agendas? Who are they allied with?

Getting stakeholders to the table to discuss global change issues can be a challenge. Some are aware and concerned. Others ask why they should allocate time to this now? Why be concerned with something that might happen 2 to 200 years into the future when they have jobs, crime, drugs, education, shareholder interests, and/or other environmental crises to deal with today? They ask for concise information laying out effects or risks or costs and benefits, in comparison with other issues competing for their attention.

Broad stakeholder involvement in answering these questions is needed to determine who is best suited to contributing to what kind of abatement measures and who is vulnerable to which primary or secondary effects of climate change. A critical need is for management or facilitation of the dialog necessary among stakeholders to answer these questions and to develop common understanding with which to make decisions about abatement or adaptation.

Previous Workshop Results

The Oak Ridge National Laboratory and the U.S. Environmental Protection Agency conducted a series of workshops in the summer of 1995 to determine options for evaluating regional vulnerabilities to climate change (Turner, et al., 1996). The southeastern United States was chosen as a prototypical region because of the variety of climate-change effects that might occur in that region. In these workshops we used the term constituents instead of stakeholders.

Three-workshop findings

Findings from the three workshops were:

Ø Climate change is controversial; many constituents question whether it is a real phenomenon. As a result, few constituents currently are willing to devote significant attention to integrated assessment.

Ø Those concerned with the effects of climate change (scientists, policy makers, and other constituents) disagree on how complete present predictive capabilities are (and those predictive capabilities that should receive priority attention), whether and why conflicting projections are being produced, and what needs to be done to improve predictions (e.g., improve models that estimate sea-level rise).

Ø The scientists present at the workshops reached little, if any, consensus on how to rank the vulnerability of human and ecological systems to climate change. The participants did, however, identify many systems that are vulnerable and, in the opinion of the participants, merited further research. Several vulnerable systems were discussed at length.

Ø Non-scientific constituents present at the second workshop had difficulty ascribing priority to any human or natural systems because their concerns focused on secondary impacts rather than on any one system. Themes of health effects and of economic and social instability were primary concerns as were impacts of potential changes in the frequency and severity of extreme events.

Ø The relative risk of impacts from climate change as compared to other drivers of change is an important consideration in climate-change assessment. The credibility and value of such an assessment will be enhanced if risks of climate change are comparable with other risks.

Ø Many questions that could serve as starting points for regional integrated assessment of climate change were identified.

Ø It was difficult for many workshop participants to conceptualize the ideal integrated assessment particularly because such an assessment probably would not be funded and implemented by a single organization.

Ø Participants tended to view the spatial scale of an assessment more as a consequence of the approach selected rather than as a factor in that selection.

Ø The motivating factors of various assessment sponsors (agency representatives, local officials, interest groups, academics, and trade organizations) are complicated, making it difficult to identify potential roles of particular organizations or people in an assessment process.

Ø In response to suggestions from the workshop participants, a catalog of ongoing assessment efforts and their specifications (e.g., focus, geographic extent, primary decision-making tool, etc.) was begun [this working document was never completed or updated]. The catalog targets efforts that should influence and could provide resources for new assessments or investigations of climate-change impacts.

Ø Many constituents are skeptical of plans to start "yet another assessment" and asked for very clear justification as to how any new efforts would add value to the current mix of assessment work.

Constituency workshop results

Goals of the second of the workshop series were to elicit the perspectives of various regional constituencies on human and natural systems, to develop an understanding of how constituents define “vulnerable systems,” to identify systems in the Southeast that are sensitive to climate change, to identify constituent concerns specific to geographic regions, to identify options for adapting to changes (e.g., in location and structure) of vulnerable ecosystems, and to determine the research and communication needed to support integrated assessment of climate-change effects.

Six main messages came out of this assemblage of concerned constituents. The first was that assessment of climate change in the Southeast would be valuable to stakeholders whose stewardship of natural resources would be affected by any significant shift in climate. It would also be valuable to decision makers, providing them with answers to basic questions, such as: What effects might be visited on the southeastern United States? What will be the magnitude of these effects? What secondary effects might be produced, in what timeframes, and with what costs (in lives, jobs, property, or investments)?

The second message was that constituents would like to see more information. Examples of some basic information requests are baseline data against which to measure change, the magnitude and timing of any effects produced by global warming, the causative agents and mechanisms of direct and indirect effects of global warming, estimations of how the people world-wide might react and then respond to these effects, the costs of such responses, methods to mitigate global warming and resultant climate change, and the costs and benefits of such mitigation efforts.

The third message was that environmental groups and stakeholders could provide technical review and constructive criticism of plans for integrated assessment of climate change, could aid in data-collection efforts, and would benefit greatly from the knowledge gained by the assessment process, both in terms of dealing with changing climate and in understanding climate-change processes and impacts on resources. Participants at the workshop began this critique by noting that the workshop series itself did not appear to have adequate focus (what exactly will be assessed?), that justification to Congress and others would be necessary and appropriate, and that the assessment community would need to continually demonstrate the value and productivity of the assessment to constituent groups. Other possible constituent contributions to assessment were noted: (1) integration of current knowledge about the possible causes and potential effects of climate change into the science curricula of schools; (2) dissemination of information about climate change to the members of their professional, social, and civic groups and verification that the information distributed is relevant; (3) assistance in data inventory during assessments of climate-change effects; and (4) assistance in the dissemination of information in Spanish and other languages spoken in the Southeast.

The fourth message was that the scientific community, in addition to compiling the baseline data against which to benchmark climate change, should develop better predictive models. In this usage, “better” means higher resolution (both spatial and temporal), greater certainty, and greater variety (i.e., not only weather models but also crop models, industrial-production models, epidemiological models, hydrologic models, glacier models, and many more).

The fifth message was that the best approach to climate change would be one of prevention rather than adaptation but that our society today lacks the political will to formulate an effective response to the threat of climate change. Partly, this lack of political will results from a perception of indecision and contradiction within the scientific community. Partly, it results from a lack of knowledge of what the future holds and what it will cost (in terms of lives, dollars, and jobs) to cope with that future. In short, decision makers are loath to commit resources to battle a threat they are not convinced exists. Instead, our society was characterized as one that reacts to crises, allocating resources to repair damage, to ease suffering, and to cope with a problem when the need arises. If that characterization is correct, mankind is more likely to adapt to climate change (sometimes successfully and other times unsuccessfully) at great cost in life, property, and capital investment than to take steps to obviate it.

The sixth message was that those who felt that climate change is occurring and is a significant threat to mankind should mobilize an educational effort to point out the signs of changing climate, enumerate the potential effects of that change on local areas (largely in economic terms), delineate the mitigative steps that could be taken to avoid the consequences of climate change, build constituencies, and influence decision makers to invest in actions that would help to avoid drastic changes in climate.

CONSTITUENT PRIORITIES AND CONCERNS

In the three breakout sessions, participants discussed their concerns with respect to the environment, their views of climate change, and possible future climate-change scenarios. One objective of these sessions was to identify key ecological and social systems that the participants thought were at significant risk from climate change and could produce significant impacts on residents of the southeastern United States. The groups spent considerable time discussing potential social issues raised by the threat of climate change. The main concerns related to the effects of extreme climate change on basic human needs, such as food and water. Participants said that they feared that an underclass would develop as a result of the impacts of extreme climate change. The range of key systems and concerns identified by the participants included:

- Medical and health: vector-borne disease (e.g., hanta virus),asthma,other health effects caused by nonpollutant drivers
- Water quality: availability and quality of drinking water, ground and surface water contamination, the quality of surface waters for recreation and fishing
- Coastal resources: effects on fisheries (species shifts and habitat access) and on the health of marine ecosystems, saltwater intrusion into wetlands; collapse of estuaries, cost

of sea walls and dikes, relationship to growth, impacts on developed shoreline, adverse effects on retirement development, increased storm effects; increased insurance costs, effects on recreation and tourism

- Agriculture: the chicken industry, farmers having difficulty getting seed in and crops out with heavy spring rainfall, changes in crop patterns, agricultural strategies, and food production
- Agroforestry: this sector is a major employer in the Southeast, forests are declining because of development and urban sprawl
- Waste management: leaching and runoff of hazardous-waste-contaminated fluids because of heavy precipitation
- Transportation: disruption of routes of travel and commerce
- Business and industry: oil and gas industry infrastructure impacts; the petrochemical industry could be affected either way, depending on whether the climate turned cooler or warmer; changes in employment
- Biodiversity: impact on unique natural resources of the Southern Appalachians and the diversity of flora and fauna
- Migrations: immigration from areas adversely affected, more emigration from the Southeast because of undesirable climate
- Land-use: zoning decisions; changes in building codes in response to increased flooding, storms, etc.; increased costs of construction
- Cultural impacts: gravesites, artifacts, and remnant constructions of Native Americans may be lost
- Risk of catastrophic events: the collapse of the West Antarctic ice shelf would produce noticeable sea-level rise around the world
- Population: growth, standard of living, quality of life, lifestyle changes, aesthetics
- Urban air quality: ozone, mix of pollutants, impacts on human health
- Extreme events: effects on urbanized areas' infrastructure and services (e.g., sewage-treatment facilities)
- High energy demands: electric utility industry infrastructure would be stressed; use of electricity for cooling would exacerbate the problem by producing more greenhouse gases from fossil-fuel burning
- Environmental justice/equity: lower-income citizens would be less able to afford ameliorations like air conditioning; areas of lower-income like coastal swamps and mountain valleys would be subject to some of the worst effects like loss of land to sea-level rise and flash flooding

INFORMATION NEEDS

The participants identified their information needs and those that they thought would be needed to cope with the threat of climate change. Some constituents presented questions with very broad implications, such as: What will be the distribution of climate change impacts? When will climate change happen? What will happen? and What will it cost? Other participants spoke to both the types of information they needed or wanted with respect to climate change effects *and* how that information should be structured.

Although the types of information needs identified by participants were widespread, effects areas that were often the topic of discussion included *sea-level rise*, *storm and extreme event frequency and intensity*, and *the costs of inaction*. With respect to sea-level rise, participants wanted predictions for specific low-relief coastal areas, information on flooding potential, and predictions for coastal land loss. Regarding costs, participants were interested in how local economies will be impacted if no additional action is taken and cost/benefit information that would enable cities and communities to plan for climate change. Participants were also interested in information that would correlate or associate extreme events with climate change. These information needs center around compiling evidence that more action (political and otherwise) on climate change is needed. Participants also cited shortcomings in the current formats and availability of information. Specifically, they requested information on climate-change effects in shorter timeframes (i.e., five to ten years into the future), estimated costs per industrial or business sector, and information directed toward the educational level of the average voter.

Other examples of information needs include the summary costs of disasters like hurricanes; the costs associated with the changes in recreation that might be forced by climate change; the changes that would be necessary in the practice of agriculture in the region; a compilation of the information resources that are currently available (such as an EPA-sponsored data inventory); identification of biological indicators of climate change; a quantification of the net loss of biodiversity; a method of valuation for biodiversity and cultural processes and artifacts; a determination of how much are people willing to pay to preserve natural areas or systems; a regional model that will tell us about the distribution and temporal patterns of rainfall, extreme events, and seasonality; the effects of different types of precipitation on erosion; the ability of systems to respond to health problems, such as vector-borne and non-vector-borne diseases; demographic projections; a method of valuing nonmarket resources; the magnitude of land subsidence, land-loss rate, and sea-level rise that coastal wetlands are currently experiencing; the economic as well as ecological effects that might be experienced by fisheries; and the effects that may be produced by and visited on the oil and gas industry. In addition, information might be needed to demonstrate the effects of climate change on immigration.

