Climate Change Commission

CITY AND COUNTY OF HONOLULU

650 South King Street, 9th Floor • Honolulu, HI 96813

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AGENDA

Tuesday, May 8, 2018
3:00 p.m.
Council Committee Room, 2nd Floor, Honolulu Hale
530 South King Street
Honolulu, HI 96813

1. Call to Order
2. Roll Call
3. Approval of the Meeting Minutes: April 19, 2018
4. Report on Activities of the Office of Climate Change, Sustainability and Resiliency
5. Presentation on the International Council on Clean Transportation (ICCT) Study by Mark Glick, Hawai‘i Natural Energy Institute
6. Discussion with the Honolulu Authority on Rapid Transportation on Matters Relating to Activities of the Climate Change Commission
7. Discussion and Action/Adoption of the draft Climate Change Brief
8. Discussion and Action/Adoption of the draft Sea Level Rise Guidance
9. Public Input for Matters Not on the Agenda
10. Next Meeting
11. Announcements
12. Adjournment

A mailing list is maintained for interested persons and agencies to receive this commission’s agenda and minutes. Additions, corrections, and deletions to the mailing list may be directed to the Office of Climate Change, Sustainability and Resiliency (CCSR) at Fasi Municipal Building, 9th Floor, 650 South King Street, Honolulu, Hawaii 96813; Telephone: (808) 768-2277 Fax: (808) 768-4242. Agendas and minutes are also available online at www.resilientoahu.org.

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CLIMATE CHANGE BRIEF, 2018

C. Fletcher, PhD, University of Hawaiʻi at Mānoa, School of Ocean and Earth Science and Technology
fletcher@soest.hawaii.edu

Excess heat, trapped by anthropogenic greenhouse gases in the atmosphere, is causing dramatic changes in ecosystems, weather patterns, and other climate-dependent aspects of Earth's surface.

Scientists are warning that human population growth, widespread destruction of natural ecosystems, and global warming are pushing Earth's ecosystems and resources toward irreversible damage[1] and that we are in the midst of Earth's sixth mass extinction.[2]

Unrelenting impacts to Earth's ecosystems[3] and natural resources have led researchers to conclude that our planet is perched on the edge of a tipping point, a planetary-scale critical transition resulting from human impacts.[4] These changes include the following.

CARBON DIOXIDE

- Carbon dioxide levels in the air have passed 400 ppm compared to a natural level of 280 ppm – an increase of over 40%. This is the highest level in millions of years.[5]
- 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.[6]

TEMPERATURE

- Global temperature has risen approximately 1°C (1.8°F) from the late 19th Century.[7]
- The likely range of global temperature increase is 2.0–4.9°C, with median 3.2°C (5.76°F) and a 5% (1%) chance that it will be less than 2°C (1.5°C).[8]
- The last time it was this warm was during the last interglacial (ca. 125,0000 years ago) when global mean sea level was 6.6 m (20 feet) above present.[9]
- Atmospheric humidity is rising.[10]
- The global water cycle has accelerated.[11]
- Air temperature over the oceans is rising.[12]

ICE

- Greenland is losing ~286 billion tons of ice annually, Antarctica is losing ~127 tons, and alpine glaciers are losing over 200 billion tons of ice annually.[13, 14, 15]
- West Antarctic ice sheet is in "unstoppable" retreat.[16]
- Melting on Greenland has accelerated.[17]
- 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.[18]
- 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.[19]
- Continental ice sheets are shrinking.[20]
- Arctic sea ice is shrinking (13% per decade) as a result of global warming.[21]
- Winter Arctic sea ice was the lowest on record in 2017.[22]
- 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.[23]
- Rapid warming in the Arctic is causing the jet stream to slow and develop large planetary waves.[24]
- Regions of Earth where water is frozen for at least one month each year are shrinking with impacts on related ecosystems.[25]
- Extreme warm events in winter are much more prevalent than cold events.[26]
- Global snow cover is shrinking.[27]
- The southern boundary of Northern Hemisphere permafrost is retreating poleward.[28]
- 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.[29]
- In North America, spring snow cover extent in the Arctic is the lowest in the satellite record, which started in 1967.[30]

OCEANS

- The Atlantic Meridional Overturning Circulation has decreased 20%. The North Atlantic has the coldest water in 100 yrs of observations.[31]
- Air temperature over the oceans is rising.[32]

- Sea surface temperature is rising.[33]
- The oceans are warming rapidly.[34]
- Sea level is rising and the rate of rise has accelerated.[35]
- Today global mean sea level is rising three times faster than it was in the 20th Century.[36]
- 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.[37]
- We have already committed to a long-term future sea level 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.[38]
- Over 90 percent 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 only 18 years ago.[39]
- Excess heat in the oceans has reached deeper waters,[40] and deep ocean temperature is rising.[41]
- Sea surface temperatures have increased in areas of tropical cyclone genesis suggesting a connection with strengthened storminess.[42]
- 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.[43]
- Marine ecosystems can take thousands, rather than hundreds, of years to recover from climate-related upheavals.[44]
- Marine ecosystems are under extreme stress.[45]
- The world's richest areas for marine biodiversity are also those areas mostly affected by both climate change and industrial fishing.[46]
- The number of coral reefs impacted by bleaching has tripled over the period 1985-2012.[47]
- By 2050 more than 98% of coral reefs will be afflicted by bleaching-level thermal stress each year.[48]
- 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.[49]
- Average pH of ocean water fell from 8.21 to 8.10, a 30 percent increase in acidity. Ocean water is more acidic from dissolved CO_2, which is negatively affecting marine organisms.[50]
- Dissolved oxygen in the oceans is declining because of warmer water.[51]
- Production of oxygen by photosynthetic marine algae is threatened at higher temperatures.[52]

