PURPOSE

Pursuant to the Revised Charter of Honolulu ("RCH") Section 6-107(h), the City and County of Honolulu ("City") Climate Change Commission is charged with gathering the latest science and information on climate change impacts to Hawai'i and providing advice and recommendations to the mayor, City Council, and executive departments as they look to draft policy and engage in planning for future climate scenarios and reducing Honolulu's contribution to global greenhouse gas emissions.

To establish the basis and broad impact of climate change, the City Climate Change Commission adopts this CLIMATE CHANGE BRIEF 2020, updated from the prior version released in 2018. The document presents historical events and current trends in both the causes and consequences of climate change. It highlights both global conditions and those specifically known to Hawai'i using peer-reviewed literature and credible empirical data sources. This brief provides a benchmark for the Commission to underpin our decisions and recommendations and act as a resource for the public.

The Commission views this brief as a comprehensive effort, but acknowledges that the topics covered are likely not complete. This document will be updated every several years as new information is available.

INTRODUCTION

Excess heat, trapped by the anthropogenic greenhouse gases* in the atmosphere, is causing dramatic changes in ecosystems, oceans, and weather patterns. These changes have profound consequences for communities across the globe. Hawai'i and other Pacific islands are already seeing the impacts of climate change, like increasing sea level and changing temperature patterns.[1]

The negative impacts of climate change tend to be experienced disproportionately by disadvantaged groups.[2] Initial inequity or vulnerabilities can be exacerbated by climate change. For example, low income people are less likely to have access to air conditioning or other cooling measures like urban greenery, making them more susceptible to the effects of a heat wave. It is important to recognize and resolve the impacts of climate change on vulnerable populations as the City meets the challenges of climate change. These changes include the following.

GLOBAL IMPACTS

Energy and Greenhouse Gases

- The U.S. Energy Information Administration (EIA) projects the following global energy patterns to the year 2040.[3]
  - Strong, long-term economic growth drives an increasing demand for energy;
  - World energy consumption grows by 28%;
  - China and India alone account for over half of this increase;
  - Fossil fuels maintain a market share of 77% through 2040, even though renewable energy experiences explosive growth;
  - World energy-related carbon dioxide emissions rise 15% by 2040.
- To hold global temperature below an increase of 3.6°F (2°C) per the 2015 Paris Agreement, it is necessary to decrease carbon emissions by 50% per decade.[4] Clearly, the projections by the EIA move in the opposite direction.
- Carbon dioxide levels in the air have passed 410 ppm compared to a natural level of 280 ppm[5] – an increase of over 45%. This is the highest level since 3 million years ago, when global temperature and sea level were significantly higher than today. Testing revealed most climate models underestimate the effects of anthropogenic greenhouse gases.[6] Models that do the best job of simulating observed climate change predict some of the worst-case scenarios for the future. If countries stay on a high-emissions trajectory, there is a 93% chance the planet will warm more than 4°C by the end of the century. Previous studies placed those odds at 62%.
- Today, release of planet-warming carbon dioxide is ten times faster than the most rapid event in the past 66 million years, when an asteroid impact killed the dinosaurs.[7]

* Greenhouse gases include carbon dioxide, methane, nitrous oxide, and fluorinated gases like hydrofluor0carbons, perflurocarbons, sulfur hexafluoride, and nitrogen trifluoride (EPA).

- Beyond the next few decades, the magnitude of climate change depends on emissions of greenhouse gases and aerosols and the sensitivity of the climate system. Projected changes range from 4.7° to 8.6°F (2.6° to 4.8°C) under a higher scenario, to 0.5° to 1.3°F (0.3° to 1.7°C) under the lowest scenario.[8]

Air Temperature

- Global temperature has risen approximately 1.8°F (1°C) from the late 19th Century.[9]
- The likely global temperature increase for this century is a median 5.76°F (3.2°C). There is only a 5% chance that it will be less than 3.6°F (2°C), and a 1% chance that it will be less than 2.7°F (1.5°C).[10]
- The last time it was this warm, which was 125,000 years ago, the global sea level was 20 ft (6.6 m) higher.[11] [12] [13]
- Atmospheric humidity is rising.[14]
- The global water cycle has accelerated.[15]
- Air temperature over the oceans is rising.[16]
- The likely (66%) range of global temperature increase this century will be a median 5.8°F (3.2°C).[17] [18] If greenhouse gas concentrations were stabilized at their current level, existing concentrations would commit the world to at least an additional 1.1°F (0.6°C) of warming this century.[19]
- What will this >5.4°F (3°C) world look like?
  - Heat waves drive a global scale refugee crisis, as low-latitude continental lands lose habitability[20];
  - Drought[21], wildfires[22], water scarcity[23], crop failure[24] and other threats to critical resources leading to increased human conflict[25];
  - Multi-meter sea level rise continuing over many centuries[26];
  - Extreme weather disasters[27], massive floods[28], great tropical cyclones[29], mega-drought[30], and torrential rainfall[31] will be widespread.

El Niño-Southern Oscillation (ENSO)

- Frequency of intense El Niño events is projected to double in the 21st century, with the likelihood of extreme events occurring roughly once every decade.[32]
- Models project a near doubling in the frequency of future extreme La Niña events, from one in every 23 years to one in every 13 years. Approximately 75% of the increase occurs in years following extreme El Niño events, thus projecting more frequent swings between opposite extremes from one year to the next.[33]
- Strong El Niño years in Hawai'i bring more hot days, intense rains, windless days, active hurricane seasons, and spikes in sea surface temperature.[34]

Extreme Weather

- The global percentage of land area in drought has increased about 10%.[35]
- The global occurrence of extreme rainfall has increased 12%.[36]
- Heavy downpours are more intense and frequent.[37]
- Extreme weather events are more frequent. [38]
- Half a degree Celsius of global warming has been enough to increase heat waves and heavy rains in many regions of the planet.[39]
- Storm tracks are shifting poleward.[40]
- The number of weather disasters is up 14% since 1995-2004, and has doubled since 1985-1994.[41]
- There has been a global increase in the frequency and intensity of extremely hot three-day periods.[42]
- The number of unusually cold days and nights has decreased, and the number of unusually warm days and nights has increased.[43]
- Extreme heat waves are projected to cover double the amount of global land by 2020 and quadruple by 2040, regardless of future emissions trends.[44]
- New records continue to be set for warm temperature extremes. For instance, in the U.S. during February, 2017 there were 3,146 record highs set compared to only 27 record lows, a ratio of 116 to 1.[45]
- Nine of the ten deadliest heat waves have occurred since 2000 causing 128,885 deaths around the world.[46]
- Nearly one third of the world's population is now exposed to climatic conditions that produce deadly heat waves.[47]
- Extreme weather is increasing.[48]

- If global temperatures rise 3.6°F (2°C), the combined effect of heat and humidity will turn summer into one long heat wave. Temperature will exceed 104°F (40°C) every year in many parts of Asia, Australia, Northern Africa, South and North America.[49]
- If global temperatures rise 7.2°F (4°C), a new "super-heatwave" will appear with temperatures peaking at above 131°F making large parts of the planet unlivable including densely populated areas such as the US east coast, coastal China, large parts of India and South America.[50]
- 2020 has been a historical year for tropical cyclones.
    - The Atlantic hurricane season goes from June to November, and the 2020 season has already had the highest number of storms in the shortest time span in history.[51]
    - The National Hurricane Center ran out of the 21 human names for tropical storms for the second time since 1953, with the first in 2005.[52]
    - The Atlantic has five simultaneous, active tropical cyclones, which has only ever occurred in 1971[53]
    - There are typically only 12 named storms in a hurricane season, but as of October 5, 2020 there are 25 named tropical storms. Of the 25, nine made landfall in the continental US.[54]
    - The accumulated cyclone energy index (ACE Index) approximates and totals wind energy created by named tropical systems, and also includes the strength and duration of tropical storms. The average ACE value per season is 106 units, and the 2020 season ACE value is projected to hit as high as 200 units.[55]

Ecosystems

- Climate change impacts have been documented across every ecosystem on Earth, including shifts in species ranges, shrinking body size, changes in predator-prey relationships, new spawning and seasonal patterns, and modifications in the population and age structure of marine and terrestrial species.[56]
- In 2017, over 15,000 scientists published a "Warning to Humanity".[57] They said humans have pushed Earth's ecosystems to their breaking point and are well on the way to ruining the planet.
- Human activities have increased the acidity of oceans; increased the acidity of freshwater bodies and soils because of acid rain; increased acidity of freshwater streams and groundwater due to drainage from mines; and increased acidity of soils due to added nitrogen to crop lands.[58]
- Researchers have labeled ecosystem impacts "biological annihilation," and identify that a "sixth major mass extinction" is underway as a result of dwindling population sizes and range shrinkages among vertebrates.[59]
- Humans are causing the climate to change 170 times faster than natural forces.[60]
- Tree lines are shifting poleward and to higher elevations.[61]
- One-third of burnt forests experience no tree regeneration at all.[62]
- Species are migrating poleward and to higher elevations.[63]
- Spring is coming sooner to some plant species in the Arctic while other species are delaying their emergence amid warm winters. The changes are associated with diminishing sea ice.[64]
- Spring is coming earlier.[65]
- The tropics have expanded.[66]
- Warmer winters with less snow have resulted in a longer lag time between spring events and a more protracted vernal window (the transition from winter to spring).[67]
- Plants are leafing out and blooming earlier each year.[68]
- Climate-related local extinctions have already occurred in hundreds of species, including 47% of 976 species surveyed.[69]
- Plant and animal extinctions, already widespread, are projected to increase from twofold to fivefold in the coming decades.[70]

Food Systems

- Harvests of staple cereal crops, such as rice and maize, could decline by 20 to 40% as a function of increased surface temperatures in tropical and subtropical regions by 2100.[71]
- One billion people are classified as food insecure.[72]
- Rising CO_2 decreases the nutrient and protein content of wheat, leading to a 15% decline in yield by mid-century.[73]
- Higher levels of CO_2 are lowering amounts of protein, iron, zinc, and B vitamins in rice with potential consequences for a global population of approximately 600 million.[74]
- Crop failure due to drought, flood, or some other extreme weather event in the course of a growing season, increases disproportionately between 1.5 and 2°C.[75] For maize, risks of multiple breadbasket failures increase the most, from 6% to 40% at 1.5 to 54% at 2°C warming. In relative terms, the highest simultaneous climate risk increase between 1.5 and 2°C of

warming is for wheat (40%), followed by maize (35%) and soybean (23%). Limiting global warming to 1.5°C would reduce the risk of simultaneous crop failure for maize, wheat, and soybean by 26%, 28% and 19% respectively.

