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Coastal Airports and Rising Sea Levels

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ABSTRACT

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Most of the world's major cities are located along coastlines, and their large international airports are typically built either very close to sea level or on filled shallow coastal waters. These large facilities handle thousands of flights and millions of passengers annually, and in addition to being critical infrastructure, they are huge economic engines. Being very close to sea level, however, many of these airports are already exposed to extreme flood events (hurricanes, typhoons, large storms, and high tides) and in the future will face increasing risks with global sea-level rise. LaGuardia, John F. Kennedy (JFK), and Newark all suffered some flood damage during Superstorm Sandy in 2012. San Francisco and Oakland airports have already developed plans to build walls to protect them from 2 to 3 ft (0.6 to 0.9 m) of additional sea-level rise. In addition to these airports, the Federal Aviation Administration has designated the airports at Philadelphia, Washington National, Miami, Tampa, Ft. Lauderdale, Louis Armstrong New Orleans, and Honolulu as at-risk from future storm surge and high water from extreme events. A rising ocean is inevitable and will be additive over time with extreme events. The existing elevations of individual airports combined with projections of future sea-level rise can provide important guidance on when these facilities are likely to be exposed to tidal flooding and, therefore, when airport management should begin to plan to respond or adapt to the future threats.

ADDITIONAL INDEX WORDS: *Sea-level rise, coastal airports, adaptation, coastal flooding, extreme events.*

INTRODUCTION

While a rising tide raises all ships, a rising sea level will gradually begin to submerge airplanes at low-lying airports. Most of the world's people are concentrated in coastal areas, and large coastal cities around the planet typically built their airports on low-lying coastal land or, in many cases, filled shallow nearshore waters, marshes, or floodplains or on artificial land. There were many reasons for construction in these places: (1) There typically was not a large tract of available flat land within or close to major cities; (2) the shallow waters or wetlands were accessible and available at low or no cost; (3) there were no tall buildings nearby that presented aviation hazards; (4) there usually were no residents right next door exposed to and concerned about the noise of takeoffs and landings; and (5) winds were usually more favorable along the coastline (Agravante, 2019).

When most of the world's major coastal airports were constructed, however, sea-level rise was not a consideration or issue of concern. Today, with well-documented global sea-level rise, these airports are facing unprecedented challenges that will affect their operations for decades to come. The combination of extreme high tides, storm surges, hurricanes, typhoons, and the occasional tsunami, as well as a gradually rising sea level, will all present significant hazards for these large shoreline airports. In the United States, the Federal

Figure 1. Mills Field in 1927 before it was expanded to become San Francisco International Airport. (Source: San Mateo County Historical Museum.)

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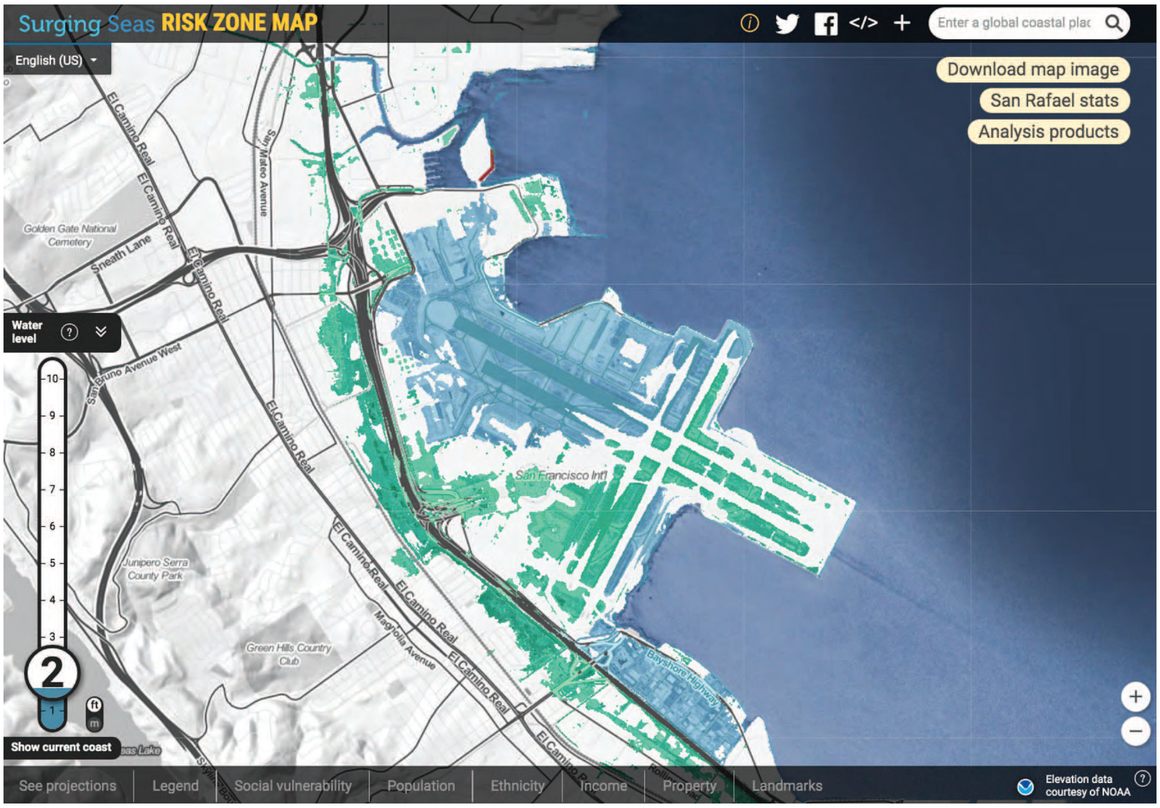

Figure 2. San Francisco International Airport with 2 ft (0.6 m) of sea-level rise above MHHW. Blue areas would be flooded; green areas are less than 2 ft (0.6 m) above MHHW but are separated from San Francisco Bay by some barrier. (Source: Climate Central Surging Seas.)

Aviation Administration (FAA) reported in 2012 that more than a dozen of the nation's 50 largest airports have low-lying infrastructure at risk from sea-level rise and flooding from storm surges. Eurocontrol (the European Organization for the Safety of Air Navigation) conducted a study in 2008 that identified 34 coastal airports that would be negatively affected by future sea-level rise over time.

According to statistics compiled by the International Civil Aviation Organization (ICAO), the total number of passengers carried on scheduled flights globally reached 4.38 billion in 2018, a 6.4% increase from 2017, while the number of departures rose to 37.8 million, a 3.5% increase from the previous year. This translates to over 100,000 flights every day, or over 5500 every hour, on average, using an 18 hour flying day. Our global society is dependent on the commercial aviation industry, whether for business or pleasure, and large international airports are also huge economic engines.