EXTREME WEATHER

- The global percentage of land area in drought has increased about 10%.[53]
- The global occurrence of extreme rainfall has increased 12%.[54]
- Heavy downpours are more intense and frequent.[55]
- Extreme weather events are more frequent.[56]
- Half a degree Celsius of global warming has been enough to increase heat waves and heavy rains in many regions of the planet.[57]
- Storm tracks are shifting poleward.[58]
- The number of weather disasters is up 14% since 1995-2004, and has doubled since 1985-1994.[59]
- In Australia, record setting hot days outnumber record setting cold days by a factor of 12 to 1.[60]
- Extreme heat waves are projected to cover double the amount of global land by 2020 and quadruple by 2040, regardless of future emissions trends.[61]
- 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.[62]
- Nine of the ten deadliest heat waves have occurred since 2000 causing 128,885 deaths around the world.[63]
- Nearly one third of the world's population is now exposed to climatic conditions that produce deadly heat waves.[64]
- Atmospheric humidity is rising.[65]
- The global water cycle has accelerated.[66]
- Extreme weather is increasing.[67]
- If global temperatures rise 2°C (3.6°F), the combined effect of heat and humidity will turn summer into one long heat wave. Temperature will exceed 104°F every year in many parts of Asia, Australia, Northern Africa, South and North America.[68]
- If global temperatures rise 4°C (7.2°F), 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.[69]

ECOSYSTEMS, FOOD, AND HUMAN HEALTH

- Humans are causing the climate to change 170 times faster than natural forces.[70]
- Tree lines are shifting poleward and to higher elevations.[71]
- Species are migrating poleward and to higher elevations.[72]
- 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.[73]
- Air temperature over land is rising.[74]
- Global wind speed has accelerated.[75]
- Spring is coming earlier.[76]
- The lower atmosphere (troposphere) is warming.[77]
- The tropics have expanded.[78]
- 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).[79]
- Plants are leafing out and blooming earlier each year.[80]
- Climate-related local extinctions have already occurred in hundreds of species, including 47% of 976 species surveyed.[81]
- Plant and animal extinctions, already widespread, are projected to increase from twofold to fivefold in the coming decades.[82]
- Rising CO_2 decreases the nutrient and protein content of wheat, leading to a 15% decline in yield by mid-century.[83]
- 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.[84]
- 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.[85]
- Certain groups of Americans—including children, elders, the sick and the poor—are most likely to be harmed by climate change.[86]
- Climate change is harming human health now. These harms include heat-related illness, worsening chronic illnesses, injuries and deaths from dangerous weather events, infectious diseases spread by mosquitoes and ticks, illnesses from contaminated food and water, and mental health problems.[87]
- Global warming is changing life on Earth on a global scale.[88]

Summary

According to Raftery et al. (2017) the likely (66%) range of global temperature increase over this century will be 2.0–4.9°C, with a median 3.2°C and a 5% (1%) chance that it will be less than 2°C (1.5°C).

What will this >3°C world look like?

- A global scale refugee crisis develops, as large parts of tropical continents become no longer habitable;
- Heat waves every summer in the middle latitudes that render the outdoors intolerable;
- Massive wildfires;
- Sea level, 10-15 m (30-50 ft), that will continue rising over many centuries;
- By 2050 wheat demand increases 60%, while actual yield decreases 15%;
- By 2100, 50% more people to feed, 50% less grain to give them;
- Among the world's major aquifers, 21 out of 37 are receding, from India and China to the United States and France;
- Extreme weather disasters, massive floods, heat waves, great tropical cyclones, mega-drought, and torrential rainfall will be widespread.

Ironically, with the ongoing global revolution in clean power, all this suffering and dystopia will be taking place in a world of solar panels, wind mills, electric cars, and cleaner air.

Hawai'i

With respect to Hawaii, heat stress to human communities will grow. Coral bleaching will be severe, probably resulting in the complete loss of many reefs and the fish they support. Rising sea level will erode the coast and flood urban areas. Seasonal waves and rising groundwater will flood coastal communities with growing frequency. Future rainfall is uncertain but is likely to change.[89] The number of extreme wet days will increase. Exposure to tropical cyclones and hurricanes will increase, and they are likely to be stronger storms. Strong El Niño years will be more frequent bringing more hot days, intense rains, windless days, and spikes in sea surface temperature.

Global Outlook

The U.S. Energy Information Administration forecasts global energy use to the year 2040. They project the following patterns: coal sustaining a 20-year-long plateau, natural gas plentiful and growing, carbon-free wind and solar growing rapidly in percentage terms but not fast enough to bring emissions down in absolute terms, and petroleum holding its own as the main source of energy for transportation, despite the arrival of electric vehicles.[90]

With populations growing and developing nations getting richer, total energy consumption will keep climbing despite gains in energy efficiency. Fossil fuels will hold a 77% market share, and as a result greenhouse gas emission will increase in parallel. The EIA (2017) projects worldwide emissions of carbon dioxide from the burning of fossil fuels will grow 16% by the year 2040. This is far away from the necessary 50% decrease per decade[91] necessary to meet the Paris Agreement target of 2°C (**Figure 1**).