- By 2050, climate change will lead to per-person reductions of 3% in global food availability, 4% in fruit and vegetable consumption, and 0.7% in red meat consumption. These changes will be associated with 529,000 climate-related deaths worldwide.[76]
- Without changes to policy and improvements to technology, food productivity in 2050 could look like it did in 1980 because, at present rates of innovation, new technologies won't be able to keep up with the damage caused by the climate change in major growing regions.[77]
- The current food system drives a majority of global environmental change and is a primary cause of chronic diseases, generating 30% of global GHG. Current agricultural practices use 70% of the world's fresh water.[78]
- Approximately 56 billion livestock are consumed annually, and this number is expected to double by 2050. Animal agriculture globally contributes to 9% of the world's total CO_2 emissions, with the sole production of fertilizer for feed crops emitting 41 MMT of CO_2 per year. Additionally, livestock feed requires a minimum of 80% of global soybean crop and over 50% of global corn crop. 35-40% of yearly anthropogenic methane emissions are a result of animal agriculture due to enteric fermentation and manure.[79]

Human Health and Disproportionately Impacted Communities

- Anyone can be harmed by climate change impacts, but more specifically, children, elders, the sick and the poor face the greatest risks.[80]
- Extreme temperature increase can lead to illness and death from heat stroke and dehydration, especially in those who work outdoors or lack air conditioning. People with cardiovascular and/or respiratory chronic illnesses are particularly vulnerable to high temperatures.[81]
- Extreme weather events like flash floods and hurricanes often result in power outages and destruction of residential, commercial, and public infrastructure. The potential blockade of evacuation routes by extreme weather events can limit evacuation and/or transportation to medical facilities. Additionally, floods and extreme weather events can contaminate drinking water supplies and recreational areas which lead to gastrointestinal issues and even organ failure, paralysis, and death.[82]
- The decrease in air quality from the increase in GHG emissions and global temperatures exacerbates asthma and allergy attacks from higher concentrations of particulates in the air from wildfires smoke and pollen. Air pollution is also the cause of over seven million global deaths due to resulting lung and heart complications. Furthermore, the increase in CO_2 in the air reduces the nutritional value of crops like wheat, rice, barley, and potatoes because plants produce less protein and intake less minerals in the presence of CO_2. This highly affects those who live in food deserts and/or struggle to meet daily nutritional requirements, furthering the inequality of climate change health impacts.[83]
- 16,000 premature deaths can be avoided in the US in 2050 if $PM_{2.5}$ concentrations are decreased to RCP4.5 minus REF. For reduction of ozone (O_3) concentrations under RCP4.5, 8,000 deaths in the US would be avoided in 2050.[84]
- The monetized co-benefits per ton of CO_2 reduced on a global scale is estimated at $50-380.[85]
- Often the areas that face the worst impacts from climate change are also socially vulnerable. Poor communities and communities of color are often more likely to live near a facility emitting hazardous local co-pollutants. Neighborhoods within 2.5 miles of a GHG emitter, like a power plant, have 22% higher proportion of residents of color and a 21% higher proportion of residents under the poverty line than neighborhoods further than 2.5 miles from such a facility.[86]

Glaciers, Sea Ice, Permafrost

Glaciers

- The world's major ice systems including Antarctica and Greenland,[87] and the mountain glaciers[88] of the world are all in a state of decline.[89, 90, 91]
- Over the past three million years, when global temperatures increased 1.8 to 5.4°F (1 to 3°C), melting polar ice sheets caused global sea levels to rise at least 20 ft (6 m) above present levels.[92]
- Under high emission pathways, a sea level rise exceeding 8 ft (2.4 m) by 2100 is physically possible.[93]
- Further melting of mountain glaciers cannot be prevented in the current century - even if all emissions were stopped now.[94] Around 36% of the ice still stored in mountain glaciers today will melt even without further emissions of greenhouse gases. That means: more than one-third of the glacier ice that still exists today in mountain glaciers can no longer be saved even with the most ambitious measures.

- Alpine glaciers have shrunk to their lowest levels in 120 years and are wasting two times faster than they did in the period 1901-1950, three times faster than they did in 1851-1900, and four times faster than they did 1800-1850.[95]

Sea Ice

- The West Antarctic ice sheet is in "unstoppable" retreat.[96]
- Atmospheric warming that exceeds 2.7 to 3.6°F (1.5 to 2°C) above present (ca. 2015) will trigger a centennial- to millennial-scale response of the Antarctic ice sheet that produces an unstoppable contribution to sea-level rise.[97] Substantial Antarctic ice loss can be prevented only by limiting greenhouse gas emissions to RCP2.6 levels. Higher-emissions scenarios lead to ice loss from Antarctica that will raise sea level by 1.9 to 9.8 ft (0.6 to 3 m) by the year 2300.[98]
- If emissions continue unabated, Antarctica has the potential to contribute more than 3.28 ft (1 m) of sea-level rise by 2100 and more than 49.2 ft (15 m) by 2500. In this case, atmospheric warming will soon become the dominant driver of ice loss, but prolonged ocean warming will delay its recovery for thousands of years.[99]
- The Greenland ice sheet is more sensitive to long-term climate change than previously thought. Studies[100] estimate that the warming threshold leading to an essentially ice-free state is in the range of 1.4 to 5.8°F (0.8 to 3.2°C), with a best estimate of 2.9°F (1.6°C) above preindustrial levels. The Arctic is on track to double this amount of warming before mid-century.[101]
- Cloud cover over Greenland is decreasing at 0.9 +/-3% per year. Each 1% of decrease drives an additional 27 +/-13 billion tons of ice melt each year.[102]
- Arctic sea ice is shrinking (13% per decade) as a result of global warming.[103]
- Winter Arctic sea ice was the lowest on record in 2017.[104]
- In the Arctic, average surface air temperature for the year ending September 2016 was the highest since 1900, and new monthly record highs were recorded for January, February, October, and November 2016.[105]
- Rapid warming in the Arctic is causing the jet stream to slow down and become unstable.[106]
- Regions of Earth where water is frozen for at least one month each year are shrinking with impacts on related ecosystems.[107]
- Extreme warm events in winter are much more prevalent than cold events.[108]
- Global snow cover is shrinking.[109]

Permafrost

- The southern boundary of Northern Hemisphere permafrost is retreating poleward.[110]
- Large parts of permafrost in northwest Canada are slumping and disintegrating into running water. Similar large-scale landscape changes are evident across the Arctic including in Alaska, Siberia, and Scandinavia.[111]
- In North America, spring snow cover extent in the Arctic is the lowest in the satellite record, which started in 1967.[112]

Oceans

Sea Level Rise

- Sea level is rising and the rate of rise has accelerated.[113]
- Today global mean sea level is rising three times faster than it was in the 20th Century.[114]
- Between 1993 and 2014, the rate of global mean sea level rise increased 50% with the contribution from melting of the Greenland Ice Sheet rising from 5% in 1993 to 25% in 2014.[115]
- With existing greenhouse gas emissions, we are committed to future sea level of at least 4.3 to 6.2 ft (1.3 to 1.9 m) higher than today and are adding about 0.32 m/decade to the total: ten times the rate of observed contemporary sea-level rise.[116]

Warming

- The Atlantic Meridional Overturning Circulation has decreased 20%. The North Atlantic has the coldest water in 100 yrs of observations.[117]
- Global sea surface temperature is rising.[118]
- The oceans are warming rapidly.[119]
- Over 90% of the heat trapped by greenhouse gases since the 1970's has been absorbed by the oceans and today the oceans absorb heat at twice the rate they did in the 1990's.[120]
- Excess heat in the oceans has reached deeper waters,[121] and deep ocean temperature is rising.[122]
- Sea surface temperatures have increased in areas of tropical cyclone genesis suggesting a connection with strengthened storminess.[123]

- Globally averaged sea surface temperature (SST) increased by 1.8°F (1.0°C) over the past 100 years. Half of this rise has occurred since the 1990s. North Central Pacific averaged SST trends follow the globally averaged trend. Over the last 5 years almost the entire tropical Pacific, in particular areas along the equator, have seen temperatures warmer than the 30-year average.[124]

Biodiversity Impacts

- Oxygen levels in the ocean have declined by 2% over the past five decades because of global warming, probably causing habitat loss for many fish and invertebrate species.[125]
- Marine ecosystems can take thousands, rather than hundreds, of years to recover from climate-related upheavals.[126]
- Marine ecosystems are under extreme stress.[127]
- The world's richest areas for marine biodiversity are also those areas mostly affected by both climate change and industrial fishing.[128]
- The number of coral reefs impacted by bleaching has tripled over the period 1985-2012.[129]
- By 2050 over 98% of coral reefs will be afflicted by bleaching-level thermal stress each year.[130]
- Scientists have concluded that when seas are hot enough for long enough nothing can protect coral reefs. The only hope for securing a future for coral reefs is urgent and rapid action to reduce global warming.[131]
- Dissolved oxygen in the oceans is declining because of warmer water.[132]
- Production of oxygen by photosynthetic marine algae is threatened at higher temperatures.[133]

Acidification

- Average pH of ocean water fell from 8.21 to 8.10, a 30% increase in acidity. Ocean water is more acidic from dissolved CO_2, which is negatively affecting marine organisms.[134]
- Widespread coral reef bleaching and mortality have been occurring more frequently.
- By mid-century bleaching events are projected to occur annually, threatening extinction of many coral species and reef ecology in general.[135]
- Bleaching and acidification will result in loss of reef structure. Reef collapse[136] leads to lower fisheries yields and loss of coastal protection and habitat.

