Climate Change Science, Observations, and Projections

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In order to base Departmental climate change planning on the most current and sound science available, in 2003 DEP began working with the Columbia University Center for Climate Systems Research, the Earth Institute and the NASA Goddard Institute of Space Studies at Columbia University (Columbia University). In addition to developing a suite of customized regional climate change projections for the Department's planning and engineering, Columbia University also significantly enhanced DEP's understanding of climate change science, historical climate trends, Global Climate Models and future greenhouse gas (GHG) emissions scenarios. Columbia University has advised DEP of uncertainties related to model projections and the efforts being made to improve those projections, and outlined various methods for scaling global projections to regional levels. This Chapter outlines these topics and establishes priority actions for further refining DEP's understanding of regional climate projections to allow for their use in project and program planning. DEP actions to work with climate scientists to improve regional climate change projections are also summarized in tabular form in Chapter 6 of the Report.

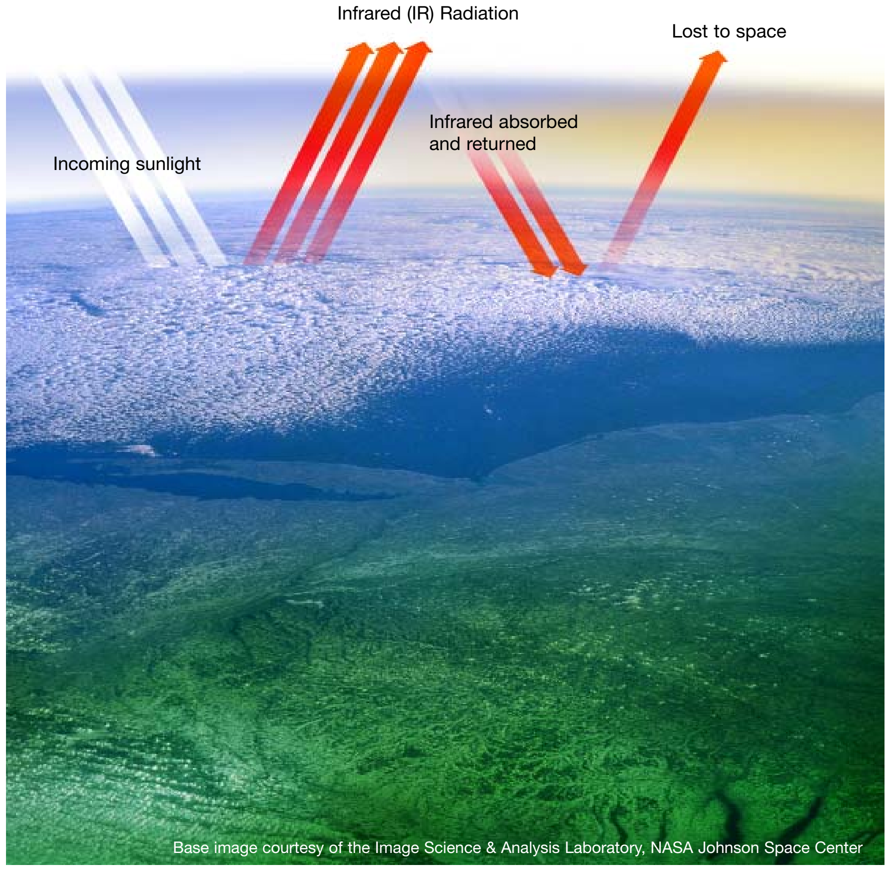
Image courtesy of NASA Johnson Space Center

Human activity now produces GHGs at a rate of 70 million tons per day. New York City emits nearly 0.25% of the world's total greenhouse gases.

NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team

1.1 Science of Climate Change

Figure 1.1
Elements of Earth's Energy Balance



The climate of the Earth is naturally variable. The energy of the sun, which heats the Earth's surface and warms the atmosphere, varies in intensity because of changes in both the distance between the Earth and the sun and the tilt of the Earth's axis and wobble, which vary in regular cycles of approximately 100,000 years and 23,000 years, respectively. The heating of the Earth's surface and atmosphere are regulated by a number of other natural variables, including cloud formation, volcanic eruptions, land and sea ice, vegetation and ocean circulation. The natural oscillation of these factors causes the Earth's temperature to fluctuate cyclically and has resulted in ice ages and glacial retreats over the geologic past. During the most recent ice age, 18,000 years ago, global average temperatures were an estimated 6ºF to 9ºF cooler than today (NECIA, 2006), and sea levels were 400 feet lower (Shackleton, 1988). Approximately 10,000 years ago, the climate had warmed by natural processes and the glaciers had retreated.

Despite this natural variability, human impacts have demonstrably affected climate patterns over the last 200 years. Since the dawn of the industrial age, human activities have produced greenhouse gases (GHGs), which have altered the natural atmospheric composition and led to noticeable and increasingly alarming warming trends. Naturally occurring GHGs, such as water vapor, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), play a critical role in determining the Earth's temperature. Thermal energy from the sun passes through the atmosphere towards the surface of the Earth, most of which is absorbed and heats the Earth (Figure 1.1). The Earth's surface then emits heat in the form of infrared radiation back to the atmosphere, some of which is lost to space and some of which remains in the atmosphere. The GHGs in the atmosphere redirect some of this infrared radiation back to the Earth, which has an additional warming effect and helps maintain the planet's habitability. However, as human activity alters naturally occurring GHG levels, more of the reflected energy is absorbed and redirected toward Earth, dramatically increasing planetary temperature. Human activity now produces GHGs at a rate of 70 million tons per day. (DEP's own GHG emissions are detailed in Chapter 4.)

Human activities have produced greenhouse gases, which have altered the natural atmospheric composition and led to noticeable and increasingly alarming warming trends.

GHG-induced planetary warming causes many climatic and hydrologic changes. As atmospheric temperatures increase, ice sheets melt, and as oceanic temperatures increase, ocean waters expand. These climatic responses cause sea level rise and change oceanic circulations. Warmer air is able to absorb more moisture, and changing oceanic circulations alter precipitation patterns, causing the hydrological cycle to become more erratic.

Not all climate changes in the Earth's history have been smooth or gradual; some periods have been marked by abrupt climate change. Anthropogenic activity is likely to push atmospheric concentrations of CO_2 and global average temperatures to heights not reached in at least the last 650,000 years, the period for which detailed records are available from Antarctic ice cores (IPCC, 2007). Although the timescales are likely to be very long for high-impact climate change scenarios, such as melting of the ice sheets, abrupt climate change remains a possibility in addition to the more gradual changes that have been observed to date.

1.2 Global and Regional Climate Trends

Historical Global Climate Trends

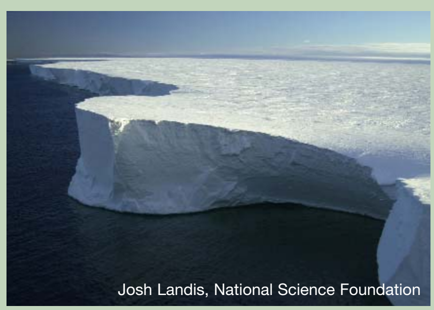
Since the end of the last ice age until recently, atmospheric GHG concentrations have been relatively stable. A 10,000-year-long global trend in the atmospheric concentration of CO_2, the most common GHG, shows an initial moderate decline before increasing slowly until approximately 1800 AD when, due to use of fossil fuels and other factors, CO_2 concentration started to increase sharply (Figure 1.2).