CONSTITUENCIES REPRESENTED AT THE WORKSHOP

- American Association of Retired Persons
- American Planning Association
- Appalachia Science in the Public Interest
- Atlanta Chamber of Commerce
- Cabot-Smethurst and Associates
- Centers for Disease Control and Prevention
- Choctaw Indian Tribe in the state of Mississippi
- Clark Atlanta University
- Climate Action Network
- Coalition to Restore Coastal Louisiana
- Duke University Geology Department
- East Tennessee State University
- Environmental Coalition
- Environmental Defense Fund
- Environmental Protection Agency (federal and regional branches)
- Florida Department of Environmental Protection
- Foundation for Global Sustainability
- Georgia Air Protection Branch
- The Town of Hilton Head Island, South Carolina
- Independent Video Producer
- Louisiana Governor’s Office
- Louisiana State University (areas of geography and climatology)
- Missouri Department of Economic Development
- Physicians for Social Responsibility
- Southeast Regional Center of the National Institute for Global Environmental Change
- Science and Policy Associates
- Sierra Club

- Southern Appalachian Mountain Initiative (SAMI)
- Southeastern Negotiation Network
- Tennessee Valley Authority (TVA)
- Tennessee Valley Energy Reform Coalition
- The Climate Institute
- The Georgia Conservancy
- 20/20 Vision
- Union of Concerned Scientists
- University of Alabama
- University of Georgia, Department of Biological and Agricultural Engineering
- USDA Forest Service
- Wildlife Management Institute
- World Wildlife Fund
- Young Harris College, Towns County Georgia

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VI. Potential Impact Areas

One objective of the Southeastern Regional Workshop is to increase understanding of high priority regional environmental issues for which current climate variations and future climate change is likely to be relevant. In this section eight potential impact areas are briefly described in the context of current climate variability and future climate change including: agriculture/forestry, coastal/fisheries, human health, water resources, weather and climate extremes, parks and public lands, urban areas, and air quality. With the exception of air quality, these potential impact areas will be the focus of the breakout session discussions during the workshop. Air quality issues and their relationship to climate variability and change will be covered in the urban discussion. The brief summaries given below provide a starting point for the subsequent workshop presentations and discussions.

a. Agriculture and Forestry

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Nature of the Problem

Agriculture has been called "the most weather dependent of all human activities" (Oram, 1989).
Because of this dependency, variability of climate from year to year results in uncertainties in agricultural production and risks to the well-being of farmers, to local and regional economies, and even to global food security. One reason that climate variability is so devastating to agriculture is that we do not know when to expect favorable or unfavorable weather. Many critical decisions must be made several months or seasons before the impacts of weather are realized, putting at risk large investments in resources applied to the crop. There are many recent examples where drought, floods, and freezing temperatures have resulted in total or partial failure of agricultural systems in the SE USA and other regions and countries (...). Agriculture's vulnerability to weather variability is expected to increase as the world's population increases and marginal lands are brought into production (Glantz, 1994), and as other sectors (urban, industry, recreation) grow and compete for land, water, energy, and other natural resources. In addition to year to year variations in climate, changes in the global climate are expected over the next 50 years as atmospheric CO_2 and other greenhouse gases increase (IPCC, 1990a). Although the magnitude of this change is not certain, many studies have shown that agriculture could be affected in many parts of the world if global climate changes as anticipated (IPCC, 1990b; Rosenzweig and Parry, 1994; Rosenzweig et al., 1995).

Characterization of Agriculture and Forestry Systems in the SE USA

The Coastal Plains region of the Southeastern United States has a very productive agricultural sector that produces many high value crops such as citrus (oranges and grapefruit), vegetables (tomatoes, green peppers, celery), strawberries, sugarcane and tobacco; and also several field crops (peanuts, cotton, maize and soybean). Rainfed field crops are vulnerable primarily to drought stress, particularly on sandy soils. Fresh vegetables, sugarcane, citrus and some field crops are irrigated. Southern Florida produces about 50% of the nation's fresh winter vegetables. Although irrigation reduces sensitivity to rainfall fluctuations, these vegetable crops are particularly vulnerable to low temperature stress, as the unanticipated January 1997 freeze painfully demonstrated. Likewise, the citrus industry has been set back by a series of severe frosts in the late 1980s .

While supplemental irrigation offers farmers options for reducing risk, irrigation raises broader concerns from the perspective of natural resource managers. The source of groundwater for irrigation in the coastal plains is rainfall in the previous one to three years. Due to the interaction between groundwater and surface waters, over drafting can have harmful effects on wetlands, lakes and streams, as well as aquifers. Aquifer recharge and water availability are likely to be least when crops need irrigation most. ENSO influences both the demand for irrigation water and its supply.

Impacts and Vulnerability

Climate variability in the SE USA has been associated with El-Nino Southern Oscillation (ENSO) activity (Ropelewski and Halpert, 1986; Kiladis and Diaz, 1989; Sittel, 1994). El Nino years tend to be cool and La Nina years tend to be warm between October and April. El Nino years tend to be wet and La Nina years dry during these months. Recent studies have confirmed vulnerabilities of some crops in the SE to climate variability. Hansen et al. (1997) analyzed historical records for six crops in four states in the SE USA (Alabama, Georgia, Florida, and South Carolina) to characterize annual variability in agriculture and to determine how much of the variability is be associated with ENSO activity. They found that corn yields were high in La Nina years and low in years that followed these years. The magnitude of ENSO influence on corn yield variability was more than $200 million, or 26% of the annual average value of corn produced by these four states. The effects of ENSO activity on the values of annual soybean, peanut, and tobacco production were also significant, but not as large as for corn. Similar findings have been shown for crops in other parts of the world (Cane et al., 1994; Handler, 1984; Carlson et al., 1996). The demonstrated influence of ENSO on agricultural production and the emerging capacity to forecast climate anomalies at seasonal lead times (...) suggest an unprecedented opportunity to tailor agricultural decisions to anticipated weather conditions, either to mitigate the impacts of adverse conditions or to take advantage of favorable conditions.

Few studies on climate change effects on agriculture and forestry in the SE USA have been conducted. Curry et al. (1990a) studied two crops (corn and soybean) grown under current and two General Circulation Model (GCM) scenarios. Their results suggested that yields of soybean would decline by 11% and 52% in the two climate change scenarios under rainfed production whereas corn yields would decline by 8% and 73% for the two scenarios, respectively. In addition, Curry et al. (1990b) estimated relatively large increases in evapotranspiration and irrigation water requirements for soybean under the two climate change scenarios. In a national study, Adams et al. (1989) suggested that shifts of field crops from the SE to other parts of the USA could occur under climate change scenarios.

Potential for Changes in Policy, Management Decisions (Adaptation)

What can be done to reduce the unwanted impacts of climate variability on agriculture and forestry and take advantage of positive impacts? Effective application of climate forecasts to agriculture depends on 1) the availability of regional climate forecasts of adequate lead time and accuracy, 2) the vulnerability of agriculture to weather variability, 3) the existence and awareness of options for using knowledge of future weather to improve decisions and policies, and 4) the ability and willingness of decision and policy makers to modify their decisions based on available information (Lamb, 1981; Sonka et al., 1986; Mjelde, 1993). These decision makers include farmers who choose crops, management practices, areas to plant, and resources to use; advisors in public and private institutions who make recommendations and supply information to farmers; those who supply seed, manage irrigation resources, and provide other resources for production; and public policy makers who develop and provide information or influence decisions by policies, such as insurance, credit, and price supports. Additional research is needed to assess the likely impacts of annual climate variability and possible changes in climate on agriculture and forestry in the SE USA, and to facilitate improved decision making to reduce unwanted impacts and reduce risks. Research should be aimed at providing the necessary information, tools, and analyses to these agricultural decision makers, tailored to specific conditions in the SE region.

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b. Climate Related Impacts on Coastal Resources and Fisheries in Southeastern U.S.

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Populations on and near the coast of the southeastern United States grew at phenomenal rates over the past thirty years and included extensive construction of buildings and infrastructure. Although the rate of population increase has slowed a bit, the combination of popularity and risk in the dynamic coastal zone insures complex social and economic concerns as we look to mitigating the impacts of climate change. While the potential range of climate related impacts on ocean and coastal resources have been fairly well documented, we still lack a comprehensive assessment of the magnitude of costs associated with coastal hazards. Nonetheless, changes in the natural range of climate variability will likely add to the risks and costs of living in what may well be the geographical area most vulnerable to those changes.

This paper is intended to provide a brief overview of the literature regarding climate change and variability in the southeastern United States and impacts on the interwoven natural systems of coastal resources.

Sea Level Rise

That the Atlantic and Gulf coasts of the United States are experiencing increasing rates of sea level rise is well documented; the effects may be augmented by natural land subsidence which seems to also be occurring. The natural process of changes in relative sea level has profound impacts on coastal systems. The areas naturally at risk include tidal deltas and low-lying coastal plains, sandy beaches and barrier islands, coastal wetlands, estuaries and lagoons, mangroves and coral reefs. These impacts may be exacerbated if the rate of increase accelerates as a function of global climate change.

Coastal habitats such as wetlands, mangroves, seagrass beds and coral reefs are always in a dynamic state. These systems play an important role in shore stabilization as well as fisheries habitat. Historically, wetlands (and mangroves and sea grass beds) usually migrate landward at a rate dictated by the landward slope and the rate of sea level rise...unless human-induced physical alterations and development serve as barriers to that landward migration .

Initially, fish production might increase as species would have greater ccess to the edges of marsh areas as they begin to fragment and more utrients become available from leaching of soils and flooded peat. Eventually, these coastal food systems would decline in productivity with the loss of habitat and nourishment: this decline would affect coastal wildlife broadly.

An analog to demonstrate the potential impact of increasing rates of sea level rise is the northern Gulf of Mexico. This area (Louisiana and parts of the Texas coast) have anomalously high relative sea level rise and erosion coupled with low elevation and mobile sediments. In particular, the marshes of south Louisiana are rapidly deteriorating (due to marsh alterations, channelization and controlled stream flows) and, as a result, are being converted to water bottoms--in a region where the principal fisheries such as shrimp (and red drum) are estuarine dependent and extensively use the flooded marsh surfaces. Open water bottoms are far less
productive as nursery areas.

Additionally, off the coast of southern Florida, coral building organisms thrive at a rather narrow range of water temperatures and depths. Although these organisms (in a healthy state) can build reefs at a rate fast enough to keep up with predicted sea level rise, other factors such as storms,
increased sedimentation and warmer water temperatures could interfere with their growth and, in some cases, could kill the organisms--this is a special concern in the Keys which lack terrigenous sediment inputs. Loss of coral reefs would change the wave and water patterns near the coast, allow for increased coastal erosion and reduce habitat availability for reef fish assemblages.

Sea level rise could also push the interface between saline and fresh waters further upstream. This salinity intrusion could have adverse impacts on freshwater aquifers in deltaic regions and coastal plains. In these areas, the effect of sea level rise may also be exacerbated by heavy rates of freshwater withdrawal which may result in either subsidence and/or replacement by seawater. Other considerations include the industrial intake systems which would need to be reengineered. And migration of the interface could dramatically affect fishery spawning and nursery habitats...especially for anadromous species.

Extreme Temperature Fluctuations and Changes

The relationship between climatic parameters and marine fisheries is complex and not well understood although evidence supports the view that relatively small changes in climate often produce dramatic changes in fish stocks because of impacts on water masses and hydrodynamics. Certainly, our understanding of these relationships have become clearer as a result of our greater focus on the impacts of the El Nino-Southern Oscillation.

As almost 80% of all marine species are considered coastal, the climate-related impacts on marine fishes and associated biota are most acute. Changes in the mean state, variability and extreme of regional climates can easily affect food availability, species-specific differences in thermal range and disease susceptibility, and shifts in species assemblages. These, in turn, could alter the success of recruitment, change population stability, and may lead to species displacement in certain areas.

Increases or significant fluctuations in surface temperatures of estuaries or the coastal ocean would have a wide range of impacts, all with complicated feedback loops. Shallow water systems like many coastal estuaries and the northern Gulf of Mexico may experience increased severity and period of summer stratification.

There is literature that suggests that significant climate change could also result in possible variations in the Gulf Stream; for instance, meanders may decline in frequency and size. Changes in the meanders and eddies have implications for upwelling and downwelling patterns along the southeastern Atlantic coast. Upwelling and downwelling patterns are important in providing nutrients for ocean species in an area where nutrients are often the limiting factor for productivity; such changes may have implications for migratory patterns of both fish and fowl.

Warming would affect especially marine species in shallow water. A particular concern might be bivalves such as oysters which would be unable to migrate to more favorable conditions. Coral reefs are especially sensitive to increases in seawater temperature: recent episodes of coral
bleaching have been linked to significant variations in the seasonal maximum temperature.

Recent studies have focused on the causal relationship between sea-surface temperature and the formation of tropical cyclones: some believe that we may see more frequent and more severe storms in the southeast. Any changes in the frequency, intensity, duration, and location of extreme meteorological events are likely to have region-specific impacts. The southeast and gulf coasts are especially vulnerable to hurricanes because of their geomorphology.

Alterations in temperatures could affect wind and water circulation patterns as discussed above. Altered patterns of current flow in the inshore and coastal ocean can cut off fisheries populations by forming thermal barriers that will block normal ingress and egress from spawning
and nursery grounds: changes in physical parameters, especially circulation patterns could also have a direct effect on mortality and recruitment as well as the current stratification of stock structure. Profound effects would be most evident with highly migratory fisheries such as menhaden.

Changes in Precipitation Patterns

In the southeastern United States, many scenarios suggest a warmer climate; while there is greater variability, many models also seem to suggest a drier climate on average. The southeast currently experiences fairly abundant rainfall patterns although tree core work provides evidence that recent precipitation patterns were the wettest on average of the past thousand years. Any long term diminution in precipitation patterns could have a number of impacts. In many coastal systems in the southeast, there is a significant amount of groundwater recharge and release that is associated with rainfall events. Recharge rates could slow, in turn affecting both surface and subsurface water systems.

In a region of the country which has fairly high rates of agricultural soil loss, reduction in the rates of precipitation could possibly decrease stream turbidity. As many fisheries species in tropical and temperate zones are nutrient limited in terms of productivity, reduction of nutrient
inputs could adversely impact certain fisheries.

