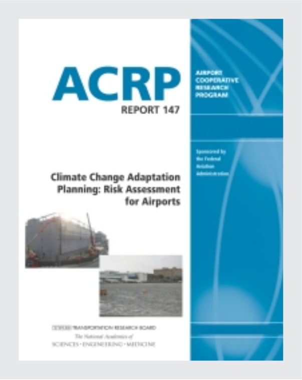

Climate Change Adaptation Planning: Risk Assessment for Airports

DETAILS

128 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-37488-0 | DOI 10.17226/23461

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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP REPORT 147

Climate Change Adaptation Planning: Risk Assessment for Airports

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Subscriber Categories
Aviation • Environment • Planning and Forecasting

Research sponsored by the Federal Aviation Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2015
www.TRB.org

AIRPORT COOPERATIVE RESEARCH PROGRAM

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ACRP was authorized in December 2003 as part of the Vision 100—Century of Aviation Reauthorization Act. The primary participants in the ACRP are (1) an independent governing board, the ACRP Oversight Committee (AOC), appointed by the Secretary of the U.S. Department of Transportation with representation from airport operating agencies, other stakeholders, and relevant industry organizations such as the Airports Council International-North America (ACI-NA), the American Association of Airport Executives (AAAE), the National Association of State Aviation Officials (NASAO), Airlines for America (A4A), and the Airport Consultants Council (ACC) as vital links to the airport community; (2) TRB as program manager and secretariat for the governing board; and (3) the FAA as program sponsor. In October 2005, the FAA executed a contract with the National Academy of Sciences formally initiating the program.

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ACRP REPORT 147

Project 02-40
ISSN 1935-9802
ISBN 978-0-309-37487-3
Library of Congress Control Number 2015953107

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Published reports of the

AIRPORT COOPERATIVE RESEARCH PROGRAM

are available from

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet by going to

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Printed in the United States of America

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FOREWORD

By Michael R. Salamone
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ACRP Report 147: Climate Change Adaptation Planning: Risk Assessment for Airports provides a guidebook to help airport practitioners understand the specific impacts climate change may have on their airport, to develop adaptation actions, and to incorporate those actions into the airport's planning processes. This guidebook first helps practitioners understand their airport's climate change risks then guides them through a variety of mitigation scenarios and examples. Accompanying the guidebook, an electronic assessment tool called Airport Climate Risk Operational Screening (ACROS) was developed to help airports ask the question, "Within the entire airport, what's most at risk to projected climate changes?" The ACROS tool uses a formula to compute an estimated level of risk for assets and operations at the airport. In addition, the research team used the most recent information available from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). These airport-specific risks are then ranked to provide an enterprise-level estimate of the relative risk posed by each asset and operation. The ACROS tool is a streamlined way to approach risk screening for an entire airport. This guidebook will be of interest to a wide range of airport practitioners, including landside planners, utilities managers, operations and maintenance personnel, and senior management staff.

Under ACRP Project 02-40, a research team led by Dewberry began with a review of literature and current practices recommended by organizations inside and outside of the airport industry. To improve understanding of the connections between climate and airport operations, the research team worked with climate adaptation specialists to draw from current research and apply the results directly to the aviation industry, bridging the gap that exists between climate science and practice. Generally, airports are well equipped to respond to daily fluctuations in weather; however, significant changes to climate (average atmospheric conditions over time) can have serious, negative effects on airport operation and infrastructure. As with many other factors affecting airports, changing climate has the potential to be costly and disruptive; however, risk assessment and planning can mitigate those effects. This guidebook and the ACROS tool, which were refined based on comments from the teams of airport staff who participated in the case study process, are the culmination of those efforts. The ACROS tool is available on the accompanying CD (CRP-CD-175) or for download from the TRB website (www.trb.org) by searching for "ACRP Report 147."

CONTENTS

PART I Introduction and Adaptation Framework

PART II A Primer on Climate Change and Uncertainty for the Airport Context

PART III **The User Guide**

PART IV Applying the Adaptation Framework

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

PART I

Introduction and Adaptation Framework

CHAPTER 1

Introduction and Purpose

1.1 From Flexibility to Resiliency: The Case for Climate Change Adaptation

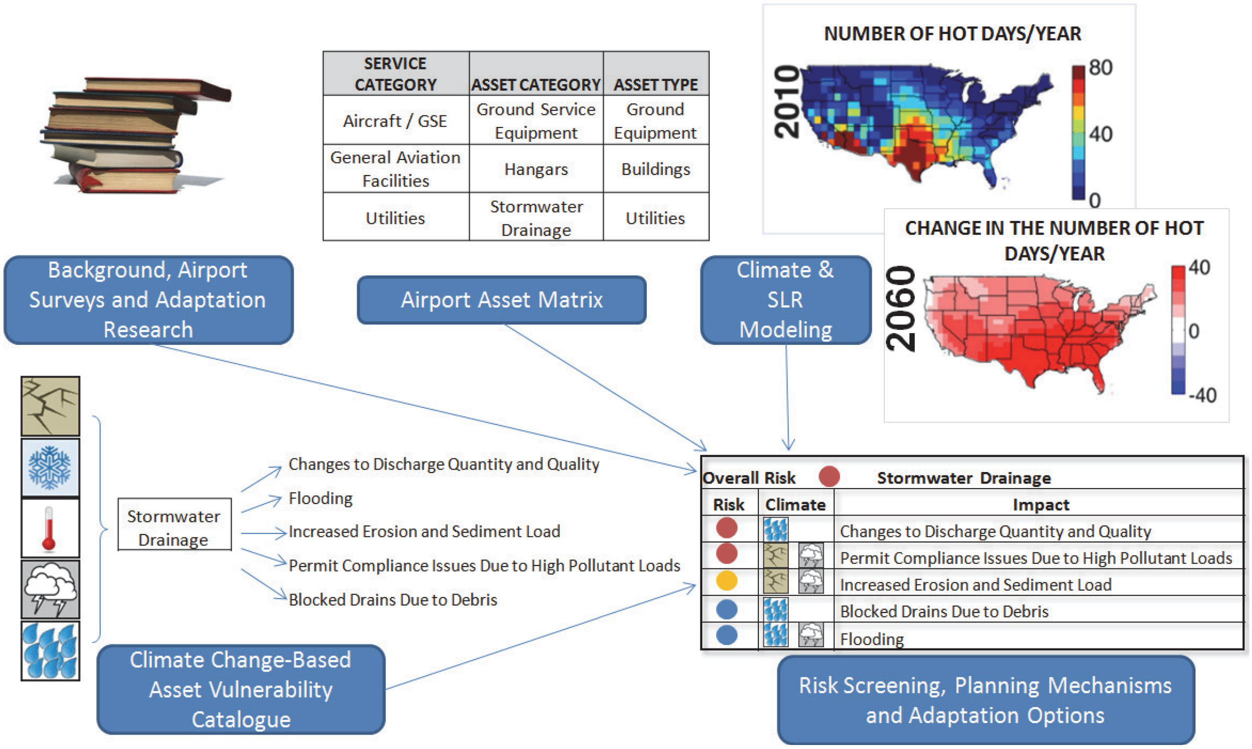
The purpose of this guidebook and accompanying Airport Climate Risk Operational Screening (ACROS) tool is to help airport managers understand the specific impacts climate change may have on their airports, and to provide guidance on developing adaptation actions and incorporating them into existing airport planning processes. While airports are well equipped to respond to daily fluctuations in weather, significant changes to climate (average atmospheric conditions over time) can negatively affect airport operation and infrastructure. This guidebook takes the perspective that understanding and addressing an airport's climate change risks is a key component of airport resilience. As with many other factors affecting airports, changing climate has the potential to be costly and disruptive; however, risk assessment and planning can mitigate those effects.

Without access to detailed information about how climate is projected to change, the need to consider adaptation strategies may not always be clear: in a poll conducted in preparation for this study effort, many airport operators and managers responded that they feel prepared for climate change because they already contend with a variety of weather-related issues. However, the science indicates that these impacts may manifest not only in disruptions to air traffic schedules, but also by:

- Increasing operating costs by gradually pushing airports into operating conditions that challenge the experience of airport staff and the capacity of facilities and equipment,
- Slowly undermining vulnerable capital investments,
- Affecting the health and safety of customers and staff, and
- Impairing the ability of airports to meet regulatory requirements.

To improve understanding of the connections between climate and airport operation, industry experts worked with climate adaptation specialists to draw from current research and apply the results directly to the aviation industry, bridging the gap that exists between climate science and practice. The research team used the most recent information available from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). This guidebook and the ACROS tool, which were refined based on comments from the teams of airport staff who participated in the case study process, are the culmination of those efforts. See Figure 1-1.

A screening-level investigation of climate change risks to airports can be accomplished using the ACROS tool that accompanies this guidebook. Developing this guidebook and the ACROS tool was a collaborative effort across multiple disciplines and included airport experts, climate scientists, coastal scientists, civil engineers, and software developers. The guidebook contains a framework for those airports wishing to conduct a climate risk screening independently. The ACROS tool contains climate information for over 500 airports in the United States, as well



SERVICE CATEGORY	ASSET CATEGORY	ASSET TYPE
Aircraft / GSE	Ground Service Equipment	Ground Equipment
General Aviation Facilities	Hangars	Buildings
Utilities	Stormwater Drainage	Utilities

Overall Risk 🔴		Stormwater Drainage
Risk	**Climate**	**Impact**
🔴	💧	Changes to Discharge Quantity and Quality
🔴	▨ ⛈	Permit Compliance Issues Due to High Pollutant Loads
🟡	▨ ⛈	Increased Erosion and Sediment Load
🔵	💧	Blocked Drains Due to Debris
🔵	💧 ⛈	Flooding

Figure 1-1. The components required to create the ACROS tool (GSE = ground service equipment, SLR = sea level rise).

as over 700 climate change-related impacts that were established for airport assets and operations. The ACROS tool provides an enterprise-level relative risk estimate for airport assets and operations for the years 2030 and 2060. The 2030 and 2060 time frames were chosen to inform the short- and long-term planning horizons (i.e., the planning and capital investment cycles for airport infrastructure). With the tool, airports can begin to understand which aspects of climate (such as high temperatures or heavy rain) will influence airport operations, what types of impacts to expect, and how to take action. This guidebook refers to general aspects of climate (e.g., high temperature) as climate stressors. More specific definitions of climate stressors that are directly related to airport operations (e.g., days when air temperatures exceed 90°F) are referred to as climate vectors.

1.2 Intended Use of the ACROS Tool

The primary purpose of the ACROS tool is to help airports ask the question, “Within the entire airport, what’s most at risk to projected climate changes?” The ACROS tool uses a formula to compute an estimated level of risk for assets and operations at the airport. These risks are then ranked from high to low and grouped to provide an enterprise-level estimate of the relative risk posed for each asset and operation. The ACROS tool is a streamlined way to approach risk screening for an entire airport. The risk groupings can then be used to support the adaptation planning process by identifying and providing insight into higher urgency risks. The risk ranking process is described in more detail in Chapter 6.

Two additional ways to use the information in the tool and guidebook were also suggested by case study participants:

1. Airport staff may benefit from the capability to review the vulnerabilities of one or a small number of assets. For example, when planning upgrades, replacements, or retrofits for equip-

ment, airports may be interested in learning about a single asset. In order to learn about a single asset or operation, staff can refer to the item of interest in the appendices of this guidebook, where a listing of possible climate stressors and adaptations for that asset is provided. It is not possible to use the tool to provide a risk ranking for a single asset at this time (ACROS was designed to compare multiple assets across the airport system).

2. Airport staff may have an interest in viewing all assets and operations that might be affected by a particular climate stressor. For example, after a storm, an airport might be interested in understanding vulnerabilities across the airport related solely to this type of event. While the ACROS tool itself is not configured to provide this functionality, airport staff can, again, use the tables provided in Appendix A of this guidebook to do so.

While an enterprise-wide risk screening is the primary intended use of the tool, it is understood that airport managers may sometimes need to focus on particular aspects of the airport. Additionally, the adaptation planning process may be initiated for a number of reasons, ranging from post-disaster recovery to recognition of the opportunity to build additional resilience into replacement facilities and infrastructure. Whatever the motivation, adaptation planning, as presented in this guidebook, delivers practical adaptation strategies to build resilience to climate change's continuing, costly impacts using a commonsense, no-regrets approach.

1.3 How to Use this Guidebook

The guidebook and ACROS tool are meant to be used together; however, the guidebook alone can serve as a roadmap for airports that wish to take stock of climate change impacts independently. By using this guidebook and tool, airport staff will be able to use the climate change adaptation framework described in Chapter 2 to:

- Develop an effective advisory team and identify other important contributing stakeholders.
- Gain an understanding of climate change projections and the limitations of the projections affecting adaptation decision making at their airport.
- Learn how climate impacts pose risks to airport assets and operations.
- Evaluate those risks from a likelihood and vulnerability perspective.
- Generate a climate adaptation plan containing strategies tailored to the mix of assets and operations present at the airport.
- Understand how to integrate adaptation strategies into existing and future airport planning documents and procedures.
- Understand how to qualitatively evaluate specific adaptation options for incorporation into individual project designs.
- Identify external partners (municipalities, utilities, transportation agencies, etc.) whose input and adaptation responses are critical to airport operation.

To skip ahead to the ACROS tool User Guide, please go to Chapter 7

CHAPTER 2

Adaptation Framework

Climate change adaptation planning is a multi-step process aimed at increasing the resilience of infrastructure and operations when confronted with the range of projected climate change impacts. The framework described below provides guidance on climate change adaptation from the early stakeholder identification process (see Chapter 3) through developing, implementing, and monitoring an airport's adaptation plan. The adaptation planning process below is based on the efforts of other airports across the nation and internationally. The ultimate objective of the process is to become familiar with the range of projected climate change impacts; understand the effects of those impacts on operations and assets; and to select, implement, and refine a corresponding set of adaptation strategies.

2.1 Components of the Climate Change Adaptation Planning Process

Whether the climate change adaptation plan is a stand-alone document or part of an existing airport document such as the master plan, the essential adaptation components are the same. Figure 2-1 shows how the ACROS tool can help, namely by assisting with the inventory, climate risk, and adaptation options components of the process (see Chapter 7). While it is possible to use the report produced by ACROS as a major component of a stand-alone adaptation plan, this guidebook also provides direction for "mainstreaming" the information by including adaptation planning elements in relevant airport documents. (Chapters 8 and 9 describe how to integrate this information into existing airport documents.) The framework shown here is suitable for all airports undergoing the climate adaptation planning process. However, the ACROS tool is tailored to airports that are just beginning to plan for climate change, especially those with limited time and resources to obtain and investigate climate projections.

2.2 Role of the ACROS Tool in the Climate Change Adaptation Planning Process

As shown in Figure 2-1, the ACROS tool provides support for several key processes, culminating in a report based on airport-specific information. Some of this information is contained within the tool and some will be provided by the user team (discussed in further detail in the Chapter 7 User Guide). The report outlines a number of potential adaptation strategies for vulnerabilities identified through the tool workflow. These adaptation options are meant to represent a menu of possibilities that can be refined or expanded upon by the stakeholder advisory team over time.

Ultimately, airport decision makers will select adaptations based on their own unique understanding of their airport's characteristics. Different airports may leverage different planning

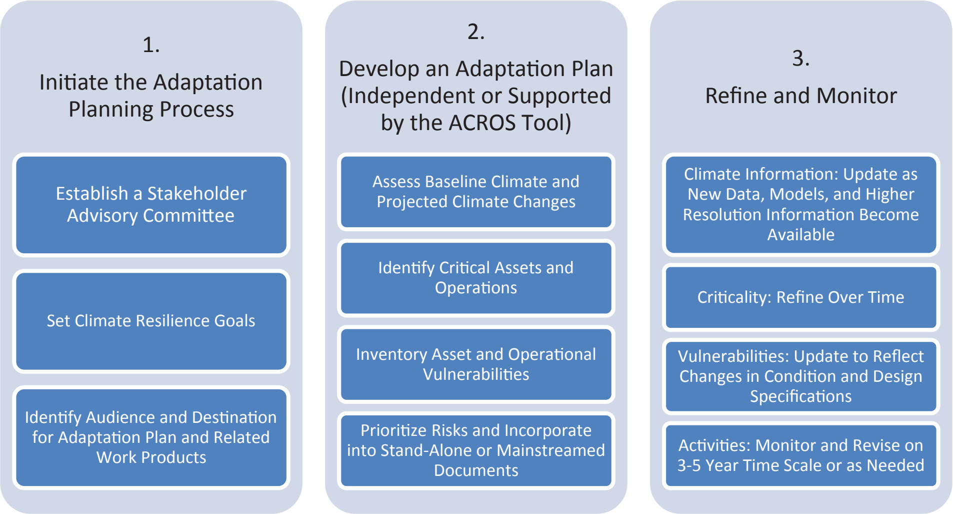


Figure 2-1. Components of the climate change adaptation planning process.*

*The first and second category activities are the focus of the ACROS tool and guidebook.

processes to support implementation of the selected options. Airport operators choosing to incorporate climate change adaptation into their operations and planning processes should take care to implement all phases of the climate change adaptation planning process, including sufficient stakeholder involvement and proper monitoring and updating. Communication and cooperation with airlines, tenants, nearby municipalities, and other organizations will be necessary throughout the process. Each step is described in greater detail in the following chapters.

CHAPTER 3

Initiating the Adaptation Planning Process

A survey of airport representatives and experts in the United States identified the following personnel as the crucial leaders or contributors to the climate change adaptation process for many airports.

- Executive Management
- Engineering
- Planning
- Operations and Maintenance
- Environmental, Sustainability, and Resilience
- Finance
- Risk Management/Legal
- Emergency Operations

Representatives of airports in the United Kingdom who conducted climate change adaptation planning comparable to the efforts described here generated similar lists. The size and composition of these committees will vary depending on the size and needs of individual airports.

For more background on climate change adaptation already under way in the United States and the United Kingdom, please see Appendix E: Resources.

3.1 Establishing a Stakeholder Advisory Committee

The selected team serves as the advisory committee to the climate change adaptation process.

3.1.1 The Core Advisory Committee

Participants at this level should be enlisted according to their ability to contribute to the planning process and to assist in the execution of airport adaptation initiatives. Their roles combine leadership and knowledge of the airport's vulnerable facilities, assets, and operations, as well as the ability to direct identified adaptation and resilience efforts in the areas for which they are responsible. Personnel identified in the previous section can be considered as a starting point. Individual airports should select the composition of this team based on their needs.

3.1.2 Other Stakeholders Inside and Outside the Airport

Other key airport personnel, airline representatives, government agencies such as the Federal Aviation Administration (FAA), and local and regional stakeholders often have perspectives and resources that will contribute to a system's overall resilience (Schaefer, 2012). Stakeholders outside the airport may be able to offer regional climate projections and may also desire or even require participation by the airport in their own climate change adaptation planning activities. Universities and other academic entities can also offer valuable contributions to adaptation efforts through research and brainstorming (C&S Engineers, Inc. and Vanasse Hangen Brustlin, Inc., 2011). Ideally, such collaboration will spur parallel efforts external to the airport, improving resilience in areas that affect airports, but are outside their purview. By engaging with the wider community, airports can attain sufficient information and support for meaningful adaptation and planning. As climate change effects continue, airport staff who know the vulnerabilities of their facility, engage their community, and plan accordingly will be at a significant advantage in surmounting the challenges posed by present and future changes to climate (see Chapter 4).

3.2 Setting Climate Resilience Goals

The adaptation goals set by the advisory committee will inform and steer the climate adaptation planning process. While goals informed by a comprehensive risk management approach with rigorous benefit-cost analyses would be ideal, the systematic application of the primary risk management strategies—accept, transfer, reduce, and/or avoid—to the assets of the enterprise is a useful technique to develop goals for the adaptation planning process.

3.2.1 Operational Goals

Accepting the risk posed by climate change may be appropriate for a set of assets not critical to the operational or financial performance portion. Transfer strategies, which involve contractually shifting risk from the airport to another entity, usually take the form of insurance coverage. Insurance can help with recovery efforts, but it is not a strategy that will provide for continuity of operations. The selection and use of either of the remaining strategies are the most likely to yield system resilience and financial wherewithal. Resilience-focused goals will seek to limit the impacts of changing climate on airport assets and operations, and may center on concepts such as:

- Avoiding delays and closures.
- Being an emergency operations center for the serviced jurisdiction or region.
- Limiting impacts to assets by specific climate stressors. For instance, coastal airports may be principally focused on the effects of SLR on runways or other impacted facilities and some inland airports may be particularly concerned with temperature-related deformations to pavement.
- Limiting revenue loss.

Goals may vary significantly between airports, but it is suggested that the SMART (specific, measurable, attainable, relevant, timely) concept, often applied in planning and management contexts, be employed during the goal-setting process. Outcome-based goal-setting will guide the adaptation planning process and will also provide useful benchmarks against which to measure progress in adaptation activities during the monitoring and refinement phase.

3.2.2 Communication and Awareness Goals

A secondary goal of the adaptation planning process may involve increased communication and awareness. This preliminary assessment process is an opportunity to facilitate open discussions across an airport system's many independent departments. The case study process that the study team employed to help develop this tool and guidebook illustrated the benefits of these conversations. Multi-department discussion of climate risks increases awareness of climate change issues and thereby improves the likelihood that an airport will address potential risks on a system-wide basis.

3.2.3 How Goals May Inform Priorities

Climate risk alone may not drive implementation schedules. The advisory committee will need to examine vulnerability and risk assessment output and set priorities. It is anticipated that the advisory committee will flag some adaptation strategies as more urgent or more easily implemented. Other adaptations, especially those requiring significant capital investment and further study, may be more appropriate to address using the 30-year planning horizon (i.e., approximately 2060 rather than 2030). Careful consideration is required at this stage, because even gradual changes in climate stressors can put pressure on operations and maintenance budgets. Case study participants have suggested that the information generated through the adaptation planning process may be used to help make the case for increased upfront expenditures on resilient infrastructure design.

3.3 Identifying the Audience and Destination for the Adaptation Plan and Related Work Products

The leadership role of the advisory committee is critical to the adaptation planning process. Once airport personnel understand airport climate vulnerabilities and generate adaptation strategies (either through the ACROS tool or through their own process), it is strongly recommended that the outputs be incorporated into appropriate documents, as defined by the Stakeholder Advisory Committee. The dissemination of this information to the right staff and incorporation into the right documents will play an important role in ensuring timely implementation.

Documents that may be useful in supporting the adaptation planning process include the following, which are described in more depth in Chapters 8 and 9.

- Safety Management Systems;
- Disaster, Business Recovery, and Emergency Response Planning;
- Risk Management Processes;
- Master Plans, Sustainable Planning, and Activities;
- Programming and Conceptual Design Processes;
- Disaster and Business Recovery Planning;
- Transportation Planning Frameworks; and
- Business Continuity Planning.

Advisory committee leadership should also communicate the need for adaptation both within and outside the airport. Some adaptations may be highly desirable, but will be outside immediate airport control or require coordination between multiple organizations. In this case, necessary adaptations can be achieved only through cooperation and communication. Adaptation tools requiring multi-organization coordination could include changes to land use, zoning, development policies, or mutual aid agreements, and changes to emergency management procedures. Nonetheless, armed with a thorough understanding of their options, the committee will be able to help their airport (and possibly the wider community) develop appropriate strategies customized to their geographic, functional, and operational characteristics.

PART II

A Primer on Climate Change and Uncertainty for the Airport Context

CHAPTER 4

Understanding Climate Change's Impact on Airports

4.1 Existing Climate and Weather-Related Events

The IPCC, a world authority tasked with evaluating climate science, notes that the effects of changing climate have been felt worldwide in recent decades. In the United States, identified changes include increasing temperature, an increasing number of heavy rain days, and a number of other impacts summarized below. In this guidebook, the term "climate vector" is used to describe aspects of climate that are known to affect airport operations. Collectively, these vectors (defined in 4.2.2, below), such as snow, ice, strong winds, heavy rainfall, or lightning, can result in delays, diversions, or stoppages that affect travelers, airport personnel and tenants, and ultimately, the airport's bottom line. This can quickly have a cascading effect on the wider aviation system, further impacting stakeholders.

Each of these climate impacts has the potential to affect air traffic and airport infrastructure. The degree to which climate change affects an airport is dependent on the magnitude of the change, the location of the airport, the airport's level of preparedness, and existing infrastructure's ability to withstand extreme weather events that exceed design criteria for the infrastructure. The selected vectors were chosen to show projections related to asset and operational vulnerabilities and the catalogue of adaptation tools and resources that exist (Burkett and Davidson, 2012) to support airport managers and staff in choosing adaptation strategies in response to a variety of climate change impacts and their associated risks. Knowing the specific impacts on an airport's region and the particular vulnerabilities of an individual airport system is critical for adaptation planning. The ACROS tool supports airport planning by reporting impacts and potential adaptation options for further assessment.

4.2 National Climate Change Projections

4.2.1 How Might Climate Change in the Future?

Climate change has increasingly affected aircraft and airport operations over the past two to three decades (IPCC, 2014a). In the period from 1980 to 2012, the United States has experienced 144 weather/climate disasters costing at least $1 billion each (Lott and Ross 2006; Smith and Katz 2013). These losses are tied to events ranging from hurricanes and tornado outbreaks to winter storms, wildfires, and droughts; however, they also relate to population increases and redistribution of the population. Extreme weather events, including heat waves, floods, and drought have become more frequent and intense over parts of the country during the past 50 years (Melillo et al., 2014). The National Climate Assessment indicates that the impact of weather on human activities is inescapable and growing, and climate change-related extreme weather events will increase disruptions of infrastructure service in the future.

Extreme events that impact population centers can be particularly damaging. In October 2012, Superstorm Sandy inflicted serious impacts on East Coast airports and national airline operations through storm surge, winds, flooding rains, and wet snows that lasted 2 to 5 days. The hurricane transitioned into a powerful, extratropical storm, resulting in thousands of delayed or cancelled flights and the closure of several major airports on the East Coast. These closures affected millions of travelers across the globe. In addition to physical damages, the International Air Transport Association (IATA) estimates that Sandy resulted in half a billion dollars in lost revenue for airlines (IATA, 2012).

Climate scientists expect further increases in the frequency of extreme weather events, and those increases, coupled with an expanding population, are likely to result in more costly impacts. Of particular importance are extreme (and by definition, rare) events that can overwhelm an airport's response resources and cause major disruptions and economic losses to airport stakeholders. Extreme events will also have significant physical and economic consequences at the regional level, which may manifest as impacts to airports (e.g., transportation infrastructure disruptions, impaired flow of goods, and reduced resource availability such as potable water and power). Furthermore, the gradual nature of change for many climate-related impacts implies that inaction may not manifest as a specific problem for years, reiterating the importance of a longer-term planning horizon.

4.2.2 Choosing Climate Vectors and Future Projection

Proper treatment of future climate change not only involves informing the user about how weather is expected to change, but also providing an overview of the reference or "baseline" period. The latter is defined in this project as the period 1979–2012, and is based largely on data availability considerations. This period is also long enough to be considered a climate period (at least 30 years) as defined by the National Climatic Data Center (NOAA, 2014). Future projections in this study (the years 2030 and 2060) were developed using the output of the IPCC AR5, the most up-to-date, comprehensive, national-scale information available at the time of research.

Table 4-1 summarizes the climate vectors chosen for the ACROS tool. The summary also includes a confidence level, which is defined here as a subjective measure of projection reliability, based on scientific literature and agreement among global climate models, also known as general circulation models or GCMs. High confidence indicates less uncertainty than medium or low confidence; low-confidence vectors have the most uncertainty. Note that even "low" confidence implies that the vector may still be of value, and contrasts sharply with no confidence, as is seen for vectors like wind and fog. In the latter case, it was either (i) unfeasible to construct the vector based on data constraints, or (ii) the vector was constructed for the historical period, but was impossible to project into the future because of biases in the GCMs.

The vectors selected for this project correspond directly to common climate-related concerns for infrastructure, based on literature sources and airport subject matter expert (SME) knowledge. Airport SMEs identified climate stressors that would impact airport operations and then worked with atmospheric scientists to identify specific climate metrics that could be analyzed. For example, high temperatures were identified as a stressor to multiple assets and operations. Examples of vectors related to high air temperature are days per year when air temperature exceed 90°F and days per year when temperatures exceed 100°F. Additional climate vectors developed to assess this stressor are shown in Table 4-1.

4.2.3 What Is a GCM?

GCMs, or general circulation models, are numerical simulations of physical processes in the atmosphere, ocean, and land surfaces, and are used to model global climate. Although GCMs

Table 4-1. Overview of selected climate vectors.

CLIMATE VECTOR	DESCRIPTION	CONFIDENCE
Hot Days	High temperature ≥ 90°F	HIGH
Very Hot Days	High temperature ≥ 100°F	HIGH
Freezing Days	High temperature ≤ 32°F	HIGH
Frost Days	Low temperature ≤ 32°F	HIGH
Heating Day	Mean temperature ≤ 65°F	HIGH
Cooling Day	Mean temperature ≥ 65°F	HIGH
Cooling Degree Days	Departure of mean temperature ≥ 65°F	HIGH
Heating Degree Days	Departure of mean temperature ≤ 65°F	HIGH
Hot Nights	Low temperature ≥ 68°F	HIGH
Humid Days	Mean dew point temperature ≥ 65°F	HIGH
Snow Days	Snow accumulation ≥ 2 in.	MEDIUM
Storm Days	Thunderstorm rainfall ≥ 0.15 in.	LOW
Heavy Rain (1 day)	Daily rainfall ≥ 0.8 in.	LOW
Heavy Rain (5 day)	Total 5-day rainfall	MEDIUM
Dry Days	Consecutive days of rainfall ≤ 0.03 in.	MEDIUM
Sea Level Rise	Daily runway flooding (National Flight Data Center elevation)	HIGH
Sea Level Rise – Base Flood Elevation (BFE)	Relatively infrequent but substantial flooding	HIGH
Wind*	Prevailing wind direction and speed	NONE
Fog*	Visibility ≤ 0.25 miles	NONE

**Vector was investigated, but not included in the ACROS tool due to lack of confidence in existing models.*

have been refined significantly since their inception in the 1960s, important caveats still exist as to what the models can and cannot simulate. As shown in Table 4-1, all temperature- and humidity-related vectors are robust in the sense that even the lower end of future projections still implies a substantially warmer and more humid climate. However, the main limitation of a GCM is its coarse scale, with a model grid as large as 150 miles. As a result of this factor, models cannot easily incorporate locally confined precipitation such as thunderstorms, which can be quite common, especially in the summertime. Additionally, GCMs are unable to simulate hurricanes with adequate intensity, implying that some of the precipitation-related findings in ACROS may be conservative, especially along the southeast coast of the United States where hurricane-related rainfall and wind pose risks. Nevertheless, the ACROS screening tool attempts to provide climate impact insights to airport managers and operators who, outside of those along the coast subject to SLR impacts, may have heard very little about the type of climate impacts they can expect. There will be ample room to refine the climate projections (as well as incorporate additional vectors such as wind and fog) as higher resolution modeling becomes available in the near future.

IPCC AR5 relies on simulations from over 30 GCMs and four different scenarios. Atmospheric carbon dioxide concentrations drive these models. The ACROS tool shows the ranges of model outcomes solely for a single scenario, representative concentration pathway (RCP) 8.5. RCP 8.5 is one of the four climate scenarios prepared for the IPCC AR5. RCP 8.5 assumes little to no global mitigation of carbon dioxide emissions. For a full climate analysis, especially one that extends significantly past mid-century, it is customary to review multiple scenarios. However, for the screening tool, only RCP 8.5 was used because this scenario does not diverge markedly from the other scenarios until *after* the period of interest for this study (present day to 2060). For more on GCMs and sources of uncertainty for climate models, please see Chapter 5.

4.3 Atmospheric Climate Vectors

Projections of the key climate vectors shown in Table 4-1 were prepared for 2030 and 2060 to assist airport managers over the short- and long-term planning horizons. The projections considered both the past 34 years of observation and the trends projected by GCMs for 2030 and 2060. Results for several selected climate vectors are presented in the figures below. These climate vectors are depicted to provide the reader with a broad overview of projected changes to United States climate. To view the full set of atmospheric vectors included in this study, including the model ranges (25th, median, and 75th percentile), please see Appendix F. To learn more about uncertainty related to climate modeling and the ramifications for engineering and planning, please see Chapter 5 of this guidebook.

Finally, please note that Hawaiian airports have been excluded from this study. The grid sizes of currently available GCMs are composed of approximately 99% ocean and only 1% landmass for the Hawaiian Islands. At these grid sizes, Hawaiian climate is not reliably reproduced, and is therefore not included in ACROS. The availability of downscaled models (i.e., with smaller grid sizes) would significantly improve the characterization of Hawaii and other islands.

4.4 Hot Days: Number of Days ≥ 90°F

Figure 4-1 shows that nearly all airports across the continental United States are likely to experience more days where the temperature reaches 90°F in 2030 and 2060. In typically warmer locations such as the southern plains and Southeast, the changes were substantial. However, strong increases were noted across the intermountain west, the northern plains, and the Northeast. All of these values suggest substantial increases over present conditions. There is agreement among all GCMs for this vector, hence the high confidence in this vector.