Fishery Impact

- Fisheries, coral reefs, and the livelihoods they support are threatened by higher ocean temperatures and ocean acidification.[137]
- Fishery productivity is projected to decline to 15% and 50% of current levels by mid-century and 2100, resp., under a high greenhouse gas emission scenario.

Record-breaking ocean temperatures, 2019.[138]

- August 2019 was the warmest month for global ocean water temperatures on record, with records to 1854. 2019 also saw the weakest North Pacific atmospheric circulation patterns in at least the last 40 years.[139]
- 2019 was the warmest year for global ocean water temperatures on record.
- Increases in ocean temperature reduce dissolved oxygen in the ocean and significantly affect sea life, particularly corals and other temperature- and chemistry-sensitive organisms.
- The increasing heat increases evaporation, and the extra moisture in the warmer atmosphere nourishes heavy rains and promotes flooding.
- Increased heat and evaporation leads to a more extreme hydrological cycle and more extreme weather, in particular hurricanes.
- The warm ocean water of 2019 is one of the key reasons why Earth experienced increasing catastrophic fires in the Amazon, California, and Australia in 2019.

Wildfires

- 90% of wildfires in the US are caused by humans, the rest are caused by lightning or lava typically.[140]
- 4.5 million US homes were identified to be at high or extreme risk of wildfire in 2019, with half in California.[141]
- In 2020, from January 1 to September 28, there have been 44,520 wildfires in the US alone, which is about 13% more than in 2019 for the same time period. About 7.5 million acres have been burned, compared to the 4.4 million acres in 2019.[142]
- The largest wildfire recorded in California is the August Complex Fire, which started initially as 38 separate fires started by lightning strikes from August 16 to 17, 2020. As of the writing date of September 29, 2020, the fire is still ongoing, with it

covering 938,044 acres at 43% containment. The fire spreads across the Mendocino, Shasta-Trinity, and Six Rivers National Forests.[143] Thus far, 86 buildings have been destroyed with three firefighter casualties.[144]

- In Oregon's 2020 fire season started July 5, but due to high winds that began on September 7, the 30 active fires spread and burned over 1 million acres, with 500,000 Oregonians on evacuation notice and more than 40,000 already evacuated. The acreage burned is twice the annual average for Oregon.[145]
- Human activities combined with peaks in the frequency of forest fires in the 1800s has resulted in a "fire deficit" in the western US. The consequences of the fire deficit are exacerbated by climate change.[146]
- Correlations between global warming and wildfire increases have been shown, with the increase in wildfire frequencies driven mainly by fire regime sensitivity due to changes in climate.[147] Additionally, a paper published in 2016 found a clear connection between forest fire area and fuel aridity (a combination of temperature and precipitation) by studying the western US. About 75% of annual differences in burned area is due to fuel aridity.[148]
- While the total area burned globally each year from wildfires have dropped about 25% since 2003 because of population growth and land development, there has been an increase in the intensity and reach of fires in western US.[149]
- By using fire and climate modeling, the driving factor of global fire trends for the 21st century has been identified as being temperature-driven in contrast with the precipitation-driven regime in the preindustrial period. This shift in the global fire regime results in a newly fire-prone global environment.[150]
- Adding additional stresses of climate change can exacerbate and highlight existing social inequities. For example, Oregon evacuated four state prisons in early September and forced thousands into one facility that had more than 100 reported cases of COVID-19.[151] Additionally, the lack of emergency management preparedness for fires at this scale, which are forecasted to become more frequent within the western US, resulted in a shortage of firefighters. The shortage was met by enlisting inmates to battle fires for $1/hour.[152]

HAWAIʻI – LOCAL AND REGIONAL IMPACTS

Energy and Greenhouse Gases

- Fossil fuel use for transportation continues to increase.[153]
- Hawaii's CO_2 emissions are 20% lower than the national average. [154]
- However, U.S. CO_2 emissions per capita are over three times the world average and Hawaii's are approximately 12 times larger than other Pacific Islands. [155]
- In 2016, Hawaii's total greenhouse gas emissions were 19.59 million metric tons of CO_2 equivalent, with 87% of the emissions from the Energy sector, 6% from the AFOLU sector, 4% from the Waste sector, and 4% from the IPPU sector.[156]
- Carbon dioxide was the largest contributor to statewide emissions in 2016, making up ~89% of total emissions[157]
- Total CO_2 emissions are about 8% lower in 2016 than in 1990, largely due to gains in the electricity sector.[158]
- Oʻahu had 20.8% of net sales of electricity from sources deemed renewable in 2017, the law requires 100% by 2045.[159]
- Total GHG emissions are projected to be 19.02 MMT CO_2 Eq. by 2020 and 17.45 MMT CO_2 Eq. by 2025 under the baseline scenario. Compared to 2016, total emissions under the baseline scenario are projected to decrease by 3% in 2020 and 5% in 2025 due to energy industries moving towards renewables.[160]
- Passed in 2018, Act 15 establishes a *Greenhouse Gas Sequestration Task Force* and sets a 2023 deadline for crafting a plan to meet a zero emissions target by 2045.
- Also passed in 2018, Act 16 directs the state Office of Planning to work with the task force to create a carbon offset program.

Air Temperature

- In Hawaiʻi, the rate of warming air temperature has increased in recent decades. Currently, the air is warming at 0.3°F (0.17°C) per decade, four times faster than half a century ago.[161]
- Statewide, average air temperature has risen by 0.76°F (0.42°C) over the past 100 years, and 2015 and 2016 were the warmest years on record.[162]
- Warming air temperatures lead to heat waves, expanded pathogen ranges and invasive species, thermal stress for native flora and fauna, increased electricity demand, increased wildfire, potential threats to human health, and increased evaporation which both reduces water supply and increases demand. Rapid warming at highest elevations impedes precipitation, the source of Hawaii's freshwater.[163]
- During the strong El Niño of 2015, Honolulu set or tied 11 days of record heat.[164] This compelled the local energy utility to issue emergency public service announcements to curtail escalating air conditioning use that stressed the electrical grid.[165]

- Some model projections for the late 21st century indicate that surface air temperature over land will increase 1.8° to 7.2°F (2° to 4°C) with the greatest warming at the highest elevations and on leeward sides of the major islands.[166]
- Under continued strong greenhouse gas emissions, high elevations above 9,800 ft (3000 m) reach up to 7.2° to 9°F (4 to 5°C) warmer temperatures by the late 21st Century.[167]
- Heat records were set across Hawai'i in the summer of 2019.[168]
  - By October 2019, Honolulu saw 45 days of record high temperature, including 29 days June to August, equal to more than two record highs per week.
  - Beginning August 10, Honolulu hit 90°F (32.2°C) each of the next 37 days.
  - Nighttime lows set records. From 1950 to 2018, only 14 nights failed to drop below 80°F (26.6°C); 2019 featured 19 such nights.
  - 2019 saw the 1st, 2nd, and 3rd hottest calendar days on record in Honolulu.
  - Honolulu hit 95°F (35°C) on the final day of August, a record for hottest August temperature in a century, and tied the record for hottest year-round temperature.
  - Of four long-running weather monitoring stations in Hawai'i, three saw their warmest summer on record. Only Hilo, did not.
  - In Lihue, Aug 24 to Sept 12 set daily heat records. In July, Aug, and Sept, 48 days set record highs, 44 nights set record high lows, and zero days or nights set record lows.
  - Over 300 records were tied or broken in 2019. Only 5 of these were for record lows, revealing a strong warming shift in median temperature across Hawai'i.
  - The likely cause, a record-setting marine heat wave, was the result of weak atmospheric circulation that produced very calm wind patterns.[169]

Forest Ecosystems

- Hawai'i is home to 31% of the nation's plants and animals listed as threatened or endangered, and less than half of the landscape on the islands is still dominated by native plants. Studies indicate that endemic and endangered birds and plants are highly vulnerable to climate change and are already showing shifting habitats.[170]
- Even under moderate warming, 10 of 21 existing native forest bird species are projected to lose over 50% of their range by 2100. Of those, three may lose their entire ranges and three others are projected to lose more than 90% of their ranges making them of high concern for extinction.[171]
- Warming air temperatures are bringing mosquito-borne diseases to previously safe upland forests, driving several native bird species toward extinction.[172]

Food Systems

- The most comprehensive estimate for the quantity of food imported into the State of Hawai'i was published in 2008. It estimates that Hawai'i imports approximately 85-90% of its food. From 1994-1995 to 2004-2005, all foods besides beef and fresh vegetables declined in production rate, meaning Hawai'i's overall level of food production has decreased.[173] At any given time, HIEMA presents that there is a 5- to 7-day supply of food in the state.[174]
- Land conversion and development have reduced potential lands that could be used for indigenous agricultural systems by 13%, and more than 40% of Hawai'i's agricultural land remains unfarmed.[175]
- From data taken from 2010 to 2011, 29% of adults in Hawai'i said they were worried within the past 12 months about having enough money to buy nutritious meals.[176] Given global projections for climate change impacts to food systems, this could further affect food security in Hawai'i.
- Restoring native agroecosystems is crucial to Hawaiian food system sustainability.[177] By using three models of Kānaka Maoli agroecosystems under current and future climate change scenarios, it was found that Hawai'i has the capability to sustainably support 250,000 acres of native farming systems and produce over 1 million metric tons of food per year, similar to food demands in Hawai'i today.[178]
- The average age of a farmer in Hawai'i is 60, and many younger generations do not continue or go into farming.[179]
- In 2016, there were 0.25 MMT of CO_2 equivalent of methane emissions from enteric fermentation (a digestive process in animals like cattle, horses, sheep, goats, and swine), which accounts for 18% of AFOLU sector emissions. Manure management of livestock resulted in 0.04 MMT of CO_2 equivalent of methane emissions in 2016, which is 3% of AFOLU sector emissions.[180]
- Improving food systems and culturally relevant food systems is important because Pacific Islanders/Native Hawaiians experience the highest rates of obesity and chronic diseases, etc.