Decreased rates and periods of precipitation could also impact the zonation between marine and freshwater in coastal estuaries. This, in turn could impact on morphology and stability, substrate composition and habitat complexity. Further, oxygen levels may be reduced from effects of stratification and increased oxygen demand associated with warming waters.

In areas already suffering from eutrophication such as the northern Gulf of Mexico and Florida Bay, this would further exacerbate that problem.

Summation

Both scientific and analog studies suggest that the magnitude of climate-related impacts on the natural coastal systems could be quite significant, perhaps disproportionately so. These impacts in turn have profound social and economic consequences. As one example, the coast of the southeastern United States is quite popular as a tourist destination: receding beaches, more severe coastal storms, and declining fisheries could reduce visitation rates which would have dire consequences for many coastal communities.

We need to improve not only our understanding of the interrelationships of these natural processes but also the societal implications. Beyond that, we also need to improve our ability to effectively communicate the nature and scope of climate-related impacts.

c. Societal Impacts of Weather and Climate Extremes

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In recent years, decision makers in government, insurance, and other sectors have demonstrated increasing concern about the actual and potential impacts of weather and climate on society. To significant degree, concern has been motivated by expectations that human-induced climate change will result in increasingly greater weather-related impacts to society. Concern has also been motivated by actual increases in weather-related impacts documented in recent years. Understanding these impacts in terms of trends, causes, and projections has significance for a range of policy decisons related to disaster mitigation and the international negotiations on climate change.

The impacts of weather on society have been defined according to a three-tiered sequence (Changnon 1996): "Direct impacts" are those most closely related to the event, such as property losses associated with wind damage. "Secondary impacts" are those related to the direct impacts. For example, an increase in medical problems or disease following a hurricane would be a secondary impact. "Tertiary impacts" are those which follow long after the storm has passed. A change in property tax revenues collected in the years following a storm is an example of a tertiary impact. The impacts discussed in this section are direct impacts.

Table 1 summarizes data presented at a recent workshop on the direct impacts of recent extreme events in the United States as measured by loss of life and current dollar losses.[4] The Southeast region is particularly vulnerable to hurricanes, floods, winter storms, extreme temperatures, and drought (see http://water.dnr.state.sc.us/climate/sercc/extreme_weather.html for further information).

While scholars agree that relatively poor quality of available data on impacts limits conclusive findings, several points do 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. Note that while drought is not included in the table, its impacts on society can be large, such as the 1993 drought in the southeast which resulted in more than $1 billion in crop losses alone (Lott 1993, ftp://ftp.ncdc.noaa.gov/pub/data/techrpts/tr9304/flood-93.txt).[5]

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.

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[4] See for example, Report of the Workshop on the Social and Economic Impacts of Weather, 2-4 April 1997, National Center for Atmospheric Research (NCAR), Boulder, CO Workshop report available at http://www.dir.ucar.edu/esig/socasp/weather1.

[5] For more on the impacts of drought see the National Drought Mitigation Center at http://enso.unl.edu/ndmc/index.html.

Trend data can mislead. 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.

On a roughly 20-year time scale, societal impacts associated with the impacts of extreme events are increasing in terms of both deaths and dollars (with the single exception of tornado-related deaths). Additionally, the increase in impacts is largely due to societal factors with respect to each phenomenon, expect for perhaps floods (Pielke 1997a). Our poor understanding of past impacts limits what can be concluded about the future, strongly suggesting a need to better understand the existing interrelationship of climatological and societal factors which underlie the trends in impacts.

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)	Source(s)
floods	96 (‘86-’95)	$2.4B (‘84-’93)	$20B (‘93) 156 (‘76)	Pielke (1996), Ye and Ye (1996), Myers (1997)
hurricanes	20 (‘86-’95)	$6.2B (‘89-’95)	$30B (‘92) 256 (‘69)	Pielke (1997), Hebert et al. (1996)
winter storms	47 (‘88-’95)	>$1B (est.)	$6B (‘93) 200+ (‘93)	Parrish (1997), Kocin (1997)
tornadoes	44 (‘85-’95)	$2.9B (‘91-’94)	$3.8B (‘93) 94 (‘85)	Roth (1996), Golden (1997)
extreme heat	384 (‘79-’92)	?	>$15B (‘80) 522 (‘95)	Parrish (1997), Adams (1997)
extreme cold	770 (‘68-’85)	?	>$30B (‘76-’77) ?	Kilbourne (1997), Adams (1997)
lightning	175 (‘40-’81)	>$1B (est.)	?	Kithil (1997)
hail	-	$2.3B (est.)	$650M (‘90)	Changnon (1997)
ANNUAL AVERAGES	**>1500**	**>$15.8B**		

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d. Human Health - Edelman's paper

e. Climate Change and Its Potential Effects on Parks and Public Lands in the Southeast

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SETTING

The Southeast has been one of the fastest growing regions in the nation over the past several decades. It is projected to remain a fast growing region in the foreseeable future. Accompanying this growth are significant changes in the region's development patterns. The economy of the southeast has shifted from one based primarily on agriculture and forestry to one based on industrialization and urbanization. The so-called sun belt phenomenon has had and continues to have a major impact on the Southeastern U.S. and its parks and public lands.

In the nineteenth century, historical settlement patterns had left much of the Southeast's natural resource base--soils, forests, rivers, wildlife--in poor condition. In the first part of the twentieth century, a concerned nation supported restoration and conservation efforts. During this period, national forests were created to protect the headwaters of major rivers in the Southeast; national parks were established to preserve some of its special places; wildlife refuges were established to protect special wildlife habitats; and a special authority was established to oversee the protection and development of the Tennessee Valley. Other lands were also set aside for public purposes; for example, defense--military bases, Oak Ridge, Tennessee Reservation, recreation areas, nature preserves; state parks and state forests; and so on.

The topography of the Southeast-- ranging from mountains containing the highest peak east of the Mississippi River to the Deltas--is as diverse as its economy, and its social and cultural patterns. This diverse topography creates major flooding problems ranging from the mountainous terrain to major sedimentation problems along the coasts.

ROLES AND FUNCTIONS OF PUBLIC LANDS

Public lands serve multiple roles and functions in our society. As Table 1 indicates, there are now a variety of uses for these lands in the Southeastern U.S.--national forests, national parks and reserves, recreation areas, wildlife refuges, marine sanctuaries, Indian reservations, military bases, and major national research facilities. These lands are managed by a variety of Federal agencies for a variety of public services. In addition state and local agencies manage a significant amount of land for a variety of public purposes--forests, parks, nature reserves, water supply watersheds, and so on.

Moreover, public lands encompass many things that society treasures beyond the production of goods--preservation and restoration of threatened and endangered species, preservation of historic structures, habitats of migratory birds, old growth forests, preservation of biological diversity and scenery, just to name a few.
However, in places where public lands form a significant portion of the landscape, especially at the county level, they are perceived both as an asset that local people enjoy and as a barrier to future economic development.

SENSITIVE ECOSYSTEMS IN THE SOUTHEAST

Parks and public lands in the Southeast are encompassed by several of the nation's most sensitive ecosystems. The Southern Appalachians, for example, contain several peaks more than 6000 feet. Also, the Great Smoky Mountains National Park, with several peaks more than 5000 feet, contains several sensitive species of trees, plants, and wildlife. It preserves one of the world's finest remaining examples of temperate deciduous forests.

Another extremely sensitive ecosystem is the South Florida/Everglades ecosystem. The Everglades National Park contains the largest remaining subtropical wilderness in the coterminous U.S. and contains extensive fresh and saltwater areas, open Everglades prairies, and mangrove forests. The adjacent Big Cypress National Preserve is a large area that protects the critical watershed for the threatened ecosystem of South Florida; this area is also home to endangered species like the Florida Panther and the red-cockaded woodpecker.

The Great Smoky Mountains National Park (over 9 million visitors per year) and the Everglades National Park are two of the most visited National Parks in the U.S. Other sensitive ecosystems in the Southeast are the system of barrier islands--South Atlantic Coast, South Florida, and the Gulf Islands. The Gulf Coast/Mississippi Delta also contains a wide variety of species and is quite sensitive to significant changes.

THREATS TO SOUTHEASTERN ECOSYSTEMS

Each of the aforementioned, and other sensitive ecosystems in the Southeast are currently under extreme stress. Further threats to them will make it extremely difficult for managers of these public lands to efficiently and effectively carry of their responsibilities, especially in view of cutbacks in budget and personnel.

Public land managers are generally not well equipped, in resources nor skills, to deal with catastrophic events--like floods, droughts, public water supply shortages, and invasion of exotic species. Moreover, they generally have no authority to deal with issues outside the boundaries of the lands they manage.

Climate change, therefore, has the potential to have a major impact on how public lands are managed in the Southeast--perhaps even more so than in any other section of the country.

Table 1. Federal lands in the Southeast

		Alabama		Arkansas		Florida		Georgia		Louisia
Department	**Type of Area**	units	net acreage	units	net acreage	units	net acreage	units	net acreage	units
Agriculture	National Forests	4	658,124	2	1,638,547	4	1,135,306	2	862,368	1
Commerce	National Marine Sanctuary	0	-	0	-	1	2,351,000	1	14,700	1
	National Estuarine Research Reserve*	1	3000	0	-	2	112,198	1	17,950	0
Defense	Military Reservation	5		2		15		10		3
	Corps of Engineers									
	Indian									

		Alabama		Arkansas		Florida		Georgia		Louisia
Interior	Reservations									
	USF&WS Wildlife Refuges	8	54,938	10	315,079	28	934,302	9	478,907	19
	National Park Service									
	National Park	0	-	1	5,549	3	1,745,474	0	-	0
	National Seashore	0	-	0	-	2	193,286	1	36,415	0
	National Preserve	1	13,699	0	-	2	762,000	0	-	1
	National Recreation	0	-	0	-	0	-	19,25 9		
	National River	0	-	1	94,309	0	-	0	-	0
	Parkway	1	See MS	0	-	0	-	0	-	0
	Other	4	2,408	3	4,694	4	414	8	18,170	3
Other										
Transpor-tation	Coast Guard Facilities									
TVA	Land Between the Lakes									
	other reservoir									
NASA										

*Includes land and water area

Table 1. Federal lands in the Southeast (cont'd)

		Mississippi		North Carolina		South Carolina		Tennessee	
Department	**Type of Area**	units	net acreage	units	net acreage	units	net acreage	units	net acreage
Agriculture	National Forests	6	1,149,466	4	1,638,547	2	609,788	1	627,730
Commerce	National Marine Sanctuary	0	-	1	640	0	-	0	-
	National Estuarime Research Reserve*	0	-	1	10,000	2	143,710	0	-
Defense	Military Reservation	5		6		6		1	
	Corps of Engineers								
Interior	Indian Reservations								
	USF&WS Wildlife Refuges	10	220,815	11	412,728	5	154,171	6	113,692
	National Park Service								
	National Park	0	-	1	See TN	0	-	1	521,053-
	National Seashore	0	see FL	2	56,562	0	-	0	-
	National Preserve	0	-	0	-	0	-	0	-
	National Recreation	0	-	0	-	0	-	1	125,000
	National River	0	-	0	-	0	-	1	5,056
	Parkway	1	51,748	1	87,934	0	-	1	See MS
	Other	4	1,846	5	1,510	6	28,198	4	4,541
Other									
Transpor-tation	Coast Guard Facilities								
TVA	Land Between the Lakes								
	other reservoir								
NASA									

*Includes land and water area

f. Urbanization and its Potential Effects on Regional Climate and Hydrometeorology

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Urbanization exists along with deforestation and agriculture, as the most profound example of human alteration of the Earth's surface. Changes that result from urbanization also impact biophysical, hydrologic, and climatic processes, which in turn, affect adjacent natural ecosystems. In transforming the natural landscape through human interactions, the city environment has evolved into a biophysical ecosystem that includes both human-modified surfaces and elements from the natural ecosystem extant within, or surrounding built-up areas. This city or urban ecosystem is extremely complex; it is the sum total of all the biophysical-social interrelationships that comprise the urban environment. Because of the complexity of the interrelationships found within the urban environment, a systematic study of cities as ecosystems requires the segmenting of biophysical, climatic, hydrologic, and social components into individual systems to understand how these functional units interact to form the urban ecosystem.

Because cities are so heterogeneous in nature, they are difficult to study from a synergistic perspective. If viewed from an organismic or systems ecology approach though, the city may be surveyed as a series of energy and material flows that cycle into and out of the urban environment. Thus, it is the interlinkage of air, land, water, and living organisms in an expansive network of interrelated human, biological, and physical processes that conjoin to delimit the urban environment. The urban ecosystem concept provides a powerful tool for understanding the dynamics of the city as a “living” entity. It furnishes a framework for perceiving the effect of human activities on the local, regional, or potentially, even global environment. It also facilitates weighing the relative costs and benefits of alternative actions that may mitigate human-induced environmental pressures. Additionally, the ecosystems approach is appropriate for examining all levels of physical, biophysical, climatic, hydrologic, and socioeconomic activities from the urban pond to the effects of the megalopolis on the regional climate. Identifying the links in the urban ecosystem and understanding their importance in the overall ecosystem, yields new insights and inspires more efficient deployment of activities, resources, and space. With such knowledge, both inhabitants and decision-makers can make better, more informed choices on how to maintain the city as a livable, ecologically viable, and sustainable urban environment.

