

Historical and Projected Climate Trends and Implications for Kalaupapa National Historical Park

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Historical climate trends

The Pacific Islands show high interannual and interdecadal climate variability due to effects of the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) (NCADAC 2013). For example, reduced rainfall is typically associated with El Niño years and increased rainfall occurs during La Niña. Nevertheless, several trends over the past century have been observed. Mean annual air temperature increased across Hawai'i at a rate of 0.08 °F (0.04 °C) per decade from 1919-2006 and precipitation showed a minor decreasing trend during this time period (Keener et al. 2012).

The Pacific Ocean has also exhibited changes directly and indirectly in response to increasing atmospheric greenhouse gas concentrations (Table 1) (NCADAC 2013). Oceans absorb roughly 25% of the CO₂ emitted each year, and as a result ocean acidity has increased 26% since preindustrial times (Feeley et al. 2009). In addition to absorbing CO₂, oceans have absorbed 90% of the warming caused by the greenhouse effect (Church et al. 2011), leading to surface waters warming as much as 3.6 °F (2 °C) around Hawai'i (Ganachaud et al. 2011). Globally, sea-level has risen about 8 inches (20.3 cm) since 1880, primarily due to thermal expansion as the waters warm. Sea-level rise around Hawai'i has been near the global rate (Keener et al. 2012, see Caffrey 2013 report for more in-depth sea level and storm trend details specific to Kalaupapa).

Future climate projections

The increasing temperature trend observed over the past century is projected to continue (Table 1, Figure 1) (Keener et al. 2012). Warming by 2100 ranges from 2.7 °F (1.5 °C) to 4.7 °F (2.6 °C), for the B1 (low emissions) and A2 (high emissions) scenarios, respectively (IPCC 2007, Keener et al. 2012). It is important to note that global CO₂ emissions are currently on a trajectory similar to the higher emissions scenarios (Friedlingstein et al. 2010). Changes in rainfall are less certain than temperature, with southern areas of the Hawaiian island chain potentially receiving increased precipitation by the end of the century and northern areas becoming drier (Figure 2) (Keener et al. 2012). Persistence of the trade-wind inversion, driven by climate change, would decrease rainfall 5-10% during the wet season and there is a projection for a 5% increase during the dry season (Timm and Diaz 2009, Fung & SWCA 2010). Similar to historical trends, ENSO and PDO cycles have strong impacts on climate projections for Hawaii and make it difficult to model conditions at the decadal to century scale (Keener et al. 2012).

The Pacific Ocean will continue to change in response to climate change (Table 1). By the end of the century, ocean acidity will further increase 37-50% compared with present levels (NCADAC 2013). Waters will also continue to warm, 2.5- 4.7 °F (1.4 - 2.6 °C) by 2090, depending on the CO₂ emissions scenario (Australian Bureau of Meteorology and CSIRO 2011). Global sea-level is projected to rise 1-4 feet (0.3-1.2 m) by 2100 and trends indicate that the rate of sea-level rise has accelerated over the past two decades (Church and White 2011). Models at the low end of projections, ~1 foot of sea-level rise, do not include contributions from the Greenland and Antarctic ice sheets and thus are likely underestimations (NCADAC 2013). Other models project that sea-level, compared with 1990 levels, will rise 2.7-4.3 feet (0.8-1.3 m) under

the B1 scenario and 3.2-5.1 feet (1.0-1.5 m) under the A2 scenario by 2100 (Vermeer and Rahmstorf 2009, see Caffrey 2013 report for more in-depth sea level and storm trend details specific to Kalaupapa).

Potential Impacts to Natural and Cultural Resources

Marine ecosystems will be impacted by sea-level rise, increasing water temperatures, ocean acidification, and more intense storms (Friedlander et al. 2008a, Fung & SWCA 2010). Coral bleaching events, which were documented in Kalaupapa from 2006-2009, are projected to expand in extent as the Pacific continues to warm (Jokiel et al. 2009, Burke et al. 2011). Kalaupapa may be especially affected by bleaching because the dominant coral species, *Pocillopora meandrina* and *P.edouxi*, do not recover quickly after bleaching events (Grimsditch and Salm 2006, Fung & SWCA 2010). Ocean acidification will further slow recovery by reducing calcification rates (NCADAC 2013).

Climate change will also impact terrestrial and freshwater systems in the park. Sea-level rise of 3.3 ft (1 m) would submerge roughly 40 hectares (98.9 acres) of coastal land in the park (1.2% of the park's land area) (Fung & SWCA 2010). This has the potential to change the quality and quantity of intertidal habitat available to the endangered Hawaiian monk seal (*Monachus schauinslandi*). Sea-level rise, in conjunction with storms will increase the number and severity of coastal flooding events and accelerate saltwater intrusion into freshwater systems (NCADAC 2013).