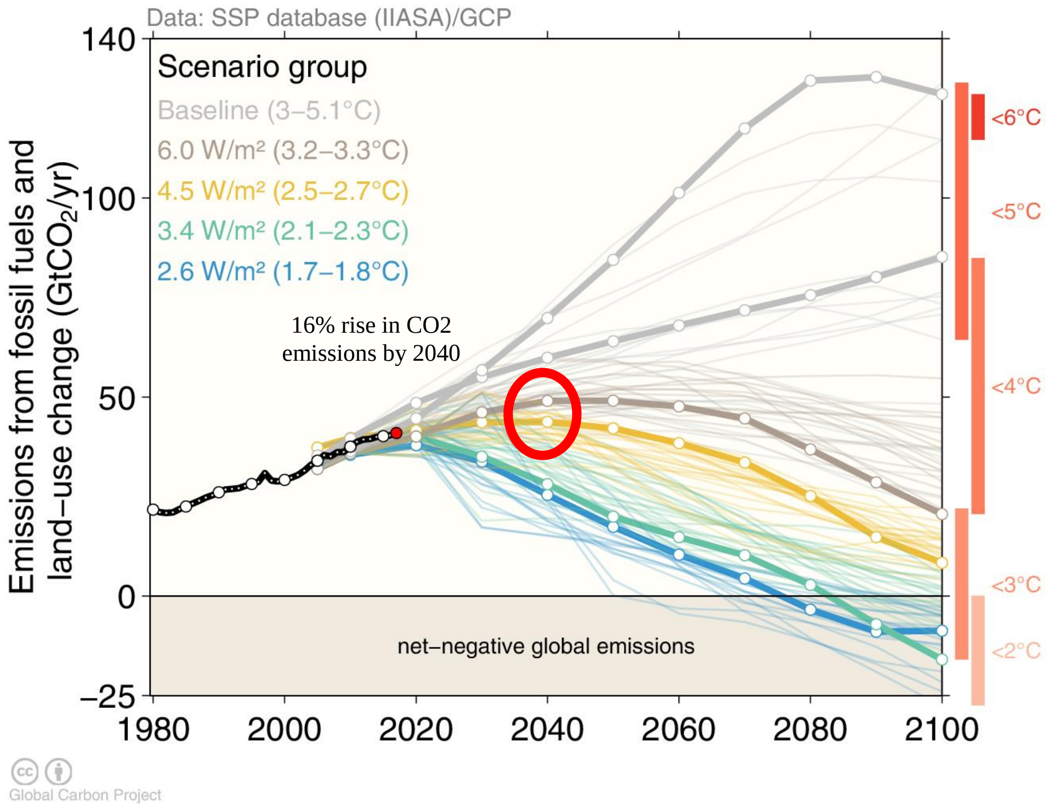

Figure 1. The EIA (2017) forecasts a 16% rise in carbon dioxide emissions by 2040 (red circle). This is consistent with warming to 3 to 4°C by the end of the century. According to the Intergovernmental Panel on Climate Change (IPCC, 2013), the only pathway to stabilizing warming at 2°C is to employ negative emissions in the second half of the century (Global Carbon Project, 2017).

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[1] Biologists Say Half of All Species Could be Extinct by End of the Century: https://www.theguardian.com/environment/2017/feb/25/half-all-species-extinct-end-century-vatican-conference

[2] Barnosky, A.D., et al. (2011) Has the Earth's sixth mass extinction already arrived? *Nature*, 471, 51-57 (03 March).

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[3] Ullah, H., et al. (2018) Climate change could drive marine food web collapse through altered trophic flows and cyanobacterial proliferation**.** *PLOS Biology*; 16 (1): e2003446 DOI: 10.1371/journal.pbio.2003446

[4] Barnosky, A.D., et al. (2012) Approaching a state shift in Earth's biosphere, *Nature*, 486, 7 June, 52-58.

[5] Tripati, A.K., et al. (2009) Coupling of CO_2 and ice sheet stability over major climate transitions of the last 20 million years, *Science*, 326(5958), 1394-1397, http://www.sciencemag.org/cgi/content/abstract/1178296

[6] Zeebe, R.E., et al. (2016) Anthropogenic carbon release rate unprecedented during the past 66 million years, *Nature Geoscience*, doi: 10.1038/ngeo2681

[7] Haustein, K. et al. (2017) A global warming index. *Nature Scientific Reports*, doi:10.1038/s41598-017-14828-5

[8] Raftery, A.E., et al. (2017) Less than 2oC warming by 2100 unlikely, *Nature Climate Change*, PUBLISHED ONLINE: 31 JULY 2017 | DOI: 10.1038/NCLIMATE3352

[9] Hoffman, J.S., et al. (2017) Regional and global sea surface temperatures during the last interglaciation, *Science*, 355(6322), 276-279, doi: 10.1126/science.aai8464

[10] Willett, K., et al. (2007) Attribution of observed surface humidity changes to human influence, *Nature,* 449, 710-712, doi: 10.1038/nature06207

[11] Durack, P., et al. (2012) Ocean salinities Reveal strong global water cycle intensification during 1950 to 2000, *Science*, 336(6080), 455-458, *doi:* 10.1126/science.1212222

[12] 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/

[13] 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, doi: 10.1038/ngeo1052

[14] Zemp, M., et al. (2015) Historically unprecedented global glacier decline in the early 21st century. *Journal of Glaciology*; 61 (228): 745 DOI: 10.3189/2015JoG15J017

[15] 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, doi: 10.1029/2011GL046583

[16] 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, *Geophysical Research Letters*.

[17] B. Wouters, et al. (2013) Limits in detecting acceleration of ice sheet mass loss due to climate variability. *Nat. Geosci*. 6, 613–616 (2013).

[18] 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, DOI: 10.1126/sciadv.1700584

[19] Zemp, M., et al. (2015) Historically unprecedented global glacier decline in the early 21st century. *Journal of Glaciology*; 61 (228): 745 DOI: 10.3189/2015JoG15J017

[20] Rignot, E., et al. (2011)

[21] 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.

[22] See http://nsidc.org/arcticseaicenews/

[23] See http://www.arctic.noaa.gov/Report-Card/Report-Card-2016

[24] Francis, J., and Skific, N. (2015) Evidence linking rapid Arctic warming to mid-latitude weather patterns, *Phil. Trans. R. Soc. A* 373, 20140170, http://dx.doi.org/10.1098/rsta.2014.0170

[25] Fountain, A., et al. (2012) The disappearing cryosphere: Impacts and ecosystem responses to rapid cryosphere loss, *BioScience* 62(4), 405-415, doi: 10.1525/bio.2012.62.4.11

[26] Guirguis, K., et al. (2011) Recent warm and cold daily winter temperature extremes in the northern hemisphere, *Geophysical Research Letters*, 38, L17701, doi: 10.1029/2011GL048762

[27] Déry, S. J. and Brown, R.D. (2007) Recent northern hemisphere snow cover extent trends and implications for the snow albedo feedback, *Geophysical Research Letters*, 34, L22504

[28] 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.