The urban ecosystem is consumption driven by human demands. As an entirely human manifestation on the land, the city is inherently consumption-oriented and utilizes vast quantities of resources located either in close proximity or distant to its specific geographic location. In return, large quantities of waste are expelled from the city in the form of hydrologic, airborne, biological, chemical, and anthropogenic (e.g., metals, plastics) effluent into the surrounding environment. In many cases, the effects of these waste byproducts can be carried far outside of the local urban environment, for example, as air pollution or contaminated water. If viewed from an ecosystem perspective, the whole spectrum of inflow and outflow interrelationships that form the urban environment can be idealized as a series of cycles or transport routes. Figure 1 provides a generalized overview of some of the key cycles that operate within the urban ecosystem. The quantities of materials moving through the cycling processes may be evaluated in terms of mass-balance or mass-budget; hence, if viewed from “classical” energy balance or water budget approaches, quantification of the input of matter or material into the city, the storage of these input properties and their transfer or conversion, along with the output of “waste” or other characteristics can be analyzed. Using this approach, it is theoretically possible to account for all matter coming into, moving through, and flowing out from the city; practically this is difficult because of the interlinkages and dependencies exhibited by the multitude of processes functioning in the urban ecosystem. Nonetheless, it is worthwhile to attempt to analyze the city as a series of cycles like those displayed in Figure 1, to assist in identifying how human activities within the urban environment affect other aspects of cities and their surroundings. In effect, the cycling of the processes innate to the city can be compared to the mass energy budget or nutrient balance of a forest or pond ecosystem.

One of the fundamental components that makes the city environment unique from its rural counterpart, is the climate that prevails over urban areas. The alteration of the landscape through urbanization involves the transformation of the radiative, moisture, and aerodynamic characteristics that displace the natural channeling of energy through the solar and hydrologic systems. Although large-scale atmospheric and climatic phenomena are global in scope, urban areas cannot be viewed in isolation because the local environment modifies the conditions in the thin air stratum above the ground, generally referred to as the atmospheric boundary layer. As humans alter the character of the natural landscape in the city-building process, they affect and impact local energy exchanges that take place within the boundary layer. The end result from this modification of the landscape influences the local (microscale), mesoscale, and potentially even the macroscale climate.

Modifications of local effects induced by human settlement usually exceed those defined as microclimatic. The city climate can justifiably be placed within the range of the regional or mesoclimate similar to the influence of a several degree shift in latitude. Moreover, the size, type of activity, and location of a city within meso-or macroclimatic zones will have profound influence on the degree of contrast in reference to heating and cooling patterns, that the urban area has with the surrounding environment. A summary of causal elements of climatic change in urban areas, is presented in Table 1. This warming of the air over cities in contrast to their rural counterparts is known as the "urban heat island" effect. As urban areas across the world continue to grow and form extensive urban megalopolis complexes, such as the "Bos-Wash" corridor between Washington, D.C. and Boston, Massachusetts, larger regions will be affected by the urban heat island phenomenon. Although there is no direct evidence of the urban heat island impacting macroscale climates, it appears plausible that urban areas exist as point sources of thermal pollution which potentially may be a contributing factor to global warming.

In addition to effects on the local, regional, and possibly even global climate, the circulation of water in the city, like that of energy, involves two-inter-linked systems: the human-modified hydrologic cycle and the human-modified artificial water supply and waste-water disposal system. The natural circulation of water is modified by the nature of the urban surface, which encourages rapid runoff and decreases infiltration. The urban heat balance affects rain-producing mechanisms and the rate of snow-melt over and within cities. Urbanization affects stream channels and flood plains, often causing water to flow through cities at higher velocities and increasing the threat of flooding and in general, increasing the cost of urban storm water management practices.

Precipitation is altered by the urban environment, but the nature of the alteration is neither well established nor common to all cities. Urbanization appears to affect precipitation by increases in hygoscopic nuclei, in turbulence via the increased surface roughness, in convection because of increased surface temperatures, and through the addition of water vapor by combustion sources. Precipitation tends to increase on the downward side of cities or large industrial complexes; i.e., the renowned "La Porte effect" where studies have shown an increase in precipitation in La Porte, Indiana, which is located downwind from Chicago, Illinois). The effect of cities on rainfall, however is difficult to determine, because few rural stations remain unaffected to some degree by human activity.

Evaporation rates from urban areas are not well understood, and although pavements and buildings may be storage areas for the release of water through time, the release of this moisture to the atmosphere is much greater than in vegetated areas, where surface water would be retained and used for evapotranspiration by plants. Paved or roofed surfaces reduce the opportunities for water to infiltrate. Lack of infiltrating water to replenish soil moisture may lead to a lowering of the water table and a reduction in groundwater levels beneath cities. In many cities, artificial application of water to unpaved areas (e.g., parks, lawns), may add much more to the subsoil than would infiltrate under non-urban conditions. If this artificial increase to the urban soil water body is added to the possible increased rainfall due to urbanization, it is evident that the urban soil water body is extremely diverse in moisture characteristics. Some areas -- especially the intensely built-up and largely paved central city -- may be virtually devoid of replenishment by infiltration, while others -- especially parks or gardens -- may possibly have more infiltration than adjacent rural lands. Thus, the role of infiltration in the urban hydrologic and urban ecosystems cycle, remains difficult to define.

Reductions in infiltration and the redirection of water from paved surfaces directly to storm water drains and stream channels results in a loss of recharge to the groundwater reservoir. Loss of water recharge affects the discharge of water from the groundwater body to stream channels during dry periods. This groundwater outflow, or baseflow, decreases with urbanization, while direct runoff, or storm water discharge, increases. These two trends in urban hydrology tend to make urban streams more subject to flash-flooding, with higher peak flows and lower dry weather flows. Compounding this propensity of streams to be more prone to flash-floods, is the nature of runoff in urban areas. Runoff in urban areas differs from that in rural areas by changing the total volume of runoff and concentration of water movement into bigger storm peak discharges. Additionally, as mentioned previously, pavements and buildings as impervious surfaces, change the overall character of the water running off these surfaces, by creating large amounts of sheet runoff and less infiltration of water into the subsoil.

Thus, examination of urban ecosystems as an integral aspect of the regions in which they are located, is imperative if we are to understand the impacts of climate variability and change on regional environmental, demographic and economic issues. Viewing cities from an urban ecosystems perspective facilitates assessing the vulnerabilities to, and opportunities associated with, climate and hydrometeorological variability and change. The urban ecosystems approach to analysis of cities also provides a more fundamental and robust scientific framework for defining the research questions important to understanding how urban areas affect their local and regional surroundings, and how they may be affected by large-scale changes in climatic variability. Moreover, evaluating the urban environment as an urban ecosystem, permits a sound basis for developing recommendations and actions to maintain or build cities as sustainable and ecologically viable urban entities.

Figure 1. Generalized diagram of the flows of processes and materials into, through, and out of the city as viewed from an urban ecosystem cycle approach. Major urban ecosystem cycle components or "nodes" are represented in ellipses. Items in red represent those processes that generally flow out of a particular major urban ecosystem cycle into another cycle. For example, aerosols and dust are a product that flow from the Urban Atmosphere cycle into the Urban Biosphere cycle.

Table 1.

Causal Elements of Climatic Change in Urban Areas
(Emphasis on Surface Cover Components)

Cause

Change in Surface Materials which Disrupts/Modifies Natural Surfaces
(e.g., pavement, buildings, introduction of non-native vegetation)

Effects

(Local and Potentially Regional Factors that are Effected)

Albedo	Water Storage Capacity
Emissivity	Evapotranspiration
Heat Capacity	Production of Latent Heat
Thermal Conductivity	Production of Sensible Heat
Soil Permeability/Pore Volume	Specific Humidity
Evaporation	Aerodynamics/Roughness

Changes as Identified by Climate Budgets

Radiation Budget

- Increased absorption of the incoming shortwave (global) radiation as a result of lower albedo
- Decrease of high rate of outgoing longwave radiation due to absorption and re-emission by city surface

Energy Budget

- Increased thermal admittance because of higher thermal conductivity
- Increased anthropogenic heat production

Humidity-Water Budget

- Decreased subsurface water storage because of lower permeability and lower pore volume (i.e., accelerated runoff)
- Decreased evapotranspiration (ie., low portion of latent heat)

Air Budget

- Reduced horizontal advection and increased vertical exchange as a result of higher surface roughness (therefore, a decrease of horizontal flux of sensible heat)
- Increased thermal turbulence

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g. Water Resources

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Evidence to date indicates that the predictable effects of climate change will not require the invention of better water resources approaches, but will make it more important to apply the best approaches available now.

Fundamental changes under climate change. Most global models indicate that temperature increases will translate into more variable precipitation; the combination will tend to warm water bodies, and change flow regimes and lake levels. The larger standard deviations in precipitation would mean longer and more severe droughts, and more severe deluges and flood flows.

Changes in the temperature stratification in lakes would effect the types and quantities of organisms they supported. Changes in runoff and groundwater flows to lakes and rivers could change nutrient and non-point source pollution loading. Biological productivity is expected to increase at high altitude and deep lakes, but extinctions would be more likely at low altitude and shallow lakes. The spatial distribution of wetlands is likely to change. The areal extent, depth, duration and frequency of flooding of wetlands would be affected Intergovernmental Panel on Climate Change, 1996. Climate Change 1995; Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analysis. Cambridge University Press., but the effects on regional and global wetlands functions have not yet been predicted and would inevitably reflect great uncertainty at this time.

Adaptation. Humans have traditionally buffered themselves from precipitation variability by creating water storage facilities and regulating his living and working patterns to minimize the effects of floods and droughts. Conceptual and case study analysis indicates that these same methods will work, and in fact, the performance of some current water supply and flood control systems may not be greatly affected, and the effects may sometimes be slightly positive. Additional structural and non-structural measures will be needed in some regions, but uncertainty about climate change and its hydrologic consequences makes it imprudent to do anything but targeted research at this point.
In watersheds without sufficient managed storage, drought preparedness planning, soil conservation, agricultural and urban non-point source pollution prevention could be expected to become more important. The costs of crop and flood insurance, and the areal coverage of and costs of agricultural water conserving irrigation systems and urban water conservation measures, including pricing, might increase.

Timing. The timing, magnitude and nature of climate change impacts are all uncertain but far enough into the future that it does not make sense to begin adaptation any time soon. It appears climate change will impact water systems more slowly than other factors, such as population growth, to which water managers have adapted relatively well.

Case study simulations of river basins under climate change.

The Corps Institute for Water Resources instigated several investigations of the economic and environmental effects of climate change in major U.S. basins. Except for the Savannah River basin study, these studies used simulation models that had been developed and reviewed as part of recent collaborative planning The results are briefly summarized below.

Great Lakes Impacts Under Climate Change.

Climate change model/scenario	Impacts on Great Lakes	Counter Measures
Geophysics Fluid Dynamics Laboratory	Relatively benign impacts	None required
United Kingdom Meteorological Office	Moderately adverse to hydropower and Lake Erie navigation	Control structure between Lakes Erie and Ontario would reduce impacts, but not cost justified
Max Planck Institute	Severe, widespread especially after 2030	Water control structures between lakes would stabilize wetlands and fisheries, and would be cost justified.

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Great Lakes (2). Researchers simulated the operation of the Great Lakes under three different climate change scenarios using a simulation model developed during an International Joint Commission (IJC) study of the lakes. IJC decision makers concluded that effects were both distant and uncertain, and that traditional management measures would reduce potential impacts, so the prudent decision was simply to continue to monitor climate change research and climate variables that reflect regional changes.

Washington, DC Metropolitan Area Water Supply System (3). Analysts forecast water demand under six climate change scenarios, including three transient GCM runs based on the latest Intergovernmental Panel on Climate Change emission scenarios. Water use was essentially the same under all scenarios compared to future water use without climate change, increasing at most by less than 6 percent in the summer.

Tacoma Water Supply System (4) These scenarios were based on results from coupled ocean-atmosphere General Circulation Models downscaled via the perturbation method, and the regional circulation pattern (RCP) method. The effects were modeled using a simulation model that had been built and verified by regional water managers and stakeholders during the National Drought Study. The simulation showed that for all climate change scenarios, the peak runoff now caused by spring snow melt would shift to a rainfall dominated event during the winter. That change in phase affected instream flows and flooding, but did not significantly affect the performance of the water supply system.

Savannah River System (5). Simulated annual average reservoir inflows were higher for two of three sets of IPCC transient climate change scenarios (Geophysics Fluid Dynamics

Laboratory and United Kingdom Meteorological Office) and slightly lower for Max Planck Institute,
compared to historical averages. The net economic effects were favorable for the first two, and essentially neutral for the MPI. Environmental effects were negligible for the first two, but violations of minimum flows based on spawning constraints would be slightly more frequent.