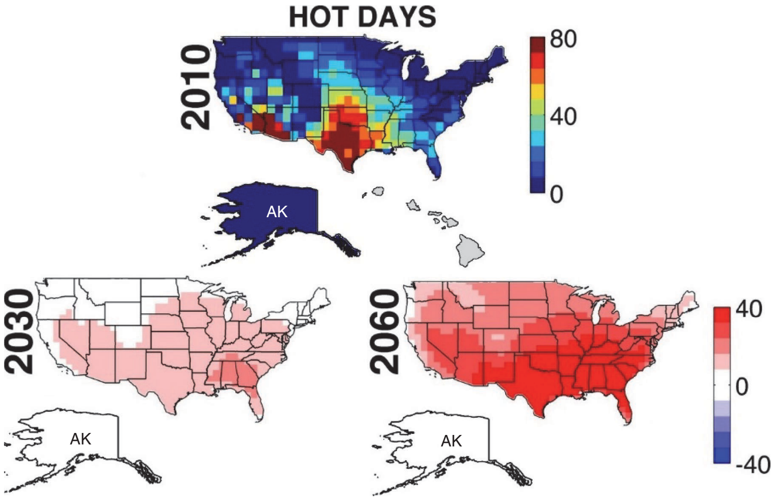


Figure 4-1. Projected changes in Hot Days from baseline to 2030 and 2060. Unit: days/year. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

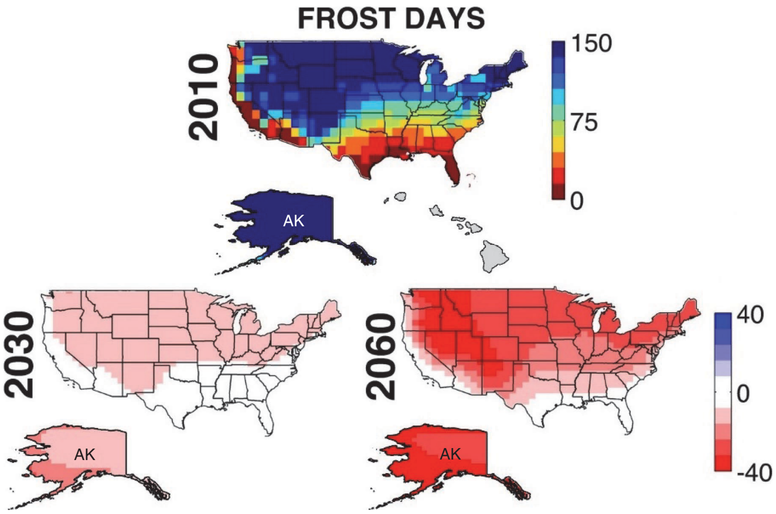


Figure 4-2. Projected changes in Frost Days from baseline to 2030 and 2060. Unit: days/year. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

4.5 Frost Days: Number of Days with Low Temperatures ≤ 32ºF

Consistent with Hot Days, there are likely to be substantial decreases in the number of Frost Days nationwide, as shown in Figure 4-2. The largest changes are projected to occur south of the intermountain west and the northern tier of the country, corresponding to areas where values are initially highest.

4.6 Cooling Degree Days

Cooling Degree Days (CDDs) are based on the day's average temperature minus 65°F and relate the day's temperature to the energy demands of air conditioning.

$$\text{CDD} = \text{Daily Average Temperature (if} > 65°\text{F)} - 65°\text{F}$$

For example, if the day's high is 90°F and the day's low is 70°F, the day's average is 80°F. From 80°F, we subtract 65°F, resulting in 15 CDDs. Thus, as the number of CDDs increases, the use of energy to provide air conditioning at airports increases. As expected from the previously described temperature-related vectors, significant increases in CDDs are noted nationwide by 2030, with additional large increases by 2060.

Figure 4-3 shows the extensive increase in CDDs across the United States. While relative humidity increases are not figured into the CDD calculation (although they are also substantial), changes of over 25 percent in the number of annual CDDs could indicate the need to change the American Society of Heating and Air-Conditioning Engineers (ASHRAE)-specified United States climate zone map used at a given airport.

4.7 Storm Days

The Storm Day vector was developed by investigating thunderstorm-related precipitation modeled by GCMs. A Storm Day is noted when that precipitation exceeds a certain threshold, and is thus anticipated to produce impacts such as flash flooding, gusty winds, hail, and,

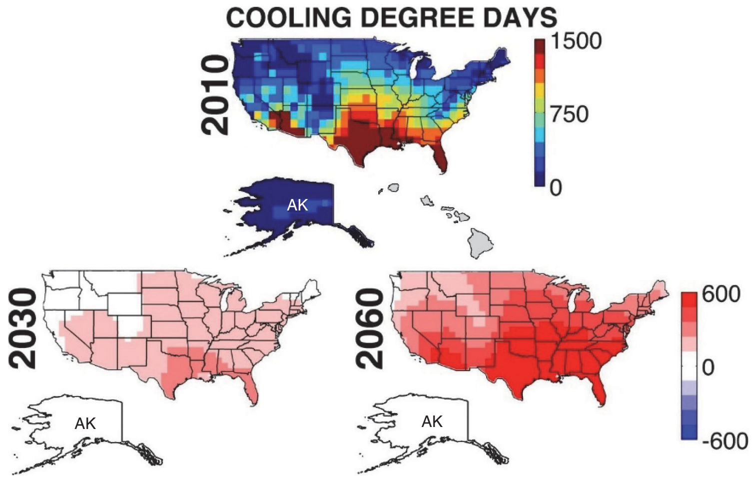


Figure 4-3. Projected changes in CDDs from baseline to 2030 and 2060. Unit: days/year. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

potentially, tornadoes. It is crucial to note that this vector is assigned low confidence because GCMs lack the horizontal resolution to explicitly resolve these severe weather features. In other words, thunderstorm precipitation was selected to describe days with stormy weather because hail and other thunderstorm-related impacts are not directly modeled. Figure 4-4 shows the baseline value of Storm Days, as well as anticipated changes by 2030 and 2060.

Unlike the previous temperature-related vectors, there are regions with both increases and decreases in Storm Day frequency. Notable increases occur mainly in the eastern part of the United States, as well as parts of the Northwest. Meanwhile, slight decreases are seen in the southern plains. It is likely that the confidence in, and approaches to, defining the Storm Day vector will rapidly increase in the coming years as higher resolution modeling enhances the capability of modeling small-scale, severe weather phenomena that is of great interest to airport managers and staff.

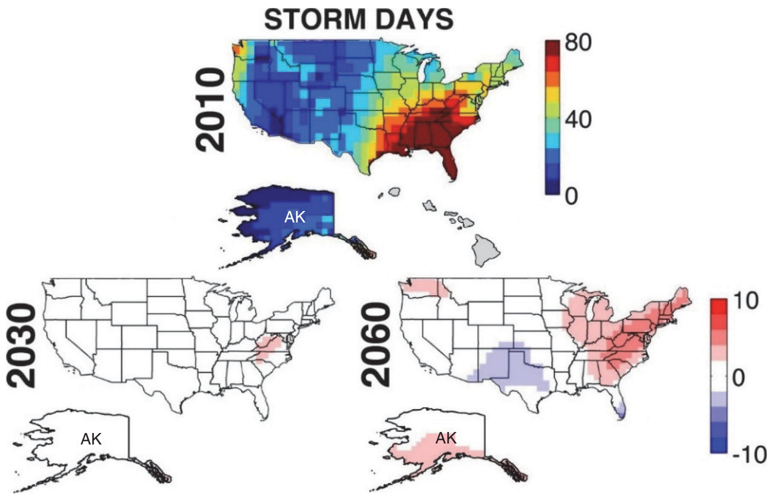


Figure 4-4. Projected changes in Storm Days from baseline to 2030 and 2060. Unit: days/year. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

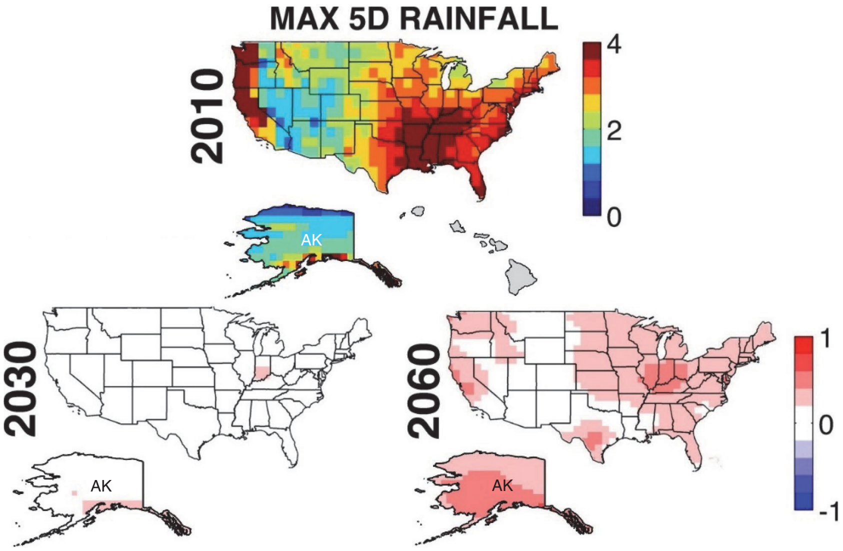


Figure 4-5. Projected changes in Heavy Rain 5-Day from baseline to 2030 and 2060. Units: inches. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

4.8 Maximum 5-Day Rainfall

While the Storm Day vector shows a relatively minimal impact nationwide, likely due to the physical constraints of the GCMs, other measures of rainfall show much more robust changes. One particular measure of rainfall is the maximum accumulated rainfall over any consecutive 5-day period during a calendar year—Heavy Rain 5-Day for short. Figure 4-5 shows the projected changes nationwide. In summary, as the atmosphere warms, it holds more water vapor that can eventually condense and turn to rainfall.

This is especially true for heavy rainfall events that rely on moisture convergence. Nearly the entire contiguous United States is expected to see a rise in Heavy Rain 5-Day by 2060, with some increases also evident in 2030. The areas most strongly affected are those that typically receive more rainfall. The Ohio River valley, the Northeast, southern Texas, and the West Coast are all projected to see increases of up to 0.5 inches, or 30 percent, of their baseline value. It is particularly important to recognize that this is likely a conservative estimate because of the previously mentioned limitations that GCMs face as a result of their coarse resolution. Numerous scientific studies have suggested that localized extreme events, such as those affecting a specific airport on a specific day, will likely increase at a faster rate than area-wide averages would suggest.

4.9 Other Climate Vectors

Projected changes were assessed for the other vectors shown in Table 4-1. In addition to the vectors shown above, all remaining temperature-related vectors listed below showed marked changes, indicating a warming climate:

- Very Hot Days,
- Freezing Days,
- Heating Degree Days,
- Hot Nights, and
- Humid Days.

For precipitation vectors, Snow Days displayed decreases nationwide, although there is marked regional variability, with the largest decreases occurring over the intermountain west. Dry Days showed inconclusive changes east of the Mississippi River, but general decreases occurred over the western United States, especially in the arid Southwest. Furthermore, as noted, several vectors of interest to airport systems were omitted from this study (wind, fog) because models for these vectors are not yet considered reliable. Despite the limited modeling currently available, it is still possible to provide information about potential adaptation and planning activities for wind and fog, so information about these vectors is included in Appendix A. Please see Appendix F for nationwide maps of projected changes to all climate vectors, including the upper and lower boundaries.

4.10 Sea Level Rise

Increases in sea level will impact airports through increasing frequency and magnitude of coastal flooding events. This includes increased flood depths during events, increased frequency of nuisance flooding, or in some cases, permanent inundation of airport grounds. Changes in sea level are a result of global and local factors. Global factors include atmospheric temperature, heat transfer to the oceans and subsequent expansion of those water bodies, as well as glacial and ice sheet melting. The primary local factor is vertical land movement, followed by water circulation. Trends in sea level are measured by the National Oceanic and Atmospheric Administration (NOAA) at water level monitoring stations (Figure 4-6).

Climate change is expected to result in a positive acceleration of historically observed trends in sea level. Projections of future sea levels were developed over short- and long-term planning horizons extending to 2030 (Figure 4-7) and 2060 (Figure 4-8) to assist airport decision makers in recognizing potential exposure to SLR impacts based on an acceleration factor derived from downstream effects of global temperature increases. Global projections in sea level change were estimated and then related to local conditions by incorporating an adjustment based mainly on vertical land movement. The potential exposure to future increases in SLR was categorized

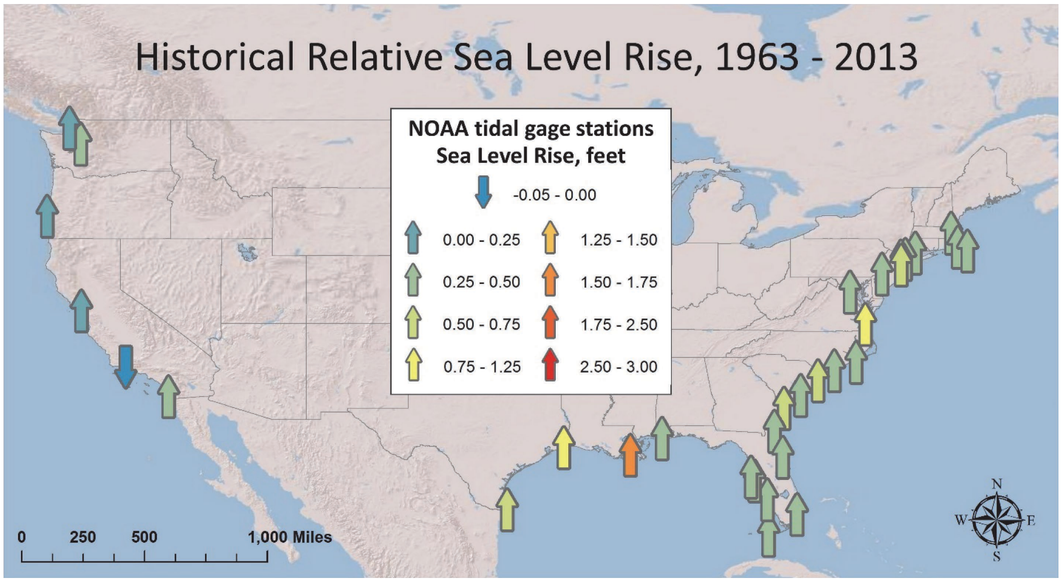


Figure 4-6. Historically observed amounts and direction of sea level change for the last half century at NOAA water level monitoring stations.

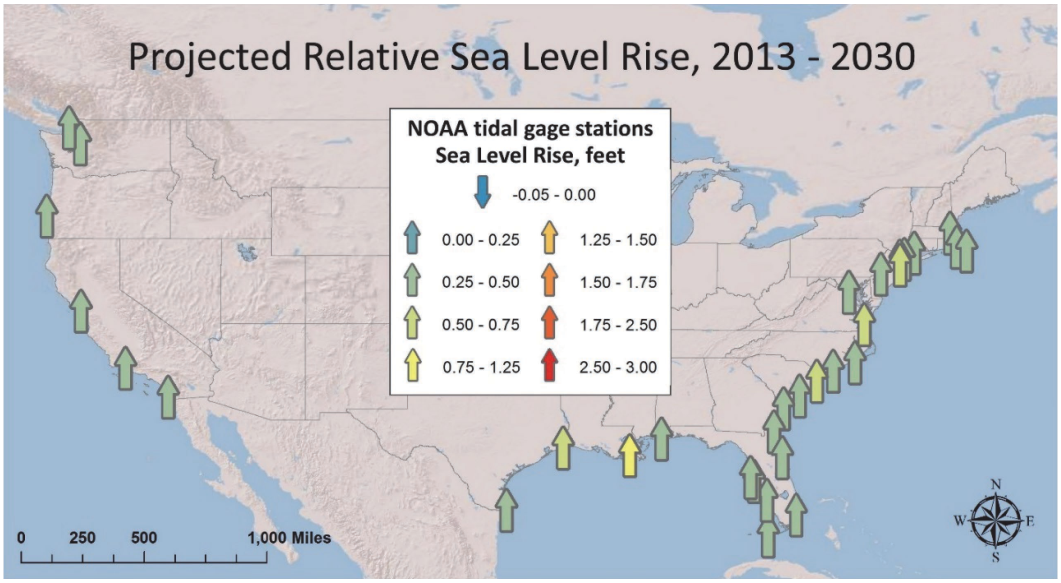


Figure 4-7. **Increases in sea level at NOAA water level monitoring stations reflecting RCP 8.5 projections for 2030.**

according to increasing impacts on airport operations and facilities. Exposure to each of these metrics was determined by assessing local changes in coastal flooding metrics against runway elevations from the National Flight Data Center (NFDC) database. The assessment included an analysis of recurrent flooding/permanent inundation and periodic flooding.

Recurrent flooding and permanent inundation: SLR will increase nuisance flooding, especially for low-lying sites, resulting in daily or permanent inundation of airport grounds. Events driving this type of flooding would include higher than normal tides and relatively small coastal storms. Such flooding will consist of standing water and/or low-velocity flooding resulting in the

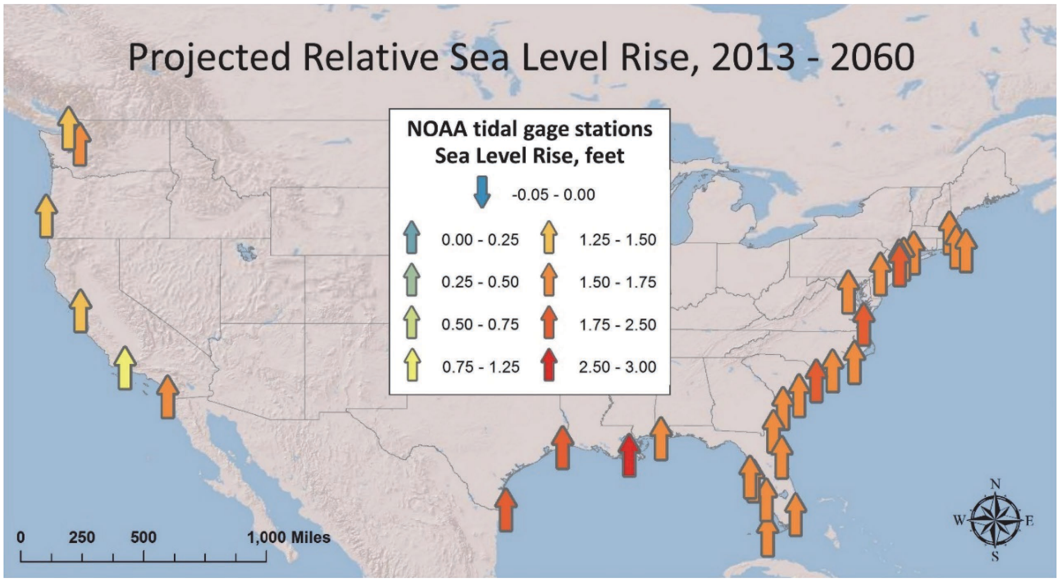


Figure 4-8. **Increases in sea level at NOAA water level monitoring stations reflecting RCP 8.5 projections for 2060.**

interruption of operations and damage to infrastructure as a result of water saturation. Inundation was evaluated by comparing future sea level to airport runway elevations. The frequency of recurrent flooding expected in 2030 and 2060 at each airport was calculated by comparing sea level conditions, past water level observations, and representative airport elevations. These attributes are specific to each facility and are summarized in the ACROS tool.

Periodic Flooding: Relatively infrequent but substantial flooding from tropical storms, hurricanes and typhoons, and nor'easters can result in significant impacts to airport facilities. Such flood hazards are captured on the Flood Insurance Rate Maps (FIRMs) developed by the Federal Emergency Management Agency (FEMA). BFEs provided on these maps represent the 1-percent-annual-chance flood condition (also known as the 100-year flood event), which is the regulatory requirement for structure elevation or floodproofing. The relationship between the BFE and a structure's elevation determines the flood insurance premium. Future changes to BFEs are specific to each facility and are presented in the ACROS tool. For more information about ACROS climate and sea level rise output, please see Chapter 7, The ACROS Tool User Guide.

CHAPTER 5

Managing Uncertainty When Planning Based on Projections

5.1 A Brief Note on Uncertainty

The concept of uncertainty inherent to evaluation of future climate outcomes can lead to the belief that climate modeling is not mature enough for decision-making purposes. Largely, this is a function of the difference between the technical usage of the word "uncertainty" and how it is used in common language. A scientist is a professional skeptic, trained to assess possibilities and likelihoods, and in this context, measuring and reporting uncertainty is a necessary, ethical requirement.

Rather than signifying unreliability or doubt, the term "uncertainty," as used by scientists, represents a measure of how well climate scientists know their models. Through their own work as well as the work of the scientific community, they gain a clearer understanding of each model's strengths and weaknesses, which they are then able to quantify. Relationships between cause and effect may be very clear to a scientist; however, no model can ever be perfect. Therefore, scientists must try to:

- Understand where model imperfections lie,
- Investigate sources of uncertainty thoroughly, and
- State what is known about uncertainty in very stark terms so that the scientific community can make further enhancements or generate guidelines on how to deal with unknowns.

In practical terms, the presence of model uncertainty does not indicate that decision makers should ignore model results until model uncertainty has been completely removed. Instead, uncertainty means:

- Numerous data inputs and variable interaction options directly affect the resulting accuracy of the output scenarios, and scientists have developed a detailed understanding of modeling strengths.
- Scientists are confident that it is time to begin using model information as an important planning tool for improving infrastructure resilience (Melillo et al., 2014). Climate models provide decision makers an additional piece of information for allocating resources when used in combination with existing planning tools.
- Readers and airport decision makers should be aware that uncertainties exist in any model when interpreting outputs and their applicability to future organizational design, planning, and investments.
- Some models are stronger than others (e.g., scientists have more confidence in air temperature models than precipitation models) and from a practical standpoint, projections with higher uncertainty indicate the need to plan for a wider variety of possible futures than do those with lower uncertainty (i.e., higher confidence).

- The output of today's best GCMs match actual historical and current values closely. However, the longer the outlook is for future projections, the wider the range of plausible inputs such as carbon dioxide emissions. Therefore, for even the most scientifically accurate models, uncertainty increases the further into the future modelers investigate.
- Models will improve and circumstances (e.g., economy, emissions, population) will change, requiring updates over time.

Scientists, planning experts, and other key decision makers worldwide are planning and acting on the projected outcomes of today's climate models, and the aim of this guidebook and tool is to provide climate information for use in airport planning and operation.

5.2 Airport Sources of Uncertainty (ACRP Report 76)

ACRP Report 76: Addressing Uncertainty about Future Airport Activity Levels in Airport Decision Making (Kincaid et al., 2012) discusses sources of uncertainty for air traffic forecasts. Much of the section concerning the uncertainty that airports face is broadly applicable here. While there is no need to reproduce the text in its entirety, the list below touches on the topic areas covered. For additional information on uncertainty in the airport context, please see ACRP Report 76 (http://onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_076.pdf).

- Global, regional, or local economic conditions;
- Airline strategy (e.g., changes to services);
- Airline restructuring or failure;
- Low-cost-carrier growth;
- Competition from other airports;
- Technology change;
- Regulatory and government policy;
- Social and cultural factors;
- Shock events (e.g., health pandemics); and
- Statistical or model error.

The last point, "statistical or model error," is an issue that holds true not only for the demand forecast models that were the focus of ACRP Report 76, but also for the climate models used in this project to develop the screening tool. However, there are a number of procedures and practices to reduce that uncertainty as well as guidelines for dealing with uncertainty. The following sections describe some of these procedures.

5.3 Climate Model Sources of Uncertainty

5.3.1 Uncertainty from the Earth System

GCMs are good at predicting climate (long-term averages in weather) and are progressing in their ability to predict shorter-term processes such as El Niño. The occurrence of the events below, which also affect climate, cannot be predicted:

- Volcanic eruptions,
- Behavior of the sun, and
- Future emissions of greenhouse gases.

Depending on magnitude, the events above can significantly affect climate for months or years after the fact. While it is possible to accurately model resulting climate scenarios based on these events, the actual occurrence of eruptions, sun behavior, and carbon emissions is difficult to predict.

5.3.2 Uncertainty from Models

The major climate drivers are well understood, and models have been used to successfully replicate past climate and make near-term predictions that have been confirmed by observation. Models capture large-scale processes in the global climate system, but downscaling methods are available to convert model results to the local scale. Modelers typically use a number of different models ("ensembles") with a number of different inputs to develop a range of future possibilities; adaptation options should ideally reflect that range.

Uncertainty comes from a number of different sources in climate models, such as:

1. Modeling approaches/type of model,
2. Assumptions,
3. Inputs,
4. Structures and processes (how the model handles inputs),
5. Sensitivity,
6. Treatment of feedbacks, and
7. Downscaling methods.

While not used in this project, downscaling is the set of procedures used to translate GCM outputs into detailed, local predictions of surface conditions. To learn more about the sources of uncertainty in climate models, please see the detailed reference in Appendix G.

5.3.3 How This Project Considers Climate Uncertainty

Model confidence for individual vectors is described further in Chapter 4. Sources of uncertainty in model selection and scenario selection, as well as the implications for vulnerability and risk assessment, are noted below.

5.3.3.1 Model Selection

For this project, a range of four to seven GCMs informed the database that was used to construct each climate vector. Having more than one GCM simulation provided the research team with an indication of the uncertainty that is always inherent with climate change projections, especially at the decadal time scales that are considered here. For example, if all seven GCMs showed that Ronald Reagan National Airport in Washington, D.C., will see 20 more Hot Days (days above 90°F) in 2060 compared to the present, it is possible to be more confident in this number than if the seven GCMs showed changes of −10, 0, 10, 20, 30, 40, and 50 days. Note that this latter range still averages to 20, but provides much less certainty since one model cannot be chosen as more accurate than another. For practical suggestions on the implications of climate vector uncertainty for planning, design, and engineering, please see Chapter 7, Section 7.6.

5.3.3.2 Scenario Selection

Typically, models examine a range of scenarios to develop projections. The IPCC's AR5 develops four greenhouse gas and aerosol emission scenarios, also called forcing scenarios. These scenarios are abbreviated as RCP 2.6, 4.5, 6.0, and 8.5. These scenarios were selected to describe a reasonable range of possible future scenarios. The lowest, RCP 2.6, describes a low-emissions scenario where emissions peak in 2035, and RCP 8.5 describes increasing emissions. Scenarios examined for this project do not appreciably diverge until after mid-century and the maximum forecast length needed for this project is for the year 2060, so only RCP 8.5 was used. It is recommended that studies considering longer time frames examine multiple forcing scenarios.

5.3.3.3 Vulnerability, Risk, and Practical Considerations

In addition to climate model uncertainty and the airport system uncertainty discussed above, other sources of uncertainty that influence vulnerability and risk include:

- The response of airport assets and operations to climate-related impact stressors;
- Imperfect knowledge about vulnerabilities to impacts and stressors; and
- Multiple possible outcomes from a single projected change (e.g., warmer temperatures may result in either less or more ice, depending on the effect on precipitation).

While it is important to understand sources of uncertainty, those sources should not be a barrier to planning. Instead, a resilience-focused approach recommends that more uncertainty calls for prioritizing high-risk, high-confidence projections and, for lower-confidence projections, planning to suit a broad range of futures. Please see Chapter 6 for guidance on prioritization and Chapter 7 for guidance on practical considerations for dealing with climate vulnerability uncertainty in engineering, planning, and design.

CHAPTER 6

Develop Adaptation Options Based on Potential Vulnerabilities

This guidebook suggests strategies for organizing asset vulnerability and risk information using the ACROS tool (see Chapter 7 for the User Guide), but the sections below also outline a methodology for performing an assessment and adaptation planning independent of the tool. The assessment process is illustrated in Step 2 as shown in Figure 2-1. These steps are shown in Figure 6-1.

6.1 Assess Baseline Climate and Projected Climate Changes

Several resources are provided within this guidebook and the ACROS tool to support this step of the climate adaptation planning process. Chapter 4 provided an overview of U.S. climate change, and more detailed figures showing model ranges can be found in Appendix F. The ACROS tool provides a site-specific walkthrough of projected changes with outlooks to 2030 and 2060. Baseline conditions and projected changes are summarized in the report generated by the tool. Advisory committees may also obtain their own projections independently. Appendix E: Resources includes a number of sources for projections, and community stakeholders such as local universities and municipal or regional planning groups may also have high-quality local projections.

When assessing baseline and projected changes, it is critical to **consider both catastrophic and long-term stressors.** Managers of exposed facilities are encouraged to consider the projected changes and resultant impacts in both their short- and long-term planning activities. Immediate, catastrophic events may be the most visible face of climate change, but many impacts, like those caused by SLR, are part of a relatively slow process. Informing planning decisions with exposure and risk information in the near term can help spur proactive infrastructure decisions that both reduce existing exposures and avoid future losses.

Another key point is that **a single climate stressor can result in a range of impacts.** It is also important to note than the same type of change (e.g., warming air temperatures) can cause seemingly opposite effects depending on local topography, the season, urbanization, and other factors. Consider the case of winter precipitation in a region that typically experiences snowy winters. On the positive side, warmer winters throughout the United States may translate into less need for snow and ice removal for many airports. Conversely, in some locations, warmer temperatures may result in an increase in ice events (as snow events are replaced by rain, freezing rain, and sleet), presenting more severe adverse impacts in some locations. It is important to understand the range of impacts that changing climate may cause. Understanding an airport's exposure to these impacts will help apprise airport management of areas that may need additional attention and investment, and allow for timely integration into existing planning, design, and construction processes to avoid costly retrofitting expenditures down the line.

6.2 Identify Critical Assets and Operations

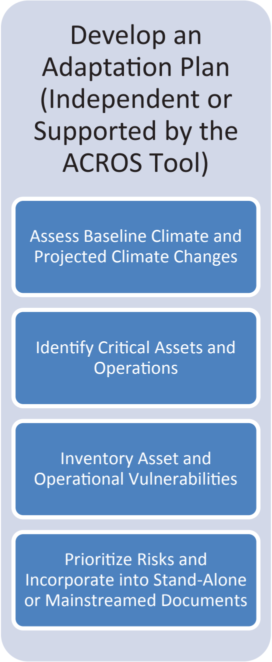


Figure 6-1. Climate adaptation planning process. Excerpted from Figure 2-1.

6.2.1 Inventory Airport Assets and Operations

With multiple potential impacts from each climate vector on each airport asset or operation, the next step in the climate change adaptation planning process is to inventory airport assets. This asset list may be partial or it may cover the entire airport system. The ACROS tool has a relatively comprehensive asset list pre-populated with assets and operations common to most airports (discussed in greater detail in Chapter 7). Advisory committees may also wish to examine assets independently of the ACROS tool, in which case asset management systems may be particularly helpful in the inventory phase.

Finally, while not addressed directly in this guidebook, advisory committees may also want to communicate with municipalities, departments of transportation, and other entities and agencies who own assets that affect airport operations. Changes in climate are likely to affect operations and infrastructure region-wide. Potential impacts to infrastructure, operations, or ancillary suppliers (e.g., electricity) may represent ongoing challenges, but may also present opportunities.

6.2.2 Critical Assets and Operations

Once an airport has defined a list of assets and/or operations with potential impacts from climate change, the next step is to assess two characteristics of each asset and operation, namely criticality and vulnerability. Criticality is defined as the importance of the asset or operation to overall functioning of the airport, and high criticality can reflect a single asset or operation that is a significant component of the airport system, as well as an asset that has a high degree of connectivity between other assets and operations within the airport system.

Criticality can be defined from a variety of perspectives:

- Service/operational.
- Public health and safety.
- Reputation.
- Restoration cost.
- Regulatory impacts.

Understanding criticality can help airport advisory committees better understand the potential for isolated failures of individual systems to escalate into a domino effect, otherwise known as "cascading failures." An example of a cascading failure in the airport system could include the failure of a pump station during a heavy precipitation event. The pump failure then results in localized ponding of stormwater. A transformer is inundated by the water, and subsequently fails. Attempts to balance the load across several transformers causes multiple failures, resulting in power loss, electric heat loss, and telecom disruptions over all or part of the airport. In this example, disruption to one, seemingly minor part of the airport system had extensive impact on operations. Discussion of "what-if" scenarios such as the above can be used to help ascertain asset criticality to airport operations.

The following sample definition of criticality is provided in the ACROS tool, although advisory committee teams are welcome to define the three tiers to accommodate other dimensions of criticality. An excellent reference on this topic is *ACRP Report 69: Asset and Infrastructure Management for Airports—Primer and Guidebook* (GHD, Inc., 2012), especially Table E-2 (http://onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_069.pdf).

1—Loss of the asset/operation would have a negligible impact on the airport.
2—Loss of the asset/operation would hamper airport function.
3—Loss of the asset/operation would significantly impair or shut down the airport until repair, replacements, etc., were secured.