[29] Kokelj, S.V., et al. (2017) Climate-driven thaw of permafrost preserved glacial landscapes, northwestern Canada, *Geology*, Feb. doi: 10.1130/G38626.1

[30] See Arctic Report Card, http://www.arctic.noaa.gov/Report-Card/Report-Card-2016

[31] Rahmstorf, S., et al. (2015) Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation. *Nature Climate Change*. DOI: 10.1038/nclimate2554

[32] 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/

[33] Levitus, S., et al. (2008) Global ocean heat content in light of recently revealed instrumentation problems, *Geophysical Research Letters*, 36, L07608, doi: 10.1029/2008GL037155

[34] Wang, G., et al. (2017) Consensuses and discrepancies of basin-scale ocean heat content changes in different ocean analyses, *Climate Dynamics*. DOI: 10.1007/s00382-017-3751-5

[35] Nerem, R.S., et al. (2018) Climate-change–driven accelerated sea-level rise detected in the altimeter era**.** *Proceedings of the National Academy of Science*, DOI: 10.1073/pnas.1717312115

[36] Dangendorf, S, et al. (2017) Reassessment of 20th Century global mean sea level rise, *Proceedings of the National Academy of Sciences*, doi: 10.1073/pnas.1616007114

[37] Chen, X., et al. (2017) The increasing rate of global mean sea-level rise during 1993–2014, *Nature Climate Change*. DOI: 10.1038/nclimate3325

[38] Strauss, B.H. (2015) Rapid accumulation of committed sea level rise from global warming, *PNAS*, 110(34), 13699-13700.

[39] 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*. doi:10.1038/nclimate2915

[40] Cheng, L., et al. (2017) Improved estimates of ocean heat content from 1960 to 2015, *Science Advances* 10 Mar., v. 3, no. 3, e1601545, DOI: 10.1126/sciadv.1601545

[41] Song, Y.T. and Colberg, F. (2011) Deep ocean warming assessed from altimeters, gravity recovery and climate experiment, in situ measurements, and a non-Boussinesq ocean general circulation model, *Journal of Geophysical Research* 116, C02020, doi: 10.1029/2010JC006601. Volkov, D.L., et al. (2017) Decade-long deep-ocean warming detected in the subtropical South Pacific, *Geophysical Research Letters*, doi: 10.1002/2016GL071661

[42] Defforge, C.L. and Merlis, T.M. (2017) Observed warming trend in sea surface temperature at tropical cyclone genesis, *Geophysical Research Letters*, doi: 10.1002/2016GL071045

[43] Schmidtko, S., et al. (2017) Decline in global oceanic oxygen content during the past five decades, *Nature*, 542, 335-339, 16 February 2017, doi: 10.1038/nature21399

[44] S.E. Moffitt, et al. (2015) Response of seafloor ecosystems to abrupt global climate change. *PNAS*, 2015 DOI: 10.1073/pnas.1417130112

[45] McCauley, D.J., et al. (2015) Marine defaunation: Animal loss in the global ocean, *Science,* 347(6219), 16, Jan, doi: 10.1126/science.1255641. 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.

[46] Ramírez, F., et al. (2017) Climate impacts on global hot spots of marine biodiversity. *Science Advances*; 3 (2): e1601198 DOI: 10.1126/sciadv.1601198

[47] 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.

[48] Heron, S.F., et al. (2016)

[49] Hughes, T.P., et al. (2017) Global warming and recurrent mass bleaching of corals. *Nature*; 543 (7645): 373 DOI: 10.1038/nature21707

[50] 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.

[51] L. Stramma, et al. (2011) Expansion of Oxygen Minimum Zones May Reduce Available Habitat for Tropical Pelagic Fishes, *Nature Climate Change* 2: 33–37, doi: 10.1038/nclimate1304.

[52] Sekerci, Y. and Petrovskll (2015) Mathematical modeling of Plankton-Oxygen dynamics under the climate change. *Bulletin of Mathematical Biology*: DOI 10.1007/sl11538-015-0126-0

[53] Dai, A. (2011) Characteristics and trends in various forms of the Palmer drought severity index during 1900–2008, *Journal of Geophysical Research* 116, D12115, doi: 10.1029/2010JD015541

---

[54] Lehmann, J., et al. (2015) Increased record-breaking precipitation events under global warming. *Climatic Change*, doi: 10.1007/s10584-015-1434-y

[55] See NOAA, https://www.climate.gov/news-features/featured-images/heavy-downpours-more-intense-frequent-warmer-world

[56] 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, doi: 10.1175/2011JCLI4115.1

[57] Schleussner, C-F, et al. (2017) In the observational record half a degree matters, *Nature Climate Change*. DOI: 10.1038/nclimate3320

[58] Bender, F. A-M, et al. (2012) Changes in extratropical storm track cloudiness 1983–2008: Observational support for a poleward shift, *Climate Dynamics* 38, 2037-2053, doi: 10.1007/s0038-011-1065-6

[59] 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

[60] Lewis, S.C. and King, A.D. (2015) Dramatically increased rate of observed hot record breaking in recent Australian temperatures, *Geophys. Res. Lett*., 42, 7776-7784, doi: 10.1002/2015GL065793. Meehl, G., et al. (2009) The relative increase of record high maximum temperatures compared to record low minimum temperatures in the US, *Geophysical Research Letters*, 36, L23701, doi: 10.1029/2009GL040736

[61] 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

[62] See Climate Central.org, http://www.climatecentral.org/news/record-high-temperature-february-21186

[63] Vaidyanathan, G. (2015) Killer heat grows hotter around the world, *Scientific American*, August 6, 2015, https://www.scientificamerican.com/article/killer-heat-grows-hotter-around-the-world/