Native Hawaiian Communities

- Indigenous populations with reliance on natural resources for sustenance will be disproportionally impacted by climate change. Native Hawaiians have a connection to the land and its resources which can be traced back to the creation story in the Kumulipo, which is a chant that connects the birth of Kānaka Maoli to Hawai'i. The Kumulipo states that Maoli are descendants of akua (ancestors/gods) and are connected to all living things in the Hawaiian Islands. Hawaiian culture embodies this idea of kuleana of caring for Hawai'i's resources.[181]
- About 550 Hawaiian cultural sites are exposed to chronic flooding with a sea level rise of 3.2 ft (0.98 m).[182]
- Sea level rise impacts on traditional and customary practices (including fishpond maintenance, cultivation of salt, and gathering from the nearshore fisheries) have been observed.[183]
- Because of flooding and sea level rise, indigenous practitioners have had limited access to the land where salt is traditionally cultivated and harvested since 2014. Detachment from traditional lands has a negative effect on the spiritual and mental health of people.[184]
- Ocean warming and acidification, sea level rise and coastal erosion, drought, flooding, pollution, increased storminess, and over-development are negatively affecting tourism, fisheries, and forested ecosystems. This directly impacts the livelihood and security of Pacific communities. For example, across all Pacific Island countries and territories, industrial tuna fisheries account for half of all exports, 25,000 jobs, and 11% of economic production.[185] In Hawai'i, between 2011 and 2015, an annual average of 37,386 Native Hawaiians worked in tourism-intensive industries; based on the 2013 U.S. census, this number represents 12.5% of the Native Hawaiian population residing in Hawai'i.[186]
- In Hawai'i, climate change impacts, such as reduced streamflow, sea level rise, saltwater intrusion, episodes of intense rainfall, and long periods of drought, threaten the ongoing cultivation of taro and other traditional crops.[187]
- Among the five largest race groups in Hawai'i of Japanese, White, Filipino, Native Hawaiian, and Chinese, Native Hawaiians have the highest poverty rates in Hawai'i for individuals and families.[188]

Wind, Precipitation, and Tropical Cyclones

Wind

- The frequency of gale-force winds is increasing in the western and south Pacific but decreasing in the central Pacific.[189]
- Average daily wind speeds are slowly declining in Honolulu and Hilo, while remaining steady across western and south Pacific sites.[190]
- Studies indicate there will be future changes to winds and waves due to climate change, which affects ecosystems, infrastructure, freshwater availability, and commerce.[191]

Precipitation

- Hawai'i has seen an overall decline in rainfall over the past 30 years, with widely varying precipitation patterns on each island. The period since 2008 has been particularly dry.[192]
- Declining rainfall has occurred in both the wet and dry seasons and has affected all the major islands. On O'ahu, the largest declines have occurred in the northern Ko'olau mountains.[193]
- Heavy rainfall events and droughts have become more common, increasing runoff, erosion, flooding, and water shortages.[194]
- Consecutive wet days and consecutive dry days are both increasing in Hawai'i.[195]
- On the Island of Hawai'i, a rare storm with daily precipitation of 300 mm (20-year return period) in 1960 was a common storm event (3–5-year return period) in 2009.[196]
- Across the state of Hawai'i, extreme precipitation events are more frequent in La Niña years and less frequent in El Niño years.[197]
- There is disagreement regarding precipitation at the end of the century.[198] Model projections range from small increases to increases of up to 30% in wet areas, and from small decreases to decreases of up to 60% in dry areas.[199] [200]
- Generally, windward sides of the major islands will become cloudier and wetter. The dry leeward sides will generally have fewer clouds and less rainfall.[201]

Tropical Cyclones

- More frequent tropical cyclones are projected for the waters near Hawai'i. This is not necessarily because there will be more storms forming in the east Pacific; rather, it is projected that storms will follow new tracks that bring them into the region of Hawai'i more often.[202]

- The zone of TC formation is shifting poleward. This is linked to Hadley Cell expansion.[203] Major TC's have become 15% more likely over the past 40 years.[204]
- Climate models project an increase in TC's near Hawai'i.[205]
- A global-average migration of TC activity is taking place as storms move away from the tropics at a rate of about one degree of latitude per decade.[206]
- With 2°C (3.6°F) of additional warming, climate models project a 10-15% increase in the average precipitation rate within 100 km of a storm.[207]
- As oceans warm, there is less cold, subsurface water to serve as a braking mechanism for hurricanes.[208]
- SLR is causing higher coastal inundation levels for TC storm surge.[209]
- Models project a 1-10% increase in tropical cyclone intensity for warming of 2°C (3.6°F), implying increasing destructive potential, assuming no reduction in storm size.[210]
- The proportion of tropical cyclones reaching Category 4 and 5 levels will likely increase.[211] Hurricanes have already become bigger and more destructive in the U.S.[212]
- There is low confidence in the global number of future Category 4 and 5 storms, since modeling studies show decreasing global frequency of all tropical cyclones combined.[213]
- The forward speed of TC's is decreasing.[214] Model simulations suggest that future global warming could lead to a significant slowing of hurricane motion.[215]

Streamflow

- Streamflow in Hawai'i has declined over approximately the past 100 years, consistent with observed decreases in rainfall.[216]
- Trends showing low flows becoming lower indicate declining groundwater levels. On Oahu, water supply is mainly derived from groundwater.[217]
- If these declines continue due to further reductions in rainfall and/or increases in evaporation, groundwater availability will be impaired.
- Chronic water shortages are possible as rainfall decreases and both evaporation and the water requirements of a growing human population increase.

Oceans

Sea Level Rise

- The mean sea level trend at the Honolulu tide station is 0.055 in (1.41 mm) per year with a 95% confidence interval of ±0.008 in (0.21 mm) per year based on monthly mean sea level data, 1905 to 2015. This is equivalent to a change of 0.46 ft (14.0 cm) over the past century.[218]
- The frequency of high tide flooding in Honolulu since the 1960's, has increased from 6 days per year to 11 per year.[219]
- With 3.2 ft (0.98 m) of sea level rise, 25,800 acres experience chronic flooding, erosion, and/or high wave impacts. One third of this land is designated for urban use. Impacts include 38 mi (61 km) of major roads, and more than $19 billion in assets.[220]
- Due to global gravitational effects, estimates of future sea level rise in Hawai'i and other Pacific islands are about 20%–30% higher than the global mean.[221]
- Over 70% of beaches in Hawai'i are in a state of chronic erosion.[222] This is likely related to long term sea level rise as well as coastal hardening.[223] [224]
- Coastal hardening of chronically eroding beaches caused the combined loss of 9% (13.4 mi, 21.5 km) of the length of sandy beaches on Kaua'i, O'ahu, and Maui.[225]

Acidification and Reefs

- Nearly 30 years of oceanic pH measurements, based on data collected from Station ALOHA, Hawai'i, show a roughly 8.7% increase in ocean acidity over this time.[226]
- Increasing ocean acidification reduces the ability of marine organisms to build shells and other hard structures. This adversely impacts coral reefs and threatens marine ecosystems more broadly.[227]
- In Hawai'i, extended periods of coral bleaching did not first occur until 2014 and 2015 as part of the 2014–17 global scale bleaching event that was the longest ever recorded.[228]
- Ocean warming and acidification are projected to cause annual coral bleaching in some areas, like the central equatorial Pacific Ocean, as early as 2030 and almost all reefs by 2050.[229] This will not only devastate local coral reef ecosystems but

will also have profound impacts on ocean ecosystems in general. Ultimately it will threaten the human communities and economies that depend on a healthy ocean.[230]

Wildfire

- Wildfire is a growing problem related to drying, invasive grasses, and human ignition.[231]
- Total burned area statewide has increased more than fourfold in the last century and fire propagates rapidly in dry nonnative grasslands.[232]
- The causes of most fires are unknown. Out of 12,000 recorded incidents statewide from 2000 to 2011, only 882, or about 7%, had a determined cause. Of those, 72% were accidental, which also means they're preventable.[233]
- Public education on the risks of fire and how to avoid sparking a fire is an important part of the solution to wildfire.
- Statewide, non-native, flammable grasses and shrubland cover 25% of the total land.
- Effective strategy includes permanently converting flammable vegetation to something less likely to burn, such as planting trees to shade grasses out.
- Essentially, two strategies are expedient:[234]
    - Target ignitions with public education.
    - Take direct control over vegetation.
- During El Niño, summers often have more rainfall which prolongs the growing season and increases potential fuel loads for fires. Drought throughout the following winter months causes vegetation to dry out and raise wildfire risk. In the 1997-1998 El Niño, which was the strongest to date, wildfires in Hawaii burned over 37,000 acres.[235]

AREAS FOR FURTHER RESEARCH

- Extreme rainfall levels in Hawaii specifically.
- Food and human health in Hawai'i specifically, related to climate change.
- Food and GHG emissions in Hawai'i specifically.

(This section needs to be finished.)