6.3 Inventory Asset and Operational Vulnerabilities

Based on an airport system inventory developed, the committee can create a matrix of potentially affected assets and operations (either independently or with the support of the ACROS tool), noting known or perceived vulnerabilities. Vulnerability is defined as the sensitivity of an asset or operation to a climate stressor. Vulnerability will be highly dependent on the robustness of existing infrastructure and operations to accommodate a specific climate change vector (e.g., higher temperatures) as well as the degree of change expected. In addition to infrastructure, various operational departments and their staff could be affected. Both are described in greater detail below.

6.3.1 Asset Condition

Major factors that should be considered in assessing asset vulnerability include:

- Capacity/current ability to handle relevant conditions,
- Age,
- State of repair—physical as well as electrical components, and
- Deferred maintenance.

Similar factors should be considered in assessing operational procedures:

- Ability to handle relevant conditions,
- Time since last update,
- Outstanding updates, and
- Training and staffing deficits.

6.3.2 Asset Vulnerabilities to Current Conditions

In Chapters 4 and 5, readers were provided with an overview of U.S. climate change using vectors that are significant for airport infrastructure and operations. Vulnerabilities from changing climate may not always be readily apparent. In order to understand and rank vulnerability, it is critical to understand current vulnerabilities.

Known weaknesses are especially relevant, and staff with first-hand knowledge of the assets or operations under consideration are invaluable resources for this part of the risk assessment. For example, extreme heat events are already damaging transportation infrastructure, including airport runways (Rakich, et al., 2011). As air temperatures increase, heating, ventilation, and air conditioning (HVAC) systems may be taxed beyond capacity, causing failures or significant passenger discomfort. Receiving water ambient temperatures may increase, causing changes in aquatic life, which could, in turn, affect an airport's regulatory requirements for stormwater discharge. Information of this type helps the advisory committee understand the *likelihood* that an asset or operation will be affected by a number of identified *consequences* or climate stressors. This scheme assumes that asset and operations at higher risk to negative impacts from identified stressors today will continue to be at high risk if the climate drivers that cause these stressors intensify.

The following sample definition of vulnerability is provided in the ACROS tool. Advisory committees may use this definition or modify as they see fit. The term "impact" refers to climate stressors, such as floods, higher temperatures, and heavy rainfall events:

1—Asset/operation is unlikely to be affected by this impact.
2—Asset/operation is likely to be impaired by this impact.
3—Asset/operation is likely to be significantly impaired or disabled by impact.

In the examples above as well as in the tool, a three-point scale was developed for both vulnerability and criticality. In the tool, default criticality estimations (on a 1 to 3 scale) are provided.

The defaults were developed by SMEs to reflect common conditions at U.S. airports. The three-point scale is in keeping with the screening-level risk estimate produced by the tool. At this level, finer gradations were not considered appropriate, though the case study process revealed some interest in using finer gradations at some airports. Airports with more time and budget to conduct criticality and vulnerability assessments might consider employing a five- or even a seven-point scale.

Table B-1 in Appendix B is available to support the recording of vulnerabilities. Vulnerabilities may include infrastructure lifecycle considerations such as age, deferred maintenance, or operational condition (e.g., ramp worker safety due to excessive heat stress). As the airport considers vulnerabilities, the following items should also be noted, because they will affect timing and appropriateness of the adaptation activities:

- Upcoming asset replacement or retrofits,
- Changes in business conditions,
- Potential regulatory issues, and
- Alterations to airport development plans.

Appendix B contains a checklist of typical airport assets and operations included in the ACROS tool. The ACROS tool provides climate change impacts for individual asset categories, as do the appendices to this guidebook. Not all airports will have all assets, and some airports may have different assets, but this list is reasonably comprehensive. Appendix B also contains a list of assets and operations that were not included in the project, but were suggested during the case study and comment period of this project. Although researching, compiling adaptation options, and tying vulnerabilities to climate vectors for these suggested assets and operations was not feasible at the time this guidebook was written, airport advisory committee teams may wish to investigate adaptation options for these items alongside the ACROS-supported planning process or other adaptation activities they may be engaged in.

6.4 Prioritize Risks and Incorporate into Stand-Alone or Mainstreamed Documents

Risk prioritization can be broken up into several steps. First, it is often useful to develop an estimate-level ranking scheme to group airport risks. Following the estimate-level grouping, the advisory committee may desire to focus on a sub-set of assets and operations that are a) high-risk, b) high-priority for other reasons (e.g., due to funding availability), or c) both. This guidebook principally focuses on the estimate-level risk ranking, with a brief discussion of deeper investigation for high-priority assets and operations.

The ACROS tool streamlines the preliminary assessment by walking users through a process to identify assets and operations unique to the individual airport. It then allows the user to evaluate collectively the criticality and vulnerability of airport infrastructure or operations independently of potential climate changes. The tool provides risk ranking as well as potential adaptation options and planning processes for airport officials to consider as they embark on their own planning, design/construction, and operations assessment programs. The intended outcome of preliminary assessment is either a stand-alone adaptation plan, or one that is integrated into existing airport planning processes or documents (see Chapters 8 and 9).

6.4.1 Estimate-Level Risk Ranking

In order to quickly begin grouping higher versus lower risk assets for adaptation prioritization, a simple three-tier grouping is recommended at this stage of the assessment, as employed within the ACROS tool. The initial ranking includes the traditional dimensions of risk described in Appendix E (likelihood × consequence = vulnerability), as well as a few additional dimensions:

- Timing: a ranking of the climate risk is provided for both the years 2030 and 2060;
- Criticality and connectivity: the importance of each asset for overall airport functioning is assessed; and
- Magnitude of change to climate vector: a larger change to a more hazardous state is considered of greater importance than smaller changes. This assumption is a simplification, but it is useful to help initially distinguish higher and lower risk assets and operations.

In keeping with an asset management approach, it is recommended that a risk estimate be provided for each asset and operation. Risks in the tool are provided for 2030 and 2060, providing information about the timing of shifts toward more hazardous conditions. As in the ACROS tool, advisory committee members may also wish to assign relative risks to all climate stressors affecting each asset. Note that in the risk estimate formula below, the projected change in climate vector does not contain a term for likelihood. To include a likelihood term, a site-level, high-resolution analysis would be required that is beyond what this screening estimate can provide. Later in the adaptation process, but prior to engineering and design activities, such an analysis is recommended.

The climate change risk estimate used by the tool is simple multiplication:

$$Risk = (Criticality) \times (Vulnerability) \times (Climate\ Vector\ \Delta)$$

Where:

Criticality: an integer from 1–3 (user input). Estimates degree of *importance to the airport.*
Vulnerability: an integer from 1–3 (user input). Estimates the *consequence* of an individual stressor × *likelihood* of negative impact *to an individual asset* (the traditional dimensions of risk).
Climate Vector Δ: the change, in number of days, for each vector (contained in the tool). Estimates *magnitude* of shift toward more hazardous conditions.

This formula is used to rank risks as a first step in developing insight into the airport's highest priority risks. The tool uses this formula to break assets and operations into three categories using natural breaks (a statistics-based data clustering method): red, yellow, and blue for higher to lower overall risk. Although the tool and process are not structured to translate risk exposure directly into cost, this qualitative approach provides an initial, reasoned judgment as to the exposures toward which airports could direct their attention and resources.

The following example illustrates how the risk estimate works. An airport's only parking garage with serious drainage issues and projected increases in rainfall intensity might rank as highly critical to the airport from a financial perspective, and it is highly vulnerable to flooding; therefore it has a high estimated risk. Together, the risk ranking above gives a qualitative indication of which risks require action (i.e., high, imminent risks), preparation (high or medium, but longer-term risks), or continued observation (medium or low risks manifesting over the longer term). Airport personnel using the tool may alter the computed priority ranking based on judgment, past impacts, and organizational goals.

6.4.2 Develop Resilience-Promoting Adaptation Strategies

As discussed above, the definition of a resilient adaptation strategy in the context of climate change adaptation is an action that addresses current and future airport needs at the asset and operational levels, without jeopardizing the flexibility of the airport system as a whole (for example, by locking an airport into a costly investment or pathway). Therefore, selected adaptations will need to be cost-effective, in accordance with airport operational and development goals, and suitable for a range of possible futures. This approach is referred to as "no regrets" climate change adaptation, where a risk assessment prompts selection of activities that yield benefits (e.g., cost savings) even in the absence of climate change. In addition to being well-suited for today's funding constrained environment, this approach also helps absorb some of the uncertainty from factors ranging from future economic conditions to climate projections (see Chapter 5 for more information on uncertainty).

The IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) (IPCC, 2012) notes that adaptation approaches can include actions that:

- Reduce exposure to risks;
- Reduce vulnerability;
- Improve resilience to changing risks;
- Transform an organization or relevant aspects thereof;
- Prepare, respond, and recover from impacts; and
- Transfer and share risks.

Functionally, adaptation projects may be classified as physical, operational, or relational [i.e., involving communication; *Transportation Research Circular E-C152* (Transportation Research Board, 2011)]. Another way to categorize adaptations is as follows:

1. Prevention: In addition to providing ways to avoid hazards in the first place, preventative activities are intended to keep hazard problems from getting worse, and are administered through actions that influence the way land is developed and buildings are constructed. They are particularly effective in reducing future vulnerability, especially in areas of an airport property where development has not occurred or capital improvements have not been substantial.
2. Structural Protection: Structural protection measures involve the modification of existing airport buildings and structures to help them better withstand the forces of a hazard, or removal of the structures from hazardous locations.
3. Natural Resource Protection: Natural resource protection activities reduce the impact of climate change by preserving or restoring an airport's natural areas and their protective functions. Such areas include floodplains, wetlands, steep slopes, and sand dunes. Park, recreation, or conservation agencies and organizations often implement these protective measures.
4. Infrastructure Projects: Structural adaptation projects are intended to lessen the impact of climate change by modifying the environmental natural progression of the climate change vector through construction. These projects are usually designed by engineers and managed or maintained by public works staff.
5. Emergency Services: Although not typically considered an "adaptation" technique, emergency service measures do minimize the impact of extreme weather events on people and property. These commonly are actions taken immediately prior to, during, or in response to an event. They are a key element of managing the residual risk after reducing risk through other adaptation actions.
6. Education, Awareness, and Collaboration: Education, awareness, and collaboration activities engage and educate airport staff, tenants, and other stakeholders about climate change and adaptation.

The ACROS tool comes pre-loaded with a number of prevention- and mitigation-oriented adaptation strategies based on adaptation literature and the expert experience and judgment of airport professionals. Adaptation activities may include:

- The use of applicable building construction standards;
- Hazard avoidance through appropriate land-use practices;

- Relocation, retrofitting, or removal of structures at risk;
- Reduction or limitation of the amount or size of the hazard;
- Segregation of the hazard from that which is to be protected;
- Modification of the basic characteristics of the hazard;
- Purchase of additional insurance coverage;
- Establishment of a climate change contingency fund;
- Provision of protective systems or equipment for both cyber or physical risks;
- Establishment of hazard warning and communication procedures; and
- Redundancy or duplication of essential personnel, critical systems, equipment, and information materials.

Over 700 impacts, paired with at least one and often several potential adaptations, were included in the tool. Those adaptation options relevant to the airport of interest are shown in the final printout produced by the ACROS tool. While this list represents the best information available in the literature and from SMEs at the time of production, users may find that as technology changes and circumstances demand, the list requires modification. It is ultimately the advisory committee's role to determine the appropriateness of potential adaptations for their airport. Guidelines and recommendations are provided as follows.

6.5 Refine and Monitor

In most cases, the ACROS tool will serve as a starting point for the climate adaptation process, resulting in additional investigation into high-risk, high-priority assets and operations. As discussed previously, high-priority risks include those where the asset or operation is critical to the entire airport system, the climate impact is present and already puts an asset or operation at risk, and the shift toward more hazardous conditions is large and imminent. The ACROS risk estimate can serve as a useful method to guide prioritization. It is suggested that airport managers initially focus on assets and operations with moderate to high levels of exposure ("red" and "yellow" risk levels; please see Chapter 7 for more information). While discussed only briefly here, monitoring changing climate and the success of adaptation activities will alert the advisory committee to needed refinements, as outlined in Figure 6-2.

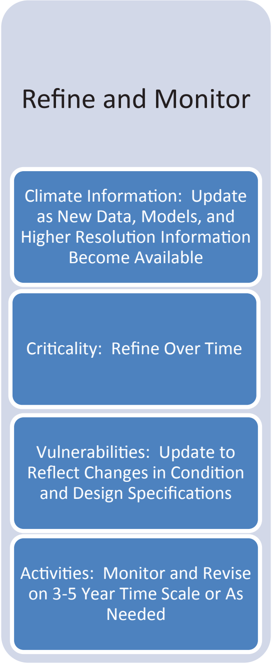


Figure 6-2. Updates to the climate adaptation planning process. Excerpted from Figure 2-1.

6.5.1 Climate Information: Update as New Data, Models, and Higher Resolution Information Become Available

For moderate- to high-risk assets and operations that are identified as high priority by the advisory committee, airport staff may wish to expand upon what the ACROS tool can offer by conducting independent, detailed assessments of potential risk. In this way, the ACROS tool output serves as a resource for developing a more detailed evaluation of system exposure and potential adaptation efforts to incorporate in ongoing planning efforts. Follow-up assessment activities may include:

- A multi-scenario climate analysis examining vectors of interest (as noted above, the ACROS tool uses a single scenario). Differing timelines than those shown in the tool may be examined.
- If applicable, investigation of the implications of the climate analysis for engineering and design specifications.
- A benefit-cost analysis of the proposed adaptation measures for particular assets to identify optimal solutions.

A number of useful resources for supporting these efforts can be found in Appendix E: Resources.

6.5.2 Criticality and Vulnerability: Update and Refine

Over the course of airport operations, previously unidentified system weaknesses may become apparent. Particularly in the wake of an incident or disaster response, adaptation priorities may need to be realigned to address the weakness to the airport system. This perspective also aligns with the concept of adaptive management, which encourages iterative problem solving as an approach to handling uncertainty. Merging adaptive management with risk assessments provides a commonsense, hybrid framework that:

- Updates as new information presents itself,
- Iterates and adjusts adaptation approaches as necessary, and
- Focuses on high-priority adaptations first.

This commonsense approach is reflected in the experience of other U.S. airports. The Port Authority of New York and New Jersey underlined the particular importance of developing feasible adaptation strategies for the highest threats (McLaughlin et al., 2011). However, both the scope of the potential adaptation options as well as additional considerations, such as the need to respond to a disaster event, may affect the timing and availability of resources to mitigate identified risks, and should therefore be considered during development of the airport's adaptation plan. Table B-2a in Appendix B provides an example checklist to facilitate comparison of adaptation options. Aspects to consider include the following.

- Determine which adaptation option(s) are appropriate to the airport size and other constraints (e.g., site layout, land availability, regulatory considerations).
- Be aware of the schedule of important document updates (master plan, etc.—see Chapter 8) and incorporate adaptation strategies as appropriate.
- Identify which adaptations are most time sensitive with respect to projected changes.
- Take advantage of any project(s) affecting the operation or asset that are already planned/underway and facilitate the adaptation.
- Use retrofits and repairs as an opportunity to replace sub-optimal components with products or technology that save operating costs over time (Landrum & Brown, Inc., 2012).
- Consider adaptation options early in the project design process to ensure efficient, cost-effective adaptation.
- Understand the costs of action as well as the costs of inaction.
- Consider the adaptations planned over the short term vs. the long term, and leave room in current projects to accommodate planned future adaptation elements.
- Look for resilience-promoting adaptation options that are "low-hanging fruit," i.e., comparable to or lower in cost than traditional methods and/or with a rapid return on investment.
- Consider lifecycle and resilience elements in the design and construction process.
- Be aware of funding availability to support implementation of the adaptation option(s).
- Identify the opportunity for partnerships and communicate with airlines, tenants, and state and community contacts as needed.
- Educate contractors about projected changes and intended adaptations so they can collaborate on achieving specific adaptation goals.

In order to adequately assess the points above, consultation with appropriate airport staff, airlines, and tenants is strongly recommended. It is also important to consider whether options are proven and under direct control of the airport (CDM, 2011), or whether cooperation with external groups (e.g., a regional transportation authority) will be necessary. Timely implementation of high-priority adaptations owned by those external to the airport will require proactive communication and cooperation. Appendix C: Adaptation Implementation Worksheets is available to assist airport users in considering the above criteria when selecting adaptation options. These worksheets can help the airport keep track of which assets and operations will be impacted by various risks, the selected adaptation option, the priority with which the option will be implemented, and the "owner" of the risk.

It is also strongly recommended that the advisory committees open a line of communication with airports facing similar impacts. The recorded experience of other airports may provide additional understanding of potential weather or climate impacts as well as information concerning the outcome of various adaptation strategies. One example is the Chicago Department of Aviation *Sustainable Airport Manual* (2010), which is an excellent reference for independently developing or supplementing the list of adaptation options provided by the tool (see Appendix E). Although the manual does not deal specifically with climate change adaptation, it does identify opportunities to make climate-appropriate selections for particular airport assets, including choice of landscape plants, ASHRAE building guidelines, airfield lighting specifications, and more. The manual also provides links to applicable case studies at airports around the nation.

6.5.3 Activities: Monitor and Revise on a 3–5 Year Time Scale or As Needed

Risk assessment using an adaptive management approach is an ongoing process and ideally should be re-evaluated as part of the master planning process or sooner. Other triggers for re-evaluation may include extreme events (e.g., Superstorm Sandy, major dust storms), new information, significant disruptions to climate, and unsatisfactory adaptation performance. Any changes should be incorporated into the adaptation plan. Finally, in acknowledgement of the uncertainty that is part of developing climate projections, it is advisable to study applicable climate metrics (e.g., changes in precipitation duration, frequency, and intensity) in greater detail during the project planning stage for a given airport project. During the design stage, specifications that may improve resilience to climate change can be considered.

PART III

The User Guide

CHAPTER 7

The ACROS Tool User Guide

7.1 Role of the ACROS Tool in Inventory, Risk Assessment, and Prioritizing Adaptation Options

The ACROS tool is designed to guide airport staff through a streamlined process to identify current and future climate risk and evaluate and prioritize potential adaptation options while bypassing the need to develop and examine climate models. To develop adaptation strategies without the tool, an airport would need to conduct its own literature review on adaptation strategies, search for available climate data, and analyze asset-relevant adaptation options. With the ACROS tool, much of this research is readily available, as the ACROS tool contains a substantial amount of site-specific information for airport assets with climate change projections, and expert-recommended adaptation options for climate-related impacts. By making use of the ACROS tool, airport managers can significantly reduce the resources needed to initiate the climate change adaptation planning process. For more information about using existing airport planning processes to implement climate change adaptations, please see Chapter 8.

7.2 User Overview

The ACROS tool guides a user through the risk screening process.

- **Step 1:** Identify a facility from the national database.
- **Step 2:** View climate hazards data for the airport of interest.
- **Step 3:** Select facility characteristics:
  - Preselected list of assets and operations will be assumed as a default, but these can be refined by the user.
  - Airport-specific assets and operations identification are necessary to complete risk screening.
- **Step 4:** Define the importance of asset/operation to the airport system (criticality).
- **Step 5:** Estimate the likelihood of asset/operation failure upon exposure to impacts (vulnerability).
- **Step 6:** Report and printout:
  - On-screen representation of risk as a factor of changing climate, criticality, and vulnerability.
  - Ability to print report, including climate hazards, asset risk screening, and potential adaptations.

It is recommended that the lead tool user be prepared to consult with airport stakeholders, as needed, for any airport-specific customization. Most users will find that additional input is necessary to complete the criticality and severity sections of the tool, which will be described in more detail below. Key stakeholders might include managers, designers, planners, and other SMEs, such as those responsible for the operations and engineering departments at the airport. Including those stakeholders responsible for managing risks to these categories will be especially important. With stakeholder input gathered, the user will be asked to provide information specific to that airport's assets in Step 3.

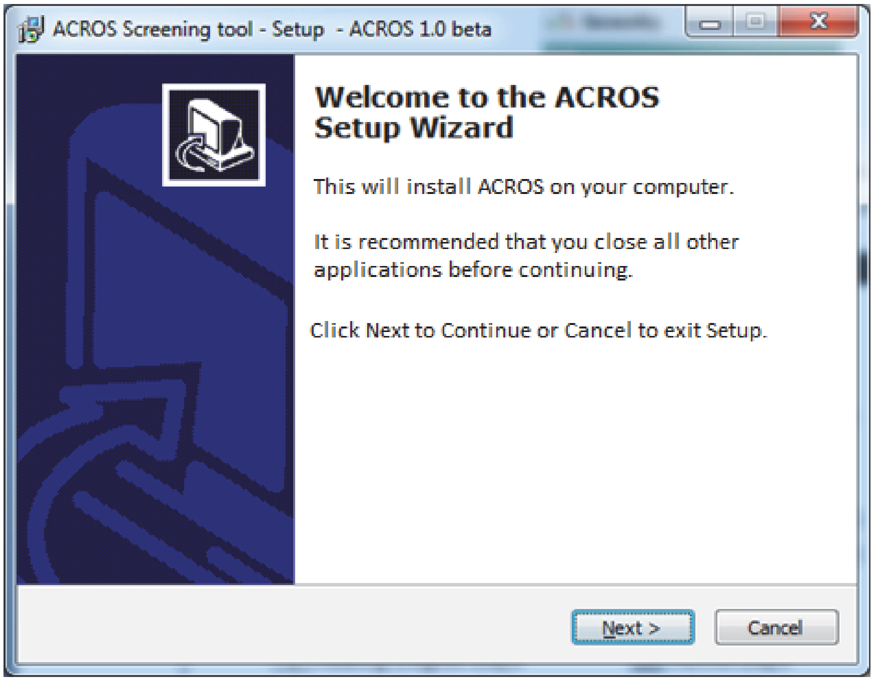
7.3 System Requirements and Display Tips

- Microsoft Windows 7 operating system and later (note: a Macintosh computer running Boot Camp is not compatible).
- Microsoft Windows Office 2007 and later.
- Microsoft .NET framework version 4.0 and later.
- Suggested resolution for display: widescreen format of 1280 × 800 or higher.
- For extended-screen desktops (with two monitors), using the tool on the left monitor is preferred, otherwise pop-up user tips will not align with the ACROS screen.

7.4 Step-by-Step User's Guide

7.4.1 Installation

Click on the application in a network location and use the Setup Wizard to install the ACROS tool. Use the default settings in the wizard (Figure 7-1).



ACROS Screening tool - Setup - ACROS 1.0 beta

Welcome to the ACROS Setup Wizard

This will install ACROS on your computer.

It is recommended that you close all other applications before continuing.

Click Next to Continue or Cancel to exit Setup.

Figure 7-1. ACROS installer.

The tool will be installed on the computer's desktop. Double-click to open the application. The shortcut icon is shown in Figure 7-2.

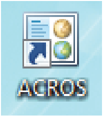
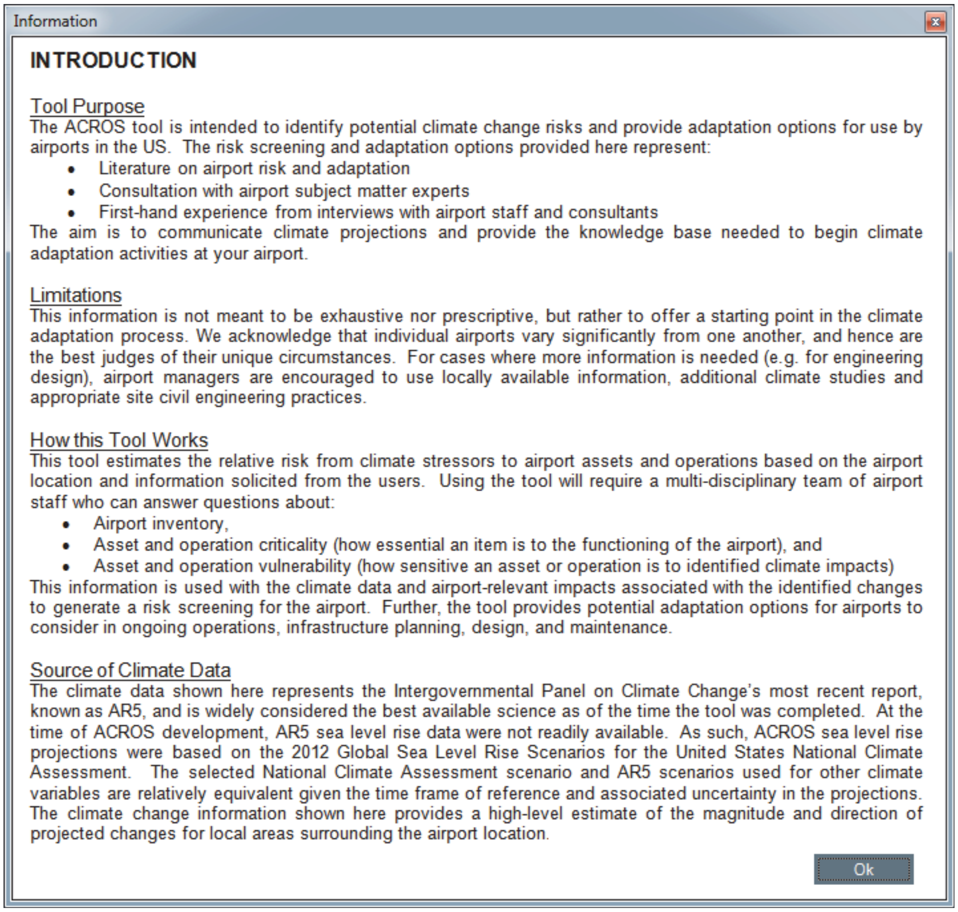


Figure 7-2. Desktop shortcut icon.

7.4.2 Welcome Screen

The purpose of the first screen is to present introductory information about the tool (Figure 7-3). Click “Ok” to continue to the **Airport Selection**.



INTRODUCTION

Tool Purpose

The ACROS tool is intended to identify potential climate change risks and provide adaptation options for use by airports in the US. The risk screening and adaptation options provided here represent:

- Literature on airport risk and adaptation
- Consultation with airport subject matter experts
- First-hand experience from interviews with airport staff and consultants

The aim is to communicate climate projections and provide the knowledge base needed to begin climate adaptation activities at your airport.

Limitations

This information is not meant to be exhaustive nor prescriptive, but rather to offer a starting point in the climate adaptation process. We acknowledge that individual airports vary significantly from one another, and hence are the best judges of their unique circumstances. For cases where more information is needed (e.g. for engineering design), airport managers are encouraged to use locally available information, additional climate studies and appropriate site civil engineering practices.

How this Tool Works

This tool estimates the relative risk from climate stressors to airport assets and operations based on the airport location and information solicited from the users. Using the tool will require a multi-disciplinary team of airport staff who can answer questions about:

- Airport inventory,
- Asset and operation criticality (how essential an item is to the functioning of the airport), and
- Asset and operation vulnerability (how sensitive an asset or operation is to identified climate impacts)

This information is used with the climate data and airport-relevant impacts associated with the identified changes to generate a risk screening for the airport. Further, the tool provides potential adaptation options for airports to consider in ongoing operations, infrastructure planning, design, and maintenance.

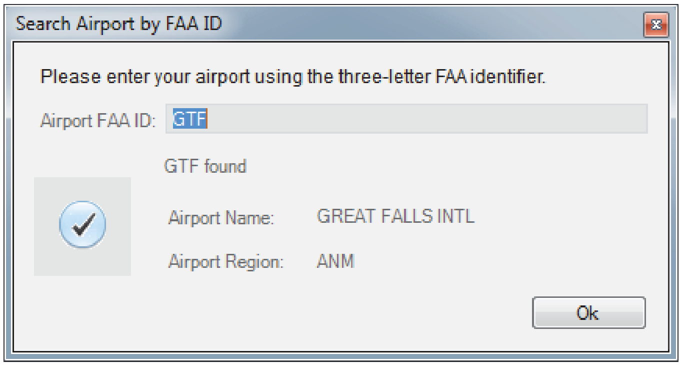
Source of Climate Data

The climate data shown here represents the Intergovernmental Panel on Climate Change’s most recent report, known as AR5, and is widely considered the best available science as of the time the tool was completed. At the time of ACROS development, AR5 sea level rise data were not readily available. As such, ACROS sea level rise projections were based on the 2012 Global Sea Level Rise Scenarios for the United States National Climate Assessment. The selected National Climate Assessment scenario and AR5 scenarios used for other climate variables are relatively equivalent given the time frame of reference and associated uncertainty in the projections. The climate change information shown here provides a high-level estimate of the magnitude and direction of projected changes for local areas surrounding the airport location.

Figure 7-3. Welcome screen.

7.4.3 Airport Selection Screen

The purpose of this section is to identify your location. Enter the airport’s three-letter FAA identifier into the **Search Airport** dialogue box (Figure 7-4). Click “Ok” to continue to the **Climate Information**.



Please enter your airport using the three-letter FAA identifier.

Airport FAA ID: GTF

GTF found

Airport Name: GREAT FALLS INTL

Airport Region: ANM

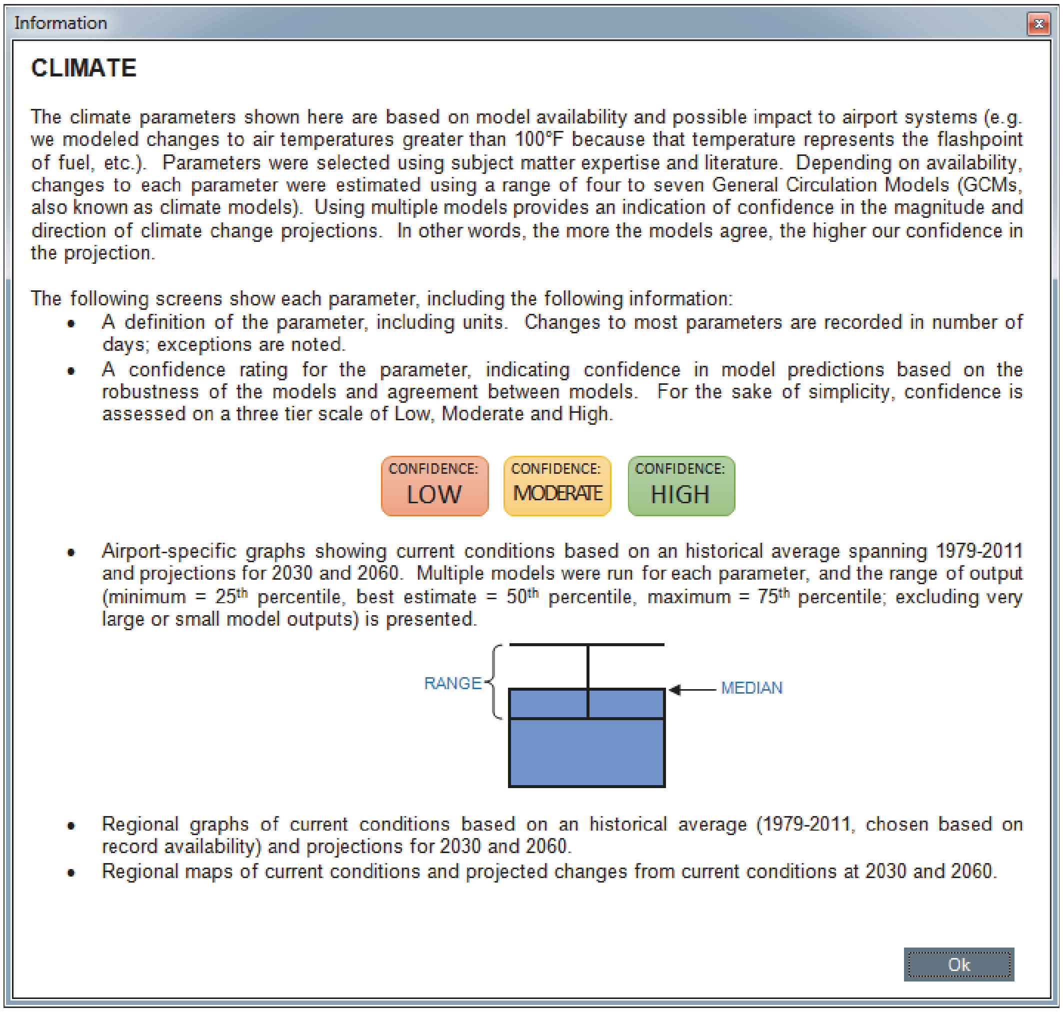
Figure 7-4. Search airport dialogue box.

Note: This tool is designed to view one airport at a time. For those users responsible for multiple airports, the tool must be used in separate sessions. To start a new session, please exit and re-open the tool. To save the session you are working on before closing, please see Section 7.5 Saving, Sharing, and Troubleshooting.

7.4.4 Climate Information Overview

By using metrics that are relevant to airport asset management concerns, this section provides information about current and projected climate specific to your location. The first screen in this section is a primer on how the **Climate Information** portion of the tool organizes the climate data that will be displayed. Data sources, units, confidence, and model ranges are briefly discussed. Click "Ok" to continue to the individual climate vectors. For more information on climate vector selection and confidence, please see Appendix D. The explanatory screen is shown in Figure 7-5.