Boston metropolitan water supply (6) This study used the same climate change scenarios and transposition to regional conditions as the Washington, D.C. study. Simulations showed that the timing of the historic runoff peaks would shift from early summer to late winter. The system
maintained complete reliability in all but one combination of climate change and demand scenario, primarily because the capacity of the water system is so large in relation to demand. (Boston metropolitan demand has been sharply reduced by water price increases and its long term demand will be reduced because of national plumbing code changes made in 1992).

Climate change could celebrate the traditional strengths and highlight the characteristic weaknesses of water managers. Public involvement, collaboration, integration of water with other environmental and infrastructure programs will be all the important; adaptive management willbe even more advisable.

Apalachicola-Chattahoochee-Flint(7) Fifteen sets of scenarios were generated from the three GCMs used in the Savannah River study, each scenario consisting of one of five decades for each of the three models. Runoff was simulated from daily precipitation and temperature data from the 60 year base historical period and from each of the climate change scenarios, using a distributed hydrologic model. Municipal and navigation water demands were varied to evaluate the sensitivity of system reliability to changes in demand as well as supply. The three GCM?s
forecast somewhat different meteorological outcomes, especially in precipitation distributions. Consequently, scenarios with both increases and decreases in streamflow were evaluated, with the timing of increases and decreases varied as well. The impacts on the basin are directly proportional to the change in streamflow, but depend on the location of runoff changes and storage (Lake Lanier controls a small portion of the drainage, but contains most of the system storage). High flow scenarios increase daily peaking energy by about 5%, the reliability
of lake levels suitable for recreation rises from about 50% to 70%, and the average annual maximum system outflow increases by 35%. Low flow scenarios reduce recreation reliability to about 42%, daily peaking energy by 4%, and navigation reliability by 15-20%. Municipal water
demands are essentially met under all scenarios because of the high priority given to meeting those demands in the operational rules. The effect of forecasted growth (through 2050) in municipal demands on system performance is of the same magnitude as the effect of climate change.

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h. Impact of Climate Change and Climate Variability on Air Quality

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Air quality is intimately related to weather and climate. The concentration of air pollutants is directly related to the dilution and dispersive characteristics of the atmosphere which in turn are related to the large scale pressure distribution and atmospheric stability. In addition, many anthropogenic and natural emissions are directly governed by weather variables and, of course, wet and dry removal processes are governed by weather conditions. Trends and distributions in air quality are then often tied to weather and climate fluctuations and trends on all timescales. The following discusses specifics of these relationships using ozone in the Southeast U.S. as an example air pollutant.

Ozone

Ozone is one of the most pervasive and complex air pollutants in the Southeast U.S. Epidemiological studies and clinical evidence indicate human health at levels above the current 120 ppb U.S. Environmental Protection Agency standard, however, there is some indication that there are a continuous range of effects even below the current standard. In addition, forest and material losses have been estimated to exceed over 6 billion per year in the U.S. Over 5 billion dollars has been spent in the Southeast in the last ten years attempting to control ozone. Ozone is a secondary pollutant in that it is formed in the atmosphere through photochemical processes from emissions of nitrogen oxides and volatile organic compounds. Like most air pollutants, there are natural quantities of ozone whose level and behavior is critical to interpreting and controlling anthropogenic perturbations.

Relationship to Weather Variables

Many studies have been carried out relating ozone to meteorological variables - temperature, cloud cover, windspeed, humidity and mixing heights (e.g., Fiester and Balzer, 1991, McNider et al. 1993, Cox and Chu 1992). In the Southeast ozone is most sensitive to temperature. The strong relationship between temperature and ozone arises through four effects. First anthropogenic emissions of VOC's are partially related to evaporative losses dependent upon temperature. Second, biogenic emissions of VOC's especially isoprene and soil emissions of NOx are highly dependent upon temperature. Thirdly, temperature is often directly correlated to insolation which in turn is related to photolysis rates in the atmosphere. Finally, chemical kinetic rates are dependent upon temperature. While difficult to quantify, an additional factor may be enhanced thermal decomposition of organic nitrates at higher temperatures that free up NOx for continued ozone production thus indirectly increasing the chain lengths in the photochemical process. Even, though ozone is most sensitive to ozone it evidently only provides a sufficient condition for extreme events. Other factors control the occurrence of maximum levels.

Ozone levels are also inversely related to cloud cover since photolysis activity is highest in clear skies. Likewise, ozone is inversely related to wind speed due to the diluting effect of emissions at higher wind speeds. Because ozone has a relatively long lifetime in the atmosphere, transport of ozone can lead to high levels some distance away from the source of emissions. Thus, trajectories which are related to large scale weather and climate patterns can be important in ozone distribution.

Losses of ozone at the from the boundary layer are also related to meteorological processes. Dry deposition can be quite effective in removing ozone. Dry deposition is strongly governed by the uptake of ozone through plant stomata during active photosynthesis and plant respiration. Since, plant photosynthesis depends on sunlight and root zone moisture it is related to weather and climate. While ozone is relatively insoluble so that wet deposition is not very effective in removing ozone, convective processes can remove ozone by venting it out of the boundary layer.

Natural levels of ozone are also related to meteorological processes. As indicated above biogenic and soil emissions can add a natural background of ozone. Additionally, a continued downward transport of stratospheric ozone to the surface is part of the tropospheric ozone budget. The rate of this transfer depends on meteorological processes such as deep convection and tropopause folds.

Relation to Climate Variation

Given the strong relationship to meteorological conditions it is not surprising that seasonal levels of ozone exposure and extreme statistics of ozone concentrations are tied to interannual climate variations. While long term trustworthy observations of surface ozone are not widely available in the Southeast, analysis of shorter term records of order ten years (Vukovich et. al. 1992) show substantial variations in seasonal ozone and peak ozone year to year. There is also some hint that these fluctuations may be related to global characteristics such ENSO.

The importance of these relations is that interpreting trends in air quality must account for the climate related fluctuations (Bloomfield et al. 1993). A recent National Academy study (National Research Council, 1991) emphasized the importance of removing the meteorological variability in evaluating these trends. This is critical to the regulatory process in that the determination of meeting air quality standards through control strategies is implicitly based on the assumption of having defined the range of meteorological variations. Not considering the range in meteorological variations can mask the success or failure of control strategies with substantial societal impacts due to error on either side.

Seasonal variations in precipitation can potentially have major impacts on ozone exposure levels. Drier conditions are correlated with decreased cloud cover leading to enhanced photolysis conditions. Reduced soil moisture conditions increases skin and surface air temperatures, as additional solar energy is partitioned into sensible heat. It is the accumulation of ozone that is important rather production. Thus, lower surface deposition as plant uptake during active photosynthesis is reduced during dry conditions, could lead to longer ozone lifetimes. Additionally, the lack of cloud venting could increase boundary lifetimes and exposures. Thus, major variations in the hydrologic cycle could lead to significant variations in ozone levels.

Relationship to Climate Change

The strong relationship between ozone and meteorology indicates that ozone may be sensitive to substantial changes in climate. Current uncertainties in climate change scenarios and our incomplete knowledge of the processes controlling natural and anthropogenic ozone, preclude an accurate depiction of ozone in the future. However, given the potential impact to society both in terms of cost of regulation and detrimental impacts of indicates that it should be a part of climate change impact assessment studies.

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VII. New Technologies, Data, and Information

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a. WSR-88SD Radar Network

The nation's new 10 cm doppler radar network, 1990-1996. Precipitation processing is performed in four stages. The first stage occurs within the radar computer system and produces quantitative precipitation estimates, short term forecasts of precipitation accumulations and flash-flood probabilities. The remaining stages are processed at National Weather Service Offices on systems external to the radar system. At stage two, the precipitation estimates from stage one are merged with data from precipitation gages. At stage three NWS hydrometeorologists interactively create quality controlled composite products for major river basins by mosaicing stage two products from several radars. This interactive quality control step is needed because radar indirectly measures precipitation rates by correlating precipitation rate with the reflectivity of the radar signal from the precipitating hydrometeors. The stage four product is a national product produced at the National Centers for Environmental Prediction and is used as an input to the mesoscale numerical weather prediction models. All of these precipitation products are produced hourly on a nationally consistent grid with a resolution of about four kilometers. Stage one and two products are for the area covered by a single radar. Eventually, the stage four product will be a mosaic of stage three products. Initially, because of operational timing requirements and system limitations, the stage four product is a composite of stage two products and does not have interactive quality control by a hydrometeorologist. Future use will be made of satellite data and other hydrometeorological data in stages two and three. The precipitation processing system produces three kinds of precipitation products: radar-only (stage one), gage-only (stages two, three and four) and merged gage-radar (stages two, three and four).

b. GCIP EAST

The World Climate Research Program (WCRP) established the Global Energy and Water Cycle Experiment (GEWEX) to study those climate mechanisms that impact variations in the hydrologic cycle. The GEWEX Continental Scale International Project (GCIP) is designed to improve our understanding of the interactions between the atmosphere and land surfaces, and to incorporate this knowledge into coupled hydrologic-atmospheric models for predictive purposes. These results will aid decision-makers in assessing the potential impact of changing climate upon water resources first on continental and then, ultimately, on global scales (IGPO, 1995).

Within GEWEX, GCIP is the World Climate Research Program's most intensive hydroclimatological experiment. It consists of focused research and data collections activities in the Mississippi River Basin during the period 1994 to 2000. The study will take place in four phases with each phase corresponding to a focus on a different Large Scale Area (LSA) in the Mississippi River Basin. The third phase of GCIP will focus on the eastern-most area of the Mississippi River Basin (i.e., the LSA East) in 1998-99.

GCIP implemented a multiscale developmental framework for LSA-SW and is about to place similar plans into action for the LSA-NC. The LSA East will follow a comparable approach that is comprised of a hierarchy of research and data collection activities including those focusing on intense observational areas, more general data collection in intermediate sized areas, and data analysis for larger areas encompassing the subbasin and the entire Mississippi Basin. The results at the basin scale will be linked with those of other regional and small GEWEX projects to provide coverage at the continental scale of North America; and with other international, regional, or local land surface experiments to provide global coverage. GCIP has adopted the strategy of selecting different research priorities in each phase of the program based on the climatic, hydrologic, and geographical features in the current focus area.

As indicated in the activities plan for 1996-97 (IGPO, 1995), the main features of the LSA East sub-basin include:

- the semi-humid, Appalachian headwater signature in the Mississippi River hydrograph from the Ohio River, and

- the highly controlled hydrology by the Tennessee Valley Authority (TVA) and US Army Corps of Engineers (USACE) in the semi-humid southeast tributaries; i.e., the Tennessee-Cumberland River systems.

The following additional unique characteristics have been identified for the LSA East region:

- topographic effects of the Appalachian Mountains,
- the greatest precipitation in the entire Mississippi River basin,
- a winter-spring precipitation maximum,
- synoptic weather systems as major precipitation cause,
- some snowmelt effect,
- rivers in steep-sided valleys,
- provides the dominant contribution to Mississippi runoff, and
- contains few large natural reservoirs, but many manmade.

The plan also notes the particular opportunity for research with the TVA and the USACE regarding how large scale reservoir/river forecasting models can be linked with GCMs and mesoscale hydroclimatological models. Data collection and management plans for the LSA-SE are now being developed.

c. NOAA/NWS Ensemble Forecasts

Significant improvements are being made at several levels of the National Weather Service (NWS) forecast system, including improvements in short-term precipitation forecasting though the National Centers for Environmental Prediction’s (NCEP) new mesoscale weather forecast model (Eta model), new ensemble forecasts from the global model, experimental ensemble forecasts from the Eta model, and improvements in medium and long range prediction. Therefore, now is a good time to improve the way Quantitative Precipitation Forecasts (QPF) are used in river and flood forecasting. It is clear that many important users of NWS forecasts want to know about the uncertainty in the forecasts. It no longer is sufficient to predict, for example, that river stages will or will not rise above the top of a levee. Users want to know about the risks as well.

A strategy for ensemble streamflow prediction (ESP) is being developed and tested by the NWS for its River Forecast Centers (RFCs) to make better use of QPF information in forecasts for all time scales from hours to seasons. This strategy has several objectives:

i. Produce bracketed confidence limits or associated probabilities to provide likelihood of occurrence for a range of specific stage, flow or volume forecasts.

ii. Resolve the inherent scale mismatch in incorporating precipitation forecasts into river forecast models that occurs because runoff response to precipitation is highly nonlinear and is sensitive to space and time variability of precipitation over a wider range of space and time scales, depending on drainage area, than is included in present precipitation forecasts.

iii. Use stochastic methods to compensate for the limitations of current scientific capability for detailed positioning of future high intensity small-scale rainfall centers. (This problem increases as both the duration of the forecast interval and target area (i.e. subbasin) decrease and as the forecast period moves further into the future.)

iv. Build upon the existing Extended Streamflow Prediction framework to include uncertainty in meteorological and climatological predictions in river forecasts and to account for the sub-scale space and time variability not included in these forecasts.

v. Provide a robust framework for producing consistent forecasts throughout a large river basin that accounts for all of the joint relationships between precipitation events at different parts of the basin in space and time.