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[1] Keener, V.W., et al. (in review, 2018) Chapter 27, Hawai'i and Pacific Islands, Fourth National Climate Assessment, U.S. Global Change Research Program.
[2] Islam, N.S. and Winkel, J. (2017) Climate Change and Social Inequality, UN-DESA Work Paper 152, http://www.un.org/esa/desa/papers/2017/wp152_2017.pdf.
[3] EIA (2017) International Energy Outlook, U.S. Energy Information Administration, https://www.eia.gov/outlooks/ieo/pdf/0484(2017).pdf
[4] Rockström, J. et al. (2017) A roadmap for rapid decarbonization. Science, 355 (6331): 1269. Gasser, T., et al. (2015) Negative emissions physically needed to keep global warming below 2oC, Nature Communications 6, DOI: 10.1038/ncomms8958. Carbon Brief (2016) Explainer: 10 ways negative emissions could slow climate change: https://www.carbonbrief.org/explainer-10-ways-negative-emissions-could-slow-climate-change
[5] NOAA, Earth System Research Laboratory, Global Monitoring Division, Frequently Asked questions: https://www.esrl.noaa.gov/gmd/ccgg/faq_cat-3.html.
[6] Brown, P.T., Caldeira, K. (2017) Greater future global warming inferred from Earth's recent energy budget, Nature 552, 45-50,DOI:10.1038/nature24672.
[7] Zeebe, R.E., et al. (2016) Anthropogenic carbon release rate unprecedented during the past 66 million years, Nature Geoscience, doi: 10.1038/ngeo2681.
[8] Hayhoe et al. (2017)
[9] Haustein, K. et al. (2017) A global warming index. Nature Scientific Reports, doi:10.1038/s41598-017-14828-5.
[10] Raftery, A.E., et al. (2017) Less than 2^{o}C warming by 2100 unlikely, Nature Climate Change, 7, 637-641, DOI:10.1038/nclimate3352.
[11] Hoffman, J.S., et al. (2017) Regional and global SST's during the last interglaciation, Science, 355(6322), 276-279, doi: 10.1126/science.aai8464.
[12] Kopp, R.E, et al. (2009) Probabilistic assessment of sea level during the last interglacial stage, Nature, 462, 863-867, doi: 10.1038/nature08686.
[13] Dutton, A., et al. (2015) Sea-level rise due to polar ice-sheet mass loss during past warm periods, Science, v. 349, Is. 6244, DOI: 10.1126/science.aaa4019.
[14] Willett, K., et al. (2007) Attribution of observed surface humidity changes to human influence, Nature, 449, 710-712, doi: 10.1038/nature06207.
[15] Durack, P., et al. (2012) Ocean salinities reveal strong global water cycle intensification during 1950 to 2000, Science, 336(6080), 455-458.
[16] NOAA National Climatic Data Center, "State of the Climate: Global Analysis for May 2011," published online June 2011, http://www.ncdc.noaa.gov/sotc/global/
[17] Raftery et al. (2017)
[18] Tollefson, J. (2018) Can the world kick its fossil fuel addiction fast enough? Nature, News Feature, 25 April.
[19] Hayhoe, K., et al. (2017) Climate models, scenarios, and projections. In: CSSR: 4NCA, v. I [Wuebbles, D.J., et al. (eds.)]. USGCRP, Wash., DC.
[20] Russo, S., et al. (2017); Mora, C., et al. (2017)
[21] Dai, A. (2013) Increasing drought under global warming in observations and models, Nature Climate Change, 3, p. 52-58, doi:10.1038/nclimate1633.
[22] Jolly, W.M., et al. (2015) Climate-induced variations in global wildfire danger from 1979 to 2013, Nature Communications 6, DOI:10.1038/ncomms8537.
[23] Richey, A. S., et al. (2015) Quantifying renewable groundwater stress with GRACE, Water Resour. Res., 51, 5217–5238, doi:10.1002/2015WR017349.
[24] Zhao, C., et al. (2017) Temperature increase reduces global yields of major crops in four independent estimates PNAS 114 (35) 9326-9331.
[25] Raleigh, C., et al. (2014) Extreme temperatures and violence. Nature Climate Change, 4, 76–77.

[26] Dutton et al. (2015) See also Golledge, N.R., et al. (2015) The multi-millennial Antarctic commitment to future sea-level rise: Nature, 2015; 526 (7573): 421.
[27] Centre for Res. on the Epidemiology of Disasters, UN Intnl. Strat. for Disaster Red.: http://reliefweb.int/report/world/human-cost-weather-related-disasters-1995-2015
[28] Arnell, N.W., and Gosling, S.N. (2016) The impacts of climate change on river flood risk at the global scale, Climatic Change, 134, 3, pp 387-401.
[29] Kossin, J.P., et al. (2017) Extreme storms. In: CSSR: NCA4, v I [Wuebbles, D.J., et al., eds.] UGCRP, Wash, DC, pp. 257-276, doi: 10.7930/J07S7KXX.
[30] Ault, T.R., et al. (2016) Relative impacts of mitigation, temperature, and precipitation on 21st Century megadrought risk in the American Southwest. Science Advances, Oct 5, v. 2, no. 10, DOI:10.1126/sciadv.1600873.
[31] Lehmann, J., et al. (2015) Increased record-breaking precipitation events under global warming. Climatic Change, doi: 10.1007/s10584-015-1434-y
[32] Cai, W., et al. (2015) Inc. frequency of extreme El Niño events due to greenhouse warming. Nature Climate Change 4, 111–116, doi:10.1038/nclimate2100.
[33] Cai, W., et al. (2015) Inc. freq. of extreme La Niña events induced by greenhouse warming, Nature Climate Change, 5, 132–137, doi: 10.1038/nclimate2492.
[34] Keener et al. (in review, 2018)
[35] Dai, A. (2011) Characteristics and trends in various forms of the Palmer drought severity index during 1900–2008, Journal of Geophysical Research 116.
[36] Lehmann, J., et al. (2015) Increased record-breaking precipitation events under global warming. Climatic Change, doi: 10.1007/s10584-015-1434-y
[37] See NOAA, https://www.climate.gov/news-features/featured-images/heavy-downpours-more-intense-frequent-warmer-world.
[38] Medvigy, D. and Beaulieu, C. (2011) Trends in daily solar radiation and precipitation coefficients of variation since 1984, Journal of Climate, 25(4), 1330-1339.
[39] Schleussner, C-F, et al. (2017) In the observational record half a degree matters, Nature Climate Change. DOI: 10.1038/nclimate3320.
[40] Bender, F. A-M, et al. (2012) Changes in extratropical storm track cloudiness 1983–2008: Observational support for a poleward shift, Climate Dynamics 38.
[41] Centre for Research on the Epidemiology of Disasters, UN International Strategy for Disaster Reduction, http://reliefweb.int/report/world/human-cost-weather-related-disasters-1995-2015.
[42] Wehner, M., et al. (2018) Early 21st Century anthropogenic changes in extremely hot days as simulated by the C20C+ detection and attribution multi-model ensemble, Weather and Climate Extremes, v. 20, June, p. 1-8, https://doi.org/10.1016/j.wace.2018.03.001.
[43] Easterling, D.R., et al. (2016) Detection and attribution of climate extremes in the observed record, Weather and Climate Extremes, 11, March, p. 17-27.
[44] Coumou, D. and Robinson, A. (2013) Historic and future increase in the global land area affected by monthly heat extremes, Environmental Research Letters, 8(3), 034018, doi: 10.1088/1748-9326/8/3/034018.
[45] See Climate Central.org, http://www.climatecentral.org/news/record-high-temperature-february-21186.
[46] Vaidyanathan, G. (2015) Killer heat grows hotter around the world, Scientific American, August 6.
[47] Mora, C. et al. (2017) Global risk of deadly heat. Nature Climate Change; DOI: 10.1038/NCLIMATE332.
[48] S. Rahmstorf and D. Coumou (2011) Increase in Extreme Events in a Warming World, PNAS 108, no. 44: 17905–17909. Francis, J.A., and Vavrus, S.J. (2012) Evidence linking Arctic amplification to extreme weather in mid-latitudes. GRL, 39, L06801. Stott, P. (2016) How climate change affects extreme weather events. Science, 352, 1517–1518, doi:10.1126/science.aaf7271.
[49] Russo, S., et al. (2017) Humid heat waves at different warming levels. Scientific Reports; 7 (1) DOI: 10.1038/s41598-017-07536-7.
[50] Russo, S., et al. (2017)
[51] "We've Run out of Hurricane Names. What Happens Now?" Nationalgeographic.com. N.p., 21 Sept. 2020. Web. 7 Oct. 2020. https://www.nationalgeographic.com/science/2020/09/weve-run-out-of-hurricane-names-what-happens-now/#close
[52] "We've Run out of Hurricane Names. What Happens Now?" Nationalgeographic.com. N.p., 21 Sept. 2020. Web. 7 Oct. 2020. https://www.nationalgeographic.com/science/2020/09/weve-run-out-of-hurricane-names-what-happens-now/#close
[53] Chinchar, Allison. "5 tropical cyclones are in the Atlantic at the same time for only the second time in history." CNN. N.p., 14 Sept. 2020. Web. 7 Oct. 2020. https://www.cnn.com/2020/09/14/weather/atlantic-ocean-5-active-tropical-cyclones/index.html
[54] Mitchell, Chaffin. "2020 Atlantic Hurricane Season Already 2nd Most Active in History." Yahoo.com. Yahoo News, 5 Oct. 2020. Web. 7 Oct. 2020. https://news.yahoo.com/2020-atlantic-hurricane-season-already-191901402.html
[55] Mitchell, Chaffin. "2020 Atlantic Hurricane Season Already 2nd Most Active in History." Yahoo.com. Yahoo News, 5 Oct. 2020. Web. 7 Oct. 2020. https://news.yahoo.com/2020-atlantic-hurricane-season-already-191901402.html
[56] Scheffers, B.R., et al. (2016) The broad footprint of climate change from genes to biomes to people. Science, Nov., DOI: 10.1126/science.aaf7671.
[57] Ripple, W.J., et al. (2017) World Scientists' Warning to Humanity: A Second Notice. BioScience.
[58] Rice, K. and Herman, J. (2012) Acidification of Earth: an assessment across mechanisms and scales, Applied Geochemistry, 27(1), 1-14.
[59] Ceballos, G., et al. (2017) Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines, PNAS, 114 (30) E6089-E6096; doi:10.1073/pnas.1704949114
[60] Gaffney, O., and Steffen, W. (2017) The Anthropocene equation, The Anthropocene Review, http://dx.doi.org/10.1177%2F2053019616688022
[61] Beck, P.S.A., et al. (2011) Changes in forest productivity across Alaska consistent with biome shift, Ecology Letters, doi: 10.1111/j.1461-0248.2011.01598.x
[62] Stevens-Rumann, C.S., et al. (2018) Evidence for declining forest resilience to wildfires under climate change, Ecology Letters, 21:243-252.
[63] Loarie, S.R., et al. (2009) The velocity of climate change, Nature, 462, 1052-1055.
[64] Post, E., et al. (2016) Highly individualistic rates of plant phenological advance associated with arctic sea ice dynamics, Biology Letters, 12(12), 20160332.
[65] The U.S. Geological Survey hails an early spring and ties it to climate change: http://www.chron.com/news/houston-weather/article/The-U-S-Geological-Survey-hails-an-early-spring-10958042.php. Kahru, M., et al. (2010) Are phytoplankton blooms occurring earlier in the Arctic? Global Change Biology, doi: 10.1111/j.1365-2486.2010.02312.x.
[66] Seidel, D.J., et al. (2008) Widening of the tropical belt in a changing climate, Nature Geoscience, 1, 21-24, doi: 10.1038/ngeo.2007.38.
[67] A. R. Contosta, et al. (2017) A longer vernal window: the role of winter coldness and snowpack in driving spring transitions and lags. Global Change Biology; 23 (4): 1610 DOI: 10.1111/gcb.13517.
[68] Wolkovich, E., et al. (2012) Warming experiments underpredict plant phenological responses to climate change, Nature, 485(7399), 494-497.
[69] Wiens, J.J. (2016) Climate-related local extinctions are already widespread among plant and animal species, PLOS Biology, 14(12), e2001104.
[70] Wiens, J.J. (2016)
[71] Battisti, D.S. and Naylor, R.L. (2009) Historical warnings of future food insecurity with unprecedented seasonal heat. Science 323, 240–244,
[72] Barrett, C.B. (2010) Measuring food insecurity. Science 327, 825–828.
[73] Myers, S.S., et al. (2014) Increasing CO_2 threatens human nutrition, Nature, 510, 139-142, doi: 10.1038/nature13179. Feng, Z., et al. (2015) Constraints to nitrogen acquisition of terrestrial plants under elevated CO_2, Global Change Biology, 21(8), 3152-3168, doi: 10.1111/gcb.12938.
[74] Zhu, C., et al. (2018) Carbon dioxide (CO_2) levels this century will alter the protein, micronutrients, and vitamin content of rice grains with potential health consequences for the poorest rice-dependent countries, Science Advances, 23 May, v. 4, no. 5, DOI:10.1126/sciadv.aaq1012.
[75] Gaupp, F, et al.(2019) Increasing risks of multiple breadbasket failure un 1.5 and 2oC global warming, Agricultural Systems, v. 175, p. 34-45, https://doi.org/10.1016/j.agsy.2019.05.010
[76] Springmann, M., et al. (2016) Global and regional health effects of future food production under climate change: a modeling study, The Lancet.