Table 1. Historical and projected climate trends for Kalaupapa National Historical Park.

Variable	Historical trends (20th century)	Projections
Mean annual temperature	+0.08 °F (+0.04 °C) per decade from 1919-2006 ^a	increase 2.7-4.7 °F (1.5-2.6 °C) by 2100 based on B1 (low emissions) & A2 (high emissions) scenarios (compared with 1971-2000 average) ^a
Annual precipitation	nonsignificant decrease ^a	-2% to +4% change by 2100 (compared with 1971-2000 average) ^a
Ocean acidity	increased 26% ^b	increase 37-50% by 2100 compared with present levels ^c
Sea surface temperature	increased 3.6 °F (2 °C) ^d	increase 2.5- 4.7 °F (1.4 - 2.6 °C) by 2090 ^e
Sea-level rise	Global: 8 inches (20.3 cm) since 1880 ^c ; 0.134 inches (3.4 mm) per year since 1990 ^a	1-4 feet (0.3-1.2 m) 21st century rise ^c ; 1990-2100 rise: B1 (low emissions): 2.7-4.3 feet (0.8-1.3 m), A2 (high emissions): 3.2-5.1 feet (1.0-1.5 m) ^d

^aKeener et al. 2012; ^bFeeley et al. 2009; ^cNCADAC 2013; ^dGanachaud et al. 2011; ^eAustralian Bureau of Meteorology and CSIRO 2011; ^fVermeer and Rahmstorf 2009