San Francisco International Airport (SFO), for example, with its 57.7 million total passengers, generated over 46,000 direct jobs and $10.7 billion in business activity in fiscal year 2018. The airport was built in 1927 on what was originally a low-lying cow pasture on the margin of San Francisco Bay, originally known as Mills Field Municipal Airport (Figure 1). Future sea-level rise was the last thing on anyone's mind 90 years ago. Within a few years, however, the name was changed to San Francisco Airport, and to accommodate the rapid growth, 350 acres[1] of coastal wetlands were raised using rock and soil from the surrounding hills to provide a foundation for expanded runways.

Today, however, major portions of the runways at SFO lie within 2 ft (0.6 m) of high tide (mean higher high water [MHHW]; Figure 2). Concern over the effects of a continuously rising sea level, as well as shorter-term events (El Niño, extreme high "king" tides, and storm surge), has led the airport management to develop a plan to construct a 10-mile (16 km) long, steel sheet-pile seawall to provide protection from rising water levels (Figure 3). They anticipate that this wall would protect the airport facilities until about 2085. The estimated cost for this wall is $587 million, and it is being planned to guard against 3 ft (0.9 m) of sea-level rise and an additional 2 ft (0.6 m) for large waves during storms.

Across San Francisco Bay, Oakland International Airport, which lies within 3 ft (0.9 m) of MHHW, is prepared to begin construction in 2020 on a $46 million project to raise a 4-mile (6 km) long earthen dike by 2 ft (0.6 m) to guard the runways against rising bay waters.

[1] There is some mixing of English and metric units in this paper, reflecting U.S. *vs.* world practice and the individual sources for the measurements. Metric equivalents are given for values originally published in English units.

Figure 3. Outline of proposed sheet-pile seawall for protecting San Francisco International Airport. (Source: Bay Area News Group.)

Figure 5. Flooding of LaGuardia International Airport, New York, during Superstorm Sandy. (Source: Reuters.)

U.S. AIRPORTS AT FUTURE RISK OF SEA-LEVEL RISE

The third U.S. National Climate Assessment (2014) references an FAA report that lists 13 of the nation's largest coastal airports having at least one runway with an elevation within the reach of moderate to high storm surge, such that future sea-level rise will pose an increasing risk (Figure 4). While future sea-level rise and extreme events (hurricanes, storm surges, extreme high tides, *etc*.) are additive, for the near-term future—likely to at least midcentury—it will be the short-term extreme events that will bring the greatest threat to coastal airports. While weather-related delays already lead to $4 billion in losses annually in the United States, higher future sea levels and the associated flooding will cause more delays, disruption, damage, and additional lost revenue.

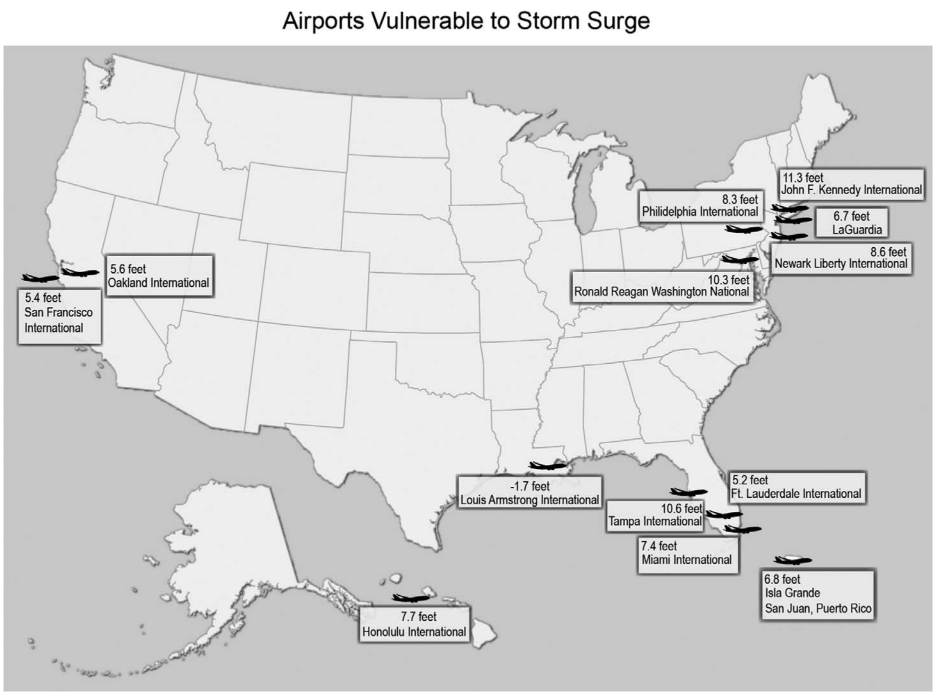

Figure 4. Coastal airports in the United States vulnerable to storm surge or high water listed by elevation above sea level. (Source: Federal Aviation Administration.)

Figure 6. Philadelphia International Airport with 5 ft (1.5 m) of storm surge or sea-level rise above MHHW. Blue areas would be flooded. (Source: Climate Central Surging Seas.)

Hurricane Sandy was an indicator of things to come for some airports built at low elevations. In late October 2012, when Hurricane Sandy hit New York City, seawater overflowed the edges of LaGuardia Airport, flooding portions of the facility's 7000 ft (2134 m) long E-W runway, and damaging navigation and lighting systems (Figure 5; Freedman, 2013). This was not the first time this had happened, and it can be expected to happen again and more frequently in the future with higher sea levels. As damaging as Hurricane Sandy was at LaGuardia, it could have been worse had the storm surge struck at the high tide 9 hours earlier. This would have raised floodwaters an additional 3 ft (0.9 m), or to a height of up to 13 ft (4 m) above ground level, likely entering the terminal buildings and resulting in associated shutdowns, cancellations, and damage (Freedman, 2013). With the help of a $28 million federal grant, La Guardia Airport is adding a flood wall, rainwater pumps, and a new drainage system for the airfield, as well as upgrading its emergency electrical substations and generators.

John F. Kennedy (JFK) and Newark, the other major airports in the New York City area, also experienced flooding from the 2012 superstorm, but with fewer impacts and damage. Knowing Hurricane Sandy was approaching, all three airports shut down on 28 October, before the storm hit, leading to a chain reaction of thousands of flight cancellations around the world. Newark and JFK were both able to resume limited service 3 days later. Nonetheless, over 20,000 flights nationwide were cancelled as a result of Hurricane Sandy, with about half of those coming from New York City area terminals (Freedman, 2013).