Please note that even "low" confidence implies that the vector may still be useful for planning purposes. This low/moderate/high ranking scheme is based on a combination of how well climate vectors matched observation, and how well the suite of models used match one another (model agreement). The high/moderate/low is a comparison between the vectors that were chosen for the study. Only vectors that were able to reliably reproduce observed climate were



CLIMATE

The climate parameters shown here are based on model availability and possible impact to airport systems (e.g. we modeled changes to air temperatures greater than 100°F because that temperature represents the flashpoint of fuel, etc.). Parameters were selected using subject matter expertise and literature. Depending on availability, changes to each parameter were estimated using a range of four to seven General Circulation Models (GCMs, also known as climate models). Using multiple models provides an indication of confidence in the magnitude and direction of climate change projections. In other words, the more the models agree, the higher our confidence in the projection.

The following screens show each parameter, including the following information:

- A definition of the parameter, including units. Changes to most parameters are recorded in number of days; exceptions are noted.
- A confidence rating for the parameter, indicating confidence in model predictions based on the robustness of the models and agreement between models. For the sake of simplicity, confidence is assessed on a three tier scale of Low, Moderate and High.
- Airport-specific graphs showing current conditions based on an historical average spanning 1979-2011 and projections for 2030 and 2060. Multiple models were run for each parameter, and the range of output (minimum = 25th percentile, best estimate = 50th percentile, maximum = 75th percentile; excluding very large or small model outputs) is presented.
- Regional graphs of current conditions based on an historical average (1979-2011, chosen based on record availability) and projections for 2030 and 2060.
- Regional maps of current conditions and projected changes from current conditions at 2030 and 2060.

Figure 7-5. Climate information explanatory screen.

selected for this project, so even a "low" value for a vector included in ACROS contrasts sharply with vectors that were excluded from this tool, like wind and fog. Wind and fog are critical to airport operations, but unlike even the "low" confidence level vectors, current models for these two climate stressors are not yet mature enough to be included in ACROS. For more in-depth guidance on this topic, please see Table 7-1.

Table 7-1. Climate vectors and confidence implications for engineering, design, and planning.

CLIMATE VECTOR	DESCRIPTION	CONFIDENCE	IMPLICATION OF VECTOR CONFIDENCE FOR ENGINEERING, DESIGN, AND PLANNING
Hot Days	High temperature ≥ 90°F	HIGH	The direction and magnitude of change in these vectors are similar among the models reviewed, and therefore confidence is high. Prioritizing resources to manage potential impacts for highly critical and vulnerable infrastructure and operations should be incorporated into existing planning and design documents.
Very Hot Days	High temperature ≥ 100°F	HIGH	
Freezing Days	High temperature ≤ 32°F	HIGH	
Frost Days	Low temperature ≤ 32°F	HIGH	
Cooling Degree Days	Departure of mean temperature ≥ 65°F	HIGH	
Heating Degree Days	Departure of mean temperature ≤ 65°F	HIGH	
Hot Nights	Low temperature ≥ 68°F	HIGH	
Humid Days	Mean dew point temperature ≥ 65°F	HIGH	
Snow Days	Snow accumulation ≥ 2 in.	MEDIUM	Some uncertainty exists as to the likely magnitude of change to these climate vectors. Consider projected impacts to high-priority infrastructure associated with the range of potential change in the future climate vectors presented in the tool when planning and evaluating future resource allocation.
Storm Days	Thunderstorm rainfall ≥ 0.15 in.	LOW	
Heavy Rain (1 day)	Daily rainfall ≥ 0.8 in.	LOW	
Heavy Rain (5 day)	Total 5-day rainfall	MEDIUM	
Dry Days	Consecutive days of rainfall ≤ 0.03 in.	MEDIUM	
Sea Level Rise	Daily runway flooding (NFDC elevation)	HIGH	Incorporate projected SLR into any planned or designed infrastructure or operations project that is potentially affected by SLR flooding.
Sea Level Rise – BFE	Relatively infrequent but substantial flooding	HIGH	Incorporate projected storm surge into any planned or designed infrastructure or operations project that is potentially affected by storm surge flooding.
Wind*	Prevailing wind direction and speed	NONE	These climate vectors were not included in this project because the direction and magnitude of the change was not consistent among the models reviewed. However, changes to these vectors could affect airport operations or infrastructure. If the airport is currently experiencing impacts to critical and vulnerable infrastructure due to these climate vectors, these impacts should be considered in planning and resource allocation.
Fog*	Visibility ≤ 0.25 miles	NONE	

**Vector was investigated, but not included in the ACROS tool due to lack of confidence in existing models. Should these issues be of interest to an airport, potential adaptation options and planning suggestions are available for reference in Appendix A.*

7.4.5 Climate Projections (days/year)

Use the menu along the left side of the **Climate** information section (shown in Figure 7-6) to view each climate vector. Airport and regional perspectives are presented, showing baseline (historical) conditions, 2030 projections, and 2060 projections for each vector. Note that there are two sections of climate vectors, "Climate Projections" (days/year) and "Additional Climate Projections." The Climate Projections (days/year) are:

- **Dry Days**
- **Freezing Days**
- **Frost Days**
- **Heavy Rain (1 day)**
- **Hot Days**
- **Hot Nights**
- **Humid Days**
- **Sea Level Rise**
- **Snow Days**
- **Storm Days**
- **Very Hot Days**
- **Cooling Days**
- **Heating Days**

These vectors are all shown in the common unit of *days per year* and contribute to the risk score of related impacts. Because having a common point of comparison to understand changes to the climate vectors is advantageous, the unit for most vectors shown in the tool is days.

7.4.6 Additional Climate Vectors

"Additional Climate Vectors" provide vectors in units pertinent to specific professional disciplines, such as Cooling and Heating Degree Days, which are of interest to HVAC professionals. This second category of climate vectors was included because it is acknowledged that many disciplines (e.g., building sciences and HVAC) may find it useful to review projected climate changes reported in terms commonly used in those fields. Thus, the following vectors are also reported:

- **Cooling Degree Days** (cumulative degree days)
- **Heating Degree Days** (cumulative degree days)
- **Heavy Rain (5 day)** (inches)
- **Sea Level Rise–BFE** (feet)

Note: With the exception of Sea Level Rise and Sea Level Rise–BFE (coastal vectors), all climate vectors are reported for all locations in the U.S. Due to the wide range of climates in the U.S. (arctic, temperate, sub-tropical, and tropical) not all vectors may be relevant to certain climates, and the user may consequently choose to focus on the most relevant vectors. For example, the Snow Days vector has limited applicability to tropical climates, and Very Hot Days (days with temperatures exceeding 100°F) has limited applicability to northern climates (e.g., much of the Northeast and Alaska).

7.4.7 Coastal Vectors

At coastal airports, the ACROS reports SLR hazard changes using one or both of the following vectors, which are defined below and depicted in Figure 7-7 and Figure 7-8.

- **Sea Level Rise:** Increased nuisance flooding
- **Sea Level Rise–BFE:** Projected changes to the base flood elevation in the Special Flood Hazard Area (the 1-percent-annual-change flood elevation, also known as the elevation of the 100-year event)

Airport: GREAT FALLS INTL

HotDays

CONFIDENCE: HIGH

A Hot Day is a day with a high temperature at or above 90°F. Hot Days are measured in days per year.

Figure 7-6. Airport-specific and regional climate projections.

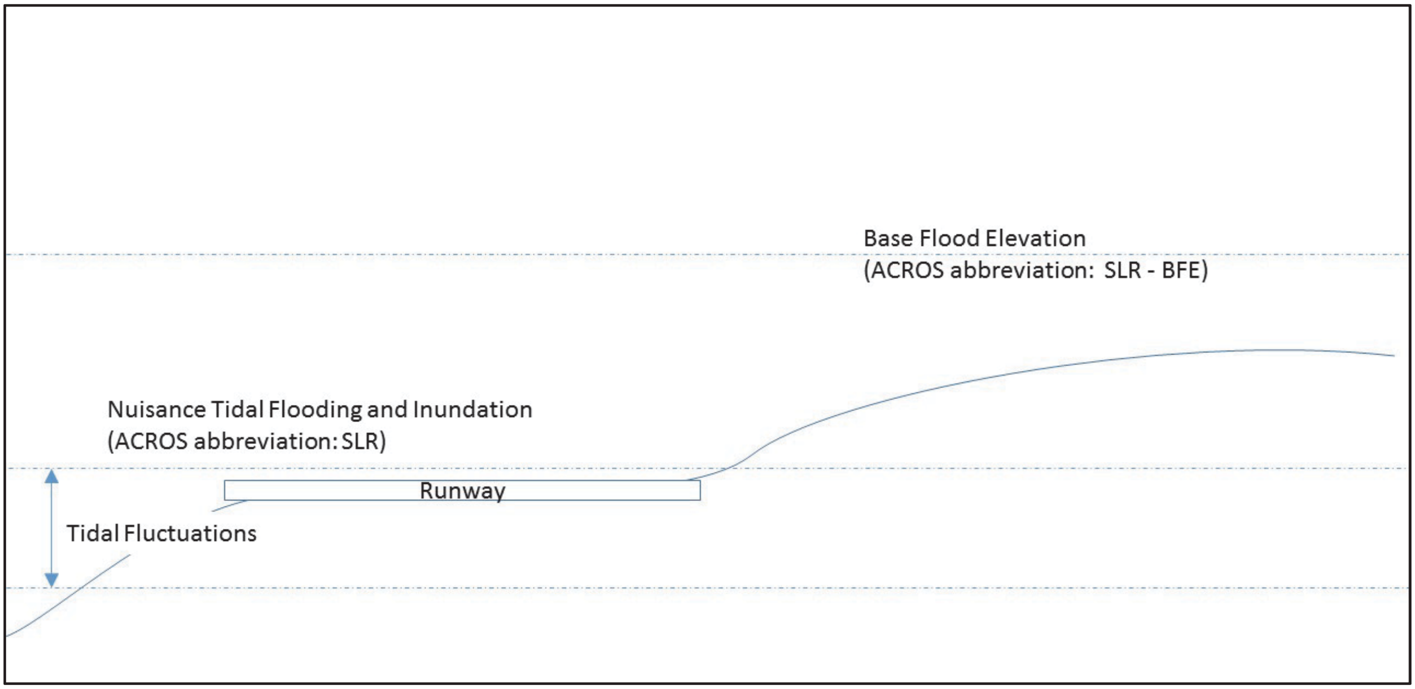


Figure 7-7. Airport campus is within the Special Flood Hazard Area and is also affected by nuisance tidal flooding and/or permanent inundation. For an airport in this type of location, the ACROS tool reports both the Sea Level Rise–BFE *and* Sea Level Rise *vectors.*

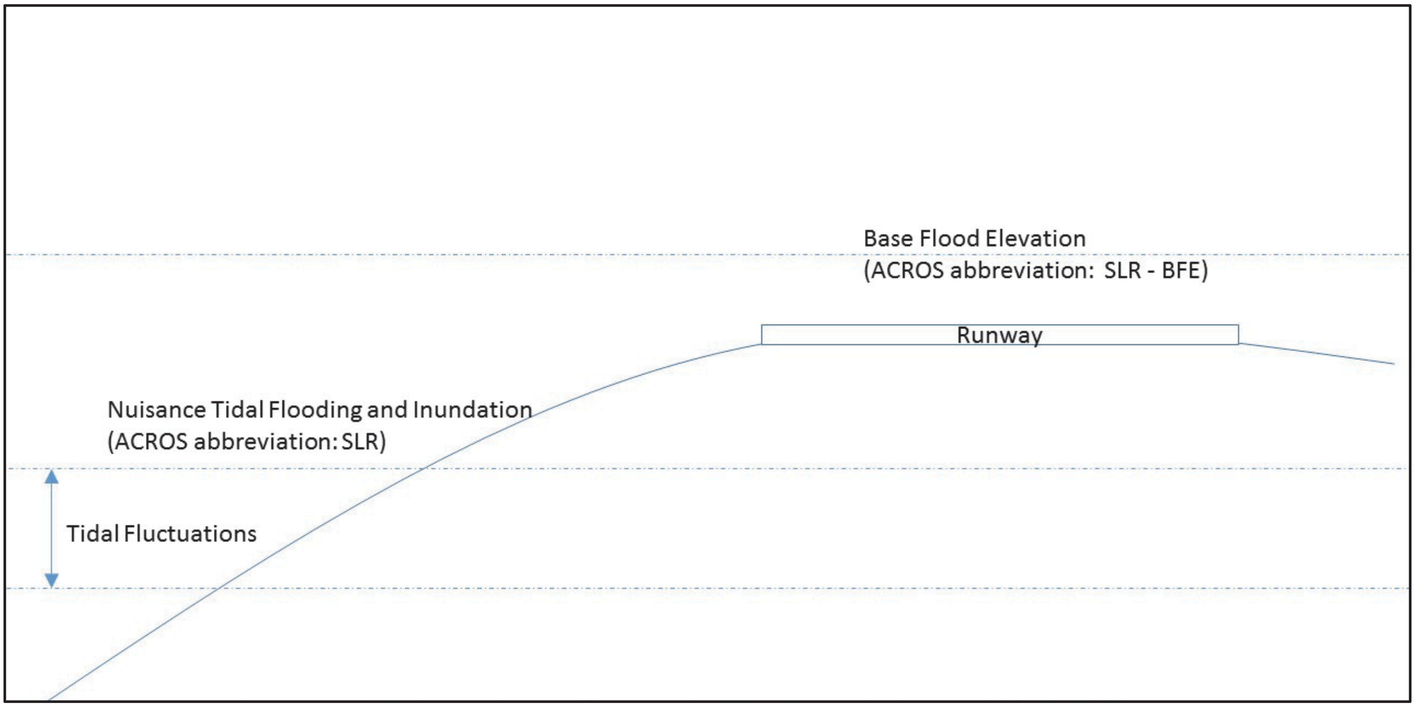


Figure 7-8. Airport campus is within the Special Flood Hazard Area but is not affected by nuisance tidal flooding. For this situation, the ACROS tool reports only the Sea Level Rise–BFE *vector. The* Sea Level Rise *vector will be grayed out.*

More coastal airports will have values for the **Sea Level Rise–BFE** vector than for the **Sea Level Rise** vector. Sea Level Rise–BFEs represent the 1% annual chance flood elevation—a relatively extreme and infrequent event as compared to nuisance flooding. BFEs are much higher than nuisance flooding levels and will impact much more land area of higher topographic elevations. Due to this, more coastal airports will have values for the **Sea Level Rise–BFE** vector than for the **Sea Level Rise** vector. A small number of lower elevation coastal airports will have values reported for both **Sea Level Rise–BFE** and **Sea Level Rise**.

For this project, airports at risk to SLR were defined based on runway elevation reported in the NFDC database. SLR information is therefore shown for some airports that may already have levees (e.g., OAK and MSY), but will not be shown for some airports that may still have concerns about SLR.

7.4.8 Asset and Operation Information

This section records which assets and operations are present at a particular airport for later use in the climate impact risk screening. This section is a simple checklist interface, with some common assets and operations already checked.

Here are a few display tips that may be helpful:

- In this section, as well as the **Criticality**, **Vulnerability**, and **Screening** sections, it is possible to sort alphabetically by **Service, Asset/Operations**, or other categories by clicking on the heading.
- Each screen is composed of several tiles, for example, the **Information** tile and the **Assets/Operations** tile, where users inventory their assets and operations as depicted in Figure 7-9. To widen the tile that is being used, click the nested box icon in the upper right corner of the tile.
- Column sizes may also be adjusted by clicking and dragging.

For more information, please refer to the instructions in Figure 7-10. These instructions are also shown on the **Assets** screen in the tool.

Airport: RONALD REAGAN WASHINGTON NATIONAL

Physical Assets (34)

SERVICE	ASSET	Exist
Aircraft / GSE	Ground Service Equipment	☑
Airfield / Airspace	Navigational Aids	☑
Airfield / Airspace	Runways, Taxiways, and Holding Areas	☑
Cargo	Air Cargo Buildings	☐
Cargo	Apron	☐
Cargo	Loading and Unloading Equipment / Operation	☐
Commercial Passenger Terminal Facilities	Apron	☑
Commercial Passenger Terminal Facilities	Commercial Passenger Terminal Facilities	☑
Commercial Passenger Terminal Facilities	Curbside Amenities	☑
Commercial Passenger Terminal Facilities	Gates	☐
Commercial Passenger Terminal Facilities	Gates (Passenger Boarding Bridges)	☑
General Aviation Facilities	Aircraft Parking Aprons	☑
General Aviation Facilities	Flight Schools and Pilot Shops	☐

Operations or Process (10)

SERVICE	OPERATIONS	Exist
Aircraft / GSE	Aircraft Performance	☑
Aircraft / GSE	Demand and Capacity	☑
Environmental and Safety	Bird and Wildlife Hazard Management	☐
Environmental and Safety	Environmental (Noise, Air Quality, Water Quality and Quantity)	☑
Environmental and Safety	Snow and Ice Control (De-Icing)	☐
Other	Construction Activities	☑
Other	Grounds and Landscaping	☑
Other	Personnel and Passengers	☑
Support Facilities	Aircraft Rescue and Fire Fighting (ARFF)	☑
Utilities	Communications	☑

ASSETS

Please select your assets and operations (the physical and operational/procedural components of your airport system). Any assets or operations which are not selected will not be included in the risk screening and adaptation report.

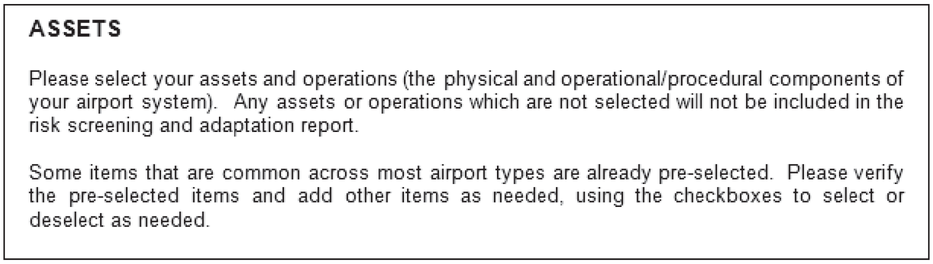
Some items that are common across most airport types are already pre-selected. Please verify the pre-selected items and add other items as needed, using the checkboxes to select or deselect as needed.

Information tile

Click the box icon to expand the tile

Assets and Operations tiles

Figure 7-9. Screen tiles and expansion icon.



ASSETS

Please select your assets and operations (the physical and operational/procedural components of your airport system). Any assets or operations which are not selected will not be included in the risk screening and adaptation report.

Some items that are common across most airport types are already pre-selected. Please verify the pre-selected items and add other items as needed, using the checkboxes to select or deselect as needed.

Figure 7-10. Asset and operation inventory instructions.

7.4.9 Defining Criticality

The purpose of this section is to determine asset and operation criticality, which is defined in the instructions below. After completing the **Assets** section above, use the left side panel to navigate to the **Criticality** section (Figure 7-11).

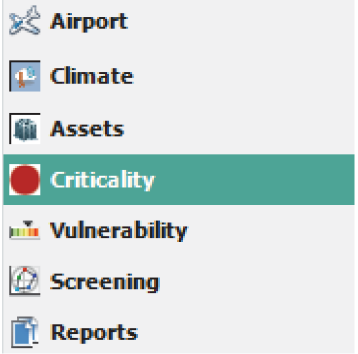
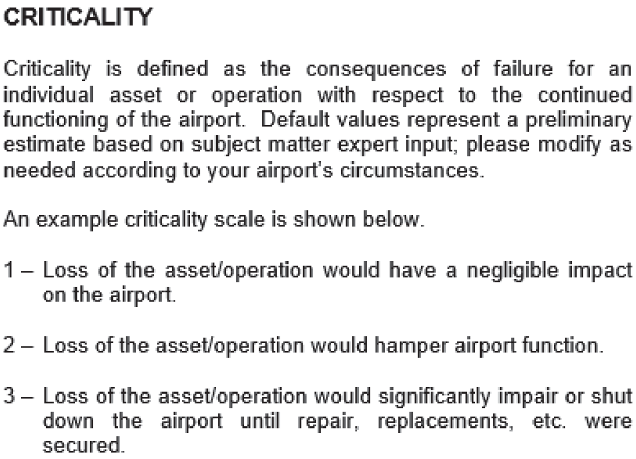


Figure 7-11. Navigation menu—criticality.

Only assets and operations selected in the previous **Assets** section are shown on this screen. Pre-assigned default values may be modified by the user. Airport user groups are encouraged to define criticality internally, although a sample definition is provided in Figure 7-12.



CRITICALITY

Criticality is defined as the consequences of failure for an individual asset or operation with respect to the continued functioning of the airport. Default values represent a preliminary estimate based on subject matter expert input; please modify as needed according to your airport's circumstances.

An example criticality scale is shown below.

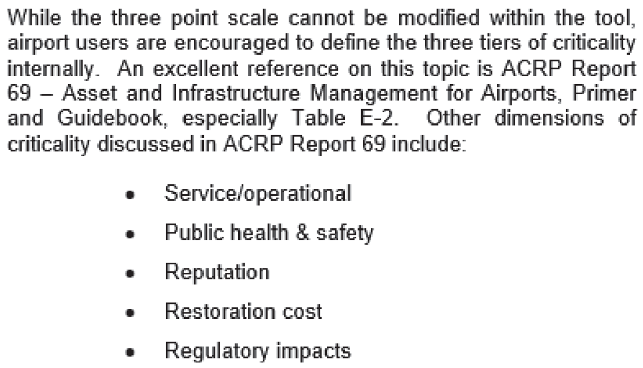
1 – Loss of the asset/operation would have a negligible impact on the airport.

2 – Loss of the asset/operation would hamper airport function.

3 – Loss of the asset/operation would significantly impair or shut down the airport until repair, replacements, etc. were secured.

Figure 7-12. Criticality definition and instructions.

(continued on next page)



While the three point scale cannot be modified within the tool, airport users are encouraged to define the three tiers of criticality internally. An excellent reference on this topic is ACRP Report 69 – Asset and Infrastructure Management for Airports, Primer and Guidebook, especially Table E-2. Other dimensions of criticality discussed in ACRP Report 69 include:

- Service/operational
- Public health & safety
- Reputation
- Restoration cost
- Regulatory impacts

Figure 7-12. **(Continued).**

7.4.10 Understanding Possible Climate Impacts and Defining Impact Vulnerability

The purpose of this section is to present impacts that are applicable to the selections in the **Assets** section based on the changes in climate vectors at the airport location. After completing the **Criticality** section, please use the left side panel to navigate to the **Vulnerability** section (Figure 7-13). This section is central to completing the risk screening.

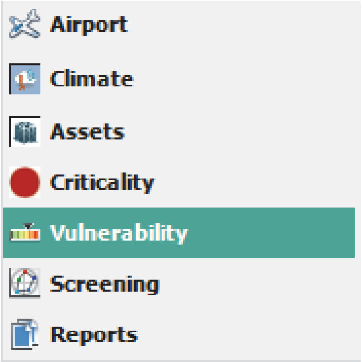


Figure 7-13. Navigation menu—vulnerability.

In the **Vulnerability** section of the tool, only climate-related impacts that satisfy both of the following conditions are shown:

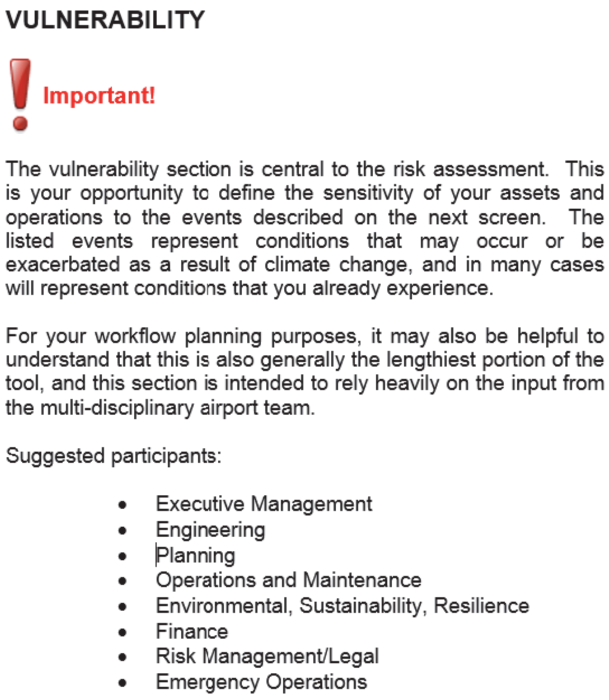
a) Change to the climate vector is significant (changes to this vector exceed 0.5 days per year), and
b) The impacts related to this climate vector are applicable to the assets and operations selected in the previous **Assets** section.

The initial screen, shown in Figure 7-14, emphasizes that this section is the keystone for the risk screening. After reading this opening screen, click "Ok" to continue to proceed to the vulnerability assessment.

The definition of vulnerability, as well as instructions for choosing the vulnerability values of potential impacts, is shown in Figure 7-15. The user may modify the pre-assigned default values.

7.4.11 Risk Screening Page

This section shows the risk to each asset (relative to all other assets at the airport) from changing climate at 2030 and 2060. After completing the **Vulnerability** section, please use the left side panel to navigate to the **Screening** section (Figure 7-16).



VULNERABILITY

Important!

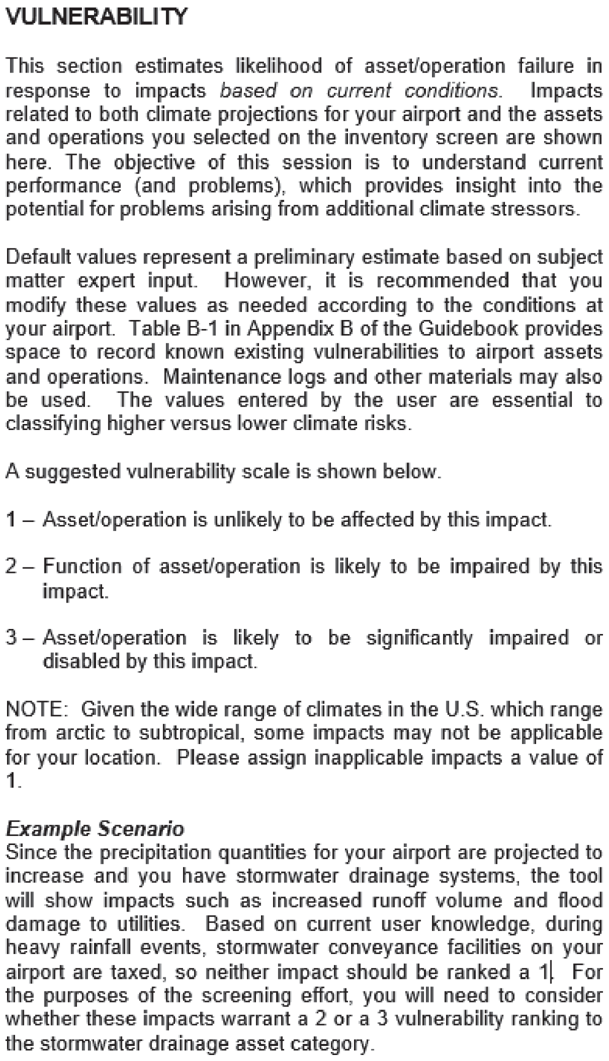
The vulnerability section is central to the risk assessment. This is your opportunity to define the sensitivity of your assets and operations to the events described on the next screen. The listed events represent conditions that may occur or be exacerbated as a result of climate change, and in many cases will represent conditions that you already experience.

For your workflow planning purposes, it may also be helpful to understand that this is also generally the lengthiest portion of the tool, and this section is intended to rely heavily on the input from the multi-disciplinary airport team.

Suggested participants:

- Executive Management
- Engineering
- Planning
- Operations and Maintenance
- Environmental, Sustainability, Resilience
- Finance
- Risk Management/Legal
- Emergency Operations

Figure 7-14. Vulnerability information screen.



VULNERABILITY

This section estimates likelihood of asset/operation failure in response to impacts *based on current conditions*. Impacts related to both climate projections for your airport and the assets and operations you selected on the inventory screen are shown here. The objective of this session is to understand current performance (and problems), which provides insight into the potential for problems arising from additional climate stressors.

Default values represent a preliminary estimate based on subject matter expert input. However, it is recommended that you modify these values as needed according to the conditions at your airport. Table B-1 in Appendix B of the Guidebook provides space to record known existing vulnerabilities to airport assets and operations. Maintenance logs and other materials may also be used. The values entered by the user are essential to classifying higher versus lower climate risks.

A suggested vulnerability scale is shown below.

1 – Asset/operation is unlikely to be affected by this impact.

2 – Function of asset/operation is likely to be impaired by this impact.

3 – Asset/operation is likely to be significantly impaired or disabled by this impact.

NOTE: Given the wide range of climates in the U.S. which range from arctic to subtropical, some impacts may not be applicable for your location. Please assign inapplicable impacts a value of 1.

Example Scenario
Since the precipitation quantities for your airport are projected to increase and you have stormwater drainage systems, the tool will show impacts such as increased runoff volume and flood damage to utilities. Based on current user knowledge, during heavy rainfall events, stormwater conveyance facilities on your airport are taxed, so neither impact should be ranked a 1. For the purposes of the screening effort, you will need to consider whether these impacts warrant a 2 or a 3 vulnerability ranking to the stormwater drainage asset category.

Figure 7-15. Vulnerability definition and instructions.

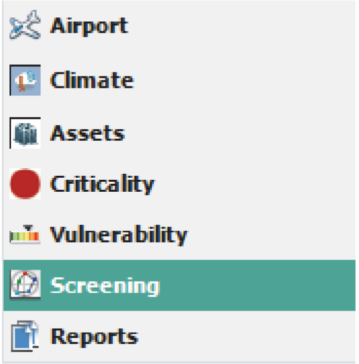
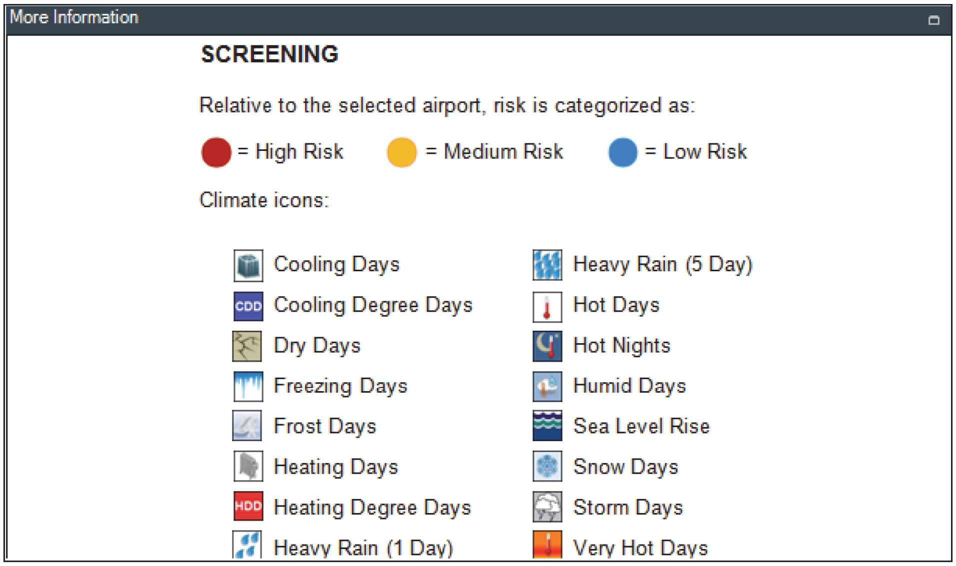


Figure 7-16. Navigation menu—screening report.

The right panel shows a key for the **Screening** information. Each asset or operation is scored using the three-color relative risk scheme shown in Figure 7-17. Icons associated with climate impacts are also defined.