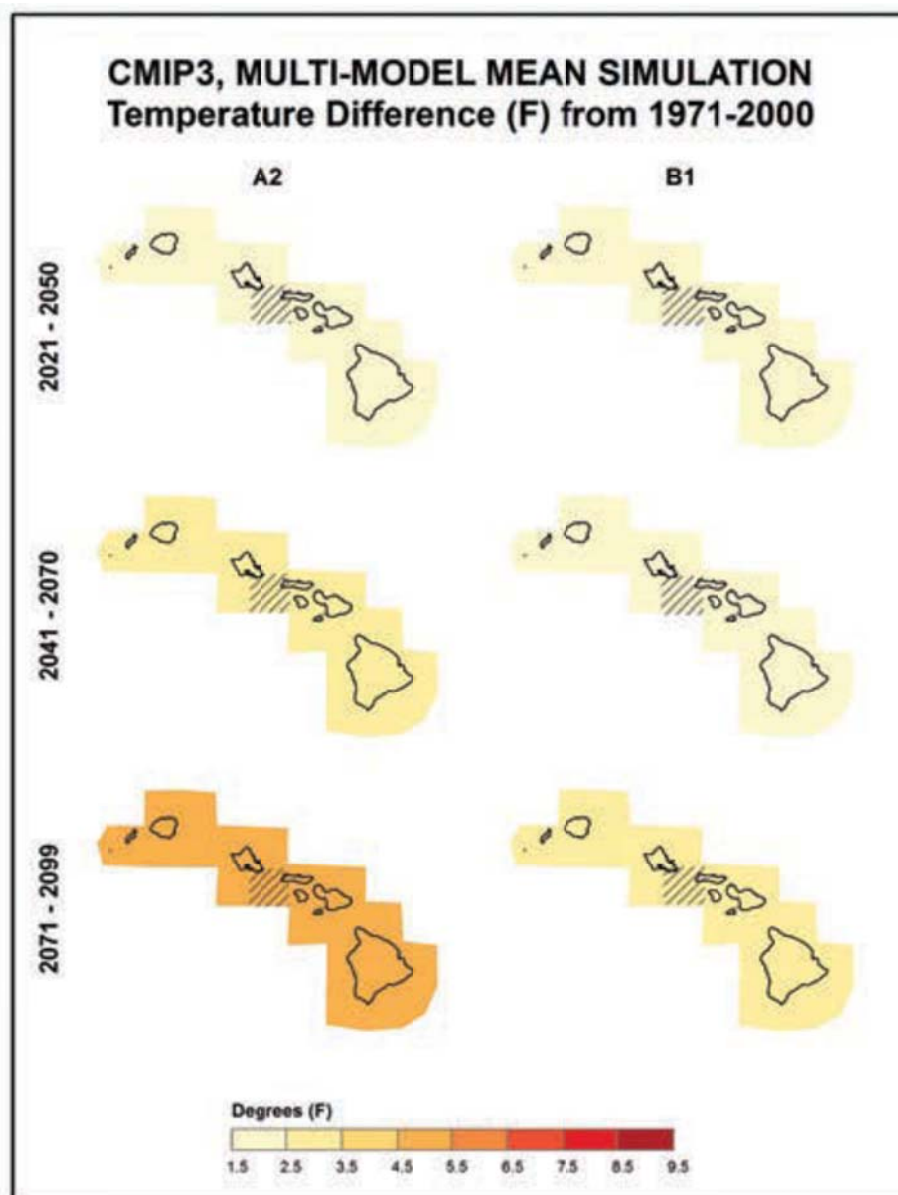


Figure 1. Projected mean annual temperature change compared with 1971-2000, based on high (A2) and low (B1) CO₂ emissions scenarios (see IPCC 2007 for definitions of emissions scenarios). Climate projections based on 15 CMIP3 model simulations (figure from Keener et al. 2012; Ken Kunkel, NOAA NCDC and North Carolina State University). Color with hatching indicates that more than 50% of the models show a statistically significant change in temperature and more than 67% agree on the sign of the change.

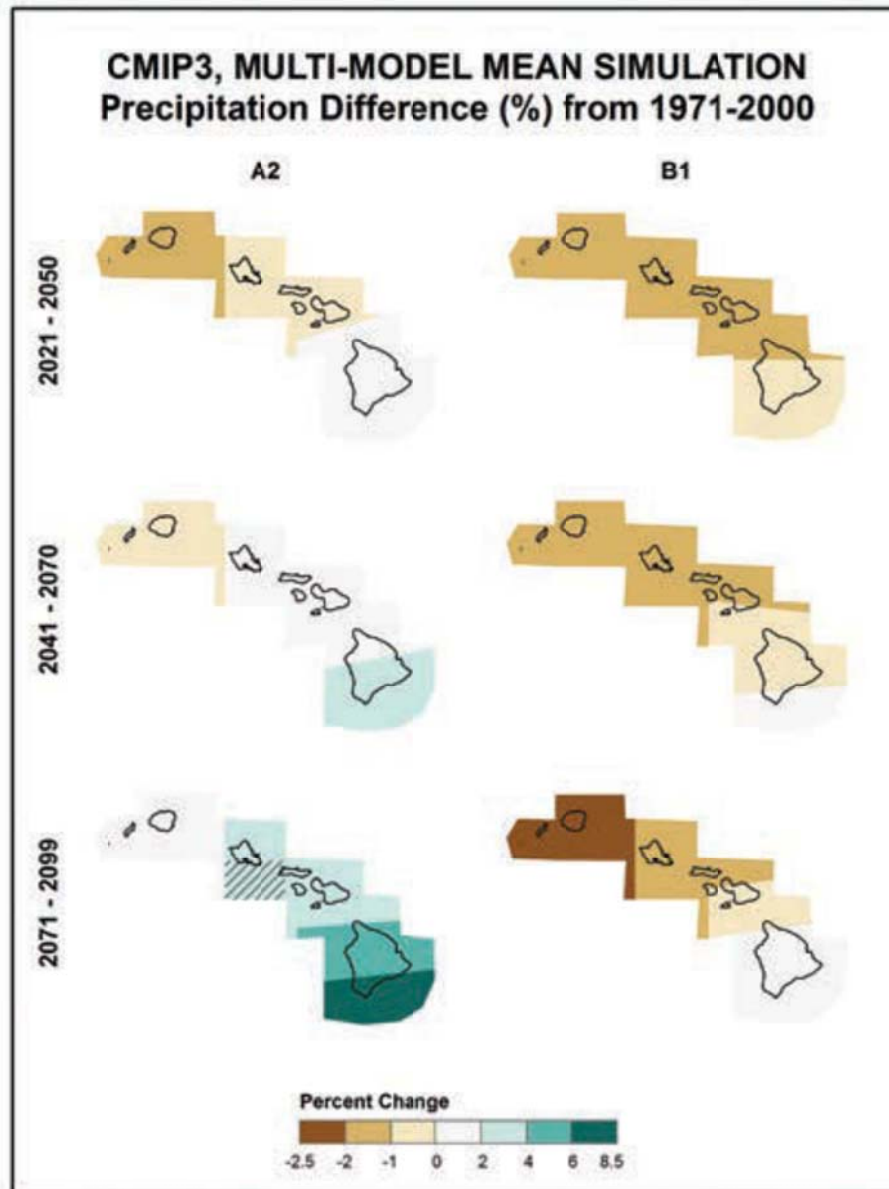


Figure 2. Projected annual precipitation change compared with 1971-2000, based on high (A2) and low (B1) CO₂ emissions scenarios (see IPCC 2007 for definitions of emissions scenarios). Climate projections based on 15 CMIP3 model simulations (figure from Keener et al. 2012; Ken Kunkel, NOAA NCDC and North Carolina State University). Color with hatching indicates that more than 50% of the models show a statistically significant change in temperature, and more than 67% agree on the sign of the change.

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