[64] Mora, C. et al. (2017) Global risk of deadly heat. *Nature Climate Change*; DOI: 10.1038/NCLIMATE332

[65] Willett, K., et al. (2007) Attribution of observed surface humidity changes to human influence, *Nature,* 449, 710-712, doi: 10.1038/nature06207

[66] Durack, P., et al. (2012) Ocean salinities Reveal strong global water cycle intensification during 1950 to 2000, *Science*, 336(6080), 455-458, *doi:* 10.1126/science.1212222

[67] S. Rahmstorf and D. Coumou (2011) Increase in Extreme Events in a Warming World, *Proceedings of the National Academy of Sciences* 108, no. 44: 17905–17909, doi 10.1073/pnas.1101766108. Francis, J.A., Vavrus, S.J. (2012) Evidence linking Arctic amplification to extreme weather in mid-latitudes. *Geophysical Research Letters,* 39, L06801. Stott, P. (2016) How climate change affects extreme weather events. *Science*, 352, 1517–1518, doi:10.1126/science.aaf7271.

[68] Russo, S., et al. (2017) Humid heat waves at different warming levels. *Scientific Reports*; 7 (1) DOI: 10.1038/s41598-017-07536-7

[69] Russo, S., et al. (2017)

[70] Gaffney, O., and Steffen, W. (2017) The Anthropocene equation, *The Anthropocene Review*, http://dx.doi.org/10.1177%2F2053019616688022

[71] 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

[72] Loarie, S.R., et al. (2009) The velocity of climate change, *Nature*, 462, 1052-1055.

[73] Post, E., et al. (2016) Highly individualistic rates of plant phenological advance associated with arctic sea ice dynamics, *Biology Letters*, 12(12), 20160332, doi: 10.1098/rsbl.2016.0332

[74] Menne, M.J., et al. (2010) On the reliability of the U.S. surface temperature record, *Journal of Geophysical Research* 115, D11108, doi: 10.1029/2009JD013094

[75] Young, I.R., et al. (2011) Global trends in wind speed and wave height, *Science* , 332(6028), 451-455, *doi:* 10.1126/science.1197219

[76] See "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

[77] Thorne, P.W., et al. (2010) Tropospheric temperature trends: History of an ongoing controversy, *Wiley Interdisciplinary Reviews: Climate Change*, doi: 10.1002/wcc.80

[78] 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

[79] 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

[80] Wolkovich, E., et al. (2012) Warming experiments underpredict plant phenological responses to climate change, *Nature*, 485(7399), 494-497, doi: 10.1038/nature11014

[81] Wiens, J.J. (2016) Climate-related local extinctions are already widespread among plant and animal species, *PLOS Biology*, 14(12), e2001104, doi: 10.1371/journal.pbio.2001104

[82] Wiens, J.J. (2016)

[83] 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

[84] Springmann, M., et al. (2016) Global and regional health effects of future food production under climate change: a modeling study, *The Lancet*, March 2, 2016, doi: 10.1016/S0140-6736(15)01156-3

[85] Liang, X.Z., et al. (2017) Determining climate effects on US total agricultural productivity, *PNAS*, www.pnas.org/cgi/doi/10.1073/pnas.1615922114

[86] 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

[87] U.S Global Change Research Program (2016) The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Crimmins, A., et al. GCRP, Washington, DC, 312 pp. http://dx.doi. org/10.7930/J0R49NQX

[88] Rosenzweig, C., et al. (2008) Attributing Physical and Biological Impacts to Anthropogenic Climate Change, *Nature* 453, no. 7193: 353–357.

[89] State of Environmental Conditions in Hawaii and the U.S. Affiliated Pacific Islands under a Changing Climate (2017) Coordinating Authors: J.J. Marra and M.C. Kruk. Contributing Authors: M.Abecassis; et al., September, NOAA NCEI.

[90] EIA (2017) International Energy Outlook, U.S. Energy Information Administration, https://www.eia.gov/outlooks/ieo/pdf/0484(2017).pdf

[91] Rockström, J. et al. (2017) A roadmap for rapid decarbonization. *Science*, 355 (6331): 1269 DOI: 10.1126/science.aah3443

Sea Level Rise Guidance 2018

City and County of Honolulu Climate Change Commission

Drafted by Charles Fletcher and Makena Coffman

There has been considerable research on the global and local implications of accelerating sea level rise. This brief by the City and County of Honolulu Climate Change Commission builds on the findings from the State of Hawaiʻi Climate Mitigation and Adaptation Commission (2017), Sweet et al. (2017), USGCRP (2017), and Sweet et al. (2018) to provide more specific policy and planning guidance on responding to sea level rise by the City & County of Honolulu (hereafter "City).

Summary of Key Findings by the City Climate Change Commission:

1. The research finds that, relative to the year 2000, global mean sea level (GMSL) is very likely (90-100% confidence) to rise 0.3–0.6 ft by 2030, 0.5–1.2 ft by 2050, and 1.0–4.3 ft by 2100.[1]
2. Future emission pathways have little effect on projected GMSL rise in the first half of the century, but significantly affect projections for the second half of the century.
    a. Table 1 (supplementary information) provides estimates of projected GMSL under NOAA scenarios.[2]
3. Emerging science regarding Antarctic ice sheet stability suggests that under high emission pathways, a GMSL rise exceeding 8 ft by 2100 is physically possible.[3]
4. Regardless of emissions pathway, it is extremely likely (95-100% confidence) that GMSL rise will continue beyond 2100.
5. High tide flooding will arrive decades ahead of any GMSL rise scenario.
    a. Table 2 (supplementary information) provides estimates of when minor high tide flooding will arrive in Honolulu 6, 12, and 24 days per year.[4]
6. Rising seas threaten human communities and natural ecosystems in the coastal zone in multiple ways.
    a. Urbanized coastal areas become increasingly vulnerable to four types of flooding during high water and high wave events:
        i. Saltwater flow across the shoreline.
        ii. Saltwater intrusion of engineered systems (e.g., drainage).
        iii. Groundwater inundation forming new wetlands.
            1. This type of flooding encompasses in-ground sewage systems.
        iv. Rainstorms, especially concurrent with high tide.
    b. Shoreline retreat.
        i. This leads to land loss (coastal erosion) in the back-beach area.
        ii. If the back-beach area is composed of sand-rich dunes, sandy paleo shoreline deposits, or high wave sand berms, the released sand nourishes the retreating beach.
        iii. If the back-beach area is hardened, a beach is prevented from retreating. This leads to beach erosion, beach narrowing, and beach loss. Hardening has caused at least 5.4 mi of beach loss on Oʻahu.[5]