The other U.S. airports listed by the FAA as at-risk from future sea-level rise and flooding from extreme events include: Philadelphia, Washington National, Miami, Tampa, Ft. Lauderdale, Louis Armstrong New Orleans, San Francisco, Oakland, and Honolulu (Figure 4).

Philadelphia International is a good example of the threats now being faced by a number of shoreline airports across the country (Phillips, 2018). As with many other big city international airports, the original objective was to build away from homes and tall buildings, but not too far away from the city, which often meant filling low-lying wetlands or other shoreline areas. However, with a slowly rising sea level, waters are gradually encroaching closer to these large and critical facilities, and flooding is already occurring under extreme conditions at some of these airports.

A storm in 2013 flooded a tunnel serving one terminal at Philadelphia International with 3 ft (0.9 m) of water, shutting down luggage conveyor belts and inundating an electrical substation, since most of the critical utilities are as much as 15 ft (4.5 m) underground (Phillips, 2018). This knocked out the power and led to the cancellation of 12 flights. Flight

Figure 7. Newark International Airport with 2 ft (0.6 m) of storm surge or sea-level rise above MHHW. Blue areas would be flooded. (Source: Climate Central Surging Seas.)

cancellation not only strands passengers, but it also can prevent delivery of critical emergency or medical supplies.

Climate Central's Surging Seas website allows a user to explore any coastal area in the United States (https://sealevel.climatecentral.org/maps/risk-zone) and insert any amount of future sea-level rise from 1 to 30 ft (0.3 to 9m) in 0.1 foot increments in order to determine the shoreline areas that will be flooded based on the most recent and accurate elevation data from the National Oceanic and Atmospheric Administration (NOAA). Figure 6 captures a simulation of the Philadelphia International Airport with 5 ft (1.5 m) of sea-level rise above MHHW. This is the depth of water (or elevation) where enough of the airport runways are flooded so as to endanger takeoffs and/or landings. The Surging Seas risk zone maps only show sea-level rise, and they do not add in any additional storm surge, terrestrial runoff, or extreme events such as hurricanes. In other words, these are minimum values.

Following Hurricane Sandy, which barely missed Boston, Logan International Airport began assessing its climate vulnerabilities, and in 2014, airport management started raising and waterproofing some of its facilities. They have elevated electrical equipment and purchased new flood barriers. A major concern would be a category 2 or 3 hurricane striking just before high tide. Airport management is beginning to also think about longer-term risks, out to 2070.

Florida is the state with the most low-lying and exposed airports. Tampa International initiated a resiliency study to assess its risks from sea-level rise and related threats that was to be completed in September 2019, but it had not been released as of April 2020. The airports at Ft. Lauderdale and Miami, however, are at significantly lower elevations than Tampa's airport.

The portions of each of the airports where significant flooding would occur based on incrementally raising sea level are illustrated in Figures 6–16. The amount of sea-level rise above MHHW in feet considered to result in significant flooding is indicated on the left side of each image. Areas in blue designate places that would be inundated with this amount of sea-level rise. Areas in green are below this elevation but are separated from bay or ocean waters by some higher elevation barrier (a highway, railway, levee, or seawall, for example). Looking at each of these figures, they illustrate that the three most vulnerable U.S. airports to future sea-level rise are San

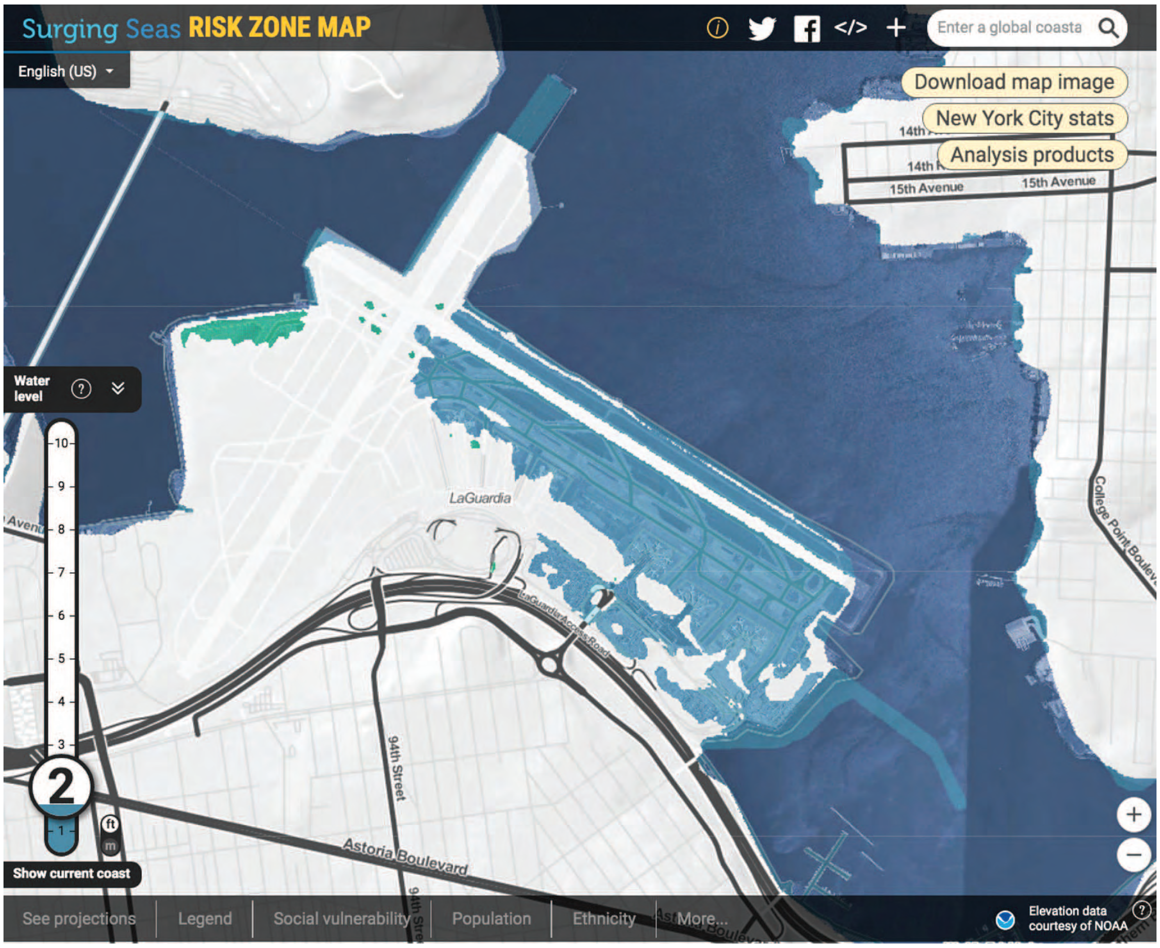

Figure 8. LaGuardia International Airport with 2 ft (0.6 m) of storm surge or sea-level rise above MHHW. Blue areas would be flooded. (Source: Climate Central Surging Seas.)