The trends for other GHGs such as CH_4 and N_2O show a very similar pattern. Global temperature increases were consistent with this pronounced increase in atmospheric GHGs since the mid-19th century. (Figure 1.3).

GHG increases are also linked to other observed changes in the climate system. Mountain glaciers and snow cover have declined on average in both hemispheres. Long-term precipitation trends from 1900 to 2005 have been observed in many regions: increases in eastern parts of North and South America, northern parts of Europe and parts of Asia; and decreases in the Sahara, other lower latitude regions, and southern Africa.

Intergovernmental Panel on Climate Change

In 1988, the World Meteorological Organization and the United Nations Environmental Programme established the Intergovernmental Panel on Climate Change (IPCC). IPCC members include hundreds of climate scientists and researchers from around the world who assess peer-reviewed scientific papers on climate change topics. The IPCC's role is to assess on a comprehensive, objective, and transparent basis the scientific, technical, and socioeconomic information relevant to understanding the scientific basis of human-induced climate change, observed climate changes and trends, projected future climate changes, its potential impacts, and options for adaptation and mitigation. The IPCC is in the process of releasing its fourth assessment report. A portion that was released in February 2007 concluded:



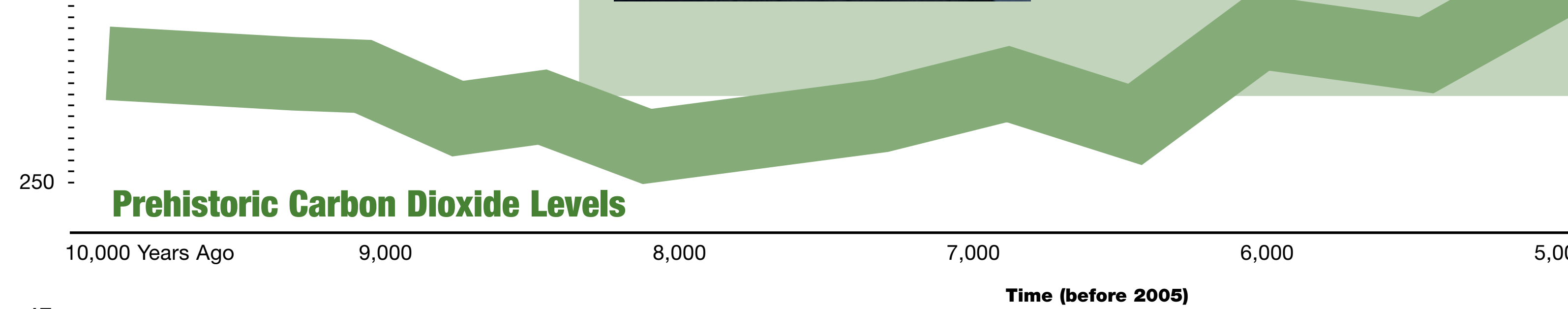
Josh Landis, National Science Foundation

- **Warming of the climate system is unequivocal**
- **Global atmospheric concentrations of greenhouse gases have increased markedly due to human activities since 1750 and currently far exceed pre-industrial values over the last 650,000 years**
- **Most of the observed increase in glob ally-averaged temperatures since the mid-20th century is very likely greater than 90% probability) due to the observed increase in anthropogenic greenhouse gas concentrations**
- **Eleven of the last twelve years (1995-2006) rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850), and the linear warming trend over the last 50 years is nearly twice that for the last 100 years**

The IPCC discounted the probability that the recent observations were caused by natural climate processes alone as less than 5%.

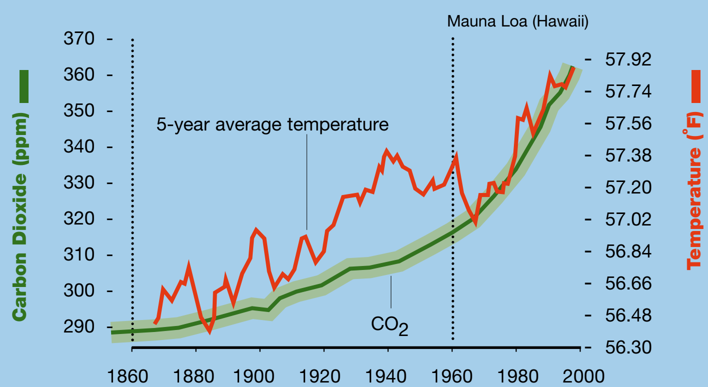
Figure 1.2
Changes in Carbon Dioxide from 10,000 Years Ago to Present CO_2 (2005)

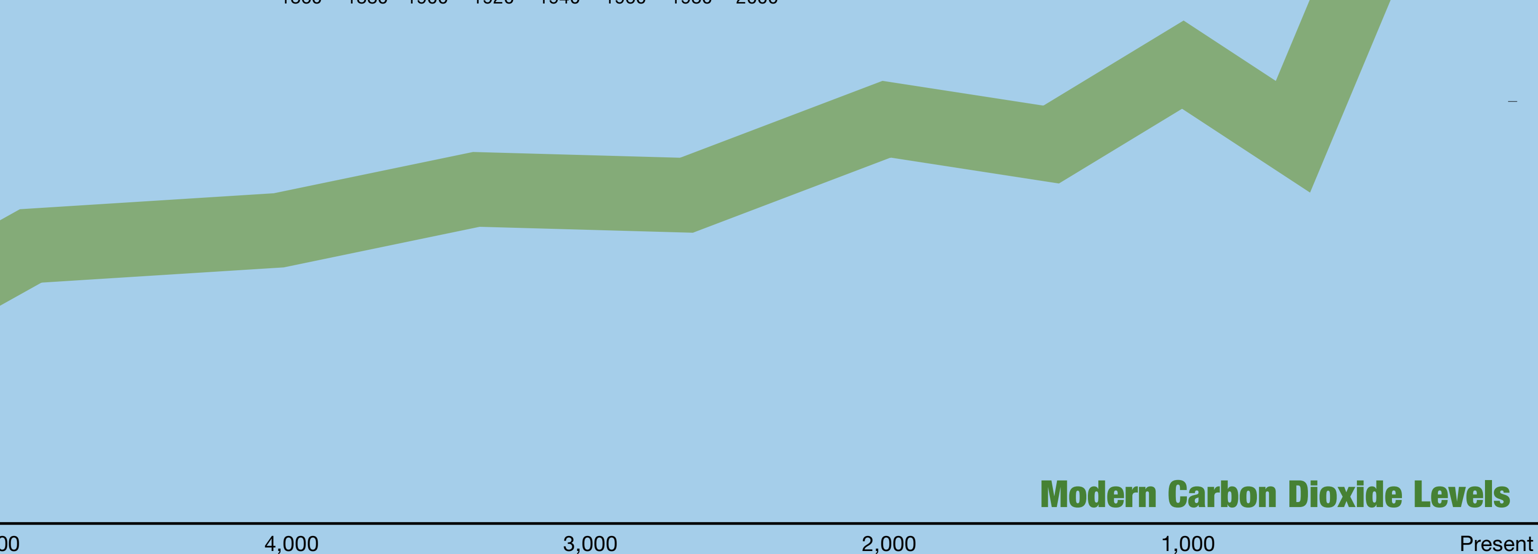
Pre-1950s data from air samples extracted from ice cores and post-1950s data from direct measurements. (IPCC, 2007)



More intense and longer droughts have been observed over wider areas of the tropics and subtropics since the 1970s. Heavy precipitation has increased in frequency over most land areas, consistent with increased atmospheric water vapor. Temperature extremes, hotter days, hotter nights, and heat waves have become more persistent, and tropical cyclones have become more intense since about 1970 (IPCC, 2007). These global trends indicate the dramatic repercussions of human GHG emissions on climate variability.