The output will be an ensemble of equally likely streamflow hydrographs at each forecast point that can be used to create probabilistic forecast products or that can be used directly by water managers in water resource management models to make operational management decisions.

The precipitation ensemble required as input will be produced by an Ensemble Precipitation Processor (EPP) that will assimilate short-term probabilistic quantitative precipitation forecasts (PQPF) provided by field forecasters as well as long-term PQPF provided by forecasters at the National Centers for Environmental Prediction. Required information about the spatial and temporal correlation structure of precipitation will be derived directly from climatology and by analysis of numerical model gridded products. The EPP will be one part of an RFC Precipitation Analysis System (PAS) that is operated by the RFC Hydrometeorological Analysis and Support (HAS) forecaster.

d. NOAA's Satellite Enhancements over the Next Decade

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NOAA will continue to operate a constellation of polar and geostationary satellites with continuing improvements in instrumentation and resolution. Current and enhanced observations are used directly in numerical prediction models of all scales and by field forecasters for the issuance of flash flood watches and warnings. Further, the long stability of these satellite programs provide nearly three decades of information on atmospheric temperatures, clouds, precipitation, snow cover, and vegetative cover that are useful to assessing the seasonal, interannual and decadal climate changes.

Early in 1998, the first of the new NOAA K-L-M-N satellite series will be launched. These satellites will carry improved sounding instrumentation, the Advanced Microwave Sounding Units (AMSU A and AMSU B). In addition to providing improved temperature and humidity soundings, three channels of the AMSU A are designed to provide information on precipitation, snow cover and sea ice. Additionally, microwave data from the DoD Defense Meteorological Satellite Program (DMSP) will be used to produce a soil wetness index. This product provides a daily view of the surface condition of the soil (wet, saturated, and flooded) that is important for hydrological forecasting of floods, agricultural activities, and for initializing weather prediction models.

The third of the new GOES I-M geostationary series of satellites, GOES 10, was launched in April 1997. These satellites provide imagery in the visible and infrared spectra at frequent (15 minute) intervals. An analysis technique to estimate heavy precipitation amounts is being upgraded to provide precipitation estimates for all the U.S. at 30 minute intervals. These estimates are particularly useful in areas where radar beams are blocked or systems are approaching from data sparse oceanic areas. The GOES satellites also carry instrumentation for atmospheric sounding. Soundings are computed every hour and provide an important continuum between the 12 hour increments of radiosonde (balloon) measurements. These are then utilized in hydrometeorological models. Further, these observations can be depicted as images of total precipitable water and atmospheric stability. Animation of these images can be used in real-time to improve local forecasting. These data sets can also be archived and utilized for assessment of regional, seasonal, and annual patterns and variations in key atmospheric variables of the hydrological cycle.

e. The New Era of Satellite Remote Sensing

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An exciting era of satellite remote sensing is at hand. Over the next few years, satellites and instruments which have ten times better spatial resolution than currently available from many existing systems will be in operation. Also, data from an instrument with very high spectral resolution will be available. Additionally governments will launch the next generation of instruments with improved capabilities as follow-on to the current earth resources remote sensing satellites. This leads to an explosion of data that can be used to address many application issues.

Understanding four characteristics of remotely sensed data; spatial resolution, spectral resolution, extent, and temporal resolution, will help to understand the impact of this explosion in data. Spatial resolution refers to the smallest element that can be sensed. Instruments used in sensing of the atmosphere have spatial resolutions as low as 1 km or as high as 100s of kilometers. Those instruments used for earth resources have resolutions of 10s of meters. The new commercial satellites will have resolutions of 1 to 4 meters.

Spectral resolution refers to the portion of the electromagnetic spectrum sensed by the instrument. UV stands of ultraviolet; sun light in this region cause sunburn. The visible (VIS) portion is the region our eyes respond too, such as red, green and blue. The infra-red portion, divided in near IR(NIR), mid IR(MIR), and Far IR (FIR), corresponds to the temperature of the objects that have been detected. Microwave (MW) region is in the spectral interval associated with the weather radar images seen on TV weather broadcast. If an instrument senses in a group of individual bands it is referred to as multispectral. Panchromatic instruments collect data over a broad portion of the electromagnetic spectrum, generally from the visible through the near infrared.

Extent is the amount of area covered by the instrument. For example, weather satellites can continuously collect data up to 3000 km wide, covering the earth every 12 hours. LANDSAT can only collect data up to 185 km. The new commercial satellites with 1 meter resolution will collect from near 4 km on either side of the satellite track.

Temporal resolution is how often a particular area is viewed by the satellite. It can range from 30 minutes to tens of days. The GOES pictures seen on TV weather shows are available every 30 minutes while the US earth resources satellite, LANDSAT, is every 16 days. The new commercial satellites will collect data from the same area every 2-3 days.

The following two tables contain information about satellites and instruments that are currently in orbit (Table 1) and those expected to be launched in the near future (Table 2). The acronym and names for instruments or sensors on each satellite are listed. For each instrument we identify how many spectral bands of data are collected and the spectral intervals used. The next two columns contain the spatial resolution and the extent or swath width. The last two columns show which government organization or company has the data and the web address for more information on the particular sensor. For example, The National Oceanic and Atmospheric Administration (NOAA) controls the NOAA 14 satellite. One instrument is the Advanced Very High Resolution Radiometer (AVHRR). This instrument collects data in the visible and infra-red data in 5 channels or bands at 1.1 km resolution. Since the field of view of the instrument is very large, 3000 km, the entire earth is covered twice each day. The data is available from NOAA’s Satellite Active Archive (SAA). Table 3 contains the web addresses for the archive locations

The recently launched Lewis satellite carries a hyperspectral instrument (HIS) with 384 visible and infra-red bands. This data can be used to discriminate a maple from an oak tree, wheat from alfalfa, and separate healthy from unhealthy growth. Three commercial companies, Space Imaging, ORBIMAGE, and EarthWatch expect to launch systems in the near future with 1 meter resolution. Starting in 1998, NASA will launch a series of satellites with multiple instruments as part of its Earth Observing System (EOS). The EOS goal is to determine the extent, causes, and regional consequences of global climate change. One EOS satellite is the next generation LANDSAT with the enhanced thematic mapper with spatial resolution of 15 meters.

While both tables show the diversity in terms of instruments, spectral intervals, spatial resolution, and organizations associated with satellite remote sensing, it is the applications of this plethora of data that are most beneficial. These applications range from more informational content for GIS, to improved disaster management, precision forestry and agriculture, better water resource management, and more objective assessment of damages for the insurance industry. Additionally, companies will use these data to generate more varied, and useful, customer tailored product. The explosion of the world wide web is making access to information and products easier.

More data, easier access, more powerful computers, and increased capability of commercially available software can be used to address the issues and concerns of the applications community.

Table 1: Satellite Information (1995-2000) -- Operational Satellites

Satellites	Sensors								Spatial Resolution	Swath Width	Sensor Description	Data Archive	Sensor Information Via the WWW (http://...)
ADEOS 1	AVNIR	5		X	X				8m-Panchromatic, 16m-Multispectral	80km	Advanced Visible and Near-Infrared Radiometer		www.eoc.nasda.go.jp/guide/guide/satellite/sendata/avnir_e.html
	ILAS	2			X		X		VIS (2kmx2km) & IR (2km-vert, 13km-horiz)	n/a	Improved Limb Atmospheric Spectrometer		www.eoc.nasda.go.jp/guide/guide/satellite/sendata/ilas_e.html
	IMG	3				X	X		8x8km	nadir	The Interferometric Monitor for Greenhouse Gases		www.eoc.nasda.go.jp/guide/guide/satellite/sendata/img_e.html
	NSCAT							X	25-50km	1200km	Active KU-band Scatterometer	JPL	www.eoc.nasda.go.jp/guide/guide/satellite/sendata/nscat_e.html
	POLDER	8		X	X				6x7km	2400km	Polarization and Directionality of the Earth's Reflectance		www.eoc.nasda.go.jp/guide/guide/satellite/sendata/polder_e.html
	TOMS	6	X						42km	2795km	Total Ozone Mapping Spectrometer	GSFC	www.eoc.nasda.go.jp/guide/guide/satellite/sendata/toms_e.html
DMSP F10…F14	SSMI	7						X	13x15km at 85GHz 43x69km at 19GHz	1400km	Special Sensor Microwave Imager	NGDG, MSFC, NCDC	www.ngdc.noaa.gov/dmsp/source/doc-ssmi.html
	SSM/T	7						X	174km (nadir)	1500km	Special Sensor Microwave Temperature Sounder	NGDG, MSFC, NCDC	www.ngdc.noaa.gov/dmsp/source/doc-ssmt.html
	SSM/T2	5						X	48km	1500km	Special Sensor Microwave Water Vapor Profiler (F11 Only)	NGDG, MSFC, NCDC	www.ngdc.noaa.gov/dmsp/source/doc-ssmt2.html
	OLS	2		X	X		X		0.55-2.7km	3000km	Optical Linescan System	NGDG, MSFC, NCDC	www.ngdc.noaa.gov/dmsp/source/doc-ols.html
EP-TOMS	TOMS	6	X						26km	50-200km	Total Ozone Mapping Spectrometer	AMES, GSFC	wocky.gsfc.nasa.gov/eptoms/tomstech.html
ERS 1,2	AMI	1						X	30m (image mode) 50m (wind mode)	80-100km (img) - 500km (sct)	Active Microwave Instrument	EOSAT, ESA	http://www.ccrs.nrcan.gc.ca/ccrs/satsens/satellit/erse.html#ers2
	ATSR	6				X	X	X	1km (IR) 22km (MW)	500km	Along-Track Scanning Radiometry		http://www.ccrs.nrcan.gc.ca/ccrs/satsens/satellit/erse.html#ers2
(ERS 2 Olny)	AATSR	7				X	X	X	0.5km	500km	Along-Track Scanning Radiometry/Microwave Sounder		http://www.ccrs.nrcan.gc.ca/ccrs/satsens/satellit/erse.html#ers2
GOES 7	VAS	4		X	X		X		1-8km (VIS), 8-14km (IR)	Horiz to Horiz	VISSR (Visible and IR Spin Scan Radiometer) Atmos. Sounder	NCDC, OFPS	
GOES 8,9	Imager	5		X		X	X		1km (VIS), 4km (IR)	Horiz to Horiz	Imaging Radiometer	NCDC, OFPS	140.90.207.25:8080/EBB/ml/gsensor.html
	Sounder	19		X			X		10km	Horiz to Horiz	Vertical Sounder	NCDC, OFPS	oldthunder.ssec.wisc.edu/sounder/desc.html
IRS 1C	PAN	1		X	X				5.8m	70km	Panchromatic Sensor	EOSAT	http://www.spaceimage.com/indexJS11.html
	LISS-III	4		X	X				23m	148km	Linear Imaging Self Scanning sensor		http://www.spaceimage.com/indexJS11.html
	WiFS	2		X	X				188m	810km	Wide Field Sensor		http://www.spaceimage.com/indexJS11.html
JERS 1	SAR	1						X	18x18m	75km	Synthetic Aperature Radar	EOSAT	www.eoc.nasda.go.jp/guide/guide/satellite/sendata/sar_e.html
	OPS	8		X	X				18x24m	75km	Optical Sensor	EOSAT	www.eoc.nasda.go.jp/guide/guide/satellite/sendata/ops_e.html
LEWIS	HIS	384		X	X	X			30m	13nm	Hyperspectral Imager	SSC, EDC	http://crsphome.ssc.nasa.gov/ssti/
	LEISA	256		X	X	X			300m	5.9nm	Linear Etalon Imaging Spectral Array		http://crsphome.ssc.nasa.gov/ssti/
LANDSAT 5	MSS	4		X	X				80m	185km	Multispectral Scanner	EDC	http://leonardo.jpl.nasa.gov/msl/QuickLooks/landsat4QL.html
	TM	7		X	X		X		30m	185km	Thematic Mapper	EOSAT	http://leonardo.jpl.nasa.gov/msl/QuickLooks/landsat4QL.html
NOAA 12, 14	AVHRR	5		X	X	X	X		1.1km (nadir)	3000km	Advances Very High Resolution Radiometer	EDC, SAA	140.90.207.25:8080/EBB/ml/pavhrr.html (NOAASIS)
	TOVS-HIRS/2	20		X		X	X		17km (nadir)	2240km	High Resolution Infrared Radiation Radiometer	SAA	saadev.saa.noaa.gov:8410/instrument_documents/tovs-hirs-sensor.html
	TOVS-SSU	3					X		147 km (nadir)	+/- 40 deg scan	Stratospheric Sounding Unit	SAA	saadev.saa.noaa.gov:8410/instrument_documents/tovs-ssu-sensor.html
	TOVS-MSU	4						X	109 km	2348km	Microwave Sounding Unit	SAA	saadev.saa.noaa.gov:8410/instrument_documents/tovs-msu-sensor.html
RADARSAT	SAR							X	Variable, 9-100m	Variable, 45-510km	Synthetic Aperature Radar	RSI	radarsat.space.gc.ca/ENG/RADARSAT/specification_sheet.html
SPOT 3	HRV	4		X	X				10m (panchromatic) & 20m (multispectoral)	60km	High Resolution Visible Imaging System	SICORP	http://www.spot.com/anglaise/system/satel/ss_tdata.htm
OTD	OTD	1			X				5km	1300x1300km	Optical Transient Detector	MSFC	wwwghcc.msfc.nasa.gov/otd.html