Francisco, Newark, and LaGuardia, all with major runway areas flooded at just 2 ft (0.6 m) above MHHW (Figures 2, 7, and 8). As described earlier, LaGuardia already experienced major flooding during Hurricane Sandy.

Oakland and Ft. Lauderdale are the two next most vulnerable airports, with major runway flooding at 3 ft (0.9 m) and 4 ft (1.2 m) above MHHW, respectively (Figures 9 and 10). Ft. Lauderdale airport is only 5.2 ft (1.6 m) above MSL, and Oakland International is at just 5.6 ft (1.7 m) above MSL. Philadelphia International Airport, which has also already experienced the impacts of flooding, lies 5 ft (1.5 m) above MHHW (Figure 6) and at an elevation of 8.3 ft (2.5 m) above MSL. Miami International is next in vulnerability, with significant runway flooding at 6 ft (1.8 m) above MHHW (Figure 11), followed by JFK and Honolulu at 7 ft (2.1 m) above MHHW (Figures 12 and 13). Washington National and Tampa airports are the least vulnerable airports on the FAA list, with no significant runway flooding until water levels reach 9 ft (2.7 m) above MHHW (Figures 14 and 15).

The Louis Armstrong New Orleans International Airport is somewhat of an anomaly on this list. Even though it is situated at 1.7 ft (0.5 m) below MSL, it is protected by levees or floodwalls to at least 10 ft (3 m) above MHHW (Figure 16). Although, as was learned during the disastrous flooding that accompanied Hurricane Katrina in 2005, when levees or floodwalls fail, which they do, areas below sea level will be quickly flooded.

GLOBAL COASTAL AIRPORTS

The United States is not alone in having large international airports in a number of large cities very close to sea level. In September 2018, Typhoon Jebi ripped through Japan, bringing heavy rainfall and a powerful storm surge that reached almost 11 ft (3.4 m), a record for Osaka Bay. For those 8000 passengers at Kansai International Airport waiting for flights, instead of looking out over a runway from the terminals, they saw only ocean water (Figure 17; Tabuchi, 2018). As with many coastal airports, the original idea was to build on a large tract of land convenient to a city, but far enough away from homes and tall buildings. Often, that meant filling coastal wetlands or shallow nearshore waters.

Kansai International Airport sits about 11 ft (3.4 m) above MSL, and it was built offshore on an artificially constructed

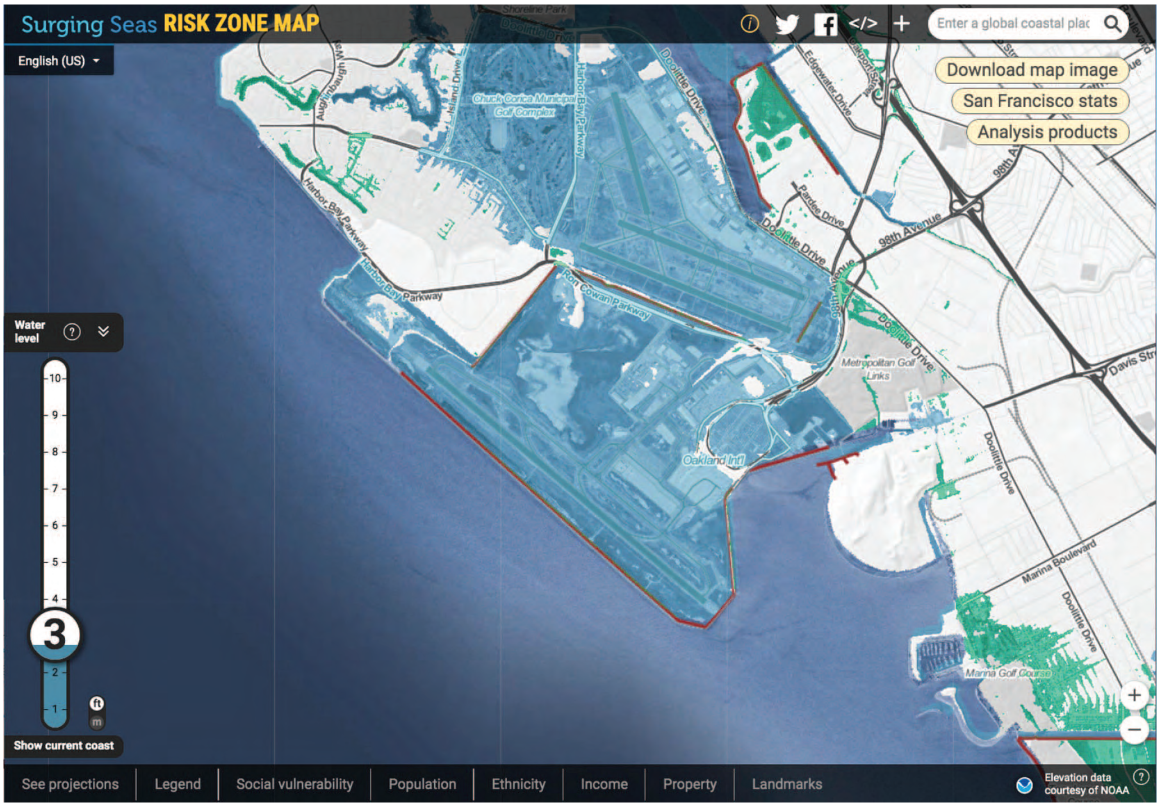

Figure 9. Oakland International Airport with 3 ft (0.9 m) of storm surge or sea-level rise above MHHW. Blue areas would be flooded. (Source: Climate Central Surging Seas.)

island to avoid noise and other encroachment problems for the surrounding cities of Osaka, Kyoto, and Kobe. When the airport opened in 1994, the engineers anticipated that the fill would undergo some settlement. However, the expectation was for less than 1 ft (0.3 m) per year as the seabed settled from the added load of fill. In the first 7 years following construction, however, the artificial island had settled over 30 ft (9 m), and this has continued, with maximum settlement now having reached 43 ft (13 m) (Tabuchi, 2018).