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[1] USGCRP (2017)
[2] Sweet et al. (2017)
[3] USGCRP (2017)
[4] Sweet et al. (2018)
[5] Fletcher et al. (2012)

   c. Saltwater will intrude streams and coastal wetlands, increasing the salinity of the environment and threatening low-lying agriculture (e.g., kalo farming) and wildlife sanctuaries.
   d. Wave, and eventually still water overtopping of Loko Iʻa kuapā (fishpond walls) will increase.
      i. Interior circulation will change (including at mākāhā).
      ii. Upland discharge into the pond will change.
      iii. Fishpond connections to the shore will become unstable.
   e. Wave energy at the shore will increase.
      i. Muddy shore deposits may be released.
   f. Damaging flooding will increase when hurricanes, tsunamis, and seasonal high waves strike.
   g. Annual high waves, which arrive in Hawaiʻi seasonally, will flood further landward and cause more damage, as sea level continues to rise.

7. State of the art modeling reveals a critical elevation in GMSL rise between 2 and 3 ft.
   a. This is a critical point where there is a rapid increase in land exposure to hazards on low-lying coastal plains such as characterize the urbanized south shore of Oʻahu.
   b. This is a dangerous elevation range, where reacting after the fact to establish adaptation strategies is likely to be less successful and costlier than taking proactive measures.
8. The research finds that high tide flooding in the 3.2SLR-XA,[6] at least two dozen times per year, will occur by mid-century and as early as 2028.
   a. “Minor” (Sweet et al., 2018) high tide flooding occurs decades before GMSL rise impacts.
9. The research finds that it is reasonable to set as a planning benchmark up to 6 ft of GMSL rise in the later decades of the century, especially for critical infrastructure with long expected lifespans and low risk tolerance.

Given the tools available to planners, stakeholders and policy-makers with the Hawaiʻi Sea Level Rise Viewer,[7] the NOAA SLR Viewer,[8] and the Climate Central – Surging Seas Risk Finder,[9] the City Climate Change Commission, pursuant to Revised Charter of Honolulu Section 6-107(h), recommends:

1. That the City utilize the 2017 Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report (hereafter “Report”) and online Viewer, for baseline planning activity and infrastructure assessment and development.

   - The mayor, City Council, and executive departments of the City must recognize that climate change poses significant, dangerous, and imminent threats to the perpetuation of Hawaiian culture, island residents and visitors, natural resources and environments, the economy, and government functions and planning. Negative impacts of climate change will tend to exacerbate socio-economic inequality in our community with amplified impacts among under-served populations.

2. That the 3.2SLR-XA, marking the land area impacted by 3.2 ft of sea level rise (mapped on the Hawaiʻi Sea Level Rise Viewer) and the area that will be affected by minor and moderate high tide flooding, be adopted as a hazard overlay for planning and to guide decisions on all new development and infrastructure that has an expected physical life extending to mid-century.

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[6] Here we use the term “3.2SLR-XA” to represent the SLR-XA (an acronym that stands for sea level rise-exposure area) as mapped by the Hawai´i Sea Level Rise viewer: http://www.pacioos.hawaii.edu/shoreline/slr-hawaii/

[7] Hawai´i Sea Level Rise Viewer: http://www.pacioos.hawaii.edu/shoreline/slr-hawaii/

[8] NOAA Sea Level Rise Viewer: https://coast.noaa.gov/digitalcoast/tools/slr

[9] Surging Seas Viewer: https://riskfinder.climatecentral.org/county/honolulu-county.hi.us?comparisonType=postal-code&forecastType=NOAA2017_int_p50&level=3&unit=ft

   - Within the 3.2SLR-XA: strict building and flood proofing requirements should be imposed, and public infrastructure should be prohibited if not specifically designed to withstand sea level rise impacts.
   - Limit or prohibit major renovation of existing development that would increase vulnerability and exposure in the 3.2SLR-XA.
   - Develop policies that generally promote managed retreat from the 3.2SLR-XA area by 2050.
   - Ensure that major transportation corridors in the 3.2SLR-XA adapt to 3.2 ft of sea level rise with flexibility to adapt to 6 ft of sea level rise later in the century.
   - In certain critical infrastructure or economic areas establish specific strategies to adapt to 3.2 ft of sea level rise in the 3.2SLR-XA. Incorporate flexibility to adapt to 6 ft of sea level rise by later in the century.
   - Wherever possible implement managed retreat strategies in the 3.2SLR-XA with the goal of redeveloping the area as parkland, designed to naturally evolve to wetland with continued sea level rise.
   - Include storm water management as a major goal of parkland and wetland in the 3.2SLR-XA.
   - Implement consistent and predictable beach conservation policies in the 3.2SLR-XA.