Figure 1.3
Carbon Dioxide and Global Temperature Trends, 1850-2000
Pre-1950s data from air samples extracted from ice cores and post-1950s data from direct measurements (U.S. OSTP, 2000)





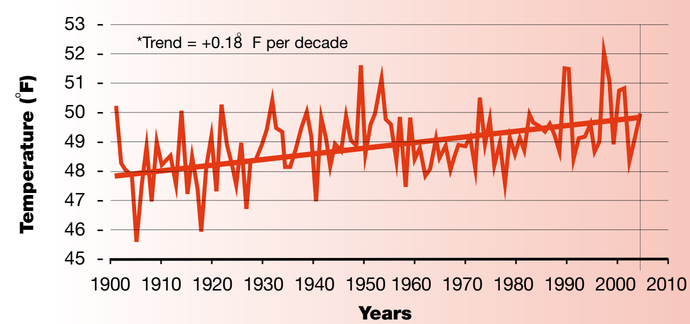
Historical Regional Climate Trends

Data demonstrate that climate trends in the NYC region have been consistent with the global increase in GHGs and the associated range of climatic and hydrologic shifts in air temperature, precipitation and sea level.

Air Temperature

From 1900 to 2005 the annual average observed temperature in the NYC region has increased approximately 1.9ºF, a statistically significant trend (Figure 1.4). Four of the warmest years during the period occurred during the last eight years of the record. This regional increase exceeds the global increase, which may be due in part to the urban heat island effect in New York City and to New York's mid-latitude location (Rosenzweig et al., 2006). Warming is occurring most rapidly in winter (Rosenzweig and Solecki, 2001).

Figure 1.4
Long-Term Annual Observed Temperature Trend in the NYC Watershed Region 1900-2005 (CCSR, 2007)

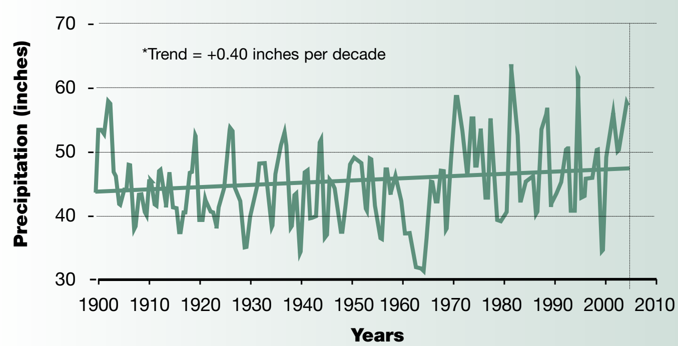


Source: CCSR. Observations were from NCDC Historical Climate Network.
From Five New York State Weather Stations: NYC Central Park, Port Jervis, Yorktown Heights, Mohonk Lake, Maryland.
* = significant at the 95% confidence interval.

Precipitation

From 1900 to 2005 the average annual observed precipitation in the NYC region increased 4.2 inches, an approximately 9.9% increase (Figure 1.5). Because variability of annual precipitation is large, this increase is not statistically significant. However, the variability of annual precipitation has increased somewhat during the latter 40-year portion of this record.

Figure 1.5
Long-Term Annual Observed Precipitation Trend in the NYC Watershed Region 1900-2005 (CCSR, 2007)

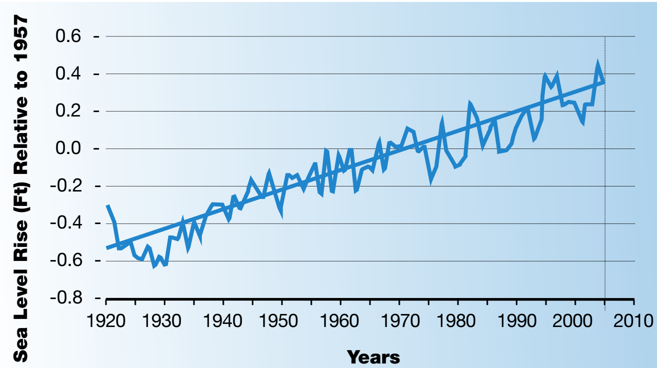


Source: CCSR. Observations were from NCDC Historical Climate Network.
From Five New York State Weather Stations: NYC Central Park, Port Jervis, Yorktown Heights, Mohonk Lake, Maryland.
* = significant at the 95% confidence interval.

Sea Level

From 1920 to 2005 the observed annual mean sea level at the Battery in New York City increased approximately 0.85 feet (Figure 1.6). This is equivalent to approximately one foot in 100 years. In addition to the climate-related factors of thermal expansion of the oceans and ice melt, regional geologic subsidence has also contributed to this increase.

Figure 1.6
The Battery Annual Mean Sea Level Rise, 1920-2005 (Columbia Center for Climate Systems Research, HydroQual, 2007)



1.3 Global and Regional Climate Projections

Some of the most important tools used by climate scientists to project changes in the Earth's climate are General Circulation Models (GCMs, also know as Global Climate Models).

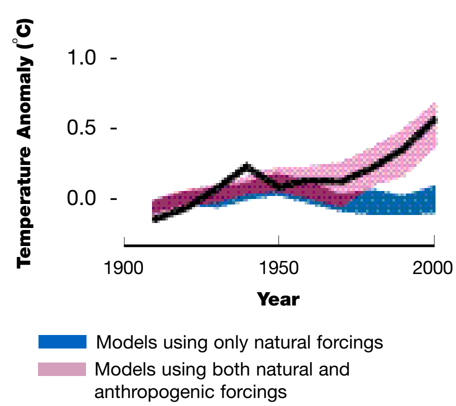
Global Climate Models (GCMs)

GCMs are mathematical representations of the behavior of the Earth's climate system throughout time. They divide the Earth's atmosphere and the ocean into multiple layers and the Earth's surface into thousands of grid boxes defined by latitude and longitude (Figure 1.7). Grid boxes vary in size from 100 to 350 miles on a side with atmospheric and oceanic grid boxes subdivided vertically into many cells. These climate models calculate and solve multiple equations for horizontal and vertical winds, moisture, temperature and pressure; contain subcomponents for radiation, dynamics, clouds, land surface, vegetation, carbon cycle, and atmospheric chemistry; and are scalable by timeframe.

GCM simulations utilize historical GHG levels and natural influences as inputs, and their outputs are validated against historical records. Existing models have effectively replicated observed warming trends from the 20th century. A comparison of observed and calculated global surface temperatures based on a large number of simulations using a variety of internationally available GCMs shows that simulations that include both natural and anthropogenic components compare favorably with observed data, while those using only natural forces do not (Figure 1.8). This affirms that GHG-producing human activities are responsible for much of the current warming.