The original engineers had designed a combination of seawalls and large pumps to drain the runways after heavy rain. Pumps were also installed to remove water from the ocean floor beneath the island in order to speed up the settlement process and stabilize the area. In a major engineering feat, the main terminal was built on supports so that it can be jacked up to keep the building level as subsidence continues (Tabuchi, 2018). As with many engineering plans, however, they are designed to deal with historic conditions, usually with some safety factors. However, climate is changing, and the historic conditions and models may well not reflect present or future conditions. The seawalls were originally designed to withstand storms as large as the 1961 Super Typhoon Nancy, which produced a 9 ft (2.7 m) storm surge. Typhoon Jebi exceeded that by 2 ft (0.6 m) and flooded the runways (Figure 17).

In Australia, most major coastal airports were built over reclaimed marshes or swamps, sitting only a few meters above modern sea level. Brisbane Airport, for example, is on reclaimed land on the coast at just 13 ft (4 m) above sea level, and it is building a new runway 3.3 ft (1 m) higher than it otherwise would have done, with a higher seawall and better drainage systems to deal with future sea-level rise. The nation's other major airports are at similar elevations: Cairns (<3 m), Sydney (<4 m), and Townsville and Hobart (both about 5 m). While most Australian airports have carried out risk assessments using Intergovernmental Panel on Climate Change (IPCC) projections for future sea levels (IPCC, 2014), the last projections of ~1 m of additional rise by 2100 may well be too low. Australia has determined that the aviation industry adds an estimated $43 billion annually to the nation's economy, so it is important to protect and buffer their airports from future sea-level rise (Mortlock *et al.*, 2018).

Singapore, which has reclaimed considerable land from the sea, but is still a low-lying island, has determined that it will take at least $72 billion to build adequate defenses against rising sea level. City planners had previously required that any new buildings be constructed at least 3 m (~10 ft) above mean sea level, leaving about a 1 m buffer against high-tide flooding. However, with a 1 m rise in sea level due to global warming, the government now requires new development to be built 4 m above sea level. Critical infrastructure like the Changi airport's new Terminal 5 must be built 5 m above sea level. The level of

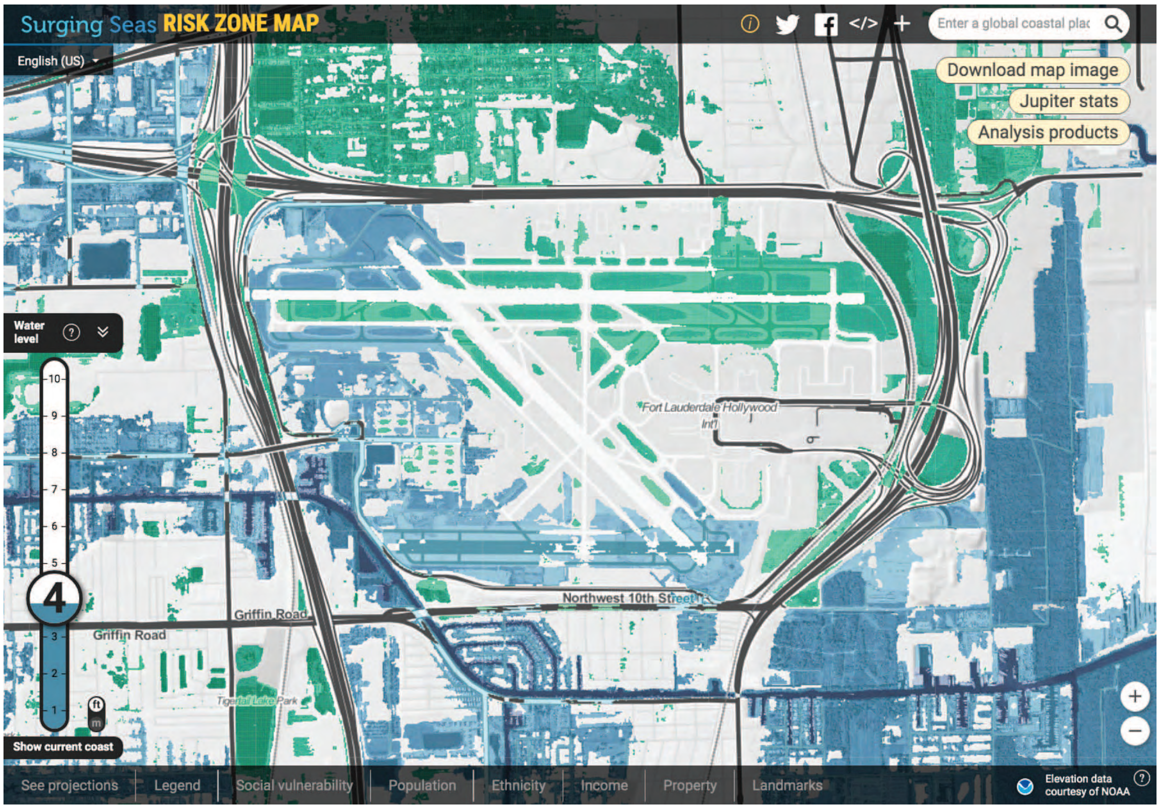

Figure 10. Ft. Lauderdale Airport with 4 ft (1.2 m) of storm surge or sea-level rise above MHHW. Blue areas would be flooded. Green areas are below 4 ft (1.2 m) but are protected by some barrier. (Source: Climate Central Surging Seas.)

the road surrounding the airport also acts as a levee for district-level flood protection.

The record for the lowest airport in the world likely goes to Amsterdam's Schiphol airport, which sits over 4 m (13 ft) below sea level. This should not be surprising, as somewhere between 26% and 33% of The Netherlands actually lies below sea level. The airport was constructed at the bottom of what was once Haarlemmer Lake, which was drained in 1852, and the first aircraft actually landed there in 1916, over a century ago. Schiphol airport serves 104 different airlines and employs about 67,000 people, so it is a big business. Dutch engineering, which includes a 240 km long network of drainage structures and pumping stations, a system of dikes, and other flood barriers, as well as operational and management practices, has been a key factor in the airport's survival. Although like any other coastal area, increasing rates of sea-level rise will pose additional challenges. The Dutch have the advantage of having lived below sea level for centuries and having developed the engineering approaches for best dealing with the sea. There are no debates in The Netherlands regarding whether or not sea level is rising or its potential consequences.

THE FUTURE—WHERE DO WE GO FROM HERE?

Many low-lying coastal airports in the United States and around the world will face challenges in the future, if not already. These include risks from extreme short-term events such as hurricanes, typhoons, cyclones, and severe storms with wave runup and storm surge at times of high tide, but also from long-term sea-level rise. It will be the extreme events, however, that will present the greatest risks to these airports over the intermediate term, probably until at least the midcentury, barring catastrophic ice-sheet collapse in Antarctica or greatly increased glacial melting on Greenland.