Table 2: Satellite Information (1995-2000) -- Future Satellites

Future Satellites	Sensors								Spatial Resolution	Swath Width	Sensor Description	Data Archive	Sensor Information Via the WWW (http://…)
ADEOS 2	AMSR	8						X	5-50km	1600km	Advanced Microwave Scanning Radiometer		http://www.eoc.nasda.go.jp/guide/guide/satellite/sendata/amsr_e.html
	GLI	34	X	X	X	X	X		250m (IR) & 1km (sfc)	1600km	Global Imager		http://www.eoc.nasda.go.jp/guide/guide/satellite/sendata/gli_e.html
	ILAS-II								1 km (vert)		Improved Limb Atmospheric Spectrometer-II		http://www.eoc.nasda.go.jp/guide/guide/satellite/sendata/ilas2_e.html
AVSat	MS			X					1km, 10km		Multispectral Scanner		www.crsp.ssc.nasa.gov/vip/avision/AVISION.HTM
CLARK	Earthwatch	3							15 m		Multispectral Scanner	SSC	http://crsphome.ssc.nasa.gov/ssti/
	Earthwatch	1							3 m		Panchromatic Sensor	SSC	http://crsphome.ssc.nasa.gov/ssti/
EARLYBIRD	PAN	1		X					3x3 km	3 m	Panchromatic Sensor	Earthwatch	http://www.digitalglobe.com/company/satellites.html
	MSS	3		X	X				15x15 km	15 m	Multispectral Scanner	Earthwatch	http://www.digitalglobe.com/company/satellites.html
EOS-AM 1	ASTER	3		X	X	X	X		15m (VNIR), 30m (SWIR), 90m (TIR)	106km (SWIR & TIR), 304 (VNIR)	Advanced Spaceborne Thermal Emission and Reflection Radiometer	JPL	http://mtpe.gsfc.nasa.gov/eos-am1/am1proj.htm
	CERES		X	X			X		21km (nadir)	Limb to limb	Clouds and the Earth's Radient Energy System	LaRC	http://mtpe.gsfc.nasa.gov/eos-am1/am1proj.htm
	MISR	4		X	X				275m, 550m, 1.1km	360km	Multi-Algle Imaging Spectro Radiometer	JPL	http://mtpe.gsfc.nasa.gov/eos-am1/am1proj.htm
	MODIS	36		X	X	X	X		250m, 500m, 1km	2300km	Moderate Resolution Spectro Radiometer	GSFC, LaRC	http://mtpe.gsfc.nasa.gov/eos-am1/am1proj.htm
	MOPIT	3			X				22km	616km	Measurments of Pollutants in the Troposphere	CSA	http://mtpe.gsfc.nasa.gov/eos-am1/am1proj.htm
GOES K,L,M	Imager	5		X		X	X		1km (VIS), 4km (IR), 8km (WV)	Horiz to Horiz	5-Channel Imaging Radiometer	NCDC	
	Sounder	19		X	X	X	X		10km	Horiz to Horiz	Vertical Sounder	NCDC	
LANDSAT 7	ETM+	8		X	X	X			30km 15km	185km	Enhanced Thematic Mapper Plus	EDC, EOSAT	http://caster.gsfc.nasa.gov/lps/ExtIntFaces/satellite.html
NEW MILLENIUM	ALI	325		X	X	X			10m, 30m 30m	60km 9.6km	Advanced Landsat Imager		
NOAA L,M,N	AMSU/A							X			Advanced Microwave Sounding Unit-A	SAA	http://www2.ncdc.noaa.gov/KLM/c8/t84161-1.html
	AMSU/B	5						X			Advanced Microwave Sounding Unit-B	SAA	http://www2.ncdc.noaa.gov/KLM/c8/t84171-1.html
	HIRS/3	20		X	X	X	X		20km (nadir)	2240km	High Resolution Infrared Radiation Sounder	SAA	http://www2.ncdc.noaa.gov/KLM/c8/t84151-1.html
	AVHRR/3	6		X	X	X	X		1.1km (at ssp)	3000km	Advanced Very High Resolution Radiometer	SAA	
ORB VIEW 3	PC	5		X	X				1-2m	8km	Panchromatic Sensor		www.orbimage.com/worbview.htm
	MS	1		X					4m	8km	Multispectral Scanner		www.orbimage.com/worbview.htm
QuickBird	PS			X	X				.82 m	22 km	Panchromatic Sensor	EarthWatch	http://www.digitalglobe.com/company/satellites.html
	MSS			X	X				3.28 m	22 km	Multispectral Scanner	EarthWatch	http://www.digitalglobe.com/company/satellites.html
Space Imaging	PAN	1		X	X				1m	11km	Panchromatic Sensor	Space Imaging	www.spaceimage.com/
	MS	4		X	X				4m	11km	Multispectral Scanner	Space Imaging	www.spaceimage.com/
SPOT 4,5	HRV			X	X	X			10m	60km	High Resolution Visible-Infrared Imaging System	SICORP	www.spot.com/anglaise/system/satel/ss_tdata.htm
	VMI			X	X	X			1km	2000km	Vegetation Monitoring Instrument		www.spot.com/anglaise/system/satel/ss_tdata.htm
TRMM	CERES		X	X	X	X			10km	+/- 80 deg	Clouds and the Earth's Radient Energy System	LaRC	http://pao.gsfc.nasa.gov/gsfc/service/gallery/fact_sheets/earthsci/trmm.htm
	LIS	1			X				5km	600km	Lightning Imaging Sensor	MSFC	http://pao.gsfc.nasa.gov/gsfc/service/gallery/fact_sheets/earthsci/trmm.htm
	PR	1						X	4.3km	220km	Precipitation Radar		http://pao.gsfc.nasa.gov/gsfc/service/gallery/fact_sheets/earthsci/trmm.htm
	TMI	9						X	37-4.6km	760km	TRMM Microwave Imager		http://pao.gsfc.nasa.gov/gsfc/service/gallery/fact_sheets/earthsci/trmm.htm
	VIRS			X	X	X	X		2km	720km	Visible Infrared Scanner		http://pao.gsfc.nasa.gov/gsfc/service/gallery/fact_sheets/earthsci/trmm.htm

Table 3: Data Archive Locations

AMES	Ames Research Center	http://www.arc.nasa.gov/
EDC	EROS Data Center	http://edcwww.cr.usgs.gov/
EOSAT	Earth Observation Satellite Company	http://www.eosat.com
ESA	European Space Agency	http://www.esrin.esa.it/
GSFC	Goddard Space Flight Center	http://www.gsfc.nasa.gov/
JPL	Jet Propulsion Laboratory	http://www.jpl.nasa.gov/
MSFC	Marshall Space Flight Center	http://msfc.nasa.gov
NCDC	National Climatic Data Center	http://www.ncdc.noaa.gov/
NGDC	National Geophysical Data Center	http://www.ngdc.noaa.gov/
OFPS	Office of Field Project Support	http://www.ofps.ucar.edu/
RSI	Radarsat International	http://www.rsi.ca/
SAA	Satellite Active Archive (NOAA)	http://www.saa.noaa.gov/
SICORP	SPOT Image Corporation	http://www.spot.com/

f. HIGH RESOLUTION SATELLITE DATA - EOS

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NASA/GSFC
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Over the next ten years, the United States will launch, in concert with other cooperating nations, a constellation of satellites to monitor the health of the earth and potential climate change. Those satellite observations will quantify the physical properties and thermodynamic states of the earth's soil, vegetation, and atmosphere that are critical for modeling forecasts of weather, climate, and water resources. Sustained observations will allow researchers to monitor Earth’s climate variables over time to determine trends.

The following is a summary of ongoing and currently planned satellites sensors and data products by NASA and other US agencies and international collaborators. The summary was extracted from:

1.) 1995 MTPE EOS Reference Handbook, and
2.) 1997 MTPE EOS Data Products Handbook

that are available at the following internet web addresses:

1.) http://eospso.gsfc.nasa.gov/eos_homepage/new.html
2.) http://eospso.gsfc.nasa.gov/eos_reference/TOC.html

Persons interested in further details on the sensor design, specifications, launch dates, etc., are referred to the above documents.

I. NASA MTPE Program

NASAis is one of several US agencies responsible for satellite-based monitoring of the earth's present and future health. Its program is defined within the Mission to Planet Earth (MTPE)concept, that uses space, ground-, and aircraft-based measurement systems to provide the scientific basis for understanding the climate system and its variations, including its impact on the nation's water resources. The MTPE program includes ongoing and planned satellite missions, and management and analysis of satellite data and data analysis.

No single orbit permits the gathering of complete information on Earth processes. For example, high-inclination, polar-orbiting satellites are needed to observe phenomena that require relatively detailed observations on a routine basis, often from a constant solar illumination angle. Geostationary satellites are needed to provide continuous monitoring of high-temporal-resolution processes.

II. Phase I - MTPE Program: 1990 - 1998

Table 1 delineates NASA’s contributions to Phase I of MTPE (the period of Earth observations preceding the first launch of NASAi’ EOS satellites in 1998). Table 2 identifies other U.S. and international Earth observation satellites that will be in place during this period.

TABLE 1 - MTPE Phase I: NASA Satellites (Launch Status)

ERBS (Operational) Earth Radiation Budget Satellite - Earth radiation budget, aerosol, and ozone data from 57o inclination orbit

UARS (Operational) Upper Atmosphere Research Satellite - Stratospheric and mesospheric chemistry and dynamic processes

NASA Spacelab Series (1992 - 1994) - A series of Shuttle-based experiments to measure atmospheric and solar dynamics (ATLAS), atmospheric aerosols (LITE), and surface radar backscatter, polarization, and phase information (SIR-C and X-SAR [joint with Germany and Italy])

TOPEX/Poseidon (Operational) Ocean Topography Experiment - Ocean circulation (joint with France)

LAGEOS-2 (Operational) Laser Geodynamics Satellite - Satellite laser-ranging for monitoring crustal motions and Earth rotation variations (joint with Italy)

SeaWiFS (1997) Sea-Viewing Wide Field Sensor - Purchase of ocean color data to monitor ocean productivity

TOMS/Earth Probe (1995) Total Ozone Mapping Spectrometer - Ozone mapping and monitoring

NSCAT/ADEOS (1996) NASA Scatterometer - Ocean surface wind vectors (joint with Japan)

TOMS/ADEOS (1996) Total Ozone Mapping Spectrometer - Ozone mapping and monitoring (joint with Japan)

TRMM (1997) Tropical Rainfall Measuring Mission - Precipitation, clouds, and radiation processes over tropical regions (joint with Japan)

TABLE 2. MTPE Phase I: Non-NASA Satellites (Launch Status)

NOAA-K through N' (U.S. Operational) - Earth’s surface visible and infrared radiance/reflectance, infrared atmospheric sounding, and ozone measurements; space environmental monitoring

Landsat-4/5 (U.S. Operational) Land Remote-Sensing Satellite - High spatial resolution visible and infrared radiance/reflectance and terrestrial surfaces

DMSP (U.S. Operational) Defense Meteorological Satellite Program - Visible, infrared, and passive microwave atmospheric and surface measurements

ERS-1 (ESA Operational) European Remote-Sensing Satellite - C-band SAR, microwave altimeter, scatterometer, and sea surface temperature

JERS-1 (Japan Operational) Japan’s Earth Resources Satellite - L-band SAR backscatter and high spatial resolution surface visible and infrared radiance/reflectance

ERS-2 (ESA Operational) European Remote-Sensing Satellite - Same as ERS-1, plus ozone mapping and monitoring

Radarsat (Canada 1995) Radar Satellite - C-band SAR measurements of Earth's surface (joint U.S./Canadian mission)

NOAA-K through -N (U.S. 1996 on) - Surface visible, infrared, and microwave radiance/reflectance; infrared atmospheric sounding; and ozone measurements

ADEOS (Japan 1997) Advanced Earth Observing Satellite - Surface visible and near-infrared radiance/reflectance, scatterometry, and tropospheric and stratospheric chemistry (joint with U.S. and France)Non-NASA Satellites (Launch Status) Mission Objectives

III. Phase II - Program: 1998-2014

The centerpiece of MTPE is the Earth Observing System consisting of a science segment, a data system, and a space segment made up of a series of polar-orbiting and low-inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. In concert with EOS, the polar-orbiting and mid-inclination platforms from Europe, Japan, and the U.S. National Oceanic and Atmospheric Administration (NOAA) form the basis for a comprehensive International Earth Observing System (IEOS). NASA, Japan, and the European Space Agency (ESA) programs will establish an international Earth-observing capability that will operate for at least 15 years. IEOS will allow scientists to obtain information at many levels of detail, covering all major Earth system processes.