More Information

SCREENING

Relative to the selected airport, risk is categorized as:

● = High Risk ● = Medium Risk ● = Low Risk

Climate icons:

Cooling Days	Heavy Rain (5 Day)
CDD Cooling Degree Days	Hot Days
Dry Days	Hot Nights
Freezing Days	Humid Days
Frost Days	Sea Level Rise
Heating Days	Snow Days
HDD Heating Degree Days	Storm Days
Heavy Rain (1 Day)	Very Hot Days

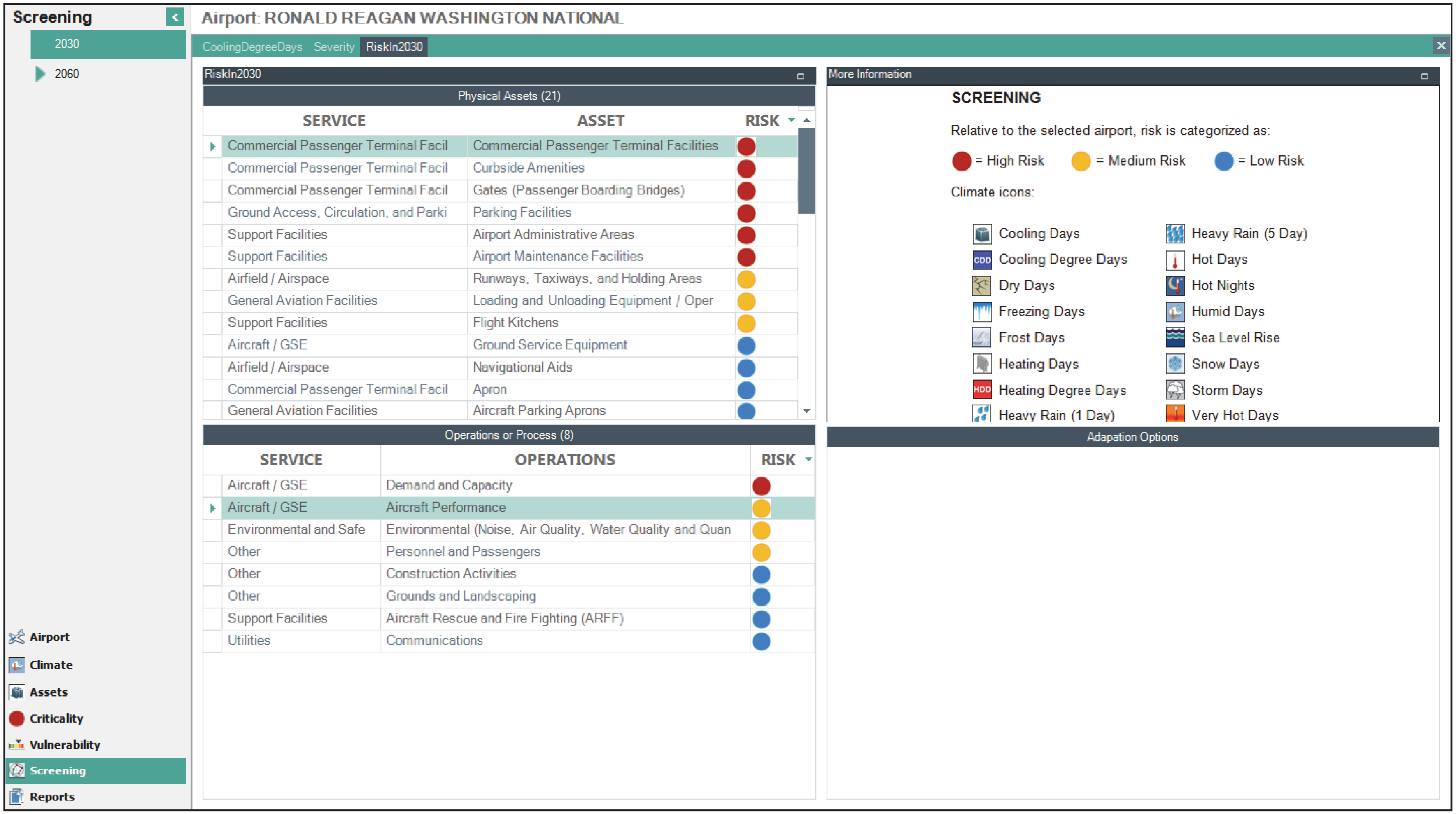
Figure 7-17. Risk and climate vector key.

Figure 7-18 shows a sample output.

When an asset or operation is selected, the bottom right panel, as shown in Figure 7-19, provides adaptation information on individual assets or operations. Click on an asset or operation on the left-hand side of the screen to see which climate vectors are responsible for which impacts, the risk level relative to other assets and operations at the airport, and possible adaptation options. The key indicates which climate vectors are responsible for each impact. The airport planning processes for which further assessment and adaptation selection can be pursued are provided in the appendices.

7.4.12 Printing a Report

This section provides instructions on creating a Word version (.docx) of the report. Please use the left side panel to navigate to the **Reports** section (Figure 7-20).



Airport: RONALD REAGAN WASHINGTON NATIONAL

Physical Assets (21)

SERVICE	ASSET	RISK
Commercial Passenger Terminal Facil	Commercial Passenger Terminal Facilities	🔴
Commercial Passenger Terminal Facil	Curbside Amenities	🔴
Commercial Passenger Terminal Facil	Gates (Passenger Boarding Bridges)	🔴
Ground Access, Circulation, and Parki	Parking Facilities	🔴
Support Facilities	Airport Administrative Areas	🔴
Support Facilities	Airport Maintenance Facilities	🔴
Airfield / Airspace	Runways, Taxiways, and Holding Areas	🟡
General Aviation Facilities	Loading and Unloading Equipment / Oper	🟡
Support Facilities	Flight Kitchens	🟡
Aircraft / GSE	Ground Service Equipment	🔵
Airfield / Airspace	Navigational Aids	🔵
Commercial Passenger Terminal Facil	Apron	🔵
General Aviation Facilities	Aircraft Parking Aprons	🔵

Operations or Process (8)

SERVICE	OPERATIONS	RISK
Aircraft / GSE	Demand and Capacity	🔴
Aircraft / GSE	Aircraft Performance	🟡
Environmental and Safe	Environmental (Noise, Air Quality, Water Quality and Quan	🟡
Other	Personnel and Passengers	🟡
Other	Construction Activities	🔵
Other	Grounds and Landscaping	🔵
Support Facilities	Aircraft Rescue and Fire Fighting (ARFF)	🔵
Utilities	Communications	🔵

SCREENING

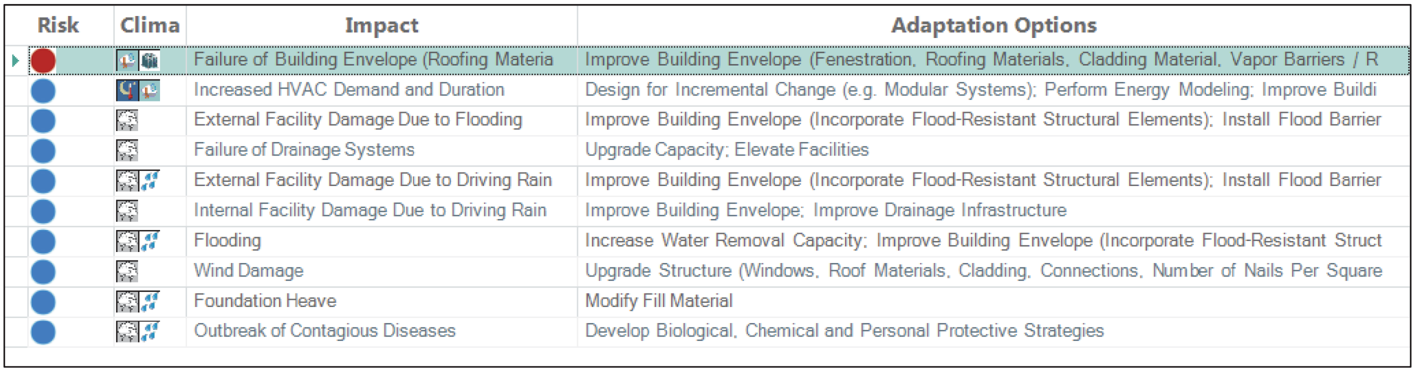
Relative to the selected airport, risk is categorized as:

🔴 = High Risk 🟡 = Medium Risk 🔵 = Low Risk

Climate icons:

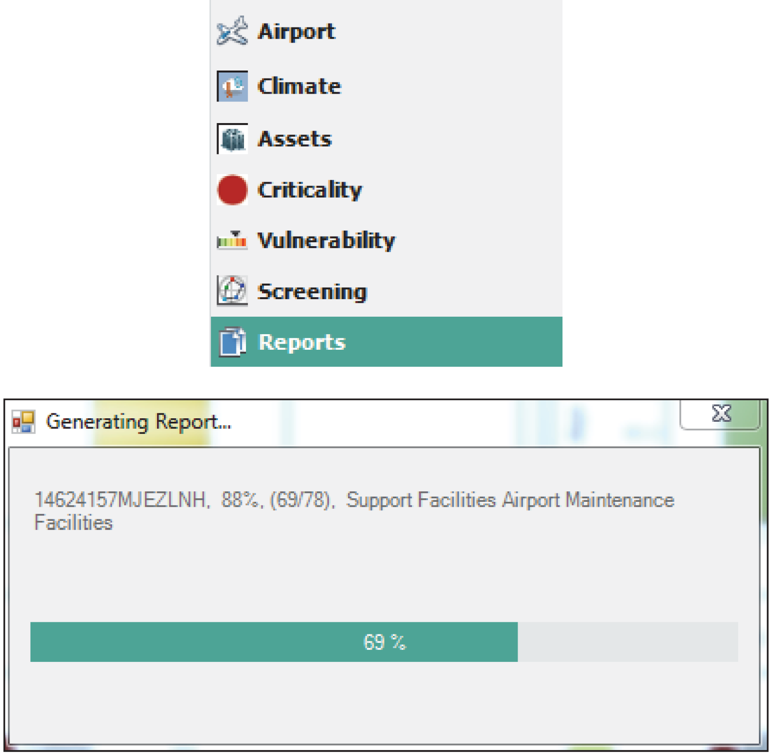
Cooling Days	Heavy Rain (5 Day)
Cooling Degree Days	Hot Days
Dry Days	Hot Nights
Freezing Days	Humid Days
Frost Days	Sea Level Rise
Heating Days	Snow Days
Heating Degree Days	Storm Days
Heavy Rain (1 Day)	Very Hot Days

Figure 7-18. Risk screening overview—desktop view.



Risk	Clima	Impact	Adaptation Options
●		Failure of Building Envelope (Roofing Materia	Improve Building Envelope (Fenestration, Roofing Materials, Cladding Material, Vapor Barriers / R
●		Increased HVAC Demand and Duration	Design for Incremental Change (e.g. Modular Systems); Perform Energy Modeling; Improve Buildi
●		External Facility Damage Due to Flooding	Improve Building Envelope (Incorporate Flood-Resistant Structural Elements); Install Flood Barrier
●		Failure of Drainage Systems	Upgrade Capacity; Elevate Facilities
●		External Facility Damage Due to Driving Rain	Improve Building Envelope (Incorporate Flood-Resistant Structural Elements); Install Flood Barrier
●		Internal Facility Damage Due to Driving Rain	Improve Building Envelope; Improve Drainage Infrastructure
●		Flooding	Increase Water Removal Capacity; Improve Building Envelope (Incorporate Flood-Resistant Struct
●		Wind Damage	Upgrade Structure (Windows, Roof Materials, Cladding, Connections, Number of Nails Per Square
●		Foundation Heave	Modify Fill Material
●		Outbreak of Contagious Diseases	Develop Biological, Chemical and Personal Protective Strategies

Figure 7-19. Vectors responsible for climate stressors, impacts and risks, and adaptation options.



14624157MJEZLNH, 88%, (69/78), Support Facilities Airport Maintenance Facilities

Figure 7-20. Navigation menu and status bar—report.

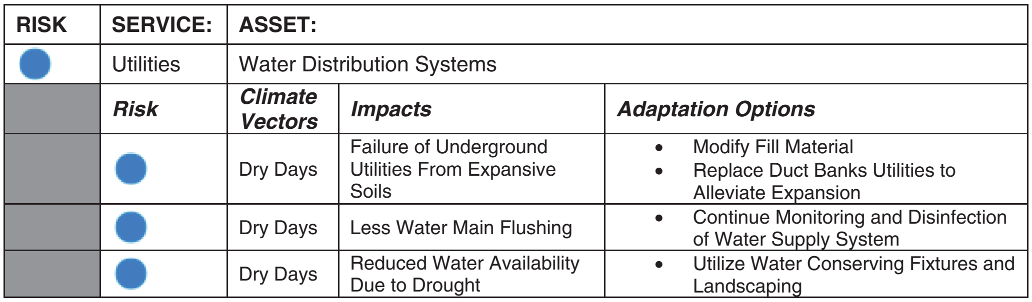
The report sections will be displayed on screen. Simultaneously, the tool will generate a Word (.docx) version of the report containing the following elements (see Figure 7-21 for excerpt):

- Climate change summary table,
- Individual climate vectors, and
- 2030 and 2060 risk, including assigned criticality and vulnerability.

7.5 Saving, Sharing, and Troubleshooting

7.5.1 Saving an ACROS Work Session

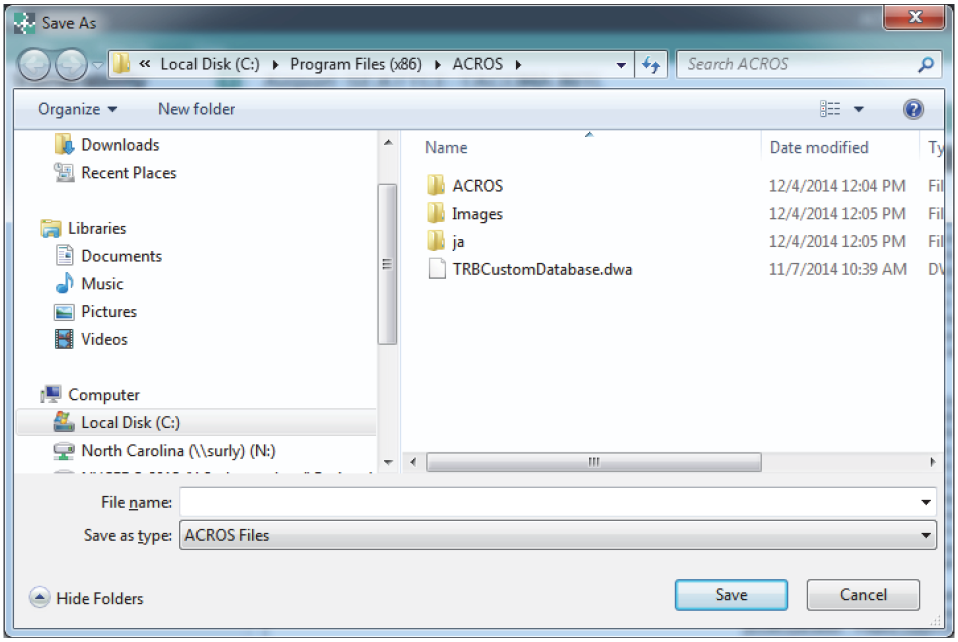
Select **File** > **Save** and use the dialogue box to name the file in a directory the user can access (Figure 7-22). To resume work on the saved file, open the ACROS tool first, and then navigate within the tool using **File** > **Open** to the file directory where the ACROS work session was saved.



RISK	SERVICE:	ASSET:
●	Utilities	Water Distribution Systems

	Risk	*Climate Vectors*	*Impacts*	*Adaptation Options*
	●	Dry Days	Failure of Underground Utilities From Expansive Soils	• Modify Fill Material • Replace Duct Banks Utilities to Alleviate Expansion
	●	Dry Days	Less Water Main Flushing	• Continue Monitoring and Disinfection of Water Supply System
	●	Dry Days	Reduced Water Availability Due to Drought	• Utilize Water Conserving Fixtures and Landscaping

Figure 7-21. Excerpt from risk report.



Name	Date modified	Ty
ACROS	12/4/2014 12:04 PM	Fil
Images	12/4/2014 12:05 PM	Fil
ja	12/4/2014 12:05 PM	Fil
TRBCustomDatabase.dwa	11/7/2014 10:39 AM	D

File name:

Save as type: ACROS Files

Figure 7-22. Save dialogue.

7.5.2 Sharing an ACROS Work Session

It is possible to share a copy of a saved ACROS work session. After saving, users may:

- Attach the file in an email
- Save a copy on a shared network site
- Place a file on an ftp or cloud resource

Files opened by the ACROS tool are locked, so files can be modified by only one user at a time.

7.6 Understanding ACROS Climate Results

7.6.1 Projected Changes

As shown in Figures 7-23 and 7-24, climate vectors are presented in bar graph form.

Users are encouraged to examine the median, upper, and lower boundary of the projections as shown in the bar graphs. It is useful to understand the following aspects of the information shown.

- **Trend:** Does the projection call for an increase or decrease in the climate vector shown?
- **Timing:** What changes are projected in 2030? 2060?

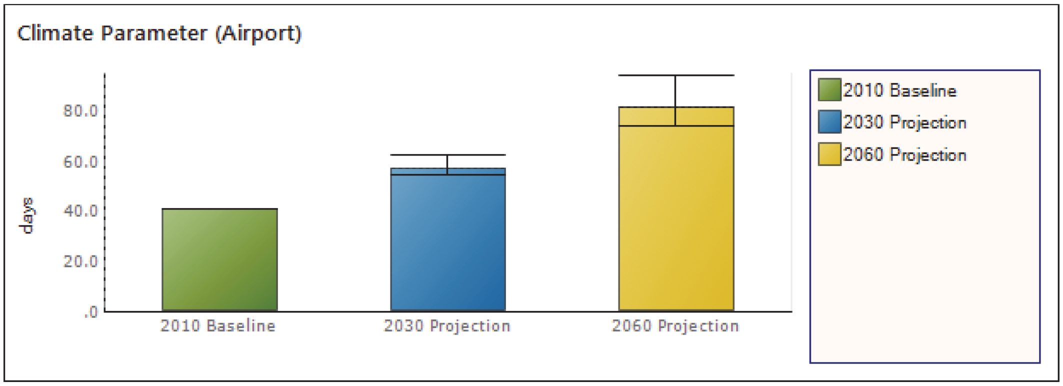


Figure 7-23. Climate vector bar graph showing baseline and projected values for 2030 and 2060. Bar chart indicates median GCM suite output and whiskers indicate the 25th and 75th percentile outputs, showing a range of model values.

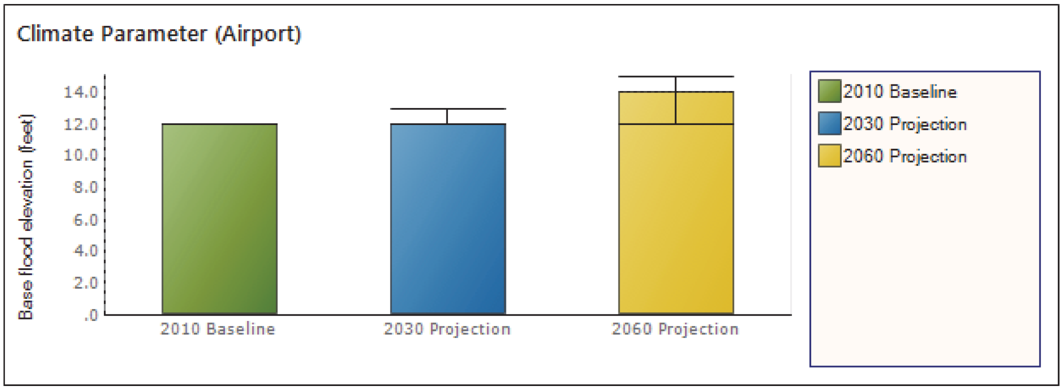


Figure 7-24. Site-specific changes in BFE at a U.S. airport reflecting current baseline and projections for 2030 and 2060. Bar chart indicates the intermediate-high SLR estimates and whiskers indicate the low and high estimates.

- **Rate of change:** How large a difference between changes is projected in 2030 and 2060? Does the change appear to be linear (a straight-line increase from baseline) or accelerating?
- **Direction of change:** Is the vector projected to increase or decrease?
- **Confidence:** What is the reported confidence in the climate vector? (During an ACROS work session, the user will find this information reported in the "Confidence" icon for each vector in the heading with the vector name and definition.) Remember that "low" confidence does not indicate unusable information, but rather that there is some disagreement in the models about the extent and direction of change. Therefore, decision makers should consider a wider range of possible future conditions than in vectors with higher reported confidence. Table 7-1 considers in greater detail the implications of confidence for planning, engineering, and design.
- **Regional perspective:** How do the changes projected for the airport compare to changes throughout the region? Are there neighboring airports to consider? If so, it may be worthwhile to discuss impacts, experiences, and best practices with officials at those airports.

7.6.2 Interpreting Projected Changes

- Compare changes to similar vectors. Example: Most locations will show changes in all temperature vectors; however, some changes may occur at different rates than others. It may be useful to graph changes, as shown in Figure 7-25.

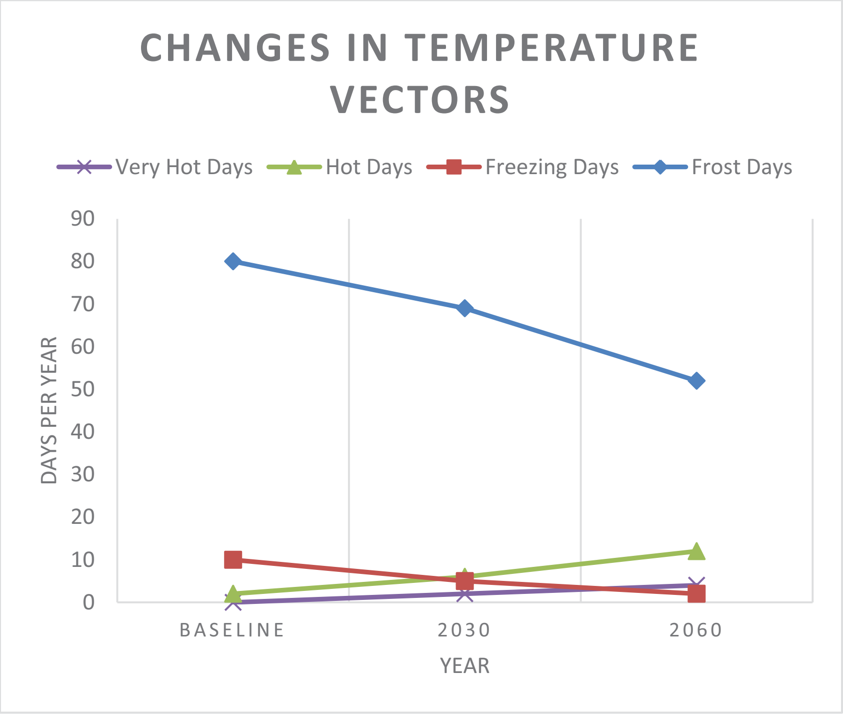


Figure 7-25. Example graph of changes in temperature vectors.

- Note changes in vectors measuring opposite conditions. For example, nationally, many locations will see increases in Dry Days as well as Heavy Rain 1-Day and Heavy Rain 5-Day events. To some degree, this reflects the less frequent, but more intense, precipitation events that many areas of the United States are already experiencing.
- Be aware that change to a climate vector can be responsible for a range of different weather conditions. For example, warming temperatures in areas that experience significant winter precipitation may result in less icy conditions as a result of warmer temperatures, or icier conditions because of changes of precipitation type from snow to freezing rain and sleet.
- The ACROS tool presents information directly relevant to airport operations (e.g., an increase in days with 90°F temperatures has implications for the health and safety of outdoor staff and customers). However, because of the complexity and regionally-specific information required, ACROS has limited ability to provide insight into changes in extreme events such as droughts, hurricane frequency, and nor'easters. Additional modeling is necessary to fully investigate events of this type.
- Even small changes may be important. Below are two examples:
  - The rain vectors (Heavy Rain 1-Day and 5-Day) show changes of only 1 to 2 days (sometimes less) by 2030 and 2060 at many locations nationwide; however, changes to the design storm may be significant. Depending on the importance of heavy rain events for the airport location, downscaling climate data and investigating possible changes to the design storm may be desirable.
  - For the Sea Level Rise–BFE vector, it is important to note that BFEs are by convention rounded to the whole foot. Therefore, small increases in sea level may not result in a change to the BFE.

PART IV

Applying the Adaptation Framework

CHAPTER 8

Mainstreaming Adaptation Strategies

The frameworks discussed in this chapter share a number of commonalities, including the assessment of vulnerabilities and/or opportunities present at the airport. The need to develop plans despite uncertainty concerning the future is typical in airport planning processes. Planning for adaptation to a range of potential climate futures is not entirely unlike demand forecasting, which examines airport needs given different future demand scenarios. In the case of adaptation planning, understanding the range of climate change projections and any associated attendant model uncertainty helps an airport determine what adaptation actions may be needed to meet a range of potential futures. Existing planning frameworks are an important communication tool for those who design and construct airport infrastructure. Consequently, thoroughly integrated and well-advocated adaptation guidelines streamline the achievement of climate change adaptation goals. Planners and designers who understand climate change adaptation objectives up front are better able to incorporate those goals in individual projects and leave room in their designs for planned adaptation upgrades in the future.

While there are advantages to integrating or "mainstreaming" adaptation into existing frameworks, climate change adaptation planning may need to be integrated into multiple airport processes. Thoughtful integration into several planning processes, such as emergency response and master planning (i.e., short-term and long-term impacts of climate change) will probably be needed to fully account for climate change adaptations. Some of the most likely planning frameworks for incorporating climate change adaptation planning are discussed briefly below.

8.1 Safety Management Systems

A Safety Management System (SMS) is a risk assessment protocol developed by the FAA and tested at airports to identify and manage risks to safe operation. The use of formal SMS tools allows users to identify the trade-offs between planning for relatively infrequent risks and the potentially significant consequences of those risks. The FAA's Advisory Circular (AC) No. 150/5200-37 (Federal Aviation Administration, 2007) provides guidance for SMS development and includes a process for identifying potential hazards, assessing the potential severity and likelihood of those hazards, and developing measures to eliminate or control the risk. ACRP Report 1 (Ludwig, et al., 2007) also provides guidance for airports developing an SMS.

Weather-related hazards pose risks that could be addressed in an airport SMS. For example, some climate impacts such as an increase in Hot Days (see Appendix D for more examples) may create hazardous operational conditions for an airport. An SMS provides a framework to systematically identify, prepare for, and set in place procedures to respond to changing conditions, including environmental weather conditions. Through the execution of an SMS, an airport may strategically mitigate potentially hazardous conditions such as aircraft and ground vehicle collisions, aircraft overruns, and other types of accidents.

8.2 Disaster, Business Recovery, and Emergency Response Planning

Airports develop emergency response plans to deal with a variety of emergency conditions. AC No. 150/5200-31C (Federal Aviation Administration, 2010) provides guidance to airports on the development and implementation of an Airport Emergency Plan. Hazard/risk analysis for emergency planning for weather events is typically based on historical data and hazard analyses [such as those conducted by FEMA, the U.S. Geological Survey (USGS), and the National Weather Service (NWS)]. However, climate projections that estimate future conditions may also be useful inputs for resilience-focused hazard analysis. The weather-related hazards considered in an emergency response plan may be impacted by climate change, including increased likelihood of flooding and heat waves. Assessing these hazards based on the understanding that climate change may increase the number of extreme weather events an airport experiences can help airports plan appropriately for emergency response during future climate conditions.

Emergency response plans address not only the recovery of the airport's operations, but also the need to provide for the possibility that the airport will be used as a regional disaster recovery supply facility, thereby experiencing an increase in traffic volume. Airport infrastructure may also be needed during a regional disaster to support the community, and emergency response plans should address incorporation of potential disaster support operations not related to aviation that could take place at the airport. Louis Armstrong New Orleans International Airport provided a stark example of this during Hurricane Katrina. Although it was damaged and partially flooded, the airport served as a makeshift triage center for those injured or displaced by the hurricane and as a regional Gulf Coast staging center for relief and security operations. During Katrina, the airport experienced a major shift in operation and function from commercial airport operation to disaster response, serving as a hub for humanitarian, rescue, and evacuation operations.

ACRP Report 65: Guidebook for Airport Irregular Operations (IROPS) Contingency Planning (Nash, et al., 2012) may further assist airports in planning for weather-related emergency situations. ACRP is also currently overseeing research to develop a guidebook for integrating community emergency response teams at airports, and a separate guidebook for evaluating the airport emergency response operations simulation tool. These guidebooks may further assist airports in preparing emergency response plans, coordinating with local community emergency response teams, and incorporating climate adaptation in prepared plans.

8.3 Risk Management Processes

Most airports engage in some form of risk management. Mid-size and large airports often have individuals or entire full-time staff devoted to minimizing airport risk through various risk management planning processes. Within smaller airports, risk management is less likely to be the sole responsibility of a particular staff member and may involve very limited planning processes. Risk management most often takes the form of procurement of insurance coverage for property, general liability, and business interruptions. Climate change risk assessment and adaptation may be approached in a similar way and/or integrated into an airport's existing risk management processes.

Risk management at airports currently includes assessing risks to infrastructure and operations and developing ways to manage or mitigate those risks. This may include planning for changes to infrastructure and operating protocols, and/or procurement of insurance coverage for property and general liability. Airports conduct risk analyses to determine the appropriate level of insurance coverage to financially manage risk of loss or disruption of service. Loss exposure from environmental concerns is one risk that may be covered by airport insurance. *ACRP*

Synthesis 30: Airport Insurance Coverage and Risk Management Practices (Rakich, et al., 2011) was developed to assist airports with risk financing and insurance purchasing decisions. Changes in climate may result in increased insurance claims for environmental-related incidents like wind damage, roof failures due to snow load, or flooding of structures from heavy rain events or frozen pipes. Considering how climate change may impact an airport's loss exposure when conducting a risk assessment may better position airports to manage future risk and better plan investments in insurance, changes to facilities, and modifications in operating protocols.

8.4 Master Plans, Sustainable Planning, and Activities

Airport master plans describe future service and infrastructure development over a 15- to 30-year period. The master plan development process includes a review of existing information and references as much information as is currently available. As a result, airport master plans provide a mechanism to strategically address infrastructure that could be affected by future changes in environmental conditions caused by climate change. In response to feedback from airports, the FAA developed a guided planning process to facilitate and incorporate climate adaptation planning through an airport sustainability planning, grant-funded program. The FAA's sustainability master/management planning process provides guidance to airports addressing economic viability, operational effectiveness, natural resources, and social aspects of an organization. Long-term infrastructure investments to facilitate the airport's adaptation to more frequent and/or extreme environmental conditions resulting from climate change further promotes the airport's long-term viability.

One way an airport may incorporate climate adaptation measures as part of the master planning process is by running possible future scenarios for the airport in the ACROS climate tool, as described in this guidebook. An airport may first identify existing infrastructure conditions and organizational response practices to establish a baseline of conditions to compare future level-of-service options. As a next step, an airport may prioritize infrastructure assets important to maintaining operations at the selected levels of service. In this step, an airport determines the minimal resources required to maintain each level of service. An airport may then evaluate the vulnerabilities of important infrastructure assets and organizational response procedures to changes in local and regional environmental conditions or other disruptive events (e.g., an airport power outage, compromised airport security, maintenance employee shortage). The selection of likely local and regional environmental conditions and the effect on select infrastructure assets are then assessed using the accompanying climate tool. Lastly, once the anticipated environmental conditions are identified and existing infrastructure and organizational response practices are assessed, the master plan is developed to allocate future resources, as needed.

Although many of the likely near-term effects of climate change will be relatively small and appear incrementally over the lifetime of facilities, identifying the planning processes and analysis needs well in advance of impacts may provide significant value to airports. Advanced planning for managing some impacts—such as the secondary impacts from higher than average temperatures on aircraft performance, including payload and flight range requirements that in turn affect airport runway length and fuel storage needs—may result in less resource intensive solutions than those implemented in reaction to an event. Another example is the increased risk of higher level storm surges that may result in the flooding of airport facilities. Identification of critical infrastructure assets and planned adaptation in advance of an extreme environmental event provides awareness of vulnerabilities and guidance for decision makers to take action when prioritizing limited resources.

The master planning process is a particularly useful mechanism for the incorporation of climate change adaptation; for more on this topic, see Chapter 9, Master Plans and Climate

Change Adaptation. For airports using the sustainability approach to address climate change adaptations, consider Los Angeles World Airports' (LAWA) *Sustainable Airport Planning, Design and Construction Guidelines*, Version 5.0 (Los Angeles World Airports/CDM, 2010), as an example. For each climate impact, the Guidelines document provides a sheet with several sections:

- Intent: The objective of the sheet, in terms of preparing for impacts to airport infrastructure and operations.
- Point Allocation: Airport-defined scoring analogous to the Leadership in Energy and Environmental Design framework.
- Actions & Targets: Instructions to attain appropriate climate models, use models to evaluate airport-specific impacts, and mitigate impacts through planning or infrastructure design.
- Benefits: Savings or other improvements resulting from using appropriate planning or design strategies (e.g., reduction of IROPs and repair costs and improvement of airport safety).
- Technical Approaches: Which impacts are tied to the change in question, potential planning and design elements, and, if applicable, possible funding resources or coordination suggestions.
- Acknowledgements: References to literature providing the scientific basis for the information on the sheet.

For more on LAWA's approach, see Appendix E: Resources.

8.5 Programming and Conceptual Design Processes

Climate change effects on building design, such as increased HVAC loads due to longer or hotter cooling seasons, increased emergency generation capacity, placement of emergency generators above higher flood levels, and increased emergency fuel storage, are issues that may be addressed in building design guidelines or incorporated in revised programming and conceptual design processes.

Designs for routine upgrades to civil infrastructure may include consideration of the need for higher elevations on airfield utility vaults, perimeter roads, containment dikes, or other facilities within the flood zone related to climate change-induced higher storm surges. Incorporation of increased design standards needed for potential future climate changes in an airport design standards manual is one way to ensure new airport infrastructure will be more robust for future climate conditions and reduce the potential need for costly future upgrades.

8.6 Disaster and Business Recovery Planning

Disruption to airport operations can result in lost revenue, lost confidence by customers and airlines, and insurance claim processing, if applicable, among other problems. Because airports are a service industry, maintaining operational performance is important to long-term viability. Setting in place contingencies for possible disruptions through the development of disaster and business recovery planning can assist the airport in limiting negative impacts and restoring timely operations.