Six large international airports in the United States are within 5 ft (1.5 m) of MHHW at present (La Guardia, Philadelphia, Newark, Ft. Lauderdale, Oakland, and San Francisco); Louis Armstrong New Orleans International Airport is below sea level. The exposure of each of these airports in the decades ahead will be driven primarily by a combination of the future rate of sea-level rise and the frequency and magnitude of extreme flooding events.

Future sea level at each location will be a combination of both global sea-level rise and any local ground motion, whether uplift or subsidence. In most cases, the closest tide gauge to each airport will provide the best local sea-level rise values over the time during which the gauge has been operating. The uncertainties, however, that affect risk of inundation lie in the height of sea level at specific times in the future. There have been many regional studies of sea-level rise for different sections of U.S. coastlines based on historic tide gauge records, which also include projections for the future (for a few examples, see Griggs *et al.*, 2017; National Research Council,

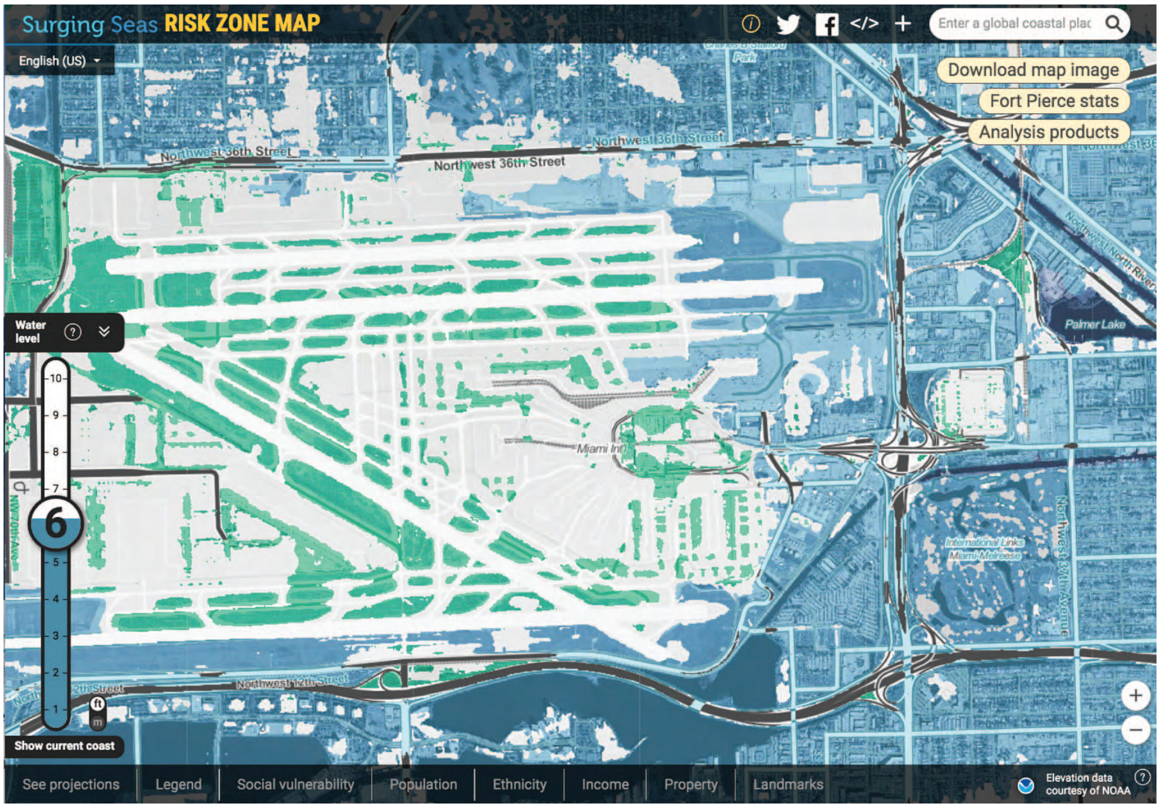

Figure 11. Miami International Airport with 6 ft (1.8 m) of storm surge or sea-level rise above MHHW. Blue areas would be flooded. Green areas are below 6 ft (1.8 m) but are protected by some barrier. (Source: Climate Central Surging Seas.)

2012; Union of Concerned Scientists, 2014, 2017, 2018). Boon *et al*. (2018) recently documented an acceleration of sea-level rise from tide gauge records around all U.S. coastlines.

Beginning in 1993, satellites began to measure absolute or global, in contrast to local or relative, sea level. The most recent average global value of sea-level rise over the 26 years of satellite altimetry has now reached 3.40 mm/y (Figure 18; AVISO, 2020). In addition to the rate of rise over the past 26 years, these satellites have also detected an acceleration of that rate (Nerem *et al*., 2018).

On a global scale, the most recent IPCC report (IPCC, 2014) provides future sea-level rise projections. These projections differ, however, based on the different greenhouse gas emission (RCP) scenarios used (Figure 19). RCP stands for representative concentration pathways and refers to heat or radiative forcing in watts per square meter of Earth's surface.

An RCP of 2.6 is the value that would result from a major global reduction in greenhouse gas emissions through a rapid transition to renewable energy sources. An RCP value of 8.5, in contrast, could be summarized as business as usual, with a continued high dependence on coal, oil, and natural gas for providing the majority of our global energy. Because of the amount of greenhouse gases already contained in the atmosphere, the differences in these two extreme scenarios do not begin to become significant until about 2050 (Figure 19). In the latter half of the twenty-first century, the differences in the two scenarios become substantially different, so that by 2100, the IPCC projections range from 21.5 in. (55 cm) (RCP = 2.6) to 49 in. (124 cm) (RCP = 8.5) of sea-level rise.

NOAA (2019) analyzed the rate of change in sea-level rise and determined that the rate has more than doubled, from 0.06 in. (1.4 mm) per year throughout most of the twentieth century to 0.14 in. (3.6 mm) per year from 2006 to 2015. This is equivalent to 14.2 in. (36 cm) per century. NOAA scientists have determined that if we follow a pathway with high emissions (which we are presently on), a worst-case scenario of as much as 8.2 ft (2.5 m) above 2000 levels by 2100 cannot be ruled out. Others have made similar or even slightly higher projections based in large part on an improved understanding of the physics of ice shelves and ice cliffs in Antarctica and the potential for collapse (DeConto and Pollard, 2016; Kopp *et al*., 2017).

RESPONDING TO EXTREME EVENTS AND FUTURE SEA-LEVEL RISE

While extreme events have already impacted some low-lying airports, sea-level rise is not yet a significant hazard for most, but it will be at some uncertain time in the future. That time is dependent upon the combined effects of both global sea-level rise and local land motion.