3. That 6 ft of sea level rise (available on the NOAA Sea Level Rise Viewer) be adopted as the basis for planning and to guide decisions on all new development and infrastructure that have an expected physical life extending into the second half of this century, or for any other reason are deemed to be development with low risk tolerance.
   - Delineate and adopt the 6SLR-XA and as a hazard overlay for planning and to guide decisions on all new development and infrastructure that has an expected physical life extending beyond mid-century.
   - Emphasize resiliency to flooding (both marine and run-off) as major design elements of the 6SLR-XA. Design and construct retention basins in selected upper watersheds, and wetlands in low-lying regions.
   - Model hazards in the 6SLR-XA using the most current climate change scenarios.
4. That all City departments be directed to use the Report, the 3.2SLR-XA, and the 6SLR-XA in their plans, programs, policies, and capital improvement decisions, to mitigate impacts to infrastructure and critical facilities triggered by sea level rise.
5. That the City Department of Planning and Permitting propose rule changes to include sea level rise in their permitting decisions and in shoreline setback calculations.
6. That the areas in the 3.2SLR-XA and the 6SLR-XA be adopted as hazard overlays for planning under the City's Development Plans and Sustainable Community Plans.
7. That the expectation of minor high tide flooding before mid-century be immediately integrated in all considerations within the special management area (SMA) permitting process.
8. That the SMA boundaries be adjusted to include all areas within the 3.2SLR-XA and 6SLR-XA.
9. That planners and other relevant parties use available Viewers to inform their decision-making to immediately support compatible activities and land uses within the 3.2SLR-XA and 6SLR-XA.

The Commission adopts the precautionary principle and a scenario-based planning approach and supports these recommendations as planning targets informed by the best available science. The Commission fully acknowledges that there is uncertainty in the timing and magnitude of sea level rise projections globally and for Hawai‘i. This is a living document that will be updated with increasing data.

Supplementary Information

Global Mean Sea Level will rise 1 m relative to the year 2000. NOAA (Sweet et al., 2017) has published scenarios that provide estimates, by decade, of when GMSL will hit this benchmark (Table 1).

Table 1 - When will global mean sea level rise 1 meter?	
Intermediate Scenario	end of the century
Intermediate High Scenario	decade of the 2080’s
High Scenario	decade of the 2070’s
Extreme Scenario	decade of the 2060’s

Gravitational forces will cause regional sea level in the North Central Pacific to rise above the global mean (Spada et al., 2015). NOAA suggests planners use higher scenarios for large projects with low risk tolerance. This recommendation is also made by the US Army Corps.

High tide flooding will arrive decades ahead of GMSL. NOAA has published a model of high tide flooding for the Honolulu Tide Station (Sweet et al., 2018). Relative to MHHW, the threshold for minor high tide flooding is 0.52 m, for moderate high tide flooding is 0.8 m, and for major high tide flooding is 1.17 m.

High tide flooding has never occurred at the Honolulu Tide Station as none of these thresholds has ever been crossed. Table 2 provides estimates of when minor high tide flooding will arrive in Honolulu 6, 12, and 24 days per year using the NOAA model.

Table 2 - When will minor high tide flooding occur in Honolulu?

Scenario	6 x per year	12 x per year	24 x per year
Intermediate Scenario	2038	2041-2042	2044-2045
Intermediate High Scenario	2030	2033	2035-2036
High Scenario	2025-2026	2028-2029	2030-2031
Extreme Scenario	2024	2026	2028-2029

Because of the exponential nature of the NOAA sea level scenarios, the doubling time of high tide flooding is brief in all scenarios. High tide flooding events are likely to cluster around the summer solstice. High tide flooding will occur first in the 3.2SLR-XA as defined in the Hawai‘i Sea Level Rise Vulnerability and Adaptation Report (2017)

High tide flooding can take several forms. Beach erosion will be pronounced during high tide flooding events. Storm drain flooding will occur where marine water blocks drainage and spills out onto the street, or where runoff cannot drain and causes flooding around storm drain sites. Groundwater inundation will develop where the water table rises to break the ground surface and creates a wetland. At first this flooding is most common when high tide and precipitation occur simultaneously, but eventually occurs without precipitation at high tide. Rainfall that occurs at high tide when storm drains are blocked and the ground is saturated will lead to widespread flooding. Marine flooding will occur at high tide when seawater flows over the shoreline. Wave flooding will occur at high tide during typical seasonal swell events as waves run-up past the shoreline and into the backshore. Tsunami and storm surge occurring at high tide will cause greater flood damage than historically.

Modeling of sea level rise impacts on O‘ahu (Report) reveals the following:

1. Over the next 30 to 70 years, homes and businesses on O‘ahu’s shorelines will be severely impacted by sea level rise. Nearly 4,000 structures will be chronically flooded with 3.2 ft of sea level rise (Figure 1).
2. Of the 9,400 acres of land located within the 3.2SLR-XA, over half is designated for Urban land uses, making O‘ahu the most vulnerable of all the islands.
3. With 3.2 feet of sea level rise, almost 18 mi of O‘ahu’s coastal roads will become impassible, jeopardizing access to and from many communities.
4. O‘ahu has lost more than 5 mi of beaches to coastal erosion fronting seawalls and other shoreline armoring. Many more miles of beach will be lost with sea level rise if widespread armoring is allowed. In the Report, Chapter 5 (Recommendations) explores opportunities to reduce beach loss by improving beach protection policies.
5. A more detailed economic loss analysis is needed of O‘ahu’s critical infrastructure, including harbor facilities, airport facilities, sewage treatment plants, and roads. State and County agencies should consider potential long-term cost savings from implementing sea level rise adaption measures as early as possible (e.g., relocating infrastructure sooner than later) compared to the cost of maintaining and repairing chronically threatened public infrastructure in place over the next 30 to 70 years.