[77] Liang, X.Z., et al. (2017) Determining climate effects on US total agricultural productivity, PNAS, www.pnas.org/cgi/doi/10.1073/pnas.1615922114
[78] If We Get Food Right, We Get Everything Right: Rethinking the Food System in Post-COVID-19 Hawai'i. N.p. Web.
[79] "Global Farm Animal Production and Global Warming: Impacting and Mitigating Climate Change." Environmental Health Perspectives. N.p., 2020. Web. 13 Oct. 2020.
[80] Medical Alert! Climate change is Harming Our Health, report by the Medical Society Consortium on Climate and Health, 24p. https://medsocietiesforclimatehealth.org/wp-content/uploads/2017/03/medical_alert.pdf.
[81] Medical Alert! Climate change is Harming Our Health, report by the Medical Society Consortium on Climate and Health, 24p. https://medsocietiesforclimatehealth.org/wp-content/uploads/2017/03/medical_alert.pdf.
[82] Medical Alert! Climate change is Harming Our Health, report by the Medical Society Consortium on Climate and Health, 24p. https://medsocietiesforclimatehealth.org/wp-content/uploads/2017/03/medical_alert.pdf.
[83] Medical Alert! Climate change is Harming Our Health, report by the Medical Society Consortium on Climate and Health, 24p. https://medsocietiesforclimatehealth.org/wp-content/uploads/2017/03/medical_alert.pdf.
[84] Zhang, Yuqiang et al. "Co-Benefits of Global, Domestic, and Sectoral Greenhouse Gas Mitigation for US Air Quality and Human Health in 2050." Environmental Research Letters 12.11 (2017): 114033. Web. 6 Oct. 2020.
[85] "Co-Benefits of Mitigating Global Greenhouse Gas Emissions for Future Air Quality and Human Health | Earth and Environmental System Modeling." Energy.gov. N.p., 2018. Web. 6 Oct. 2020.
[86] Cushing, Lara et al. "Carbon Trading, Co-Pollutants, and Environmental Equity: Evidence from California's Cap-and-Trade Program (2011–2015)." Ed. Jonathan Patz. PLOS Medicine 15.7 (2018): e1002604. Web.
[87] Data from NASA's GRACE satellites show that the land ice sheets in both Antarctica and Greenland have been losing mass since 2002. Both ice sheets have seen an acceleration of ice mass loss since 2009: https://climate.nasa.gov.
[88] Marzeion, B., et al. (2018) Limited influence of climate change mitigation on short-term glacier mass loss, Nature Climate Change.
[89] Radić, V. and Hock, R. (2011) Regionally differentiated contribution of mountain glaciers and ice caps to future sea-level rise, Nature Geoscience, 4, 91-94.
[90] Zemp, M., et al. (2015) Historically unprecedented global glacier decline in the early 21st century. Journal of Glaciology; 61 (228): 745.
[91] Rignot, E., et al. (2011) Acceleration of the contribution of the Greenland and Antarctic ice sheets to sea level rise, Geophysical Research Letters, 38, L05503.
[92] Dutton, A., et al. (2015) Sea-level rise due to polar ice-sheet mass loss during past warm periods, Science, 10 Jul., v. 349, Is. 6244.
[93] USGCRP (2017)
[94] Marzeion et al. (2018)
[95] Zemp et al. (2015)
[96] Joughlin, I., et al. (2014) Marine ice sheet collapse potentially underway for the Thwaites Glacier Basin, West Antarctica, Science, May 12. Rignot, E., et al. (2014) Widespread, rapid grounding line retreat of Pine Island, Thwaites, Smith and Kohler glaciers, West Antarctica from 1992 to 2011, GRL.
[97] Golledge, N.R., et al. (2015) The multi-millennial Antarctic commitment to future sea-level rise, Nature, 526 (7573): 421 DOI: 10.1038/nature15706.
[98] Golledge et al. (2015)
[99] DeConto, R.M. and Pollard, D. (2016) Contribution of Antarctica to past and future sea-level rise, Nature, 531 (7596):591–597.
[100] Robinson, A., et al. (2012) Multistability and Critical Thresholds of the Greenland Ice Sheet, Nature Climate Change, 2, 429–432.
[101] Smith, S.J., et al. (2015) Near-term acceleration in the rate of temperature change, Nature Climate Change, March 9, DOI: 10.1038/nclimate2552.
[102] Hofer, S., et al. (2017) Decreasing cloud cover drives the recent mass loss on the Greenland ice sheet. Science Advances, 28 June, v. 3, no. 6, e1700584.
[103] Arctic Report Card: http://www.arctic.noaa.gov/Report-Card/Report-Card-2016. Serreze, M., et al. (2007) Perspectives on the Arctic's shrinking sea-ice cover, Science 315, 1533-1536.
[104] See http://nsidc.org/arcticseaicenews/.
[105] See http://www.arctic.noaa.gov/Report-Card/Report-Card-2016.
[106] Francis, J., and Skific, N. (2015) Evidence linking rapid Arctic warming to mid-latitude weather patterns, Phil. Trans. R. Soc. A, 373, 20140170.
[107] Fountain, A., et al. (2012) The disappearing cryosphere: Impacts and ecosystem responses to rapid cryosphere loss, BioScience 62(4), 405-415.
[108] Guirguis, K., et al. (2011) Recent warm and cold daily winter temperature extremes in the northern hemisphere, Geophysical Research Letters, 38, L17701.
[109] Déry, S. J. and Brown, R.D. (2007) Recent NH snow cover extent trends and implications for the snow albedo feedback, GRL, 34, L22504
[110] Thibault, S. and Payette, S. (2009) Recent permafrost degradation in bogs of the James Bay area, Northern Quebec, Canada, Permafrost and Periglacial Processes, 20(4), 383, doi: 10.1002/ppp.660.
[111] Kokelj, S.V., et al. (2017) Climate-driven thaw of permafrost preserved glacial landscapes, northwestern Canada, Geology, Feb. doi: 10.1130/G38626.1
[112] See Arctic Report Card, http://www.arctic.noaa.gov/Report-Card/Report-Card-2016
[113] Nerem, R.S., et al. (2018) Climate-change–driven accelerated sea-level rise detected in the altimeter era. PNAS, DOI: 10.1073/pnas.1717312115.
[114] Dangendorf, S, et al. (2017) Reassessment of 20th Century global mean sea level rise, PNAS, doi: 10.1073/pnas.1616007114
[115] Chen, X., et al. (2017) The increasing rate of global mean sea-level rise during 1993–2014, Nature Climate Change. DOI: 10.1038/nclimate3325
[116] Strauss, B.H. (2015) Rapid accumulation of committed sea level rise from global warming, PNAS, 110(34), 13699-13700.
[117] Rahmstorf, S., et al. (2015) Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation. Nature Climate Change.
[118] Levitus, S., et al. (2008) Global ocean heat content in light of recently revealed instrumentation problems, GRL, 36, L07608, doi: 10.1029/2008GL037155
[119] Wang, G., et al. (2017) Consensuses and discrepancies of basin-scale ocean heat content changes in different ocean analyses, Climate Dynamics.
[120] Cheng L., et al (2015) Global upper ocean heat content estimation: recent progress and the remaining challenges. Atmospheric and Oceanic Science Letters, 8. DOI:10.3878/AOSL20150031. Glecker, P.J., et al. (2016) Industrial era global ocean heat uptake doubles in recent decades. Nature Climate Change.
[121] Cheng, L., et al. (2017) Improved estimates of ocean heat content from 1960 to 2015, Science Advances 10 Mar., v. 3, no. 3, e1601545.
[122] Song, Y.T. and Colberg, F. (2011) Deep ocean warming assessed from altimeters, GRACE in situ measurements, and a non-Boussinesq ocean general circulation model, JGR 116, C02020. Volkov, D.L., et al. (2017) Decade-long deep-ocean warming detected in the subtropical South Pacific, GRL.
[123] Defforge, C.L. and Merlis, T.M. (2017) Observed warming trend in sea surface temperature at tropical cyclone genesis, GRL.
[124] Marra and Kruk (2017)
[125] Schmidtko, S., et al. (2017) Decline in global oceanic oxygen content during the past five decades, Nature, 542, 335-339, 16 February.
[126] S.E. Moffitt, et al. (2015) Response of seafloor ecosystems to abrupt global climate change. PNAS, 2015 DOI: 10.1073/pnas.1417130112.
[127] McCauley, D.J., et al. (2015) Marine defaunation: Animal loss in the global ocean, Science, 347(6219), 16, Jan. Henson, S.A., et al. (2017) Rapid emergence of climate change in environmental drivers of marine ecosystems, Nature Communications, 8, 14682, doi: 10.1038/ncomms14682.
[128] Ramírez, F., et al. (2017) Climate impacts on global hot spots of marine biodiversity. Science Advances; 3 (2): e1601198 DOI: 10.1126/sciadv.1601198.
[129] Heron, S.F., et al. (2016) Warming trends and bleaching stress of the worlds coral reefs 1985-2012, Scientific Reports, 6, 38402, doi: 10.1038/srep38402.
[130] Heron, S.F., et al. (2016)
[131] Hughes, T.P., et al. (2017) Global warming and recurrent mass bleaching of corals. Nature; 543 (7645): 373 DOI: 10.1038/nature21707.