Using available tools such as the ACROS tool to identify and inform decision makers of external factors that may contribute to a disruption of operations may allow an airport to focus resources on strategic business vulnerabilities. Response action and recovery plans channel resources to systematically restore infrastructure and operational practices to minimize negative impacts from disruptions.

8.7 Transportation Planning Frameworks

Airports are integral to regional transportation plans and often are involved with the regional planning commission to develop regional plans and policies. Sharing of information, such as local and regional climate data available through the use of the ACROS tool, provides an opportunity for a coordinated effort to address changing environmental conditions common to other regional transportation providers. Identifying how changing environmental conditions (flooding, more ice days, etc.) affect regional transportation networks may further assist the airport to identify additional vulnerabilities. For example, if employees are unable to get to the airport, are there accommodations airport management may consider for operationally critical staff during extreme events? Separately, if during a snow or ice event, roads adjacent to the airport are not accessible due to a different response priority by the regional transportation authority, airport inbound passengers will be stranded at the airport and outbound passengers may not be able to reach it.

Opportunities to leverage regional resources to respond to possible extreme environmental conditions, for instance, may lessen the economic impact for the airport while maintaining a timely and effective response. The output of the airport climate adaptation process should inform and be informed by regional planning commission activities, as applicable. Coordination with such entities in the area of adaptation will be critical to addressing the reality that the airport is one component within a regional transportation system and has numerous dependencies on the larger system to function.

8.7.1 Design and Construction

When designing and building the infrastructure identified in an Airport Master Plan, architects and engineers rely on standards and codes based on the local climate. Design standards and codes are primarily based on historic climate and weather patterns, and as an airport looks to future facilities, it should review the basis for the existing codes and standards and determine if different codes or standards may be more appropriate in the future climate. Airport architects and engineers should assess the cost of designing to potential future applicable codes and standards for the facilities they are designing and constructing.

Several airports have already established airport-specific design criteria to guide designers. Dallas-Fort Worth International Airport has a Design Criteria Manual that is regularly updated. Incorporation of likely local and regional environmental conditions expected from a changing climate during future manual updates will benefit planned airport designs. Use of airport design criteria that account for climate change also helps other parts of the organization, such as the capital improvement program, as the information has been standardized over time.

Changing environmental conditions resulting from climate change may affect the timing of typical airport construction in unexpected ways. For example, Indianapolis International Airport plans construction to avoid impacting the Indiana Bat, which is listed as an endangered species by U.S. Fish and Wildlife Service. If changing environmental conditions result in warmer temperatures and an extended mating season for the Indiana Bat, the time available to complete construction projects may decrease.

Changing climate conditions may mean that some building materials require more frequent maintenance or replacement. A lifecycle cost considers both the initial investment and maintenance costs, as well as the lifespan of the investment, to determine the lowest long-term cost to the airport. Incorporating lifecycle cost considerations in airport selection criteria may help an airport better understand the long-term investment requirements for each option.

8.8 Business Continuity Planning

Business continuity planning is a process for identifying an airport's exposure to internal and external threats and synthesizing ways to increase resiliency. A business continuity plan provides a road map for maintaining critical infrastructure and continuing operations under adverse conditions, including natural disasters that may become more likely because of climate change. Identifying critical utility needs and planning for emergency power and water, developing backup plans to support operations, coordinating with local emergency plans, and designing infrastructure that accounts for the potential consequences of climate change will enable an airport to maintain operations following a natural disaster.

CHAPTER 9

Master Plans and Climate Change Adaptation

As described in Chapter 8, many airport planning processes provide opportunities to incorporate climate change adaptation. Addressing likely changes in climate and weather is an iterative process, and the approach an individual airport organization takes depends on available staff, political will, financial resources, risk tolerance, external drivers, and capital improvement plans. Leveraging those existing planning processes familiar to airport staff will facilitate a long-term, successful climate change adaptation program. The following sections describe how an airport could incorporate climate change adaptation into updates to the Airport Layout Plan (ALP) and Airport Master Plan.

9.1 ALP and Master Plan Development

The FAA master plan development guidelines present two forms for updates that include multi-stakeholder collaboration and input. The first includes ALP updates, which are a prerequisite to federal funding and often consist of an abbreviated review based on existing planning documents. The second is a comprehensive Airport Master Plan update that addresses facility infrastructure and operational requirements based on projections extending up to 20 years into the future. The ALP is included as one component of an Airport Master Plan.

For reference, the following components are contained in an Airport Master Plan:

1. Pre-planning,
2. Public Involvement,
3. Environmental Considerations,
4. Existing Conditions,
5. Aviation Forecasts,
6. Facility Requirements,
7. Alternatives Development and Evaluation,
8. ALPs,
9. Facilities Implementation Plan, and
10. Financial Feasibility Analysis.

9.2 Aligning Climate Change Adaptation with Master Plan Development

The Airport Master Plan development process incorporates a stepwise assessment of the airport's infrastructure assets, operational capacity, and funding needs as determined by forecasted enplanements and existing infrastructure condition (e.g., age). Expanding this assessment to account for expected changes in climate during each planning step is an efficient method for determining how the airport may adapt. Addressing climate change adaptation considerations as part of the Airport Master Plan can provide overarching guidance and efficient use of resources during the earliest stages of a project. Philadelphia International Airport notes, "In theory, climate change could be considered early on as part of a visioning process and later in the development and evaluation of alternative improvement strategies to consider future services and their location."

Updates and revisions to the facilities implementation plan may provide the opportunity to revisit identified climate change risks on a short-term basis. As conditions at the airport change or a new project is initiated, consider revisiting the adaptation measures previously identified as part of the Airport Master Plan process to account for new climate, operational, or risk management information.

To illustrate, Table 9-1 provides a stepwise overview of how a possible climate impact can be addressed following the Airport Master Plan development process. Consideration of when to incorporate the ACROS climate tool and any identified adaptation strategies may vary according to organizational preferences. For additional assessment, an Adaptation Implementation Worksheet, with an example, is provided in Appendix C.

Table 9-1. Overview of climate response activities.

Master Plan Step	Activity	Evaluation Response Examples
1. Pre-planning	Run the ACROS tool to identify likely risks to infrastructure assets and operations	• SLR to cause storm surge flooding more frequently and extensively (e.g., 500-year storm)
2. Public Involvement	Participate in stakeholder meetings and communicate financial and staff time savings achieved by addressing likely climate change adaptation measures during this process	• Sea levels are rising within the vicinity of the airport and may cause damage to airport property during storm events • The airport is evaluating the vulnerable assets to SLR flooding (e.g., water levels expected, salt corrosion risks) • The airport is interested in collaborating with other local officials to develop a risk management strategy for SLR flooding • The airport collaborates on level of service to provide disaster assistance desired by the community and the requirements for getting the airport back up and running following a storm surge

Table 9-1. (Continued).

Master Plan Step	Activity	Evaluation Response Examples
3. Environmental Considerations	Identify the storage capacity of wetland buffer areas and compare to likely SLR estimates	• Natural flood storage options should be identified and protected from development on airport property
4. Existing Conditions	Inventory existing infrastructure, staff, and financial resources Identify vulnerable assets	• Transformers in the north and west parking lots are elevated 12 inches above ground surface • The only access road connecting the Maintenance Shop to the terminal was flooded and impassible for 3 hours during the flooding last spring • Insurance deductibles for next year have doubled • 75% of operational staff access the airport via the underground subway, previously prone to flooding • The south end of Runway 10-28 was just 2 inches above the high-water mark during the flooding last spring
5. Aviation Forecasts	Compile annual enplanement projections through 2030	• Annual enplanements are projected to increase 10% over the next 20 years
6. Facility Requirements	Determine infrastructure and staff operational requirements to maintain level of service	• Access Roads A and B need to remain open at all times • Runway 10-28 is a priority to maintain operations • Critical Operations and Maintenance staff are required to be at the airport to maintain operations and need means of access
7. Alternatives Development and Evaluation	Run scenario analyses of at least two alternative development options as impacted by an 8-foot storm surge that floods the property	• Scenario 1 (no adaptive management actions) results in a five-day loss of service and an estimated $30 million in damages to assets

(continued on next page)

Table 9-1. (Continued).

Master Plan Step	Activity	Evaluation Response Examples
		• Scenario 2 (operational adaptive management actions) requires $200,000 in operations expenses to implement, and results in a one-day loss of service and an estimated $30 million in damages to assets • Scenario 3 (operational and infrastructure adaptive management actions) requires $200,000 in operations expenses and $10 million in capital expenses to implement, and results in a four-hour loss of service during the storm and no significant infrastructure damage
8. ALPs	Develop a layout plan with infrastructure plans for the selected scenario	• Include planned adaptive management infrastructure improvements in the ALP over the next 10 years
9. Facilities Implementation Plan	As part of the facilities implementation plan, create a climate change adaptation plan that lists the risks to assets and associated adaptation measures	• Elevate at-risk transformers above the 500-year flood elevation • Elevate the maintenance driveway between the Maintenance Shop and the terminal • Provide onsite accommodations for operationally critical staff during forecasted storm events with storm surge flooding, or work with local officials to prioritize a transportation option for staff during flood conditions • Construct a flood wall to protect Runway 10-28 during flood conditions
10. Financial Feasibility Analysis	Conduct a financial assessment of infrastructure and staff level-of-service requirements when impacted by an 8-foot storm surge; include review of insurance premiums	• Assess insurance premiums for airport property restoration due to SLR and storm surge flooding before adaptation measures are implemented, and compare them to premiums after measures are implemented

9.3 Monitor and Update

The Stakeholder Advisory Committee will continue to have a role in updating the adaptation plan as necessary. The recommended schedule for revision is three to five years or in response to important new data or conditions. Revise the plan as necessary in response to new information regarding climate change, the effectiveness of adaptation efforts, or other relevant factors (e.g., changes in regulations, technology, etc.) that may have major impacts on airport activities. In some cases, it may be desirable to pursue additional high-resolution climate modeling to inform engineering and design activities. For more guidance on this topic, please see Appendix E: Resources.

CHAPTER 10

Glossary of Terms and Acronym List

Glossary of Terms

Adaptation—Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, e.g., anticipatory and reactive, private and public, and autonomous and planned. Adaptation increases resilience to future impacts. Adaptation puts an understanding of hazard and risk first and considers impacts, costs, and acceptance in addition to return on investment.

Airport Layout Plan (ALP)—Depicts existing facilities and planned development [required by the Federal Aviation Administration (FAA) in the grant application process]. Plans must be kept up-to-date at all times and should be updated as needed or requested by the FAA to meet airport design standards; accurately reflecting existing features, land-use changes, and airport operations; and to keep pace with future needs.

Airport Sustainability Planning—See Sustainability Master Plans.

ALP Updates—See Airport Layout Plan.

Base Flood Elevation (BFE)—Estimates the height to which floodwater is anticipated to rise during a 100-year flood event. The BFE is measured in feet relative to the North American Vertical Datum of 1988 (NAVD88).

Climate—The long-term pattern (i.e., expected frequency) of weather in a particular location, including the interactions between atmospheric, oceanic, and land states. Climate generally refers to a larger area than weather. Climate is comprised of average weather conditions or patterns over a period of time for a region. Standard averaging period is 30 years.

Climate Change—A change in the state of the climate that can be identified (by using statistical tests, for example) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forces, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate changes as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.

Climate Change Risk—The potential losses associated with climate change and, defined in terms of expected probability and frequency, exposure and consequences (Federal Emergency Management Agency, 1997).

Climate Projections—Model-derived estimates of future climate. Likelihood that something will happen several decades to centuries in the future for given developing conditions. Model projections typically include global temperature and precipitation, precipitation extremes and droughts, and snow and ice.

Climate Stressor—Changes due to or directly related to changing climate. Examples include sea level rise, increased global and regional temperatures, and shifts in precipitation patterns.

Climate Vector—Similar to climate stressor, but more specific and directly related to airport operations. Airport SMEs identified climate stressors that would impact airport operations and then worked with atmospheric scientists to identify specific climate metrics that could be analyzed. For example, high temperatures were identified as a *stressor* to multiple assets and operations. Specific climate *vectors* developed to assess this stressor included days per year where air temperature exceed 90°F and days per year where temperatures exceed 100°F.

Confidence Level—A subjective measure of projection reliability, based on scientific literature and agreement among Global Climate Models, also known as General Circulation Models or GCMs. High confidence indicates less uncertainty than medium or low confidence; low-confidence vectors have the most uncertainty.

Cooling Days (measured in days per year)—A day with an average temperature at or above 68°F.

Cooling Degree Day (CDD) (measured in yearly accumulation)—A unit of measure that reflects the energy demand needed to cool a building. The daily CDD is calculated by subtracting 65 from the day's average temperature. Daily CDDs are summed to obtain the accumulated CDDs per year.

Dry Day (measured in days per year)—A day with a rainfall accumulation of less than 0.03 inch.

Emergency Planning—A formal plan outlining essential emergency-related actions planned to ensure the safety of and emergency services for the airport populace and the community in which the airport is located. The plan also includes provisions for including local communities and state, and federal organizations as appropriate.

Exposure—The number, types, qualities, and monetary values of various types of property or infrastructure and life that may be subject to an undesirable or injurious hazard event (FEMA Multi-Hazard Identification and Risk Assessment, 1997).

Extreme Weather Event—An event that is rare at a particular place and time of year. Definitions of "rare" vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of the observed probability density function. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. Single extreme events cannot be simply and directly attributed to anthropogenic climate change, as there is always a finite chance the event in questions might have occurred naturally. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season).

Flooding—When normally dry areas become wet due to episodic storm events (e.g., land in a floodplain, or land subjected to coastal storm surge or riverine flooding)

Freezing Day (measured in days per year)—A day with a high temperature at or below 32°F.

Frost Day (measured in days per year)—A day with a low temperature at or below 32°F.

Greenhouse Gas Emissions—Naturally existing or human-produced and -emitted gases that trap heat in the atmosphere. Human emissions are considered to be the chief cause of potential man-made climate change. Greenhouse gases are gases in the atmosphere that absorb and emit radiation, which is the cause of the greenhouse effect. Examples of primary greenhouse gases include carbon dioxide, water vapor, and methane.

Heating Day (measured in days per year)—A day with an average temperature at or below 62°F.

Heating Degree Day (HDD) (measured in yearly accumulation)—A unit of measure that reflects the energy demand needed to heat a building. The daily HDD is calculated by subtracting the day's average temperature from 65.

Heavy Rain 5-Day—A measure of the maximum amount of rainfall that accumulates, in inches, over a five-day period.

High- or Low-Emissions Scenarios—Alternative visions of how the future might unfold with respect to the emission of greenhouse gases. Scenarios are generated based on factors such as population projections, economic development, technological changes, etc., and may contain both a narrative and qualitative component. The Special Report on Emissions Scenarios by the IPCC is an example of greenhouse gas emissions scenarios to make projections of possible future climate change. Emission scenarios are based on technological development and economic development.

Hot Day (measured in days per year)—A day with a high temperature at or above 90°F.

Hot Night (measured in nights per year)—A night with a low temperature at or above 68°F.

Humid Day (measured in days per year)—A day with an average dew point temperature above 65°F. The dew point temperature is the temperature at which water vapor in the air condenses into dew.

Infrastructure Lifecycle—The planned useful life of a building or other infrastructure.

Inundation—When currently dry areas become permanently submerged or wetted on a daily basis by tidal action.

Irregular Operations (IROPs)—Events that involve such impacts as unexpected, long-term passenger delays and require actions and capabilities beyond those considered typical.

Mitigation Strategy—Sustained action that reduces or eliminates long-term risk to people and property from natural hazards and their effects.

Monitoring—Collecting necessary data, reviewing performance, and comparing performance to estimates for a given system or asset.

Natural Climate Variability—Variations in climate (often short term) due to changes in the Earth system such as volcanic eruptions, El Niño, or La Niña. Natural climate variability is caused by natural factors and exists on all time scales. Changes include solar energy, volcanic eruptions, and natural changes in greenhouse gas concentrations.

"No Regrets" Climate Adaptation Approach—Situation-specific measures that yield benefits (e.g., cost savings) even in the absence of climate change. This approach helps absorb some of the uncertainty in factors ranging from future economic conditions to climate projections.

One-Day Heavy Rain Day (measured in days per year)—A day with a rainfall accumulation of more than 0.80 inch.

Planned Adaptation Upgrades—Strategies that will be implemented at a later point due to considerations such as planning timelines, the onset of a given impact, and cost.

Possible Climate Change Outcomes—See Climate Projections.

Resilience—The ability of a system to bounce back after experiencing a shock or stress. Resilient systems are usually characterized by flexibility and persistence.

Return on Investment—Financial returns resulting from expenditures. A high return on investment results when the initial expenditure compares favorably to the return.

Risk Assessment—A process or method for evaluating risk associated with a specific hazard and defined in terms of probability and frequency of occurrence, magnitude and severity, exposure, and consequences (Federal Emergency Management Agency, 1997).

Safety Management System (SMS)—An approach that systemizes safety risk management and safety assurance concepts for the purpose of managing safety. SMSs employ mechanisms such as communication and knowledge sharing, organizational structures, policies, and procedures for decision making.

Scenario-Based Approach—See High- or Low-Emissions Scenarios.

Sea Level Rise (SLR)—The change in global and relative (local) sea level trends. Global sea level changes are attributed to changes in ocean volume due to ice melt and thermal expansion. Relative sea level changes include global sea level changes as well as changes in land elevation caused by factors such as glacial rebound (readjustment of land elevations since the retreat of the last Ice Age) and subsidence (sinking land). SLR measures the number of days per year where the runway elevation is inundated by tidal flooding. In the ACROS tool, SLR is shown as the number of days per year where the runway elevation (provided in the FAA's NFDC database) is inundated by tidal flooding.

Snow Day (measured in days per year)—A day with a snowfall accumulation of more than two inches.

Stakeholder Involvement—The meaningful, timely engagement of various groups, such as passengers, tenants, state and federal agencies, and the general public, who have an interest in airport activities.

Storm Day (measured in days per year)—A day with a thunderstorm rainfall accumulation more than 0.15 inches. May include high wind events and hail.

Storm Surge—A rise in ocean water generated by the winds of a storm. Storm surge combined with tides (storm tides) during events such as a hurricane causes severe coastal flooding, particularly during high tides. Rise of water is associated with low-pressure weather systems. Surges are caused by high winds pushing the surface of ocean water, causing water to pile up higher than the mean sea level. The effects of storm surge rise of water is associated with the rise in water from storm, tide, and wave run-up. Storm surge is measured as the height of water above the predicted astronomical level.

Sustainability Master Plans—An FAA initiative to incorporate sustainability into the master planning process.

Sustainability Principles—Guidelines to assist planners and managers in meeting today's needs without compromising future operations.

Uncertainty—Captures knowledge of probability and consequence. In climate modeling, uncertainty refers to a way of specifying how precisely something is known.

Vertical Land Movement—See SLR.

Very Hot Days (measured in days per year)—A day with a high temperature at or above 100°F.

Vulnerability—The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

Weather—Qualities such as the temperature, moisture, wind direction and speed, and barometric pressure of the atmosphere in a given time and location. Weather is day-to-day atmospheric properties (temperature, precipitation, humidity). Weather is the set of all phenomena in the atmosphere at a given time.

Weather and Climate Disasters—A serious weather- or climate-related disruption resulting in a significant number of deaths, injuries, and/or economic damages. Examples include tornadoes, hurricanes, droughts, and wildfires. Major event resulting from natural processes that can cause loss of life, etc., and could relate to resilience

Acronym List

AC	Advisory Circular
ACI–NA	Airports Council International–North America
ACRM	Airport Climate Risk Matrix
ACROS	Airport Climate Risk Operational Screening [Tool]
ACRP	Airport Cooperative Research Program
ALP	Airport Layout Plan
AMS	American Meteorological Society
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
ASHRAE	American Society of Heating and Air-Conditioning Engineers
BAA	British Airports Authority
BFE	Base Flood Elevation
CDD	Cooling Degree Day
CMIP5	Coupled Model Intercomparison Project
CSS-Wx	Common Support Services—Weather
DEFRA	Department for Environment, Food, and Rural Affairs (U.K.)
ERD	Entity-Relationship Diagram
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FIRM	Flood Insurance Rate Map
GCM	Global Climate Model, also known as General Circulation Model
GIS	Geographic Information System
GSE	Ground Service Equipment
GUI	Graphical User Interface
HDD	Heating Degree Day
HVAC	Heating, Ventilation, and Air Conditioning
IATA	International Air Transport Association
IPCC	Intergovernmental Panel on Climate Change
IROP	Irregular Operation
LAWA	Los Angeles World Airports
LEED	Leadership in Energy and Environmental Design
LiMWA	Limit of Moderate Wave Action
MAG	Manchester Airports Group
MHHW	Mean Higher High Water
MSL	Mean Sea Level
NAS	National Airspace System
NAVD88	North American Vertical Datum of 1988

NCA	National Climate Assessment
NFDC	National Flight Data Center
NFHL	National Flood Hazard Layer
NFIP	National Flood Insurance Program
NGS	National Geodetic Survey
NGVD29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Administration
NRDC	National Resources Defense Council
NWS	National Weather Service
PHL	Philadelphia International Airport
QA/QC	Quality Assurance/Quality Control
RCP	Representative Concentration Pathway
SLR	Sea Level Rise
SMART	Specific, Measurable, Attainable, Relevant, Timely
SME	Subject Matter Expert
SMS	Safety Management System
SWEL	Stillwater Elevation
TRID	Transport Research International Documentation
TRB	Transportation Research Board
UKCIP	United Kingdom Climate Impacts Programme
UNFCCC	United Nations Framework Convention on Climate Change
USACE	U.S. Army Corps of Engineers
U.S.DOT	United States Department of Transportation
USGCRP	United States Global Change Research Program
USGS	United States Geological Survey

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APPENDIX A

Airport Asset Impacts

Please see the Excel file that accompanies this guidebook, available on the accompanying CD, CRP-CD-175, and for download from the ACRP Project 02-40 description page: http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3245.

APPENDIX B

Asset Inventory and Criticality Checklist

Table B-1. Asset inventory and criticality checklist.

Category	Asset or Operation	Asset Criticality	Existing Vulnerabilities
Aircraft/GSE	Aircraft Performance		
	Demand and Capacity		
	Ground Service Equipment		
	Navigational Aids - FAA Owned		
	Navigational Aids - Airport Owned		
	Runways, Taxiways, and Holding Areas		
Cargo	Air Cargo Buildings		
	Apron		
	Loading and Unloading Equipment/Operation		
Commercial Passenger Terminal Facilities	Apron		
	Commercial Passenger Terminal Facilities		
	Curbside Amenities		
	Gates		
	Gates (Passenger Boarding Bridges)		
Environmental and Safety	Bird and Wildlife Hazard Management		
	Environmental (Noise, Air Quality, Water Quality and Quantity)		
	Snow and Ice Control (Deicing)		
General Aviation Facilities	Aircraft Parking Aprons		
	Flight Schools and Pilot Shops		
	General Aviation Terminal Facilities		
	Hangars		
	Loading and Unloading Equipment / Operation		
	Tie-Down Areas		
	Transient Aircraft Parking Apron Areas		
Ground Access, Circulation, and Parking	Access Roads		
	Parking Facilities		
	Rail (Internal to the Airport, e.g., Monorail)		

(continued on next page)

Table B-1. (Continued).

Category	Asset or Operation	Asset Criticality	Existing Vulnerabilities
Other	Finance and Insurance		
	Personnel and Passengers		
	Parks		
	Regional Infrastructure		
Support Facilities	Aircraft Fuel Storage/Fueling		
	Aircraft Rescue and Fire Fighting		
	Airline Maintenance Facilities		
	Airport Administrative Areas		
	Airport Maintenance Facilities		
	FAA Facilities (Air Traffic Control Tower)		
	Flight Kitchens		
	Weather Reporting Facilities		
Utilities	Communications		
	Onsite Electrical Infrastructure		
	Sanitary Sewer		
	Stormwater Drainage		
	Water Distribution Systems		

Addendum to Table B-1. Assets and operations not included in ACROS.*

Category	Asset or Operation	Asset Criticality	Existing Vulnerabilities
	IT/Server Rooms		
	Pump Stations		
	Mitigation Land		
	Underground Fueling Systems		
	Cell Phone Towers		
	Military Facilities		
	Airline Reservation/Call Centers		
	Tunnels		
	Airline Glycol Storage		
	Glycol Recovery Systems		
	Ground Run-Up Enclosure		
	On-Airport Underground Pipeline		
	Chemical Support Facility (Runway Deice and Prevention)		

*Airport advisory committees may wish to investigate adaptation options for the assets and operations listed above. The list above was generated by case study participants and other SMEs after the research and software development phase of the project.

Table B-2a. An example worksheet for prioritizing adaptation options and noting ownership of the asset/operations.

Asset or Operation	Climate Impact	Adaptation Option	Priority	Ownership
Aircraft Performance	Reduced Lift	Lengthen Runway	1	Airline
Demand and Capacity	Change in Seasonality of Passenger Travel	Account for in demand projections	2	Airport
Commercial Passenger Terminal Facilities	Increased HVAC Demand	Consider increasing capacity of HVAC systems	3	Airport
FAA-owned NAVAIDS	Electrical Damage	Install transient voltage surge suppressor	4	FAA

Table B-2b. Blank copy of adaptation priority worksheet.

Asset or Operation	Climate Impact	Adaptation Option	Priority	Ownership

APPENDIX C

Adaptation Implementation Worksheets

Table C-1. Adaptation implementation worksheet example.

Adaptation Implementation Worksheet

Service Category		Asset/Operation		Climate Impact		Impact Severity	Impact Timeline
Aircraft/GSE		**Aircraft**		Change From Snow to Ice (Deicing)		-More winter precipitation -More winter precipitation falling as rain, freezing rain, and sleet	Over the next five years

Airport Operational Needs:
-Ice-free aircraft
-Compliance with environmental permitting
-Reasonable estimate of materials needed (deicing fluid)

Adaptation Option		General Applicability Considerations		Planning Processes		Cost and Funding
Modify Ice Control and Removal Strategies	x	- Is appropriate for airport size and other constraints		- Safety Management Systems	x	- Adaptation option is comparable to or lower in cost than traditional methods - Return on investment for adaptation option is relatively rapid - Funding is available for implementation
	x	- Meets or exceeds current and future operational needs		- Disaster, Business Recovery, and Emergency Response Planning		
	x	- Fits a wide range of scenarios		- Risk Management Processes		
	x	- Existing operation/asset does not meet current needs		- Master Plans, Sustainable Planning and Initiatives		
		- Project(s) affecting the operation or asset are already planned/underway and facilitate inclusion of the adaptation option		- Programming and Conceptual Design Processes		
		- Implementation does not require coordination with an external partner		- Disaster and Business Recovery Planning		
				- Transportation Planning Frameworks		
				- Design and Construction		
				- Business Continuity Planning		

Table C-2. Blank adaptation implementation worksheet.

Adaptation Implementation Worksheet

Service Category		**Asset/Operation**		**Climate Impact**		**Impact Severity**	**Impact Timeline**

Airport Operational Needs:

Adaptation Option		**General Applicability Considerations**		**Planning Processes**		**Cost and Funding**
	☐	- Is appropriate for airport size and other constraints	☐	- Safety Management Systems	☐	- Adaptation option is comparable to or lower in cost than traditional methods
	☐	- Meets or exceeds current and future operational needs	☐	- Disaster, Business Recovery, and Emergency Response Planning	☐	- Return on investment for adaptation option is relatively rapid
	☐	- Fits a wide range of scenarios	☐	- Risk Management Processes	☐	- Funding is available for implementation
	☐	- Existing operation/asset does not meet current needs	☐	- Master Plans, Sustainable Planning and Initiatives	☐	
	☐	- Project(s) affecting the operation or asset are already planned/underway and facilitate inclusion of the adaptation option	☐	- Programming and Conceptual Design Processes	☐	
	☐	- Implementation does not require coordination with an external partner	☐	- Disaster and Business Recovery Planning	☐	
	☐		☐	- Transportation Planning Frameworks	☐	
	☐		☐	- Design and Construction	☐	
	☐		☐	- Business Continuity Planning	☐	

(continued on next page)

Table C-2. (Continued).

Adaptation Option		General Applicability Considerations		Planning Processes		Cost and Funding
		- Is appropriate for airport size and other constraints		- Safety Management Systems		- Adaptation option is comparable to or lower in cost than traditional methods
		- Meets or exceeds current and future operational needs		- Disaster, Business Recovery, and Emergency Response Planning		- Return on investment for adaptation option is relatively rapid
		- Fits a wide range of scenarios		- Risk Management Processes		- Funding is available for implementation
		- Existing operation/asset does not meet current needs		- Master Plans, Sustainable Planning and Initiatives		
		- Project(s) affecting the operation or asset are already planned/underway and facilitate inclusion of the adaptation option		- Programming and Conceptual Design Processes		
		- Implementation does not require coordination with an external partner		- Disaster and Business Recovery Planning		
				- Transportation Planning Frameworks		
				- Design and Construction		
				- Business Continuity Planning		
		- Is appropriate for airport size and other constraints		- Safety Management Systems		-Adaptation option is comparable to or lower in cost than traditional methods
		- Meets or exceeds current and future operational needs		- Disaster, Business Recovery, and Emergency Response Planning		- Return on investment for adaptation option is relatively rapid
		- Fits a wide range of scenarios		- Risk Management Processes		- Funding is available for implementation
		- Existing operation/asset does not meet current needs		- Master Plans, Sustainable Planning and Initiatives		
		- Project(s) affecting the operation or asset are already planned/underway and facilitate inclusion of the adaptation option		- Programming and Conceptual Design Processes		
		- Implementation does not require coordination with an external partner		- Disaster and Business Recovery Planning		
				- Transportation Planning Frameworks		
				- Design and Construction		
				- Business Continuity Planning		

APPENDIX D

Overview of Climate Change Science

Climate Versus Weather

The term climate is defined by very long-term processes over many years to decades, whereas the term weather deals with day-to-day weather variations that we experience. Despite the fact that climate is simply a long-term average of many weather events, it is often the impact of the latter (e.g., Hurricane Katrina in 2005, Superstorm Sandy in 2012, California drought of 2013–2014) that is more vividly remembered. The research team has attempted to convey this message by choosing climate vectors that are weather centric (e.g., days with a high temperature above 90°F) as opposed to climate centric (e.g., average annual temperature).

Physical Basis

The concept of a "greenhouse effect," by which an accumulation of critical gases such as carbon dioxide can affect the global temperature, was introduced in the early 1800s. Those early arguments have stood the test of time and their physical basis is now fully incorporated in three dimensional earth system models known as Global Climate Models (GCMs). For a GCM to accurately simulate earth's climate, it must be forced with the concentration of carbon dioxide (and other greenhouse gases). The interplay among the feedbacks between the carbon dioxide concentration and global temperature can crudely be called the science of climate change. Meanwhile, estimating how future CO_2 concentrations will be affected by a suite of factors such as population and energy usage is the backbone of climate change projection experiments such as those conducted by the IPCC.

Model Components

A GCM is an interconnected series of computer code that, based on the known physical equations of the earth system (atmosphere, land, ocean, etc.), attempts to forecast the evolution of the weather. The typical GCM has a time step of about 30 minutes and a horizontal resolution of about 100 miles implying that, while it may be able to directly simulate a process such as a cold front moving across the Northeast United States, it will have a difficult time simulating one small thunderstorm over the Arizona desert. To account for the processes that cannot be directly simulated, GCMs must employ "parameterization schemes" in which a small process such as a lone thunderstorm is described by other known variables such as the combination of temperature and dew point. These kinds of approximations maintain the necessary energy balance that the GCM must adhere to, but are also responsible for the inability to resolve small-scale features. Despite these features, the GCM data can be used to approximate the climate for any location in the world. Furthermore, due to rapidly increasing computing power, GCM horizontal resolution will continue to increase in the near future, allowing for a more realistic simulation of small-scale processes that are crucial for day-to-day weather variability.

Data Output

GCM output of important climate stressors such as air temperature, relative humidity, and precipitation are commonly available at six-hour, daily, and monthly frequencies. The choice of frequency depends strongly on the problem, and for this study, the research team elected to use daily data. The horizontal resolution of the data depends on the GCM, and ranges from about 60 miles to about 140 miles. The research team strongly considered using post-processed "statistically downscaled" data, which is available with resolution as high as 8 miles. However, this was not readily available for the timeline of the project.

Climate Change in the U.S.

There is a wide range of extreme weather events that can impact an airport, including tornadoes, severe thunderstorms, hurricanes, derechos, droughts, extreme heat waves, coastal flooding, storm surge, and extreme snowfall and rainfall.

Figure D-1 shows record-breaking weather events that affected the United States *during the single year* of 2011. Most of the country experienced at least one extreme weather event during the year, and many areas were impacted by several events. This appendix summarizes the mounting evidence showing that extreme weather events are already responding to climate change across the United States. The main sources are the IPCC AR5 report, the 2013 National Climate Assessment (Melillo et al., 2014), and research by the National Resources Defense Council (NRDC).