Figure 1.7
Schematic Representation of Global Climate Model Spatial Segmentation (ACIA, 2004, Level M)

Figure 1.8
Comparison of Observed and Calculated Global Surface Temperature Using GCMs with Natural and Anthropogenic Forces (IPCC, 2007)

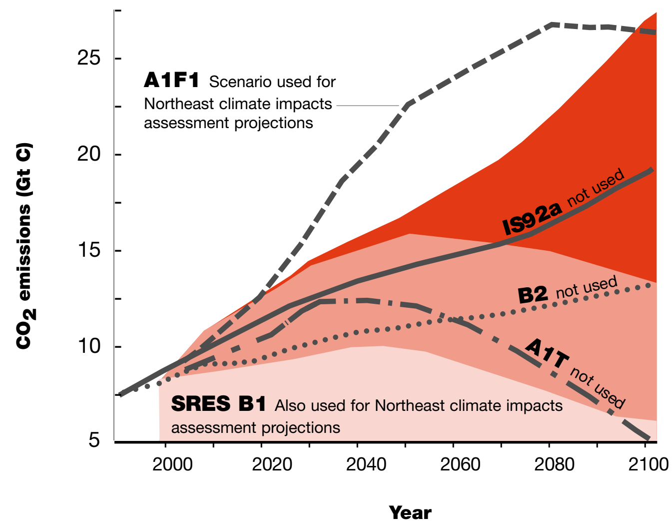


The IPCC endorses GCMs as indicators of future climate trends and changes; however, despite continued improvements, even calibrated models have a level of uncertainty. Therefore, the IPCC recommends the use of several models to develop a plausible range of projected climate outcomes for the future.

Because projection of future climate conditions is dependent upon the future concentrations of GHGs in the atmosphere, the IPCC also recommends running the models with a range of potential future levels of atmospheric GHGs to forecast future temperature, precipitation, sea level and other climate conditions. The IPCC issued a Special Report on Emissions Scenarios (SRES) in 2000 which projects scenarios of future GHG concentrations due to anthropogenic forces (Figure 1.9).

The SRES emissions scenarios are based upon the many factors that will determine the future level of GHGs in the atmosphere: population growth, economic development, technological innovation, energy consumption, land-use, agricultural development, and environmental policy.

Figure 1.9
Anthropogenic Emissions of CO_2 in SRES Emissions Scenarios (IPCC, 2001)



Scenarios used for NYCDEP projections

SRES B1	PRODUCES THE LEAST AMOUNT OF GHG BY 2100
SRES A1B	PRODUCES AN INTERMEDIATE GHG INCREASE
SRES A2	PRODUCES THE MOST GHG BY 2100

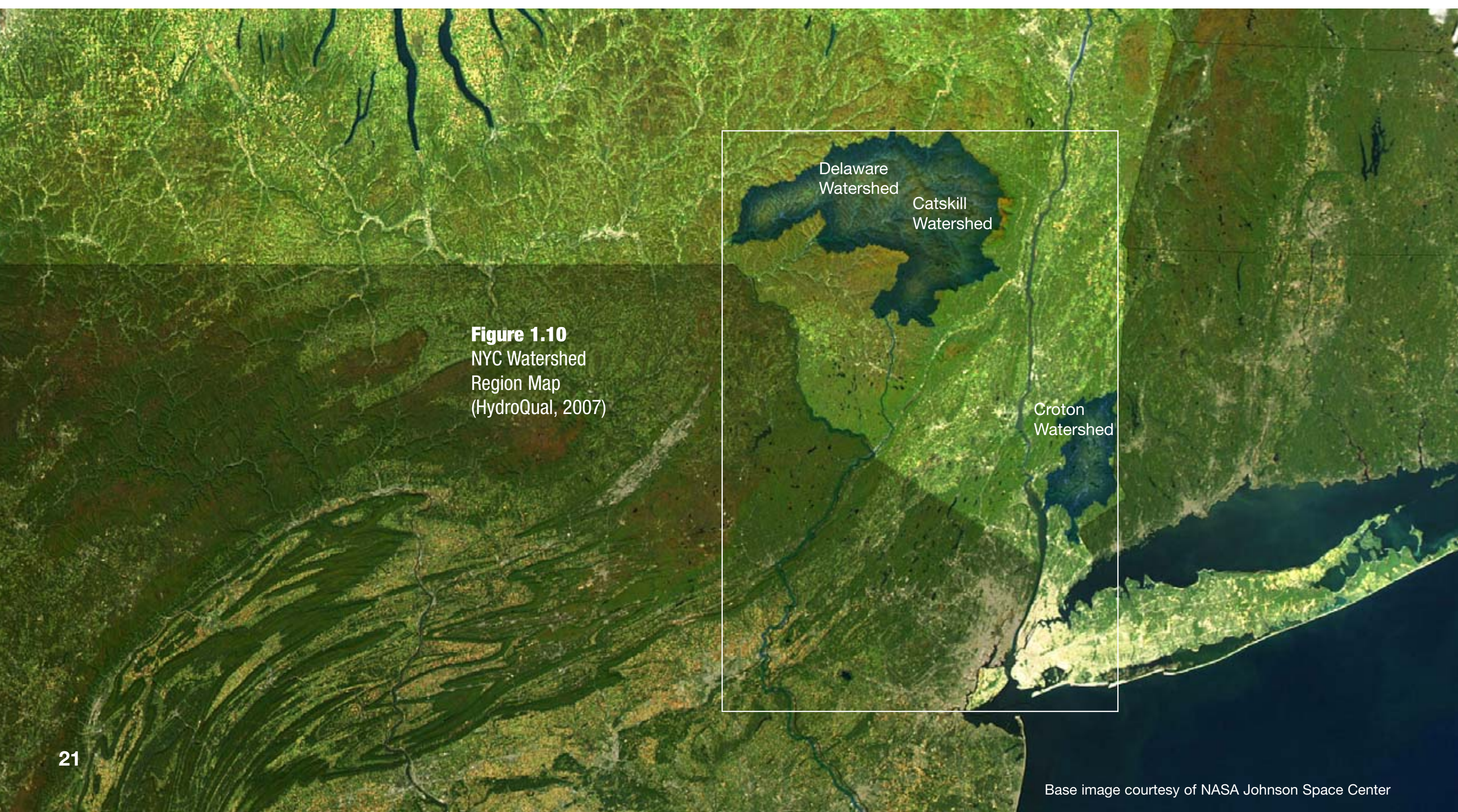


Figure 1.10
NYC Watershed Region Map (HydroQual, 2007)

Base image courtesy of NASA Johnson Space Center

NYC Watershed Region Projections

Columbia University has obtained GCM data for the NYC Watershed Region, which, as defined for these climate projections, spans 40.5 N to 42.5 N and 73.5 W to 75.5 W and includes both the NYC metropolitan area and the upstate watersheds (Figure 1.10). To obtain regional projections Columbia University selected the following five available GCMs for application from the 22 models recognized by the IPCC:

1. GFDL CM2.1
Geophysical Fluid
Dynamics Laboratory (Princeton, NJ)

2. GISS ModelE
NASA/Goddard Institute
for Space Studies (New York, NY)

3. MPI ECHAM5
Max Planck Institute (Hamburg, Germany)

4. NCAR CCSM3.0
National Center for Atmospheric Research (Boulder, CO)

5. UKMO HadCM3
United Kingdom Meteorological Office (Devon, UK)

Three of the seven SRES emissions scenarios depicted in Figure 1.9 were used for model calculations: B1, A1B, and A2 (Table 1.1). These three scenarios were chosen because they span a range of possible futures and are used by most modeling centers. The B1 scenario produces the least amount of GHG increase over the course of the 21st century, while the A2 scenario leads to the most GHG increase by 2100. A1B produces an intermediate GHG increase by 2100, although over the next several decades it actually produces more GHGs than A2, since it initially allows GHGs to increase at 1% each year, which is close to the recent observed rate of increase (IPCC, 2000).