[132] L. Stramma, et al. (2011) Expansion of Oxygen Minimum Zones May Reduce Available Habitat for Tropical Pelagic Fishes, Nature Climate Change 2: 33–37.
[133] Sekerci, Y. and Petrovskll (2015) Mathematical modeling of Plankton-Oxygen dynamics under the climate change. Bulletin of Mathematical Biology.
[134] Barton, A., et al. (2012) The Pacific oyster, Crassostrea gigas, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects, Limnology and Oceanography 57(3), 698-710, doi: 10.4319/lo.2012.57.3.0698.
[135] Heron, S.F., et al. (2016) Warming trends and bleaching stress of the worlds coral reefs 1985-2012, Scientific Reports, 6, DOI:10.1038/srep38402
[136] Yates, K. K., Zawada, D. G., Smiley, N. A., and Tiling-Range, G. (2017) Divergence of seafloor elevation and sea level rise in coral reef ecosystems, Biogeosciences, 14, 1739-1772, https://doi.org/10.5194/bg-14-1739-2017.
[137] Keener, V., et al. (2018)
[138] Cheng, L., et al. (2020) Record-Setting Ocean Warmth Continued in 2019. Adv. Atmos. Sci. 37, 137–142. https://doi.org/10.1007/s00376-020-9283-7
[139] Amaya, D.J., et al. (2020)
[140] "Facts + Statistics: Wildfires | III." Iii.org. N.p., 2019. Web. 29 Sept. 2020. https://www.iii.org/fact-statistic/facts-statistics-wildfires#:~:text=2017%3A%20In%202017%20there%20were,than%20the%2010%2Dyear%20average.
[141] "Facts + Statistics: Wildfires | III." Iii.org. N.p., 2019. Web. 29 Sept. 2020. https://www.iii.org/fact-statistic/facts-statistics-wildfires#:~:text=2017%3A%20In%202017%20there%20were,than%20the%2010%2Dyear%20average..
[142] "Facts + Statistics: Wildfires | III." Iii.org. N.p., 2019. Web. 29 Sept. 2020. https://www.iii.org/fact-statistic/facts-statistics-wildfires#:~:text=2017%3A%20In%202017%20there%20were,than%20the%2010%2Dyear%20average..
[143] Service, Forest. "August Complex Information - InciWeb the Incident Information System." Nwcg.gov. N.p., 2020. Web. 29 Sept. 2020. https://inciweb.nwcg.gov/incident/6983/
[144] Suzanne Espinosa Solis. "One Firefighter Killed in Mendocino County Wildfire, Second Firefighter Injured." SFChronicle.com. San Francisco Chronicle, Sept. 2020. Web. 29 Sept. 2020. https://www.sfchronicle.com/california-wildfires/article/One-firefighter-killed-in-Mendocino-County-15529229.php
[145] "2020 Oregon Wildfire Spotlight." ArcGIS StoryMaps. Esri, 11 Sept. 2020. Web. 6 Oct. 2020.
[146] Marlon, J. R. et al. "Long-Term Perspective on Wildfires in the Western USA." Proceedings of the National Academy of Sciences 109.9 (2012): E535–E543. Web. 6 Oct. 2020.
[147] "Factcheck: How Global Warming Has Increased US Wildfires | Carbon Brief." Carbon Brief. N.p., 9 Aug. 2018. Web. 29 Sept. 2020. https://www.carbonbrief.org/factcheck-how-global-warming-has-increased-us-wildfires
[148] Abatzoglou, John T., and A. Park Williams. "Impact of Anthropogenic Climate Change on Wildfire across Western US Forests." Proceedings of the National Academy of Sciences 113.42 (2016): 11770–11775. Web. 29 Sept. 2020. https://www.pnas.org/content/113/42/11770
[149] Just, in. "A Look at Two Decades of Wildfires Globally in Just 30 Seconds." Yale E360. N.p., 2019. Web. 6 Oct. 2020.
[150] Pechony, O., and D. T. Shindell. "Driving Forces of Global Wildfires over the Past Millennium and the Forthcoming Century." Proceedings of the National Academy of Sciences 107.45 (2010): 19167–19170. Web. 6 Oct. 2020.
[151] Levin, Sam. "Oregon Prisoners Evacuated Due to Fires Are Being Pepper Sprayed by Guards." the Guardian. The Guardian, 14 Sept. 2020. Web. 6 Oct. 2020.
[152] Chapman, Isabelle. "An Inmate Firefighter Crew Works in Los Angeles' Pacific Palisades Neighborhood in October." CNN. N.p., 31 Oct. 2019. Web. 6 Oct. 2020.
[153] State Energy Data System (SEDS) 1960-2015. https://www.eia.gov/state/seds/seds-data-complete.php?sid=HI#CompleteDataFile
[154] State Carbon Dioxide Emissions Data. https://www.eia.gov/environment/emissions/state/
U.S. Department of Commerce, Census Bureau. https://www.census.gov/programs-surveys/popest/data/tables.html
[155] CO2 emissions (metric tons per capita). https://data.worldbank.org/indicator/EN.ATM.CO2E.PC?year_high_desc=false
[156] Hawaii Greenhouse Gas Emissions Report for 2016 Final Report. N.p., 2019. Web. https://health.hawaii.gov/cab/files/2019/12/2016-Inventory_Final Report_December2019-1.pdf
[157] Hawaii Greenhouse Gas Emissions Report for 2016 Final Report. N.p., 2019. Web. https://health.hawaii.gov/cab/files/2019/12/2016-Inventory_Final Report_December2019-1.pdf
[158] State Carbon Dioxide Emissions Data. https://www.eia.gov/environment/emissions/state/
[159] Renewable Portfolio Standards Law Examination, Docket No. 2007-0008. https://puc.hawaii.gov/wp-content/uploads/2018/02/RPS-HECO-2017.pdf
[160] Hawaii Greenhouse Gas Emissions Report for 2016 Final Report. N.p., 2019. Web. https://health.hawaii.gov/cab/files/2019/12/2016-Inventory_Final Report_December2019-1.pdf
[161] Giambelluca, T.W., et al. (2008) Secular Temperature Changes in Hawai'i, Geophysical Research Letters, 35:L12702.
[162] McKenzie, M.M. (2016) Regional temperature trends in Hawai'i: A century of change, 1916–2015 (MS thesis). Dept. of Geog., University of Hawai'i at Mānoa.
[163] See for example: University of Hawai'i Sea Grant College Program (2014) Climate Change Impacts in Hawai'i - A summary of climate change and its impacts to Hawai'i's ecosystems and communities. UNIHI-SEAGRANT-TT-12-04.
[164] New York Times weather chart: https://www.nytimes.com/interactive/2016/02/19/us/2015-year-in-weather-temperature-precipitation.html#honolulu_hi.
[165] http://www.hawaiinewsnow.com/story/26551141/hawaiian-electric-asks-oahu-customers-to-conserve-power-tonight
[166] Zhang, C., et al. (2016) Dynamical downscaling of the climate for the Hawaiian Islands. Part II: Projection for the late twenty-first century, Journal of Climate 29: 8333–8354. doi:10.1175/JCLI-D-16-0038.1.
[167] Timm, O.E. (2017) Future Warming Rates over the Hawaiian Islands Based on Elevation-Dependent Scaling Factors. Int. J. Clim., doi:10.1002/joc.5065.
[168] Washington Post, Hawaii goes 20 days in a row setting a heat record during its hottest summer ever: https://www.pennlive.com/nation-world/2019/09/hawaii-goes-20-days-in-a-row-setting-a-heat-record-during-its-hottest-summer-ever.html
[169] Amaya, D.J., et al. (2020) Physical drivers of the summer 2019 North Pacific marine heatwave. Nature Communications; 11 (1) DOI: 10.1038/s41467-020-15820-w
[170] Jacobi, J.D., et al. (2017) Baseline land cover. In Selmants, P.C., et al., eds., USGS, http://pubs.er.usgs.gov/publication/pp1834.
[171] Fortini, L., et al. (2015) Large-scale range collapse of HI forest birds under CC and the need 21st century conservation options. PLoS ONE, 10.
[172] Paxton, E.H., et al. (2016) Collapsing avian community on a Hawaiian island. Science Advances, 2, e1600029.
[173] Leung, Pingsun, and Matthew Loke. Economic Issues Economic Impacts of Increasing Hawai'i's Food Self-Sufficiency. N.p., 2008. Web. 13 Oct. 2020.
[174] "Critical Systems: Vulnerabilities Overview." State of Hawai'i Department of Defense, 8 Mar. 2018, dod.hawaii.gov/hiema/files/2018/04/HI_EMA-vulnerability-presentation.pdf.
[175] "(PDF) The Potential of Indigenous Agricultural Food Production under Climate Change in Hawai'i." ResearchGate (2019): n. pag. Web. 13 Oct. 2020.
[176] "Investigating Measures of Social Context on 2 Population-Based Health Surveys, Hawaii, 2010–2012." N.p., 2020. Web. 13 Oct. 2020.
[177] "(PDF) The Potential of Indigenous Agricultural Food Production under Climate Change in Hawai'i." ResearchGate (2019): n. pag. Web. 13 Oct. 2020.
[178] "(PDF) The Potential of Indigenous Agricultural Food Production under Climate Change in Hawai'i." ResearchGate (2019): n. pag. Web. 13 Oct. 2020.