Some airports have already completed or are undertaking vulnerability or risk assessments for long-lasting infrastructure, such as terminals, runways, and maintenance facilities. Man-

Figure 12. JFK International Airport with 7 ft (2.1 m) of sea-level rise above MHHW. Blue areas would be flooded. Green areas are below 7 ft (2.1 m) but are protected by some barrier. (Source: Climate Central Surging Seas.)

agers of New York City's airports, as well as San Francisco and Oakland International Airports, have taken initial steps to assess their vulnerabilities, often in association with broader regional studies. Most airports have not yet begun that work, however.

In October 2018, the Airports Council International (ACI) launched its Airports' Resilience and Adaptation to a Changing Climate policy. This brief encourages airports to consider the impact of climate change as they develop master plans, and it allows airport operators to learn from their peers' experiences, as it includes case studies of best practices adopted at other airports.

To guard against flooding and future sea-level rise risks, both the Organization for Economic Cooperation and Development (OECD) and the ICAO have strongly urged immediate construction of higher runways, protective seawalls, better drainage systems, and even the establishment of early warning systems for flooding. Airports can protect their perimeters using levees, tidal gates, and detention ponds and pumping stations to manage floodwaters, although for airports underlain by permeable limestone, such as in Florida, seawalls and pumps may not be effective mitigation strategies. They could also find ways to minimize damage if seawalls are breached; in the wake of Hurricane Sandy, Boston's Logan Airport raised the levels of electrical equipment and constructed new flood barriers. For those large international airports along shorelines, the most obvious short-term approach would be to build a higher seawall around the airport, such as that being proposed for San Francisco and Oakland International Airports. There is a practical limit, however, as to how high such a wall can be built to both protect against rising water levels, but also not obstruct aircraft takeoffs and landings.

All of these adaptation measures will be costly, but airport owners and investors are beginning to pressure operators to bolster the defenses of these critical and valuable facilities. With the FAA's claim that weather-related events account for more than 70% of all airport delays and costs, the price of adapting to these hazards will be worth it in the potentially hazardous years to come. The first step is to accept the problems, the second step is to recognize the seriousness of the problems, and the third step is to agree on solutions and implement them.

Figure 13. Honolulu International Airport with 7 ft (2.1 m) of sea-level rise above MHHW. Blue areas would be flooded. Green areas are below 7 ft (2.1 m) but are protected by some barrier. (Source: Climate Central Surging Seas.)

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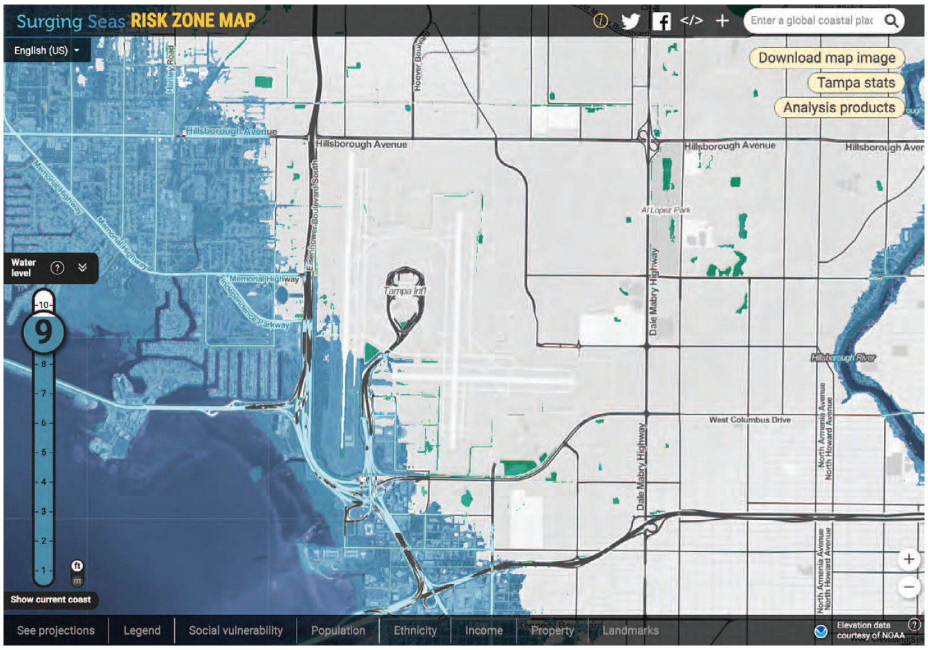

Figure 14. Tampa International Airport with 9 ft (2.7 m) of storm surge or sea-level rise above MHHW. Blue areas would be flooded. (Source: Climate Central Surging Seas.)

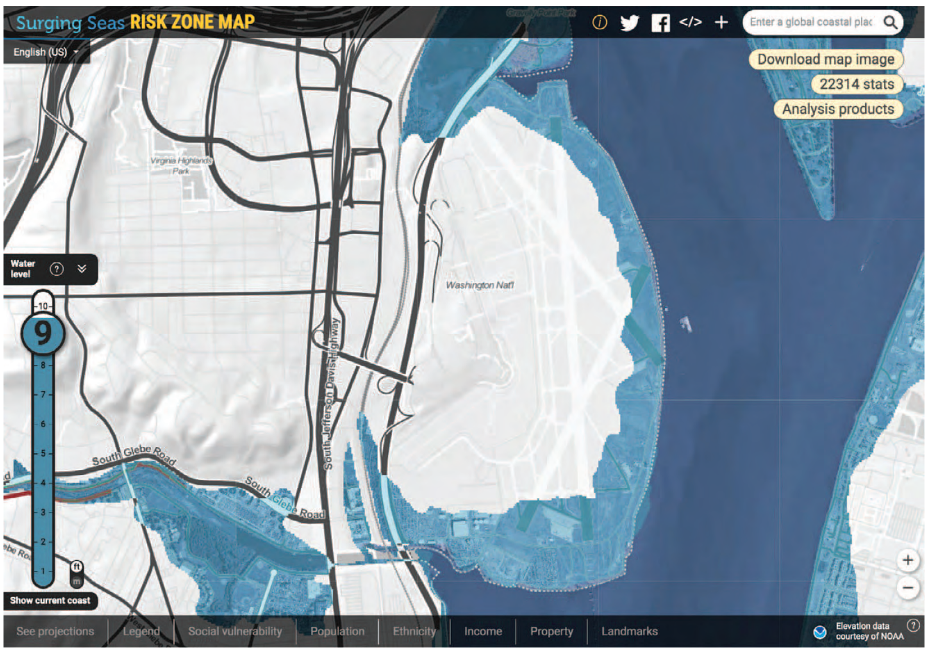

Figure 15. Washington National Airport with 9 ft (2.7 m) of storm surge or sea-level rise above MHHW. Blue areas would be flooded. (Source: Climate Central Surging Seas.)