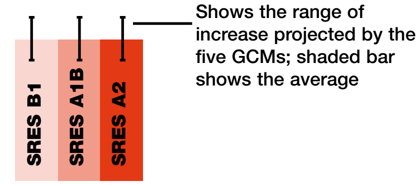
To project a range of potential future temperature and precipitation scenarios for the NYC Watershed Region, Columbia University had to interpolate the five GCMs' run results, each with the three emissions scenarios, for a total of fifteen projections for three different decades: the 2020s, 2050s and 2080s. Due to the differing characteristics of the models, only three of the five GCMs were run in conjunction with the three emissions scenarios to produce sea level projections for the same three decades. The interpolation was necessary because the grid boxes of the various GCMs are spatially larger than the NYC Watershed Region; Columbia University interpolated all results to the local region using a scientifically-accepted method (Cressman, 1959).

SRES Emissions Scenarios

The SRES emissions scenarios are based upon the many factors that will determine the future level of GHGs in the atmosphere: population growth, economic development, technological innovation, energy consumption, land-use, agricultural development, and environmental policy.

Table 1.1
Characteristics of IPCC SRES Emissions Scenarios (Columbia University Center for Climate Systems Research, 2006)

	SRES B1	SRES A1B	SRES A2
PPM CO_2 in 2100	550	720	850
Population Growth	Low	Low	High
GDP Growth	High	Very high	Medium
Energy Use	Low	Very high	High
Land-Use Changes	High	Low	Medium/High
Resource Availability	Low	Medium	Low
Pace of Technological Change	Medium	Rapid	Slow

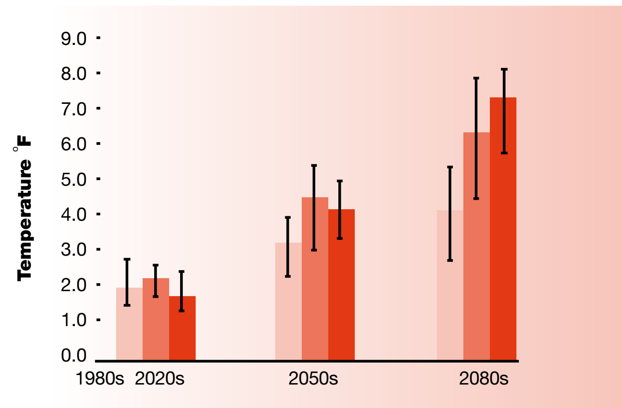


SRES Emission Scenarios and Range of GCM Projections

Air Temperature

The average regional temperature increase for the 15 scenarios over the base period (1970 - 1999) is 2.0°F for the 2020s, 4.0°F for the 2050s, and 5.9°F for the 2080s (Figure 1.11). Although there is a fair amount of variability across the GCMs, they all show a future progression of warming temperatures in all seasons. Seasonal projections from Columbia University show summer increases slightly greater than winter increases. These projections are for the larger NYC Watershed Region. Temperatures in the City might exceed these projections because of the urban heat island effect. The projected temperature increases for the NYC Watershed Region exceed globally averaged changes, indicating that the New York City region might be especially sensitive to the effects of climate change.

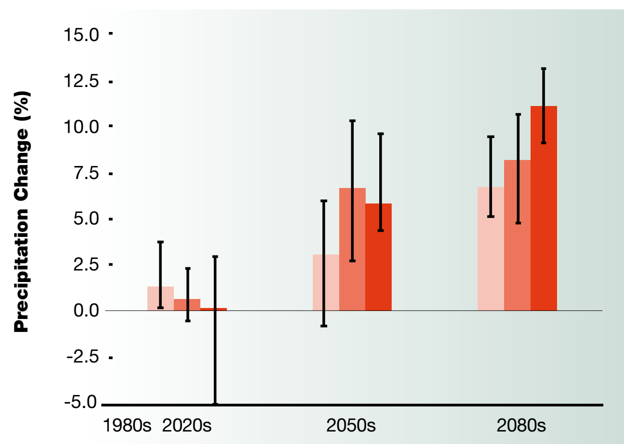
Figure 1.11
Modeled Annual Temperature Changes For the NYC Watershed Region Relative to the 1980s (Columbia Center for Climate Systems Research, 2006)



Precipitation

The average regional precipitation increase for the 15 scenarios over the base period (1970 - 1999) is 0.7% for the 2020s, 5.7% for the 2050s, and 8.6% for the 2080s (Figure 1.12). There is more variability across the models for projected change in precipitation than for temperature. Especially in the 2020s, the models forecast a range of wetter to drier conditions. By the 2050s, however, most projections show increased precipitation for the region. Seasonal projections from Columbia University show precipitation increases may be greater during the winter than in summer in the 2050s and even more so in the 2080s. The synergistic effect of parallel increases in temperature and precipitation are not yet fully evaluated; it remains unclear how much of the increased precipitation will fall as snow, or how snowpack and thaw in the NYC Watershed Region will be affected.

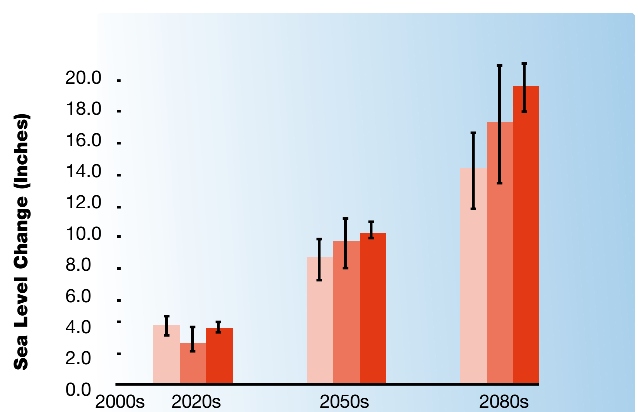
Figure 1.12
Modeled Annual Precipitation Changes For the NYC Watershed Region Relative to the 1980s (Columbia Center for Climate Systems Research, 2006)



Sea Level

The average projected rise in sea level for the 9 scenarios over the base period (1970 - 1999) is 3.2 inches for the 2020s, 9.0 inches for the 2050s, and 16.5 inches for the 2080s (Figure 1.13). There is somewhat less variability across the GCMs for sea level than for air temperature and precipitation; however, these projections do not account for recent research that suggests that the rate of ice melt is accelerating more quickly than most sea level projections have indicated to date. A new study by the National Snow and Ice Data Center found that the area of Arctic sea ice in September, the month when it shrinks the most, has decreased at an average rate of 7.8% per decade since 1953, yet computer climate simulations have used an average ice loss rate of 2.5% per decade for this period (Stroeve, 2007). DEP's long-term planning should include the risk of