Table 3 identifies the NASA, other U.S., and international contributions of Earth observing satellites during the EOS period. EOS will carry two classes of instruments: Facility Instruments supplied by NASA in response to general mission requirements, and Principal Investigator (PI) Instruments selected through a competitive process and aimed at the focused research interests of the selected investigators. Of course, the PI Instruments are also responsive to overall EOS objectives. To quantify changes in the Earth system, MTPE's principal element, the Earth Observing System (EOS), will provide systematic, continuous observations from low Earth orbit for a minimum of 15 years.

TABLE 3: EOS Era Remote-Sensing Satellites

EOS AM Series (1998) Earth Observing System Morning Crossing (Descending) - Clouds, aerosols, and radiation balance, characterization of the terrestrial ecosystem; land use, soils, terrestrial energy/moisture, tropospheric chemical composition; contribution of volcanoes to climate, and ocean primary productivity (includes Canadian and Japanese instruments)

Landsat-7 (1998) Land Remote-Sensing Satellite - High-spatial-resolution visible and infrared radiance/reflectance to monitor land surface (joint with NOAA and USGS)

EOS Color (1998) EOS Ocean Color Mission - Ocean primary productivity (under review)

ENVISAT Series (ESA61998) Environmental Satellite - Environmental studies in atmospheric chemistry and marine biology, and continuation of ERS mission objectives

ADEOS II (Japan61999) Advanced Earth Observing Satellite II - Visible-to-thermal infrared radiance/reflectance, microwave imaging, scatterometry, ozone, aerosols, atmospheric temperature, winds, water vapor, SST, energy budget, clouds, snow and ice, ocean current, ocean color/biology (includes French and U.S. instruments).

EOS Radar ALT Series (1999) EOS Ocean Altimetry Mission - Ocean circulation (joint with France)

EOS PM Series (2000) Earth Observing System Afternoon Crossing (Ascending) - Clouds, precipitation, and radiative balance; characterization of terrestrial processes; air-sea fluxes of energy and moisture; and sea-ice extent (includes European instruments)

ATMOS Series (Japan and NASA6Proposed for 2000) Tropical Rainfall Measuring - Mission Precipitation and related variables and Earth radiation budget in the tropics and higher latitudes; also trace gases

METOP Series (EUMETSAT/ESA62000) Meteorological Operational Satellite - Operational meteorology and climate monitoring, with the future objective of operational climatology (joint with NOAA)

ALOS (Japan-2001) Advanced Land Observation Satellite - Land surface, cartography, and disaster monitoring

EOS CHEM Series (2002) EOS Chemistry Mission - Atmospheric chemical composition; troposphere-stratosphere exchange of energy and chemicals; chemistry-climate interactions; air-sea exchange of chemicals and energy (includes an ozone-measuring Japanese instrument)

EOS Laser ALT Series (2003) EOS Ice-Sheet Altimetry Mission - Ice sheet mass balance and cloud top and land-surface topography Satellites (Launch Status) Mission Objectives

IV. EOS DATA PRODUCTS

The EOS data products will contribute to science research in the understanding, analysis, and monitoring of global climate change. Table 4 provides a listing of the 24 critical science measurements as identified by the EOS Project Science Office and the instruments that relate to them. Readers should be aware that this reference is only the htip of the iceberg of information available on the EOS data products.

Table 4. The 24 Critical EOS Science Measurements

ATMOSPHERE
Cloud Properties (amount, optical properties, height): MODIS, GLAS, AMSR, MISR, AIRS, ASTER, EOSP, SAGEIII

Radiative Energy Fluxes (top of atmosphere, surface): CERES, ACRIM, MODIS, AMSR, GLAS, MISR, AIRS, ASTER, SAGE III

Precipitation: AMSR
Tropospheric Chemistry (ozone, precursor gases): TES, MOPITT, SAGEIII, MLS, HIRDLS, LIS

Stratospheric Chemistry (ozone, ClO, BrO, OH, trace gases): MLS, HIRDLS, SAGIII, ODUS, TES

Aerosol Properties (stratospheric, tropospheric): SAGEIII, HIRDLS, MODIS, MISR, EOSP, GLAS

Atmospheric Temperature: AIRS/AMSU, HIRDLS, TES, MODIS

Atmospheric Humidity: AIRS/MHS, MLS, SAGEIII, DFA/MR, MODIS, TES

Lightning (events, area, flash structure): LIS

Total Solar Irradiance: ACRIM

Ultraviolet Spectral Irradiance: SOLSTICE

Land Cover & Land Use Change: ETM+/LATI, MODIS, MISR, ASTER

Vegetation Dynamics: MODIS, MISR, ETM+/LATI, ASTER

Surface Temperature: ASTER, MODIS, AIRS, ETM+

Fire Occurrence (extent, thermal anomalies): MODIS, ASTER, ETM+

Volcanic Effects (frequency of occurrence, thermal anomalies, impact): MODIS, ASTER, MISR

Surface Wetness: AMSR

Surface Temperature: MODIS, AIRS, AMSR

Phytoplankton & Dissolved Organic Matter: MODIS

Surface Wind Fields SeaWinds: AMSR, DFA/MR

Ocean Surface Topography (height, waves, sea level): DFA/MR

Ice Sheet Topography & Ice Volume Change: GLAS

Sea Ice (extent, concentration, motion, temperature):AMSR, DFA/MR, MODIS

Snow Cover (extent, water equivalent): MODIS, AMSR, ASTER, ETM+/LATI In

V. INTERNATIONAL COOPERATION

The Earth Observations International Coordination Working Group (EO-ICWG) is the forum within which the U.S., Europe, Japan, and Canada discuss, plan, and negotiate the international cooperation essential for implementation of the International Earth Observing System (IEOS) in the 1990s and beyond. The delegations to EO-ICWG are led by the Earth observations offices of their respective space agencies: The National Aeronautics and Space Administration (NASA); the European Space Agency (ESA); the Japanese Science and Technology Agency (STA); and the Canadian Space Agency (CSA). The delegations also include respective operational environmental monitoring and Earth observation agencies: The United States National Oceanic and Atmospheric Administration (NOAA); the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT); the National Space Development Agency (NASDA) of Japan, the Japanese Ministry of International Trade and Industry (MITI), the Japan Meteorological Agency (JMA), and the Japan Environment Agency; and the Canadian Atmospheric Environment Service (AES). The EO-ICWG meets two to three times per year, addressing a full range of tech-nical and policy issues, which include payload, operations, data management, data policy, and instrument interfaces. EO-ICWG has defined the elements listed below as the space-based component of IEOS:

NASA’s Earth Observing System (EOS), beginning with AM-1;

Japanese Earth Observing System (JEOS), beginning with the Advanced Earth Observing System (ADEOS);

NASA/Japanese Tropical Rainfall Measuring Mission (TRMM) and its follow-on;

the European ENVISAT and METOP missions; and NOAA's Polar-Orbiting Operational Environmental Satellite (POES) series, beginning with NOAA-N.

Tables 11a through 11c (provided by EO-ICWG) list the IEOS satellites and their respective instrument complements. These Tables are located on pages 69-71 of three 1995 EOS Reference Handbooks identified above.

Given the transience of national budget scenarios (and consequently scheduling), these charts should be considered planning documents. Refer to the Mission Elements section of this Handbook for more detail on the various spacecraft and sensors that constitute the space-based elements of IEOS. The following paragraphs offer brief synopses of the partner nation contributions.

Europe

European Earth observing satellites include ENVISAT-1 for environmental monitoring and atmospheric chemistry and the METOP series (METOP-1/2/3) for operational meteorology and climate monitoring. The spacecraft, instrumentation, launch, operations, and associated data system are provided through ESA, individual member state contributions, EUMETSAT, and contributions from NOAA for the operational payload on METOP. ESA's plans call for launch of ENVISAT-1 in 72 December 1998. ENVISAT-1 will contribute to environmental studies in land surface properties, atmospheric chemistry, aerosol distribution, and marine biology. The second satellite series, METOP, will fly an operational meteorological package and climate monitoring instrumentation in cooperation with EUMETSAT and NOAA. This series will take over morning operational satellite coverage from the NOAA POES system in the 2000 timeframe. EUMETSAT does not consider METOP to be formally part of IEOS, although EUMETSAT participates in the EO-ICWG. Further European contributions to IEOS include provision of the Multifrequency Imaging Microwave Radiometer (MIMR) by ESA for flight on EOS PM-1; EUMETSAT's provision of the Microwave Humidity Sounder (MHS) for flight on the NOAA POES series; and NASA cooperation with the UK on the High-Resolution Dynamics Limb Sounder (HIRDLS) on EOS-CHEM-1. The EOS Radar Altimetry mission may be conducted jointly with France as a follow-on to TOPEX/Poseidon. European scientists participate in these and other instrument investigation teams. Finally, France and the U.K. are sponsoring several EOS Interdisciplinary Science Investigations (see Interdisciplinary Science section.)

Russia

The Russian Space Agency is providing the spacecraft, the 1998 launch, and operations for NASA's Stratospheric Aerosol and Gas Experiment III (SAGE III). Russia is also participating in the full range of SAGE III science team activities, and plans for their data system interconnectivity with EOSDIS are under study.

Canada

The Canadian Space Agency (CSA) is providing MOPITT for flight on EOS AM-1 and possible reflight on a flight of opportunity. This instrument will measure atmospheric carbon monoxide and methane. CSA is also sponsoring two of the EOS Interdisciplinary Science Investigations. In the Phase I time period, prior to EOS, CSA and NASA are cooperating on a Canadian synthetic aperture radar mission, Radarsat. The spacecraft, instruments, and ground segment will be provided by Canada, and NASA is providing the Radarsat launch (scheduled for September 1995) and a data acquisition station in Alaska.

Japan

Japanese contributions to IEOS include the ADEOS missions and co-sponsorship of the TRMM mission. The U.S. will supply some instruments for flight on the ADEOS spacecraft. Japan will supply the launch vehicle and precipitation radar for TRMM. As the first launch of IEOS, Japan plans to launch the polar-orbiting ADEOS mission in 1996. The objectives of ADEOS include Earth surface, atmospheric, and oceanographic remote sensing. ADEOS will be launched into a sun-synchronous, 98.63 inclination orbit with an ~800-km altitude, and an equatorial crossing time of 10:30 a.m. Agreements have been concluded between NASDA and NASA for the two U.S. instruments that will fly on ADEOS, and between NASDA and CNES for POLDER. The
satellite will have a ground-track repeat cycle of 41 days, providing global OCTS coverage every three days and daily coverage (sampled) for AVNIR. ADEOS is designed for a three-year mission lifetime; ADEOS-II is expected to be launched in 1999.

ADEOS-II

ADEOS-II is a post-ADEOS polar orbiting Earth observation satellite. Its mission is to obtain Earth science data regarding the global water cycle. In order to achieve this mission, two core instruments developed by NASDA will be flown: a microwave imaging radiometer named AMSR (Advanced Microwave Scanning Radiometer) and a wide-coverage visible-to-thermal-infrared multi-spectral optical imager named GLI (Global Imager). In addition, three instruments, ILAS-II, SeaWinds6 a modified NSCAT6and POLDER, are to be developed and delivered to ADEOS-II by the Environment Agency of Japan, NASA/JPL, and CNES respectively. ADEOS-II also carries a DFata Collection System (DCS) payload, which is not only compatible with ARGOS but also has a newly designed message forwarding capability. Japan is also providing ASTER for the EOS AM-1 mission and ODUS for the CHEM-1 mission.

TRMM

Conducted in cooperation with the U.S., TRMM is a joint NASA/NASDA mission with the major objective of measuring precipitation, undoubtedly the most difficult atmospheric variable to quantify, and the crucial driver of the hydrologic cycle and atmospheric dynamics. TRMM will measure the diurnal variation of precipitation in the tropics from a low-inclination orbit using a variety of sensors. The goal of this mission is to obtain a minimum of three years of significant climatological observations of rainfall in the tropics; in tandem with cloud models, TRMM observations will provide accurate estimates of vertical distributions of latent heating in the atmosphere. NASA will provide the TRMM spacecraft, a microwave imager, a visible/infrared imager, a lightning imaging sensor, a radiation budget instrument, and instrument integration. Japan is providing a precipitation radar and the H-II rocket to launch the
satellite in 1997. TRMM will have a 350 km, 353 orbit. As a follow-on to TRMM, NASDA is considering a series called ATMOS (Atmospheric Observations Satellite). As the basis for Phase A studies, NASDA is considering that ATMOS-A would fly in a mid-inclination (453, 500 km) orbit, and would make TRMM-type measurements. A subsequent ATMOS-B would focus on clouds and radiation in a polar, non-sun-synchronous orbit, and ATMOS-C would look at trace gases in the atmosphere in a 603, 700- km orbit. All three satellites would be open to international sensor contributions.

VIII. Summary of Actions Needed (to be developed)