[179] "Study Examines Indigenous Agriculture, How It Could Help State Food Problems | Hawaii Tribune-Herald." Hawaii Tribune-Herald. N.p., 11 Mar. 2019. Web. 6 Oct. 2020.

[180] Hawaii Greenhouse Gas Emissions Report for 2016 Final Report. N.p., 2019. Web.

[181] Sproat, D. Kapua'ala. "An Indigenous People's Right to Environmental Self-Determination: Native Hawaiians and the Struggle against Climate Change Devastation." Stanford Environmental Law Journal, vol. 35, no. 2, 2016, p. 157-222. HeinOnline, https://heinonline.org/HOL/P?h=hein.journals/staev35&i=194.

[182] Hawaiʻi Climate Change Mitigation and Adaptation Commission (2017).

[183] Sproat, D. K. (2016) An Indigenous People's Right to Environmental Self-Determination: Native Hawaiians and the Struggle Against Climate Change Devastation. Stanford Environmental Law Journal, 35.

[184] Akutagawa, M., et al. (2016) Health Impact Assessment of the Proposed Moʻomomi Community-Based Subsistence Fishing Area (Report). The Kohala Center.

[185] Gillett, R., et al. (2001) Tuna: a key economic resource in the Pacific Islands. Pacific studies series. Manila, Philippines: Asian Development Bank.

[186] Keener et al. (in review, 2018)

[187] Sproat (2016)

[188] Hawaii State DBEDT "Selected Racial Characteristics Report" 2018.

[189] Marra, J.J., and Kruk, M.C. (2017) State of Environmental Conditions in Hawaiʻi and the U.S. Affiliated Pacific Islands under a Changing Climate: https://coralreefwatch.noaa.gov/satellite/publications/state_of_the_environment_2017_hawaii-usapi_noaa-nesdis-ncei_oct2017.pdf.

[190] Marra and Kruk (2017)

[191] Storlazzi, C.D., et al. (2015). Future wave and wind proj. for US and US-API, USGS OFR No. 2015–1001, http://dx.doi.org/10.3133/ ofr20151001.

[192] Frazier, A.G. and Giambelluca, T.W. (2017) Spatial trend analysis of HI rainfall from 1920 to 2012. Int. J. Climatol, 37: 2522-2531, DOI: 10.1002/joc.4862.

[193] Frazier and Giambelluca (2017)

[194] Kruk, M. C., et al. (2015), On the state of the knowledge of rainfall extremes in the western and northern Pacific basin, Int. J. Climatol., 35(3), 321–336.

[195] Kruk et al. (2015)

[196] Chen, Y. R., P.-S. Chu (2014) Trends in precipitation extremes and return levels in the Hawaiian Islands under a changing climate. Int. J. Climatol, 34, 3913-3925.

[197] Chen, Y. R., P.-S. Chu (2014)

[198] PIRCA (2016) Expert Consensus on Downscaled Climate Projections for the Main Hawaiian Islands. PIRCA Information Sheet, HI. http://bit.ly/2yoY0Il.

[199] Zhang et al (2016)

[200] Timm, O.E., et al. (2015), Stat. downscaling of rainfall changes in HI, based on CMIP5 model proj., JGR Atmos, 120(1), 92–112, doi:10.1002/2014JD022059.

[201] Zhang et al (2016)

[202] Murakami, H., et al. (2013) Projected increase in tropical cyclones near Hawaiʻi. Nature Climate Change, v. 3, August, pp. 749-754.

[203] Sharmila, S., and Walsh, K.J.E. (2018) Recent poleward shift of tropical cyclone formation linked to Hadley cell expansion. Nature Clim Change 8, 730–736. https://doi.org/10.1038/s41558-018-0227-5

[204] Kossin, J.P., et al. (2020) Global increase in major tropical cyclone exceedance probability over the past four decades. PNAS, DOI: 10.1073/pnas.1920849117

[205] Murakami, H., Wang, B., Li, T. et al. (2013) Projected increase in tropical cyclones near Hawaii. Nature Clim Change 3, 749–754. https://doi.org/10.1038/nclimate1890

[206] Kossin, J., Emanuel, K. & Vecchi, G. (2014) The poleward migration of the location of tropical cyclone maximum intensity. Nature 509, 349–352. https://doi.org/10.1038/nature13278

[207] Global Warming and Hurricanes, an Overview of Research Results (2020) Geophysical Fluid Dynamics Laboratory, Princeton University, NOAA: https://www.gfdl.noaa.gov/global-warming-and-hurricanes/

[208] Global Warming and Hurricanes, an Overview of Research Results (2020)

[209] Global Warming and Hurricanes, an Overview of Research Results (2020)

[210] Global Warming and Hurricanes, an Overview of Research Results (2020)

[211] Global Warming and Hurricanes, an Overview of Research Results (2020)

[212] Grinsted, A., et al. (2019) Normalized US hurricane damage estimates using area of total destruction: 1900-2018; PNAS: http://dx.doi.org/10.1073/pnas.1912277116

[213] Global Warming and Hurricanes, an Overview of Research Results (2020)

[214] Kossin, J.P. Reply to: Moon, I.-J. et al.; Lanzante, J. R.. Nature 570, E16–E22 (2019). https://doi.org/10.1038/s41586-019-1224-1

[215] Zhang, G., et al. (2020) Tropical Cyclone Motion in a Changing Climate, Science Advances, DOI: 10.1126/sciadv.aaz7610

[216] Bassiouni, M., and D. S. Oki (2013) Trends and shifts in streamflow in Hawaiʻi, 1913–2008. Hydrological Processes, 27 (10), 1484–1500. doi:10.1002/hyp.9298

[217] Oki, D. S., et al. (1999) Hawaii. Ground Water Atlas of the United States, Segment 13, Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands. Miller, J. A., et al., Eds., U.S. Geological Survey, Reston, VA, N12–N22, N36.

[218] Marra and Kruk (2017)

[219] Marra and Kruk (2017)

[220] Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report (2017) Tetra Tech, Inc. and the State of Hawaiʻi DLNR, OCCL, DLNR Contract No: 64064.

[221] Marra and Kruk (2017)

[222] Fletcher, C.H., et al. (2012) National Assessment of Shoreline Change: Historical shoreline change in the Hawaiian Islands. USGS OFR 2011-1051, 55p.

[223] Romine, B.M., et al. (2013) Are beach erosion rates and sea-level rise related in Hawaii? Global and Planetary Change, 108: 149-157.

[224] Romine, B.M. and Fletcher, C.H. (2012) Armoring on eroding coasts leads to beach narrowing and loss on Oʻahu, HI. DOI 10.1007/978-94-007-4123-2_10.

[225] Fletcher et al. (2012)

[226] Marra and Kruk (2017)

[227] Marra and Kruk (2017)

[228] Marra and Kruk (2017)

[229] Van Hooidonk, R., et al. (2014) Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs. Global Change Biology, 20.

[230] Marra and Kruk (2017)

[231] Trauernicht, C., E. et al. 2015 The contemporary scale and context of wildfire in Hawaii. Pacific Science 69:427-444

[232] Trauernicht, C., et al. (2015) The Contemporary Scale and Context of Wildfire in Hawaiʻi. Pacific Science, v. 69, no 4, October, pp. 427–444. https://doi.org/10.2984/69.4.1; Trauernicht, Clay, & Elizabeth Pickett (2016) Pre-fire planning guide for resource managers and landowners in Hawaiʻi and Pacific

Islands, Forest and Natural Resource Management, College of Tropical Agriculture and Human Resources, https://www.ctahr.hawaii.edu/oc/freepubs/pdf/RM-20.pdf.
[233] Restoration of Forest Key to Fire Control, Feb. 12 (2019) https://www.hawaiiwildfire.org/news-center/tag/Maui+%28West%29
[234] Dr. Clay Trauernicht, wildland fire specialist Univ. of HI at Mānoa: https://www.nrem-fire.org/clay-trauernicht
[235] El Niño and Long-Lead Fire Weather Prediction for Hawaii and US-affiliated Pacific Islands PFX Fact Sheet 201 5_1. N.p. Web. 13 Oct. 2020.