Figure 1.13
Modeled Regional Sea Level Rise Relative to the 2000s (Columbia University Center for Climate Systems Research, 2006)



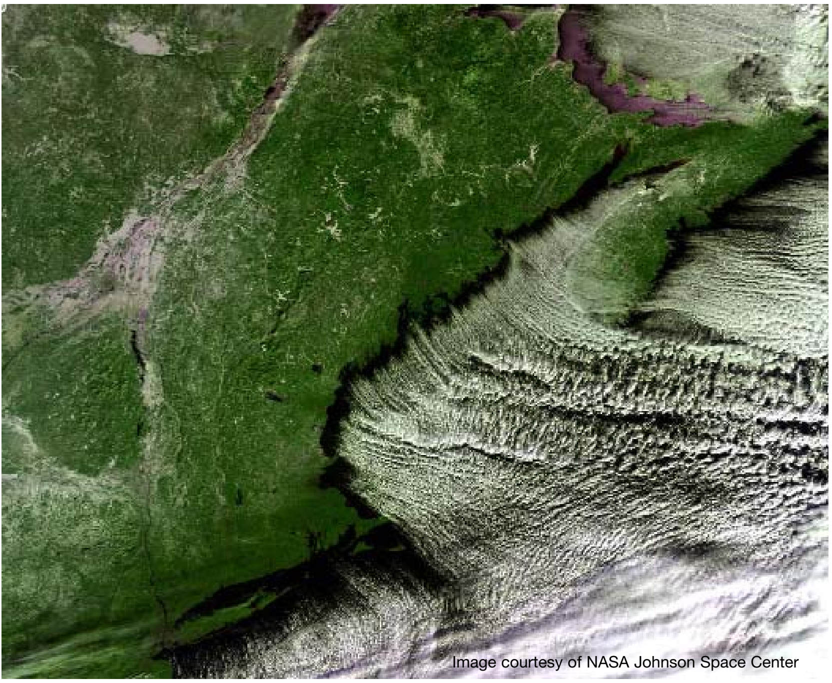


Image courtesy of NASA Johnson Space Center

Extreme Events

In planning for climate change it is also important to consider the increased likelihood of severe and extreme weather events, such as storms, coastal and inland flooding, drought, and heat waves. These events are not as well modeled in current GCMs as are long-term trends in temperature, precipitation and sea level, so forecasts are more uncertain. Nevertheless, because of rising sea levels and the intensification of the hydrologic cycle due to rising temperatures, it is expected that many types of extreme events will occur more frequently (IPCC, 2007). Recent scientific studies have shown a strong correlation between powerful hurricanes and ocean temperature in the North Atlantic (Mann & Emanuel, 2006). New York City and its watershed, particularly because of NYC's coastal geography, may experience more frequent and intense storms in the future as the atmosphere and ocean continue to warm. This is an active area of scientific research that will become more refined and precise over time, though existing data enables the formulation of some broad global projections (Table 1.2).

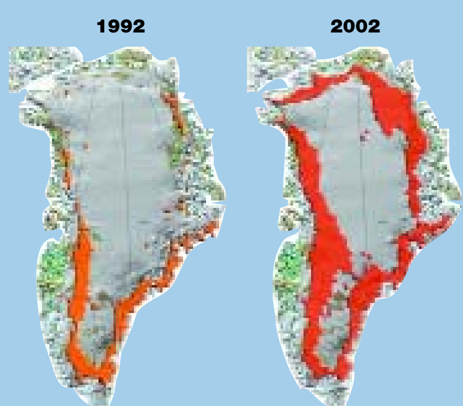
Table 1.2
Recent Global Trends and Anticipated Changes in Potentially Severe and Extreme Events During the 21st Century (IPCC, 2007)

Virtually certain > 99% probability of occurrence
Very likely > 90%
Likely > 66%

Phenomenon and Direction of Trend	Likelihood that Trend Occurred in Late 20th Century (typically post 1960)	Likelihood of Future Trends Based on Projections for 21st Century using SRES Scenarios
Warmer and fewer cold days and nights over most land areas	Very likely	Virtually certain
Warmer and more frequent hot days and nights over most land areas	Very likely	Virtually certain
Warm spells / heat waves. Frequency increases over most land areas	Likely	Very likely
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	Likely	Very likely
Area affected by droughts increases	Likely in many regions since 1970s	Likely
Intense tropical cyclone activity increases	Likely in some regions since 1970s	Likely
Increased incidence of extreme high sea level (excludes tsunamis)	Likely	Likely

Greenland Ice Sheet

This map shows the inland expansion of the summer melt zone of the surface ice in Greenland between 1992 and 2002. If the Antarctic Ice Sheet or the Greenland Ice Sheet were to melt, global mean sea level could rise on the order of 17 feet and 23 feet, respectively. Scientists have conjectured that this would occur over millennia, but recent data suggest that melting is occurring more quickly than previously anticipated.



Source: Cooperative Institute for Research in Environmental Sciences, University of Colorado at Boulde (2007).

Flooding

Flooding due to rainfall is likely to increase because of the expected increase in the intensity of rainfall events.

Mean values of climate change are of great importance in planning as are extreme events: storms, coastal and inland flooding, droughts, and heat waves. As indicated by IPCC (2007), there is currently large uncertainty about future changes in extreme events, and climate modeling of extreme events is an emerging science.

It is therefore anticipated that scientific understanding of extreme events will continue to evolve. As new data become available from GCM simulations associated with the next IPCC report in approximately 3-4 years, scientific understanding is likely to improve, since these GCMs will feature more advanced physics, higher spatial (and possibly temporal) resolution (critical for modeling extreme events), and more variables will be stored with longer temporal coverage. Therefore, the current model projections offer the best guidance for future changes in extreme events. While it may be premature to use the precise quantification of changes in extreme events to guide policy, the general direction of many changes, such as a tendency for more heat waves, enhanced coastal flooding, and an intensified hydrological cycle, can be viewed with high confidence, as described by IPCC (2007).

A range of other extreme events is expected to become more severe with global climate change. Heat waves are also almost certain to increase in the region. As mean temperature increases, extreme heat is expected to increase in frequency, intensity, and duration. Even relatively small changes in heat statistics can have large societal impacts, given the severe stresses imposed by heat waves in the current climate. Flooding due to rainfall is likely to increase because of the expected increase in the intensity of rainfall events. Droughts may become more frequent in the region, because as temperatures rise, evaporation rates will increase; droughts may become more common even with increased precipitation.

As the mean sea level increases, smaller storms are able to produce the amounts of flooding previously associated with larger storms.

Further, changes in the intra-annual distribution of rainfall could also contribute to droughts and floods in the region. While evaporation is a relatively steady process, precipitation is highly variable, spatially and temporally. If, as much research suggests (Karl and Knight, 1998 for example), precipitation becomes concentrated in intense events, this could contribute to increased duration and frequency of both floods and the dry intervals between rainfall events.

Coastal flooding is almost certain to become a more serious problem due to increasing sea level. As a result, the recurrence interval for coastal floods at each level of inundation is expected to decrease as sea levels rise. Therefore, any increase in storm frequency or intensity would further contribute to higher incidence of coastal flooding.