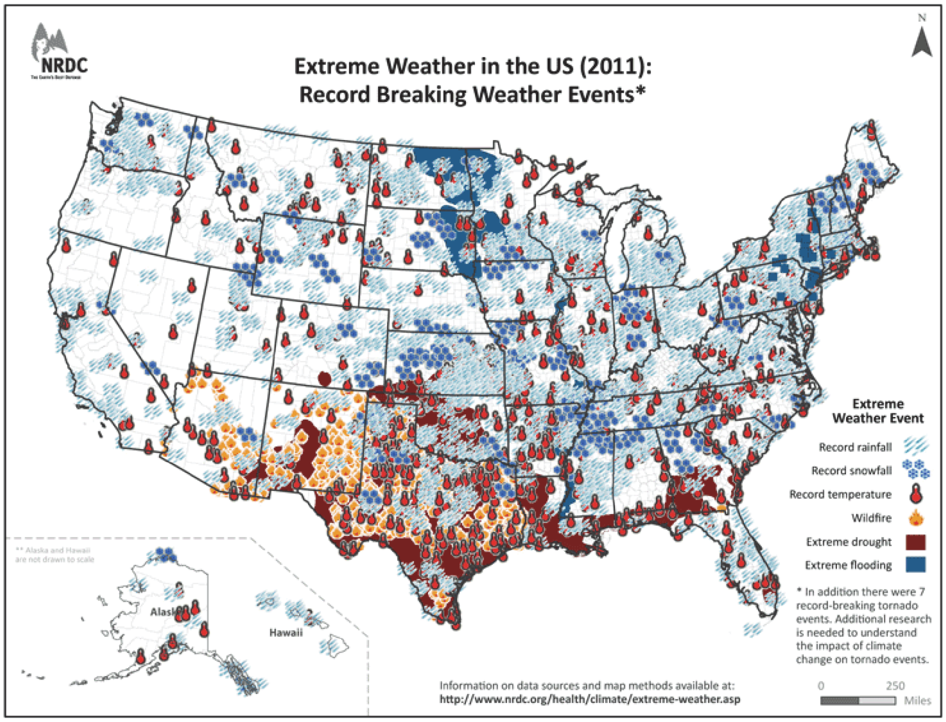


Figure D-1. Extreme weather event in the United States during 2011. Source: NRDC.

According to the IPCC report, there is substantially higher confidence in the projections of increasing temperature compared to precipitation. This is also conveyed in the climate vector confidence, as determined by the research team. In fact, this can also already be seen when analyzing the past 50+ years of data at observation stations across the country. For example, Figure D-2 shows the observed increase in yearly average temperature since 1900, on a regional level. For all regions of the country except for isolated portions of Southeast, temperatures have increased. Some places, especially across the North, have warmed by more than 2°F. These changes are also consistent in other, more impactful climate measures such as frost-free days (increase) and days with high temperatures above 90°F (increase).

In contrast to temperature that shows nearly nationwide increases, Figure D-3 shows that the changes in yearly average precipitation have been much more variable. For example, most of the Midwest has seen a modest increase, up to 15%, while other parts of the country such as the Southeast and arid Southwest have actually slight decreases. Despite the somewhat inconsistent signal in the yearly average precipitation, Figure D-4 clearly shows that there has been a marked increase in heavy precipitation nationwide, with the Northeast seeing a 71% increase in the amount of very heavy daily rainfall. The fact that heavy daily rainfall is clearly more relevant to airport operations than yearly average precipitation highlights the importance the research team placed in building impactful climate vectors for the climate change adaptation analysis.

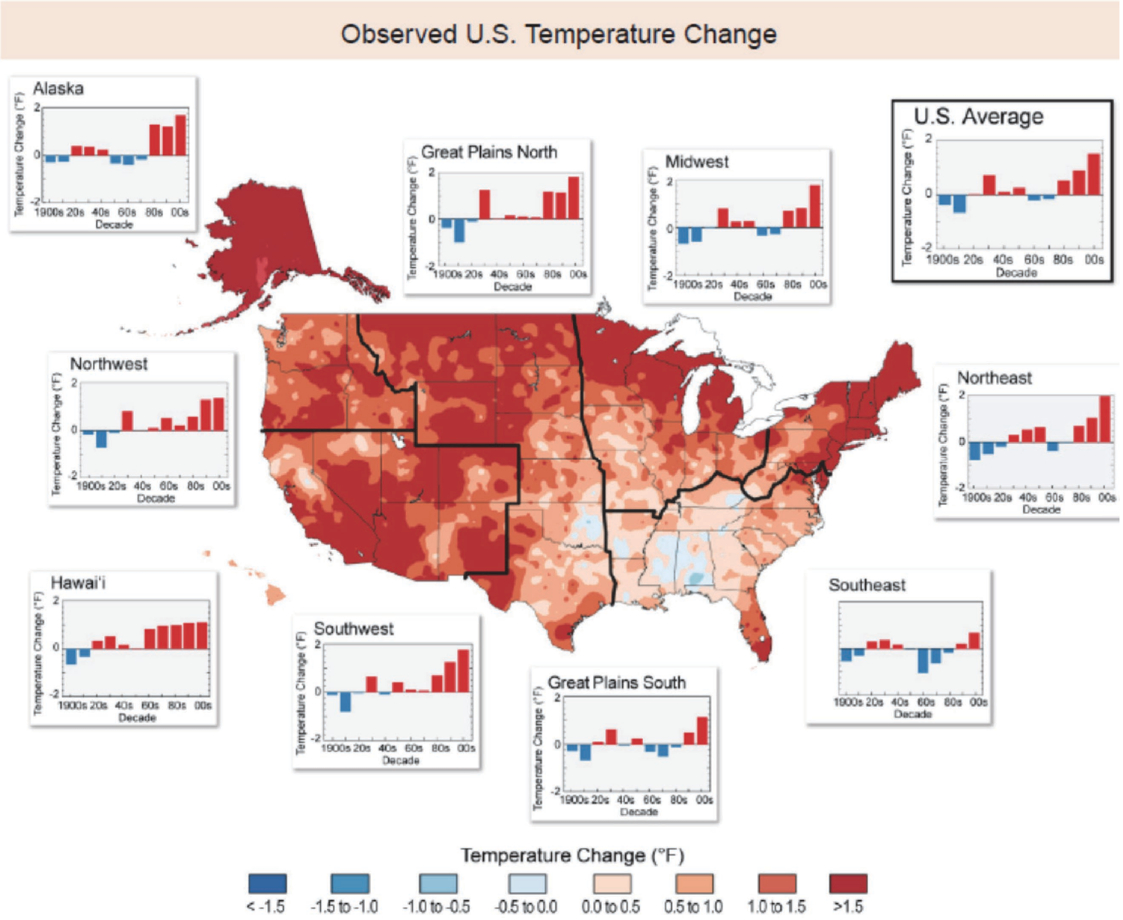


Figure D-2. Observed changes in air temperature on a regional level across the United States from 1900 through the present. Source: Melillo et al., 2014.

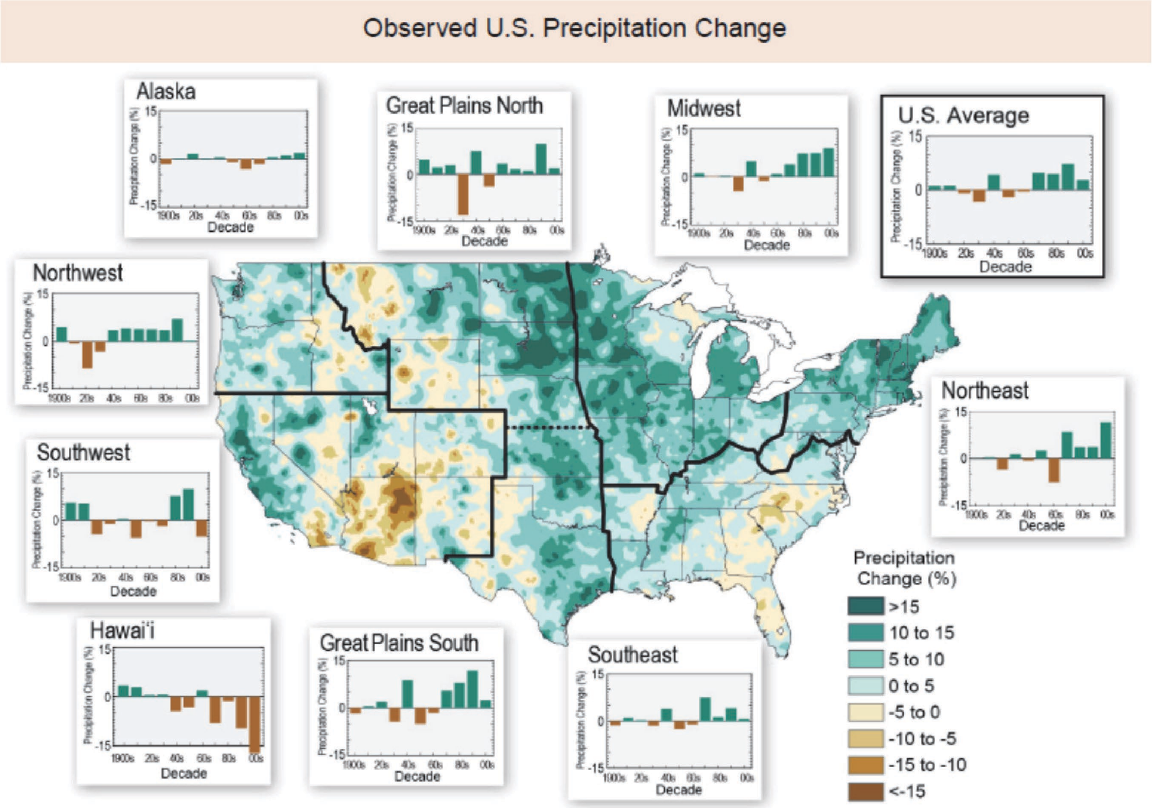


Figure D-3. Observed changes in precipitation on a regional level across the United States from 1900 through the present. Source: Melillo et al., 2014.

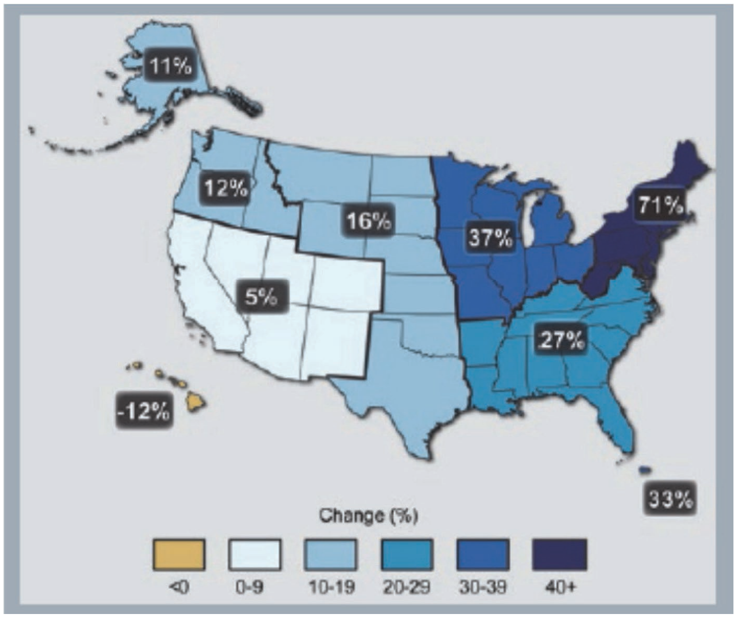


Figure D-4. Observed change in extreme daily precipitation events across the United States from 1958–2012. Source: Melillo et al., 2014.

Not all aspects of extreme weather have responded to climate change. For example, despite an increase in the number of tornado reports since 1950, Figure D-5 shows that the number of strong and violent tornadoes has remained steady or actually decreased. This suggests that the increase in all tornado reports may have simply occurred due to better detection and awareness. In fact, peer-reviewed literature suggests similar findings for tropical cyclone (tropical storms and hurricanes, collectively) activity in the Atlantic Ocean: the number of all tropical cyclones has increased, but the number of major hurricanes (category 3 or stronger) has remained constant. The IPCC has addressed these issues by assigning a low confidence on projections of both hurricanes and tornadoes. Nonetheless, it is likely that future climate change projections will greatly benefit from higher resolution models that will be able to better simulate extreme weather events.

One robust metric of a warming climate is SLR, impacted largely by expansion of the water and melting, or transfer of land-based glaciers and ice sheets to the oceans. A trend of SLR has been observed and well documented, at local water level recording stations and more recently by satellite (Figure D-6). For example, the amount of SLR in Norfolk, VA, is about twice that of Boston, MA. The primary driver of differences is vertical land movement (such as subsidence or post-glacial rebound). Other factors such as ocean currents contribute to the variability.

Collectively, the global trend of SLR is expected to continue, and potentially accelerate through this century in response to the projected increases in global temperatures due to climate change (Figure D-7). The range of future sea level is uncertain as a result of the varying projections of temperature increase, rate of thermal expansion, and anticipated melting of land-bound ice. Due to these uncertainties, scenario analysis is frequently used for assessing future sea level conditions. Based on IPCC projections, recently compiled scenarios for the range of potential global SLR by 2100 are estimated from one to four feet (Figure D-7). This range is a direct reflection of the uncertainty in atmospheric warming, transfer of atmospheric warming to the oceans, and glacier and ice sheet loss.

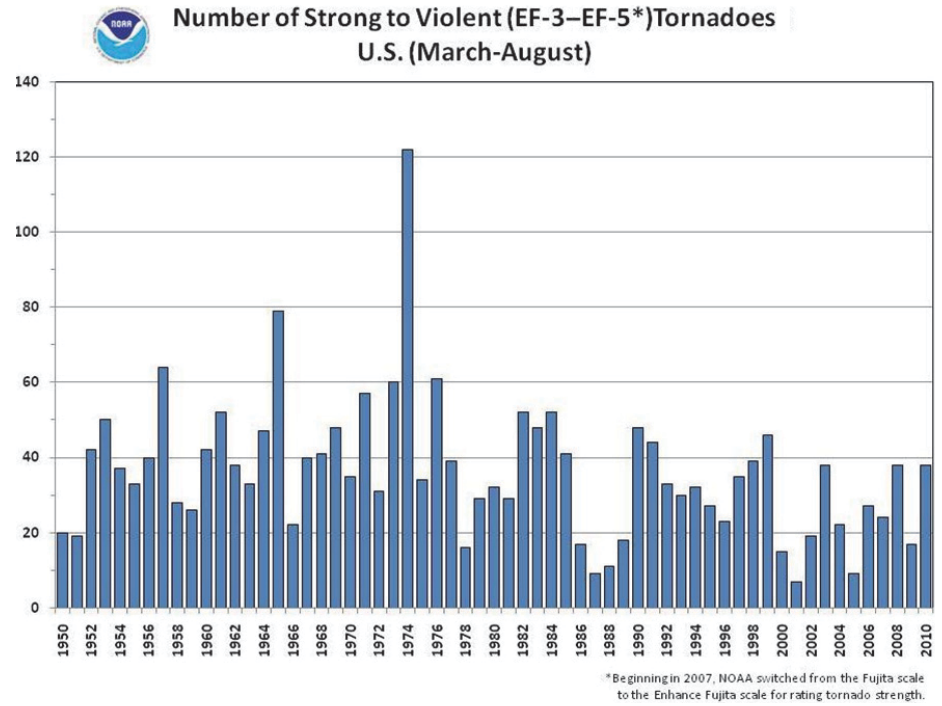


Figure D-5. Number of EF-3 to EF-5 tornadoes from 1950 to 2010 in the U.S. Source: NOAA.

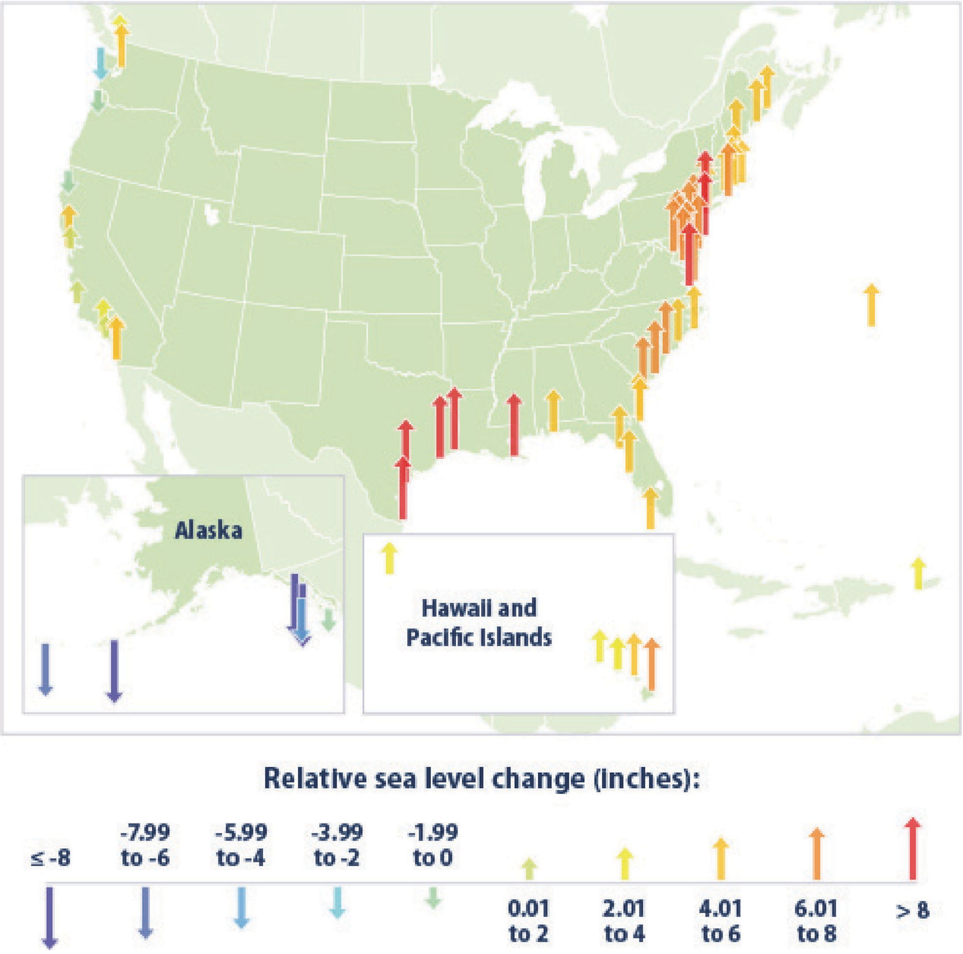


Figure D-6. Sea level trends around the continental United States, Alaska, and Hawaii from 1960–2013. Source: NOAA.

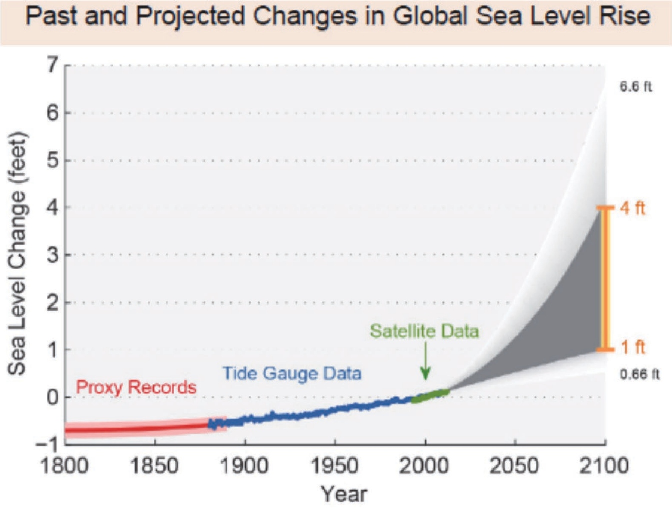


Figure D-7. Observed and projected global sea level since 1800. Source: Melillo et al., 2014.

APPENDIX E

Resources

This appendix contains links to supplementary information on climate change, adaptation planning, as well as U.S. and international experiences performing climate change risk assessments and considering adaptations.

Climate Background

Listed below are key sources of information regarding climate change projections and adaptation that are especially relevant for airport personnel and stakeholders.

➢ Intergovernmental Panel on Climate Change (IPCC)

The most comprehensive source of climate change information is available through the IPCC, which was established in 1988 by the United Nations. The latest IPCC report was the Fifth Assessment Report, released in 2014. Though the chief goal of the IPCC is to advance the knowledge of climate change, recent efforts have broadened the subject matter to include specific consideration of impacts, adaptation, and vulnerability. Particularly relevant literature includes:

- *Climate Change 2013: The Physical Science Basis (Summary for Policymakers)*
  This report contains a summary of the technical report that describes the evidence for climate change in the atmosphere, land, and oceans. It also explains the global climate models that were used in the IPCC AR5. (IPCC, 2013)
- *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects.*
  Provides an overview of considering climate change in context relative to decision makers. Particularly relevant chapters include 14–17 that discuss adaptation, and 18–20 that highlight resilience. (IPCC, 2014a)
- *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects.*
  An extension of Part A, this report shows regional scale evidence for climate change, as well as sector specific adaptation and vulnerability examples. Chapter 26 deals with North America. (IPCC, 2014b)

➢ National Climate Assessment (NCA)

The third NCA was released in 2014, and focuses on communicating the latest climate change findings to decision makers across the United States. The full report can be accessed online: http://nca2014.globalchange.gov/downloads

Particularly relevant sections include Chapter 5 on the Transportation sector, Chapters 16–25 that show the observed climatic change and projections on a regional level, and Chapters 26 and 28 that describe how to direct climate change projections to inform decision support and adaptation needs.

➢ Additional reports and peer-reviewed literature

- Curry, J., 2011: Reasoning about climate uncertainty. *Climatic Change*, 108, 723–732.
- Webster, M., 2003: Communicating climate change uncertainty to policy makers and the public. *Climatic Change*, 61, 1–8.

Adaptation Planning

While stand-alone climate adaptation plans are rare in the U.S., a number of airports have included climate adaptation considerations in their sustainability master plans or similar documents. The cases of sustainability plans in the U.S. are also instructive in providing some understanding of how climate change adaptation fits into existing sustainability initiatives. The FAA proposed the use of sustainable master plans to incorporate sustainability principles in the master planning process, or separately as a sustainable management plan, to enhance environmentally sound decision making in the design, project implementation, and financial arenas (FAA, 2010).

Examples

Many of the documents in the following list are described in greater detail in the U.S. Climate Change Adaptation Planning Efforts section below. The links provided below are not exhaustive; online documents are not accessible for all airports engaging with climate change.

United States

- Chicago Department of Aviation's Sustainable Airport Manual: http://www.airportsgoinggreen.org/documents/2013/CDA%20SAM%20v3.1%20-%20November%2012,%202013%20-%20FINAL.pdf
- Ithaca Tompkins Regional Airport's Sustainable Airport Master Plan: http://flyithaca.com/content/view/sustainable-airport-master-plan.html
- Los Angeles World Airports' Sustainable Airport Planning, Design and Construction Guidelines (see the section on climate change adaptation planning): http://www.lawa.org/uploadedFiles/LAWA/pdf/LSAG%20Version%205.0%20021510.pdf

Internationally

- Heathrow Climate Change Adaptation Reporting Power Report (2011): http://archive.defra.gov.uk/environment/climate/documents/adapt-reports/08aviation/heathrow-airport.pdf
- Manchester Airports Group Climate Change Adaptation Report (2011): http://archive.defra.gov.uk/environment/climate/documents/adapt-reports/08aviation/manc-airport.pdf

Other Advanced Airports in the Community of Practice

While the airports listed below have limited documents available for climate adaptation planning online as of the date of this guidebook's publication, their work in the climate adaptation and risk assessment field is considered advanced among U.S. airports. It is recommended that airports just beginning the adaptation process who also have contacts at the airports below consider reaching out to learn from fellow practitioners.

- Boston Logan International Airport
- Philadelphia International Airport
- Port Authority of New York and New Jersey Airports

- Portland International Airport
- Seattle-Tacoma International Airport

Experiences and Lessons Learned: U.S. Climate Change Adaptation Planning Efforts

The dominant location for most climate adaptation documentation at U.S. airports is the sustainable master plan or sustainable management plan.

- The master plan format was proposed for airports looking to update their master plans, and contains traditional master plan elements as well as sustainability considerations.
- The sustainable management plan format was proposed for airport personnel who were not updating their master plan at the time, but were interested in examining sustainability at their airports.

Sustainable master plans were found to have the advantage of ease-of-use compared to a stand-alone sustainable management plan, particularly when sustainability considerations are included in each section rather than isolated to a single chapter on the subject (FAA, 2012). Ithaca Tompkins Regional Airport, one of the pilot airports to initiate a sustainable master plan, quickly saw the value of using the master plan as a vehicle through which to communicate their sustainability goals to engineers and architects, who were then able to accommodate future goals for sustainable infrastructure improvements in their designs.

One example in the FAA's sustainability master plan pilot program report noted an apron rehabilitation project that left room for future implementation of electric ground power for aircraft (FAA, 2012). This example indicates that thoroughly integrated and well-advocated sustainability guidelines may have a substantial impact on achieving climate change adaptation goals, because designers who understood the sustainability objectives up front were better able to incorporate sustainability goals in individual projects and to leave room in their designs for sustainability upgrades in the future. The FAA report also notes that it is sensible to plan for initiatives that can be incorporated as airports expand (FAA, 2012), and potential changes to climate could fit in here, too. Such a planning process directly intersects with the need of adaptation planners in an airport setting to work with long-term planning horizons. Indeed, the underlying principle of applying sustainability master plan guidelines to climate change is to leave room, wherever possible, in the planning and design process for projected contingencies.

To date, many airports that have completed FAA sustainable master plans or management plan engaged principally with the aspects of climate change through the following topics: greenhouse gas emissions, water conservation, and energy efficiency (e.g., C&S Engineers, et al., 2012; Barnard Dunkelberg Company, et al., 2012). While these topics are of critical importance with respect to sustainability and climate change, there is also ample room for sustainability plans to include climate change adaptation options. Los Angeles World Airports (LAWA) provides a good deal of insight into how one might accomplish this task.

LAWA outlines a comprehensive approach that instructs airport staff involved in airport projects to conduct climate change risk assessments and provides considerations for adaptive planning and design. LAWA's *Sustainable Airport Planning, Design and Construction Guidelines* (Los Angeles World Airports/CDM, 2010) includes a climate change adaptation plan in the section on sustainable construction standards. The design guidelines offer recommendations for incorporating adaptation into design for future projects for four changes to local climate: increased temperature, severe weather, SLR and storm surge, and ecosystem changes.

The LAWA document lists actions to address each potential impact. Technical approaches to implement each adaptation action are detailed and a list of the benefits the actions are likely to achieve is provided. The LAWA guidelines also make recommendations on inter-departmental coordination.

For each climate impact, the guidelines provide a sheet with several sections:

- Intent: The objective of the sheet, in terms of preparing for impacts to airport infrastructure and operations.
- Point Allocation: Airport-defined scoring analogous to the Leadership in Energy and Environmental Design scoring.
- Actions & Targets: Instructions to attain appropriate climate models, to use models to evaluate airport-specific impacts, and to mitigate impacts through planning or infrastructure design.
- Benefits: Savings or other improvements resulting from using appropriate planning or design strategies (e.g., reduction of IROPs and repair costs and improvement of airport safety).
- Technical Approaches: Which impacts are tied to the change in question, potential planning and design elements, and, if applicable, possible funding resources or coordination suggestions.
- Acknowledgements: Reference to literature providing the scientific basis for the information on the sheet.

A similar format may be helpful for other airports wishing to map out the process for bringing planned adaptations to fruition.

Although Philadelphia International Airport's (PHL) climate adaptation report (Urban Engineers, 2010) was developed for the City of Philadelphia, outside the sustainable master plan framework, their efforts are also significant. The PHL report provides insight into some overall practices that may be useful when generalized to other airports developing adaptation strategies. In addition to the points discussed above, the report recommends:

- Examining existing airport infrastructure for climate vulnerabilities and screening currently planned projects;
- Examining where vulnerabilities in the above exist and considering changes in design and materials;
- Communicating climate initiatives, including building relationships with regulatory agencies involved in climate change issues and learning from other airports; and
- "Mainstreaming" climate change adaptation into existing planning processes (discussed throughout the guidebook—please see Chapters 8 and 9).

Climate Change Adaptation at Airports in the United Kingdom

Several U.K. examples provide particularly detailed insight into possible approaches to climate change adaptation for airports. U.K. airports have already been compelled to examine potential climate change impacts by the U.K. Department for Environment, Food, and Rural Affairs (DEFRA) as a result of the United Kingdom's Climate Change Act of 2008. Consequently, airport groups have already made significant progress in assessing their climate risks and developing options to adapt. The following framework provided some guidance for risk assessment.

Originally detailed in a technical report (Willows et al., 2003) released in 2003, the UKCIP, DEFRA, and the U.K. Environment Agency provide an example of a step-by-step climate change risk assessment framework. Figure E-1 shows the eight steps of the iterative framework, which was designed to enable decision makers to evaluate risks posed by climate change to assets, policies, and projects. Like the examples mentioned previously, it involves a risk assessment component as well as developing, evaluating, and implementing options for adapting. Monitoring of climate change science and changes to risk that may impact already implemented or future adaptation options is emphasized.

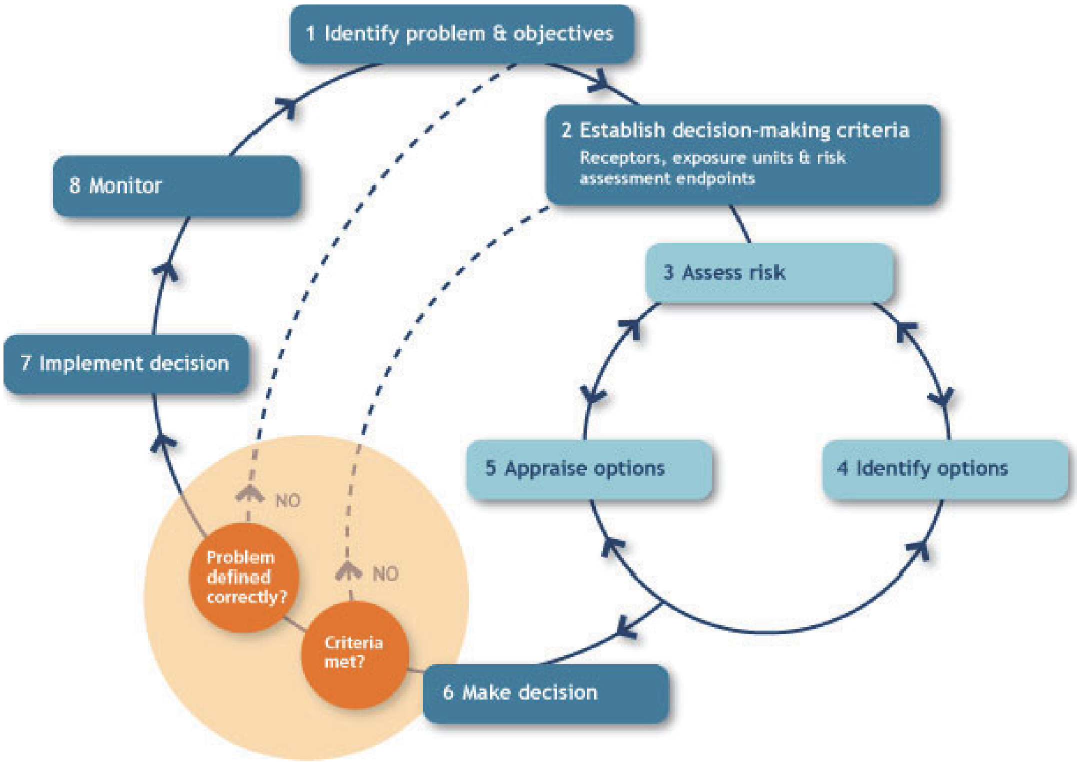


Figure E-1. U.K. Environment Agency, UKCIP, and DEFRA climate change risk decision-making framework.

The risk assessment component of the framework can be approached at varying levels of complexity. Manchester Airport in the U.K. used a simple list format to develop a register of risks related to climate change and probable adaptation actions, which often involved both short-term actions and "investigation" items, requiring more work to understand the risk and potential adaptation options. The risk assessment component falls within the airport's "standard corporate risk methodology," and fits neatly into its existing risk documentation.

The London Heathrow Airport report assessed climate change risk to their airport in four parts: a literature review, use of best available modeled climate data, Heathrow's existing risk registers and contingency plan, and interviews with key staff and its partner organizations. The assessment, led by Heathrow's Corporate Responsibility and Environment Department, relied on a risk assessment methodology developed by the airport's owner British Airports Authority (BAA). Part of its overall risk management process, the methodology is used to assess a broad array of risk types that range from human-caused to natural hazards. The airport's existing risk assessment methodology required modification when assessing climate change risk. Heathrow's methodology typically did not include projections in risk assessment calculations.

Its eight basic steps are included in Figure E-2.