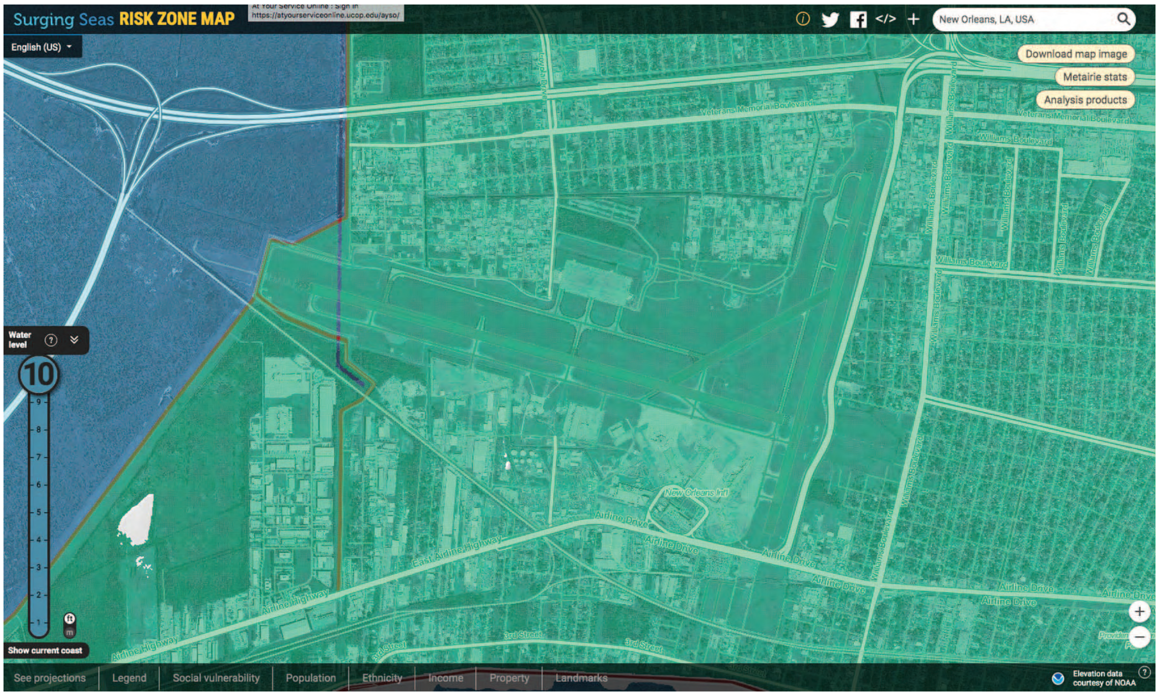

Figure 16. Louis Armstrong New Orleans International Airport with 10 ft (3 m) of storm surge or sea-level rise above MHHW. Blue areas would be flooded. Green areas are lower than this but are protected by levees or floodwalls. (Source: Climate Central Surging Seas.)

Figure 17. Flooding of Kansai Airport, Japan, during Typhoon Jebi, September 2018. (Source: AP.)

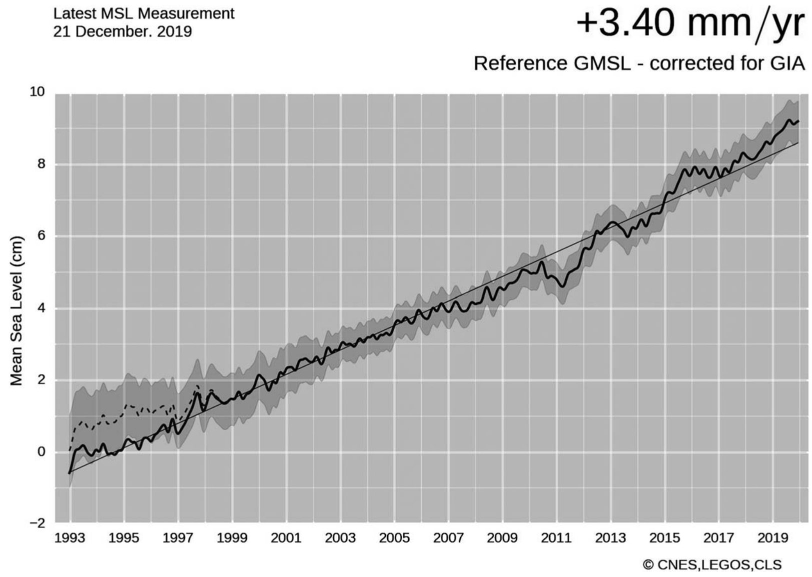

Figure 18. Satellite altimetry record of global sea-level rise from 1993 to 2020. (Source: Centre National d'Etudes Spatiales [CNES], Laboratoire d'Etudes en Géophysique et Océanographie Spatial [LEGOS], Collecte Localisation Satellites [CLS].)

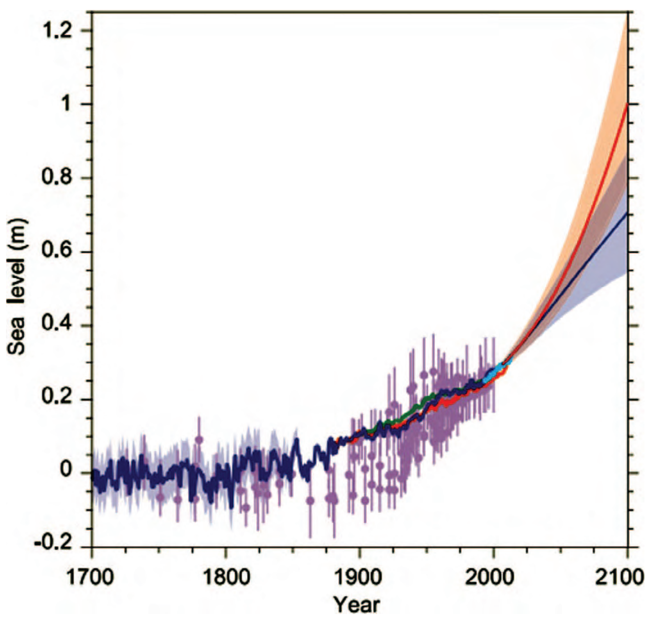

Figure 19. Compilation of paleo–sea level data, tide gauge data, altimeter data, and central and likely estimates of global mean sea-level rise for RCP = 2.6 (blue) and RCP = 8.5 (red). (Source: IPCC [2014] sea-level rise scenarios.)