1.4 Model Uncertainty and Validation

Quantitatively Comparing Data with Historical Hindcast Simulations

As with all forecasting, some level of uncertainty in climate change projections is unavoidable. Uncertainties in GCM projections stem from the difficulty of understanding and expressing the physics of the weather and climate systems, grid sizes, topography, and the amount of future GHG emissions. Given the uncertainties, an approach that considers the range, frequency and general confidence of various levels of change is more appropriate than basing decisions on mean changes. Columbia University used multiple GCMs and GHG emissions scenarios to produce a range of projections (Table 1.3). For the three climate variables, considering only the modeling projections from the 15 model-emission scenarios framework created by Columbia University, it is most probable that the increase in sea level will be within the GCM-projected range shown, followed by air temperature then precipitation increases, based on the modeling probabilities associated with the various ranges.

Columbia University validated the temperature and precipitation projections for the NYC Watershed Region by quantitatively comparing data from historical hindcast simulations of the GCMs to historical observed data. This process is undertaken to gain assurance as to the appropriateness of the models for projecting future climate scenarios. The differences in hindcast values and observed values are not part of the process of developing future scenarios, which are based on assumptions about future GHG emissions and on generated future climates that are different from the present climate. Rather, the forecasting procedure applies the difference between the GCM projections and the hindcast values for the base period to the observed average values for the base period (1970-1999).

The calculated GCM ensemble hindcast average temperature is 2ºF less than the observed 30-year average for the period 1970 to 1999, just outside of one standard deviation of the measurements.

Melting Glaciers

When meltwater seeps through cracks in the ice sheet, it may accelerate melting and, in some areas, allow the ice to slide more easily over the bedrock below, speeding the movement of the ice sheet to the sea.

Table 1.3

Model-Based Probability of Change[1] in Climate-Related Characteristics in the NYC Watershed Region

	Air Temperature[2]		Precipitation[2]		Sea Level Rise[3]	
Decadal Average	**Range (°F)**	**Model-Based Probability (%)**	**Range (%)**	**Model-Based Probability (%)**	**Range (Inches)**	**Model-Based Probability (%)**
2020s	1.0 to 3.0	100	0 to 2.5	60	2 to 6	100
2050s	3.0 to 5.0	80	2.5 to 7.5	64	6 to 12	100
2080s	5.0 to 8.5	67	7.5 to 15.0	74	12 to 22	89

(1) Model-based probability that the projected increase will be within the range shown across selected GCMs and three emissions scenarios.

(2) Relative to the 1970-1999 base period from five GCMs.

(3) Relative to the 1970-1999 base period from three GCMs. Percentages rounded to nearest integer.

Source: Columbia University Center for Climate Systems Research (2006).

For precipitation it is approximately 0.2 inches/month (5.4%) greater than the 30-year average, and within one standard deviation of the measurements (Table 1.4). These are considered strong performance comparisons, but even these minor inaccuracies should be considered in the application of GCM projections in those cases where forecasted changes are on the same order as these variances. Modeled sea level rise can not be validated through comparing model hindcasts to observed sea level because sea level rise is not a direct GCM output. IPCC experts determine global sea level projections based on the historical relationship between observed sea level rise and observed temperature increase over the 20th century (IPCC 2001, 2007 and Rahmstorf, 2007).

Regional projections for sea level rise at the Battery in NYC are based on three additional factors:

- **Change in land height (primarily due to Glacial Isostatic Adjustment, which is causing land subsidence in the NYC region)**
- **Change in global mean sea level (projected based on a linear fit with GCM projections of global temperature change, as described above)**
- **Regional distribution of sea surface height, which is a function of ocean temperature, surface wind, salinity, current velocity, and atmospheric pressure**

Standard techniques were also used to assess the statistical significance of the projected changes in mean temperature, precipitation, and sea level. Analysis shows that all regional temperature projections are significantly different statistically from the historical base period; that is, in each case there is less than a 2.5% chance that future warming of that magnitude would occur by chance alone. Similarly, 7 of the 15 projected precipitation changes for the 2050s and 14 of the 15 projected precipitation changes for the 2080s are significantly different statistically.

The precipitation projections for the 2020s are not yet distinguishable from natural variability (although increases are projected in 11 of the 15 models, the trend is not statistically significant at the 2.5% level). The sea level rise projections are all statistically significant at the 95% level; that is, given sea level variability over the 20th century, there is less than a 5% chance that the projected level of rising would occur by chance alone (i.e., without global warming).

Table 1.4
Model Validation for the NYC Watershed Region Annual Temperature and Precipitation Hindcast Projections for 1970-1999

	Observed Data (± Standard Deviation)	Average of Model Hindcasts	Model Hindcast Range
Temperature (°F)	48.0 ± 1.0	46.0	43.5 - 48.5
Precipitation (inches/mo)	3.7 ± 0.5	3.9	3.2 - 4.5

* Model results based on five GCMs.
* Sea level rise projections are not validated through hindcasting.
Source: Columbia University Center for Climate Systems Research (2006).

"Although there is certainty that many climate changes will be experienced, there is uncertainty as to the magnitude and timescale of these changes."

Image courtesy of the Image Science & Analysis Laboratory, NASA Johnson Space Center

1.5 Scientific Uncertainty and the DEP

Despite documented changes in historical climate records and great advances in climate science, uncertainties remain. For instance, although there is broad agreement that the global climate is warming and that sea level is rising, precipitation trends are not as clear. An analysis that compared the most recent 50 years of rainfall records in the New York City metropolitan area to those from the preceding 50 years showed a very small change to date in short-term rainfall intensity and duration relationships (Vieux & Associates, Inc., 2006).

Similarly, although there is certainty that many climate changes will be experienced, there is uncertainty as to the magnitude and timescale of these changes. In addition, projections for how the climate system will change globally are currently more certain than projections for particular regions. Some changes that are projected to occur in much of the world may be experienced to a greater or lesser degree in New York.

Much of the data generated by scientific studies is not yet sufficiently detailed and site-specific for infrastructure planning. DEP's current infrastructure planning and design practices rely on data that is much more precise than that which can be readily extrapolated from GCM projections. For instance, the precipitation projections that have been developed to date for DEP are daily and monthly averages, and the smallest time interval that can be calculated by GCMs is 3 hours, yet the existing sewer system is designed according to the amount of precipitation that falls in much shorter time intervals, 5 minutes in some cases.

DEP needs to find ways to bridge the gap between broad and evolving global climate science and site-specific infrastructure engineering planning and design. Important first steps have been taken, but more are needed to quantify both potential impacts and risks at a level of detail sufficient for the development of planning strategies.

1.6 DEP Actions to Reduce Uncertainty in Regional Climate Change Trends and Projections

To enhance climate change projections for New York City and its Watershed Region, DEP will:

ACTION 1

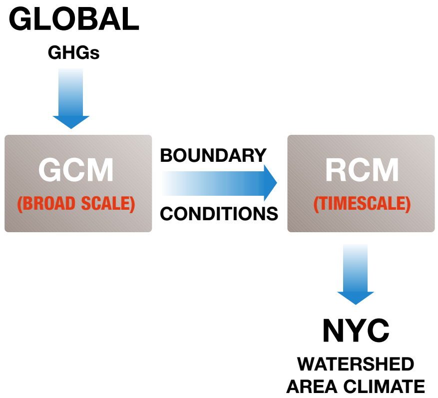
Work with the scientific community and other governmental and non-governmental organizations to develop more refined regional climate change projections.