Once the key stakeholders were identified and included in the planning process, the method directed personnel to catalogue present climate conditions, including extreme events and the airports' responses to them. Future climate was considered by using short- and medium-range projections under a medium greenhouse gas emissions scenario from U.K. Climate Projections 2009, a data program funded by the British Government and other stakeholder organizations, as well as peer-reviewed science. A literature review supplemented climate projections and modeling in determining potential future climate impacts.

Risk Assessment Methodology

1. Inclusion of key stakeholders in the risk assessment/planning process
2. Determination of current climate and its impacts (as a baseline)
3. Model future climate
4. Literature review
5. Interview of key stakeholder groups
6. Risk identification and prioritization
7. Prioritization of adaptation options
8. Reporting of results and monitoring of plan

Figure E-2. London Heathrow Airport's pre-existing risk assessment methodology, adapted to address climate change.

The airport's key stakeholder groups were then interviewed to gain on-the-ground knowledge of the full range of current airport responses to current climate. Airport assets were classified according to types, values, priority, and weather-related critical thresholds. Stakeholders also characterized and prioritized risk.

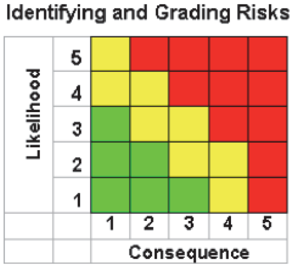
Next, Step 6—Risk identification and prioritization—was further broken down into a step-by-step process (Figure E-3).

Risk Identification and Prioritization

1. Identify risks and consequences from climate change
2. Evaluate likelihood of consequences (short-, medium-, long-term)
3. Evaluate severity of consequences (short-, medium-, long-term)
4. Establish risk priority based on likelihood and severity (short-, medium-, long-term)
5. Rate risk control measures currently in place (excessive, optimal, adequate, inadequate)
6. Consider the uncertainty/confidence with the projections (low, moderate, significant uncertainty)
7. Define adaptation response required

Figure E-3. London Heathrow Airport elaborates on the components of risk identification and prioritization in their 2011 Climate Change Adaptation Reporting Power Report (Heathrow Airport Limited, 2011).

Using climate change projections and data collected through the other steps of the methodology, the risks and potential consequences were identified and likelihood and severity determined through judgments of the airport's SMEs. Likelihood, considered probability of occurrence, and consequence were considered across five potential areas of impact: safety, security, environment, financial, and reputational and legal. The likelihood and consequence of a particular climate change impact were scored on a scale from 1 to 5, then overall risk due to the impact (Red = Significant; Yellow = Moderate; Green = Low) was determined as shown in Figure E-4.


Identifying and Grading Risks

Likelihood	5	🟨	🟥	🟥	🟥	🟥
	4	🟨	🟨	🟥	🟥	🟥
	3	🟩	🟨	🟨	🟥	🟥
	2	🟩	🟩	🟨	🟨	🟥
	1	🟩	🟩	🟩	🟨	🟥
		1	2	3	4	5
		Consequence				

Figure E-4. Heathrow's existing risk scoring system. (Heathrow Airport Limited, 2011)

The airport then assessed existing risk control measures for each anticipated impact to determine the measures' adequacy for mitigating the risk associated with the impact. Airports then developed adaptation responses based on the severity of each risk, the uncertainty in either the climate change projections or response needed, and the urgency of response required. The responses fell into one of three categories:

- Action: a specific response required in the short term.
- Prepare: identifies need for additional research or information before specific actions can be taken.
- Watching brief: applies to longer-term risks that should be monitored based on new scientific data or on-the-ground climate effects observed.

The airport estimates that the level of effort for conducting the climate change assessment was approximately 580 person hours. The same methodology was applied to develop the London Stansted Airport Climate Change Adaptation Plan in May 2011. Both Heathrow and Stansted are owned and operated by BAA.

General Climate Adaptation Resources

A number of climate risk assessment and adaptation models or frameworks exist and with some modifications can be easily applied to airports. The frameworks share a number of commonalities, including the assessment of climate risk in the face of uncertainty in future climate projections and impacts. Below is a summary of current practices.

The U.S. Transportation Sector

The Federal Highway Administration (FHWA) has developed a framework for assessing vulnerability and developing prioritized adaptation actions based on the assessment's findings.[1] The framework has been tested through a series of pilot studies for several locations across the country. The key steps of the framework are shown in the Figure E-5.

The FHWA identifies defining the objectives and scope of a study as important first steps to determine the level of detail of analysis required and the data that might be needed. Determining the climate change study's target audience, the products they need, and how the assessment's products will be used will help in setting the objectives and scope. When putting together the team that will participate in the study, inclusion of cross-disciplinary members is recommended. At minimum, team composition should include knowledgeable representatives from staff involved in planning, engineering, and assessment management.

Assessing vulnerability using the FHWA framework involves selecting which assets to evaluate and then determining the relevant characteristics. Asset characteristics should include (but

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[1] The Federal Highway Administration's Climate Change & Extreme Weather Vulnerability Assessment Framework; December 2012 (U.S.DOT, 2012).

FHWA Vulnerability Assessment Framework

1. **Define Study Objectives and Scope**
2. **Assess Vulnerability**
3. **Incorporate Results into Decision Making**

Figure E-5. FHWA vulnerability assessment framework.

are not limited to) location, useful life, and value of critical assets. It is helpful to determine the criticality of the asset as a way of prioritizing the most important. Vulnerability of individual assets and the system as a whole is a function of sensitivity and exposure to climate effects as well as the ability to adjust to changing climate. The team will also need to decide which climate variables to consider. These may vary by region and by study objective and might include things like temperature, extreme precipitation, permafrost thaw, SLR, storm surge, and snow melt. Data sources for future climate projections may include the United States Global Change Research Program (USGCRP), other federal or state agencies, or projections coming from an increasing number of local and regional climate change studies.

In assessing risk, a determination must be made of the potential severity or consequence of a climate impact along with the probability or likelihood that an asset will experience that impact. The criticality of the asset, along with its value, might be used in determining potential consequences of a climate impact. Determining probability of occurrence (likelihood) of a climate impact can be difficult. Certainty of climate change projections varies. Looking at projections from several models and averaging is one way to overcome the uncertainty. Projections available from various sources have already accomplished this task. Assigning a higher likelihood to those projections for which several models agree is another way to approach the determination of future probability.

Once vulnerability and risk are assessed, the next step of the FHWA framework focuses on integrating the results into practice. Part of this process involves identifying, analyzing, and prioritizing options for adapting to climate change. A higher priority might be assigned to addressing those assets that have been assessed as high likelihood and high consequences. Adaptation options might involve relocating or developing climate-resistant new assets, or retrofitting existing assets. Results might also be integrated into existing and updated planning processes such as asset, risk, or emergency management as well as environmental planning.

APPENDIX F

National Heat Maps with Ranges

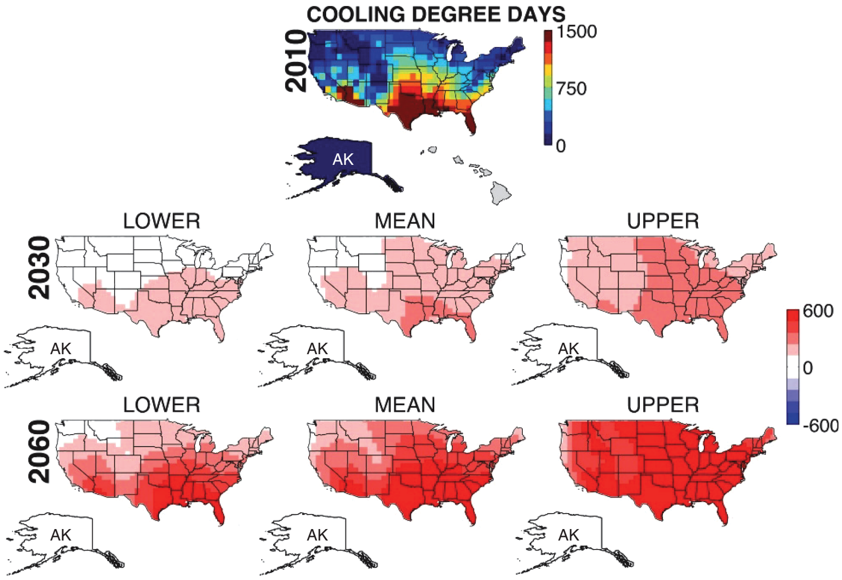

Figure F-1. Cooling Degree Days. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

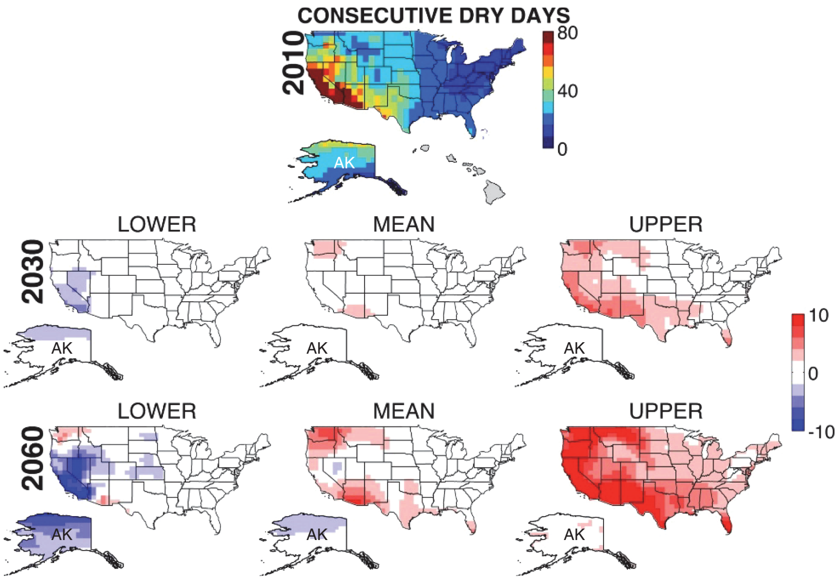

Figure F-2. Consecutive Dry Days. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

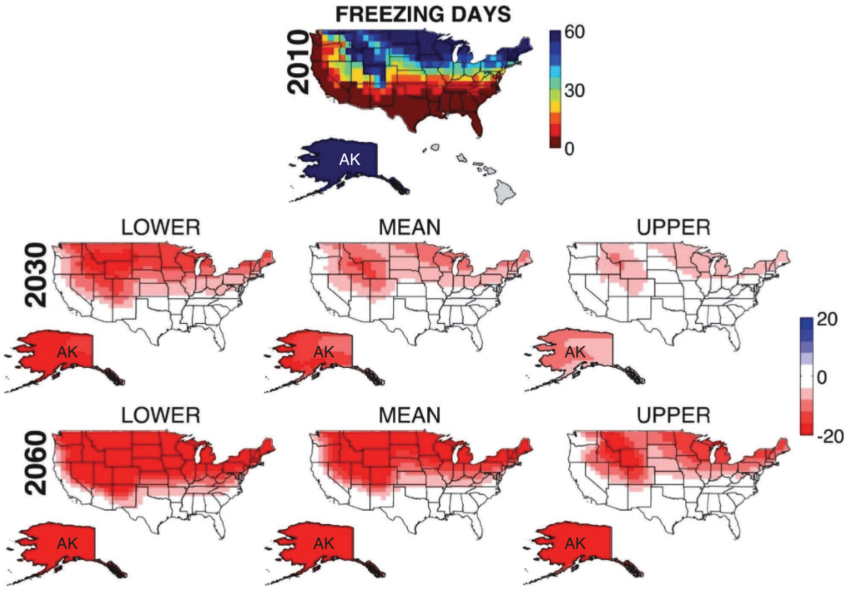

Figure F-3. Freezing Days. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

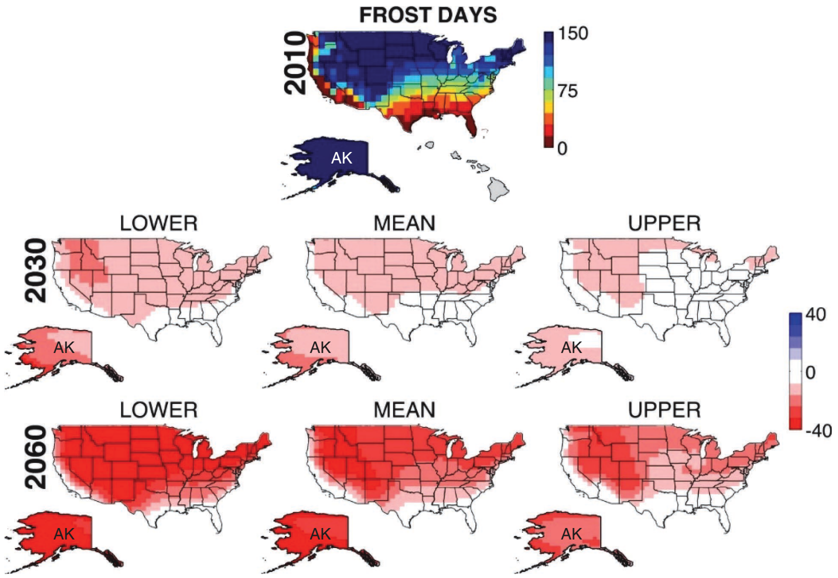

Figure F-4. Frost Days. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

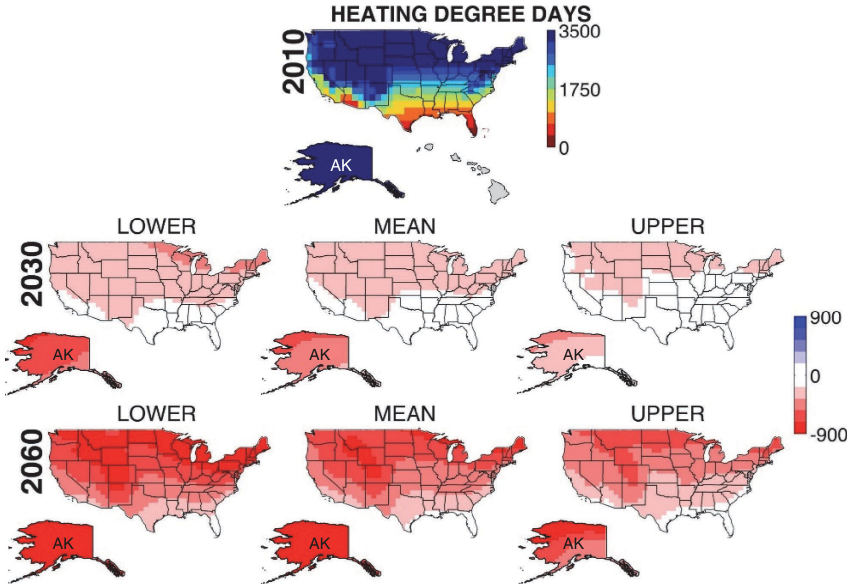

Figure F-5. Heating Degree Days. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

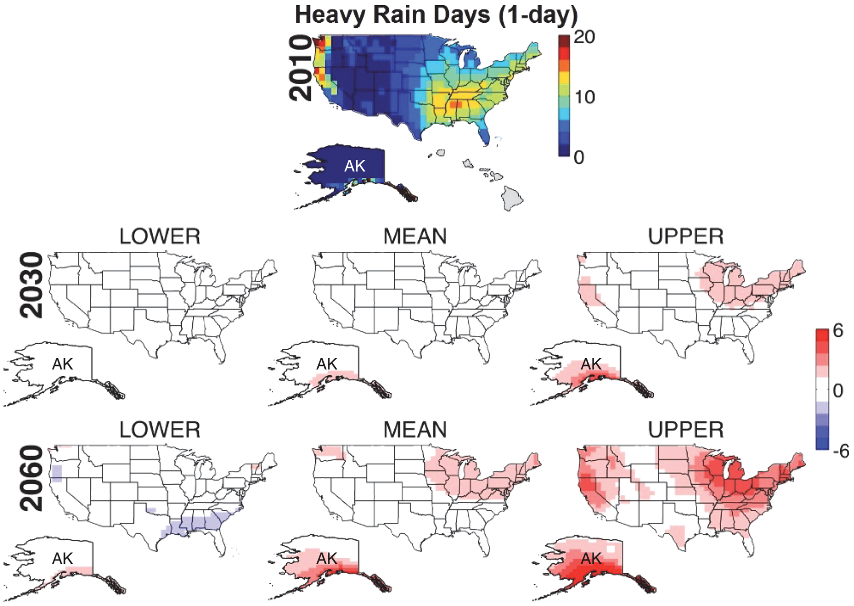

Figure F-6. Heavy Rain Days. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

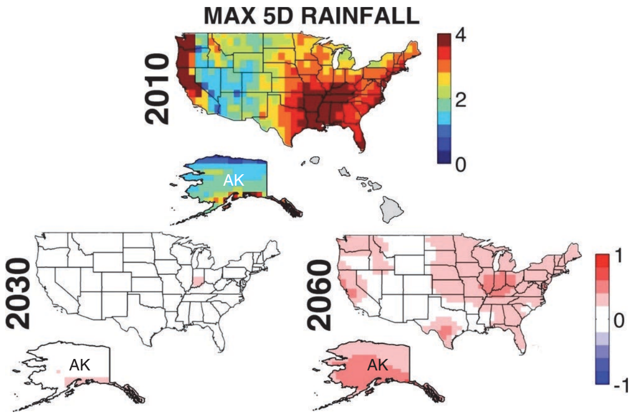

Figure F-7. Max 5d Rainfall. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

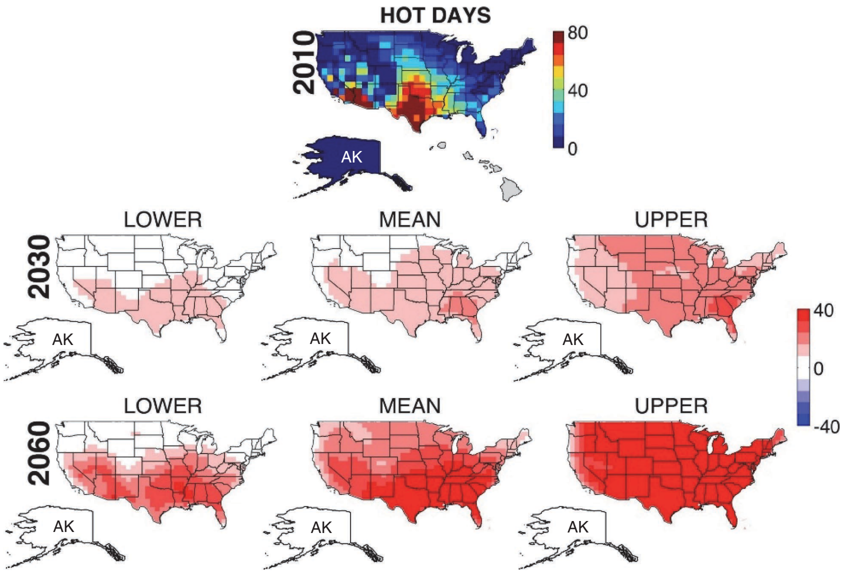

Figure F-8. Hot Days. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

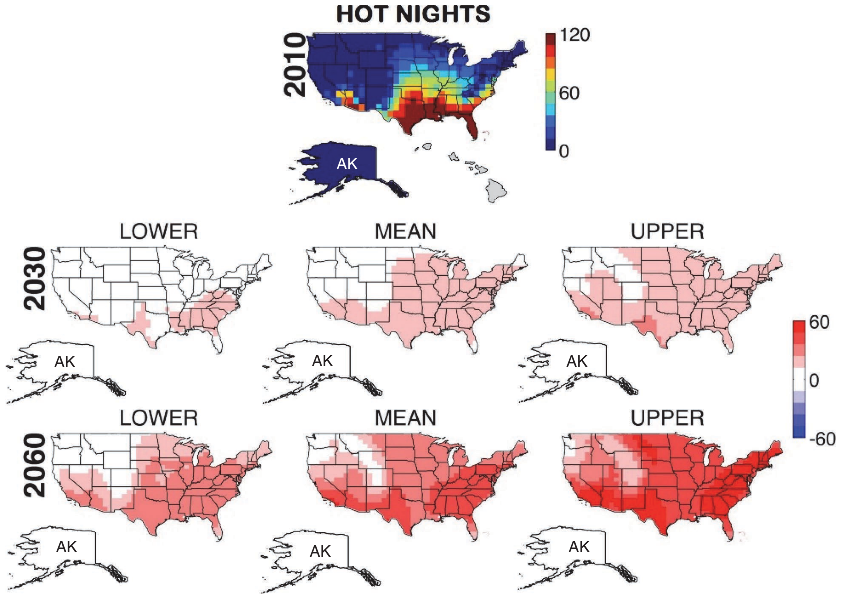

Figure F-9. Hot Nights. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

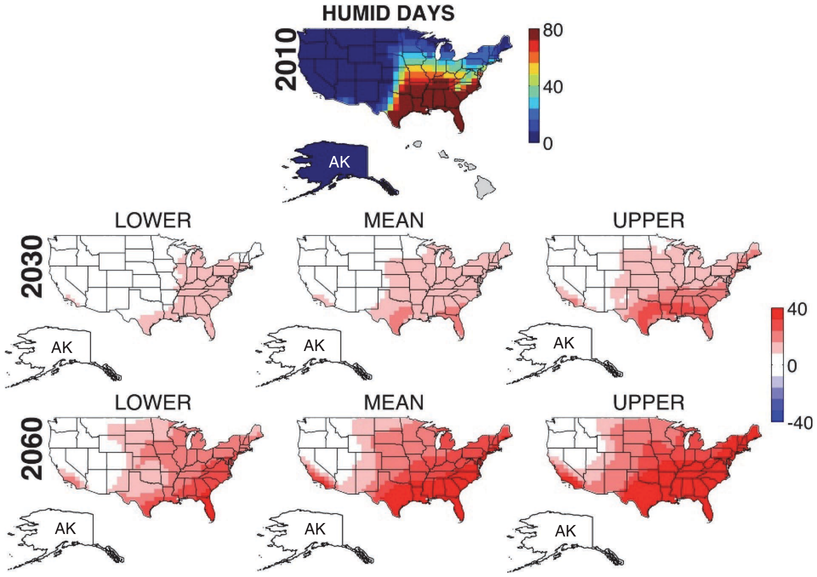

Figure F-10. Humid Days. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

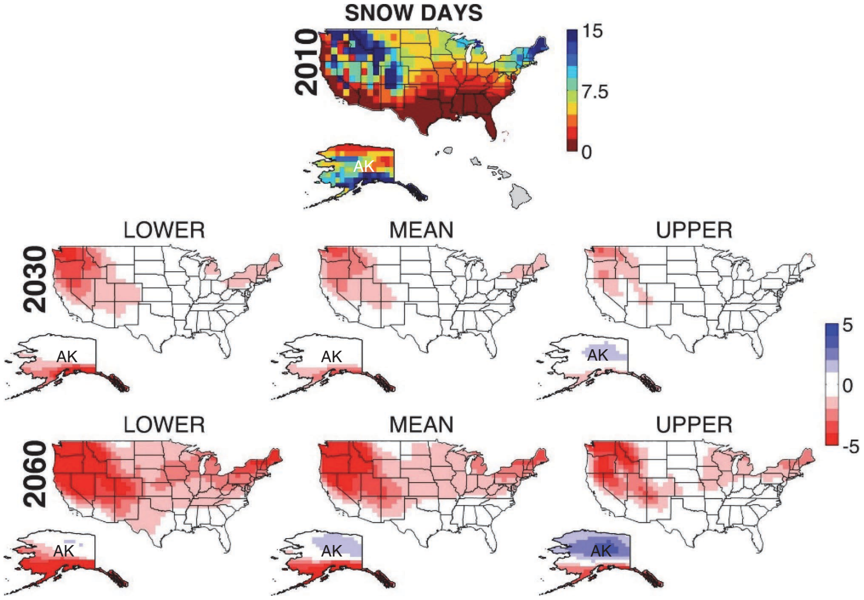

Figure F-11. Snow Days. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

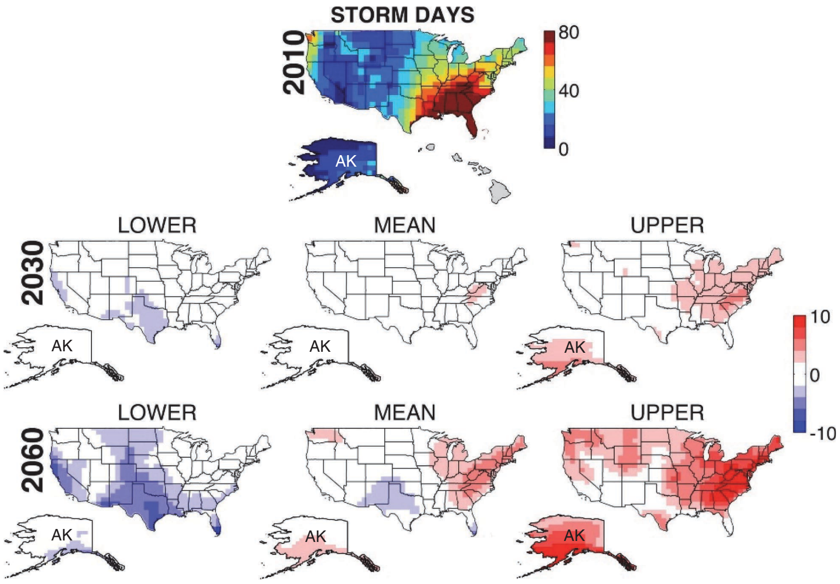

Figure F-12. Storm Days. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

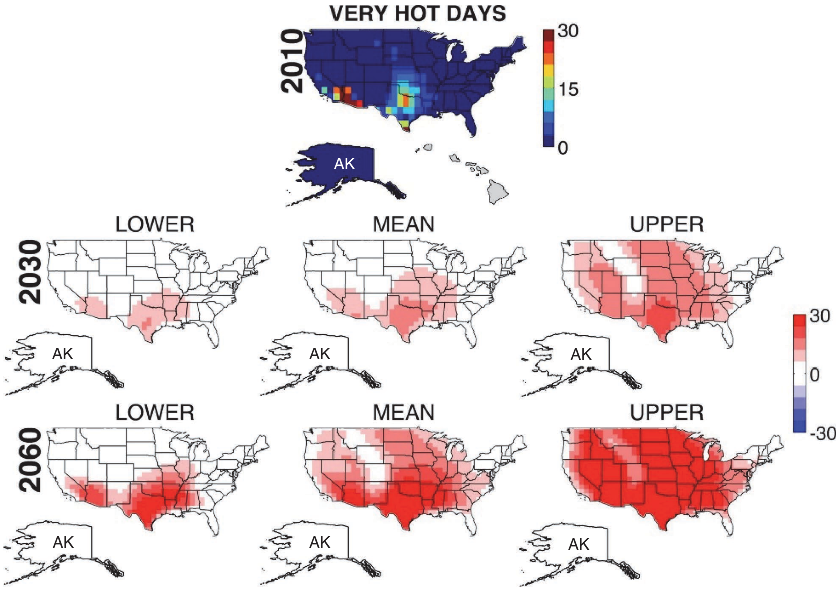

Figure F-13. Very Hot Days. Hawaii was considered, but omitted from this analysis as GCM grid size is too large to produce reliable atmospheric projections for Hawaii at this time.

APPENDIX G

ACRP Climate Model Uncertainty Table

Cause of Uncertainty	What Are They?	Specific Examples	How Climate Modelers Deal with This
Boundary conditions	Boundary conditions are typically fixed parameters describing existing characteristics such as the planet's radius, period of rotation, land cover type, topography, and bathymetry. Human-produced and naturally occurring CO_2 emissions across the globe are also considered a boundary condition. High-resolution data sets for many boundary conditions are now available through satellites.	Land cover examples include desert sand, grassland, forest and tundra. The extent of land cover as well as the proximity to other land cover types creates different local, regional and global weather and long-term climate conditions. For example, desert sand has large expanses of flat land surface, which contributes to high and frequent wind, few clouds due to limited local vegetation releasing water vapor through transpiration and extreme temperature changes between day and night.	The model forecast will differ depending on how the boundary conditions are changed. Where unpredictable external influences are concerned, such as the future emission of greenhouse gases, modelers typically examine a range of scenarios, producing a range of possible futures. Given that scenarios examined for this project do not appreciably diverge until after 2060 (the final point examined here), the tool only presents one scenario.
Climate feedbacks	The interaction between climate processes often influence, or feedback on, one another. For example, Process A may trigger a change in Process B, which as a result may either intensify or reduce the original Process A.	A warmer climate will tend to have a smaller area of polar sea ice. Less sea ice will decrease the planet's reflectance and tend to reinforce the original warming.	The accuracy of climate models improves as more feedback interactions are included. Capturing as many feedbacks as possible, while potentially increasing uncertainty, provides for a more realistic projection. For example, including aerosol particles adds an element of realism, but because the physics are still being developed, their inclusion into models has actually led to a slight increase in the range of possible future global temperatures. In the longer term, as our understanding of the influence of aerosols improves, forecast accuracy will also improve.

Emissions scenario	Emissions of CO_2 and other greenhouse gases vary based on natural processes and human activities such as burning of fossil fuels, decreasing tree canopy, and increasing release of methane from landfills and agriculture. As a result, changes in the global human population, associated lifestyles, and prevailing government greenhouse gas emission policies impact resulting emissions.	In the most recent IPCC report, four emissions scenarios are discussed. The low emission RCP 2.6 scenario assumes greenhouse gas emissions peak in about 2035 due to aggressive reduction of human-produced emissions, while the high emission RCP 8.5 scenario assumes an indefinite increase. Differences in climate outcomes due to these scenarios are most pronounced after 2060.	Instead of picking one greenhouse gas emission scenario over another, modelers consider the range of climate change outcomes among each previously defined scenario. The IPCC sets out numerous guidelines on how to do so, accounting for future emissions, socio-economic characteristics, and other characteristics. Future human activity is difficult to model and as a result, it is recommended that decision makers engage in planning activities that are suitable for a variety of possible futures.
Horizontal scale	Models can provide global, regional, or local average values for climate characteristics. The scale of model outputs can be as low as 1 mile (for downscaled data) to as high as 140 miles. Both observation-based and climate model data products are becoming available at increasingly higher resolutions.	The range of GCM output ranges from about 60 to 140 miles, and different resolutions will sometimes produce different outputs. Though higher resolution may be more *realistic*, it does not necessarily improve the model accuracy.	Where possible, it is desirable to choose models that produce outputs suitable for the desired application. Regional models are often useful local-scale complements to GCMs. For this national-scale screening study, semi-local-scale data was acceptable, but the research team strongly suggests the use of higher resolution data for engineering and design applications.
Initial conditions	Initial conditions are the selected baseline atmosphere, ocean, and/or land conditions, often averaged over decades of recorded data. Specifically, initial conditions are supposed to represent the natural variability of the global atmosphere. Initial conditions can influence the forecast produced by the model from as little as a day to as long as 10 years.	Initial conditions with a severe cold wave over the United States only impacts the forecast for a week or two. However, an initial condition with a strong El Niño in the Pacific Ocean may affect the model forecasts for several years.	Modelers often compare a set of randomly chosen initial conditions. These sets of initial conditions vary widely in order to reflect numerous possible atmospheric states. Also, initial conditions such as volcanic eruptions or extreme cold snaps may result in limited periods of reduced warming that do not contradict the overall trend toward rising global temperatures. The initial conditions usually only affect the short-term output of the model and are essentially irrelevant to long-term climate studies such as the ones performed for this project.

Cause of Uncertainty	**What Are They?**	**Specific Examples**	**How Climate Modelers Deal with This**
Atmospheric physics	Models work by simulating atmospheric processes, such as extent of cloud cover, precipitation, or even land-atmosphere interactions. This simulation involves the use of many parameters describing atmospheric processes. Please see two example parameters in the next column.	Increasing the amount of mixing in clouds tends to suppress thunderstorm activity. Decreasing the amount of friction of wind over the land surface increases the wind speed. For example, large expanses of deserts often have higher observed wind speeds than forested areas.	Climate scientists work to improve understanding of the physics governing the atmosphere. As understanding improves, the range of physical processes represented and accounted for in models expands. Scientists then verify outputs against observed climate.
Span of study	Modelers may choose to examine projections over varying time scales depending on the intended application of the modeling outputs. The longer the timeframe being examined, the greater the uncertainty, because it is difficult to precisely understand future conditions.	For this project, the research team used daily data to produce outputs for the years 2030 and 2060, which are compatible with airport master planning time scales.	Shorter-term projections (in the 10–20 year range) are inherently less uncertain than longer-term projections. For this reason, climate adaptation activities are often organized according to an “act, plan, watch” framework, with highest priority given to imminent, high-risk, low-uncertainty impacts.
Temporal resolution	Models can provide results at time spans ranging from minutes to years, depending on which climate processes are being studied.	Detecting a cold front passage requires hourly data. Detecting how El Niño may influence California precipitation requires monthly or even seasonal data.	It is important to choose time scales that are appropriate for the intended application of the information. Daily data was needed to generate relevant temperature vectors (Freezing Days, Hot Days, etc.) rather than more generic vectors, such as annual average temperature, which was insufficiently detailed to address relevant airport-specific concerns. The time steps used in the models (e.g., daily) do not necessarily have any relationship to the span of the study.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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ISBN 978-0-309-37487-3
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