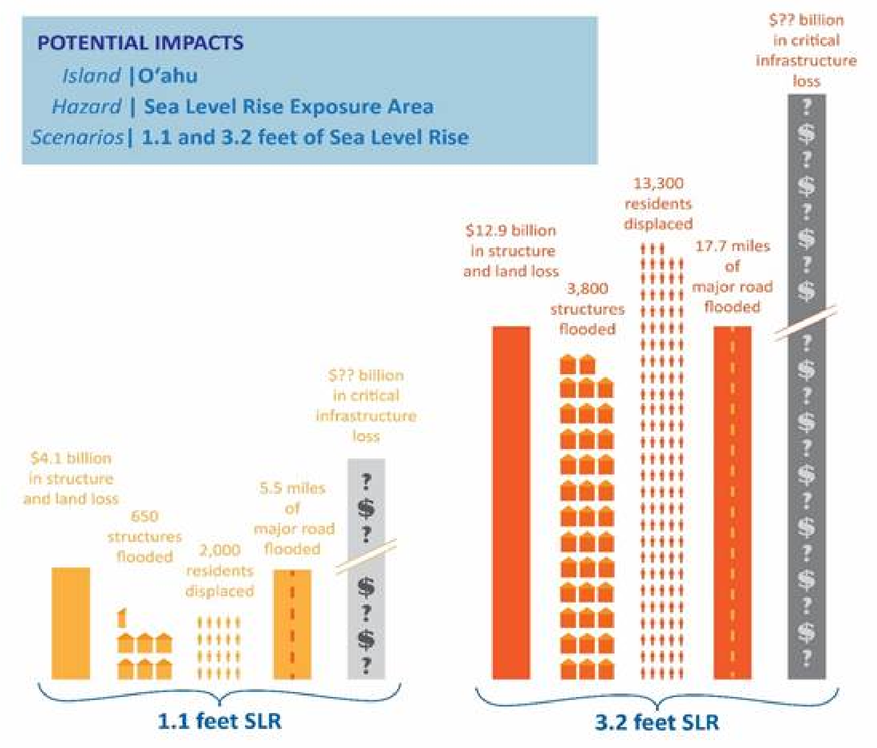

Figure 1. Sea level rise impacts on Oʻahu.

<u>References and Additional Reading:</u>

Anderson, T. R., Fletcher, C. H., Barbee, M. M., Frazer, L. N., & Romine, B. M. (2015) Doubling of coastal erosion under rising sea level by mid-century in Hawaiʻi. *Natural Hazards*, 78(1), 75–103. https://doi.org/10.1007/s11069-015-1698-6.

Anderson, T.R., et al. (in review) Modeling recurrent sea level rise stresses reveals 50% more land at risk. *Manuscript*

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, DOI: 10.1126/science.aaa4019

Fletcher, C.H., Romine, B.M., Genz, A.S., Barbee, M.M., Dyer, M., Anderson, T.R., Lim, S.C., Vitousek, S., Bochicchio, C., and Richmond, B.M. (2012) National assessment of shoreline change: Historical shoreline change in the Hawaiian Islands: *U.S. Geological Survey Open-File Report 1051*.

Golledge, N.R., et al. (2015) The multi-millennial Antarctic commitment to future sea-level rise: *Nature*, 2015; 526 (7573): 421 DOI: 10.1038/nature15706.

Habel, S., Fletcher, C.H., Rotzoll, K. and El-Kadi, A. 2017. Development of a model to simulate groundwater inundation induced by sea-level rise and high tides in Honolulu, Hawaiʻi. *Water Research*. ISSN 0043-135.http://dx.doi.org/10.1016/j.watres.2017.02.035

Hawaiʻi Climate Mitigation and Adaptation Commission (2017) *Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report*. Prepared by Tetra Tech, Inc. and the State of Hawaiʻi Department of Land and

Natural Resources, Office of Conservation and Coastal Lands, under the State of Hawai‘i Department of Land and Natural Resources Contract No: 64064.

Kane, H. H., Fletcher, C. H., Frazer, L. N., Anderson, T., Barbee, M. (2015) Modeling sea-level rise vulnerability of coastal environments using ranked management concerns. *Climate Change*. DOI 10.1007/s10584-015-1377-3

Kopp, R.E., et al. (2017) Evolving understanding of Antarctic ice-sheet physics and ambiguity in probabilistic sea-level projections, *Earth’s Future*, 5, 1217-1233, https://doi.org/10.1002/2017EF000663, Dec. 13.

Lentz, E. E., Thieler, E.R., Plant, N.G., Stippa, S.R., Horton, R.M. and Gesch, D.B. (2016) Evaluation of dynamic coastal response to sea-level rise modifies inundation likelihood. *Nature Climate Change*, 6, 696–700, doi:10.1038/nclimate2957.

Levermann, A., et al. (2013) The multimillennial sea-level commitment of global warming: *Proceedings of the National Academy of Sciences*, July 15, DOI: 10.1073/pnas.1219414110.

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.

Romine, B. M., Fletcher, C. H., Frazer, L. N., & Anderson, T. R. (2016) Beach erosion under rising sea-level modulated by coastal geomorphology and sediment availability on carbonate reef-fringed island coasts. *Sedimentology*, 63(5), 1321-1332.

Spada, G., Bamber, J. L. & Hurkmans, R. T. W. L. The gravitationally consistent sea-level fingerprint of future terrestrial ice loss. *Geophys. Res. Lett.* **40,** 482–486 (2013).

Sweet, W.V., Dusek, G., Obeysekera, J., Marra, J.J. (2018) Patterns and projections of high tide flooding along the U.S. coastline using a common impact threshold. *NOAA Technical Report NOA CO-OPS 086*.

Sweet, W.V., et al. (2017) Global and regional sea level rise scenarios for the United States, *NOAA Technical Report NOS CO-OPS 083*.

Sweet, W.V., et al. (2018) Patterns and projections of high tide flooding along the U.S. coastline using a common impact threshold. *NOAA Technical Report NOA CO-OPS 086*.

Tollefson, J. (2018) Can the world kick its fossil fuel addiction fast enough? Nature, 556, 422-425, DOI: 10.1038/d41586-018-04931-6.XXX

USACE, Frequently Asked Questions about the Sea Level Rise Planning Tool, “Which sea level rise scenario should I use?” http://www.corpsclimate.us/Sandy/FAQs.asp

USGCRP, 2017: Climate Science Special Report: Fourth National Climate Assessment, Volume I[Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 470 pp, doi: 10.7930/J0J964J6.