ASSEMBLE A COMPREHENSIVE SUITE OF REGIONAL CLIMATE PROJECTIONS

Columbia University has provided DEP with comprehensive sets of climate data for the New York City Watershed Region. The datasets include daily temperature, precipitation, solar radiation, wind, humidity and other variables. The data will be used as a basis to provide DEP with the ability to identify the range of potential impacts using its various watershed, sewershed, and harbor water quality modeling tools.

APPLY A REGIONAL CLIMATE MODEL TO NEW YORK CITY AND ITS WATERSHEDS

Under the direction of Columbia University, the University of Connecticut is applying a Regional Climate Model (RCM) that runs on smaller spatial and time scales and includes localized topographic features important for finer scale monthly temperature and precipitation projections. This technology is promising but still in a developmental stage. Results from this research will be shared and discussed by the Department with other utilities and regional authorities to facilitate a collaborative approach toward understanding the impacts of climate change at a local scale.



ACTION 2

Work with regulatory and other agencies on the PlaNYC initiative to update the existing 100-year flood elevations using current sea level data, and develop agreed-upon estimates of future 100-year flood elevations, sea level rise, storm intensity, and maximum probable flood using climate change projections.

Using historical data and climate change projections, DEP will work with other agencies and regional authorities to advance the PlaNYC initiative of updating the current 100-year flood elevations using current sea level data. The current elevations, which are used by DEP for flood protection criteria in facilities planning, are based on coastal engineering work conducted by regional authorities approximately 25 years ago. DEP will also work with other agencies and authorities to use climate change projections to develop estimates of future 100-year flood elevations, sea level rise, storm intensity, and maximum probable flood so that the factors used for safety and design are standardized City-wide.

ACTION 3

Identify additional data and monitoring stations needed to track global and regional climate changes.

As projected climate change impacts are long-term in nature, DEP will institutionalize a monitoring program across all planning and operational Bureaus to track change over time. This will help DEP advance projects and programs along a time schedule that is consistent with the projected climate changes. For factors such as temperature and sea level rise, data that can be appropriate as indicators generally already exist and are routinely collected from regional weather stations, tide gauges, and other monitoring locations. However, DEP must identify the other key indicators that will be needed to effectively monitor and analyze changes and implement appropriate adaptations.

NYCDEP Watershed Meteorological Station

ACTION 4

Track developments in climate change science, improvements in global climate models, and emerging estimates of changes in the severity, duration, and frequency of weather events.

Climate change projections are dependent on a range of complex mathematical GCMs that will continue to be improved over time. DEP is particularly interested in advancements in regional climate modeling, an area of research that is not yet as well developed as global climate modeling. DEP will continue to track climate change science in order to keep abreast of evolving climate change issues and progress by the world scientific community. This will allow DEP to determine when advances in climate science and models merit the development of new regional projections to keep DEP's engineering and design processes as scientifically current as possible.

In addition, DEP will closely monitor qualitative and quantitative estimates of changes in the severity, atmospheric energy, duration, and return frequency of extreme events and discuss these estimates with other City and regional collaborators. At this time, changes in extreme events, such as hurricanes, are not well-modeled and projected.

However, because New York City is at-risk to hurricanes and other extreme events, and climate change may increase the frequency and severity of these extreme and potentially catastrophic events, DEP will benefit from any developments that are made in this area of research.

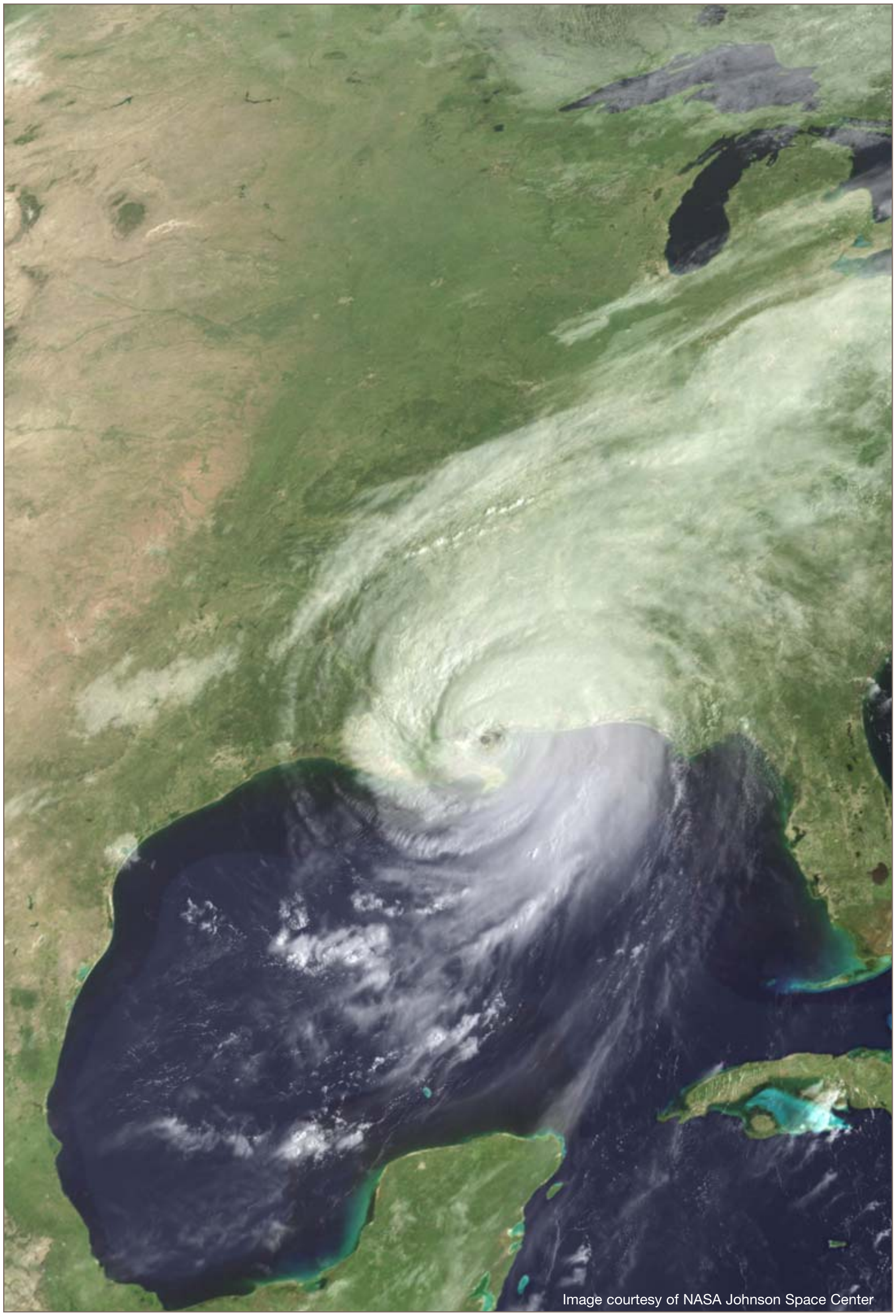


Image courtesy of NASA Johnson Space Center