Climate change in the Pacific region: The physical setting

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When you say “Pacific climate” to most people, they often think “El Niño”
El Niño of 2015-2016—largest on record
El Niño impacts

La Niña impacts

Observed precipitation anomalies Sept.-Nov., 2015
The flip side of El Niño is “La Niña”
The weak La Niña of 2017-2018 with nearly opposite impacts to El Niño.
El Niño impacts

The future: As average ocean temperatures continue to warm, the impacts from El Niño events will worsen
Coral Bleaching

Corals expel symbiotic algae that live and photosynthesize within their tissues.

- Coral bleaching has increased in frequency and severity since the mid 20th Century.
- During the 1997-1998 ENSO, ~30% of reefs worldwide experienced bleaching.
- Some think that for most reefs, bleaching frequency will exceed capacity to recover by the middle of the 21st Century.
Coral bleaching in progress in 2015 at Pago Pago, American Samoa

In Hawaii, bleaching occurred in Kaneohe Bay, Waimanalo on Oahu and Olowalu on Maui. On the Big Island, bleaching was reported from Kawaihae to South Kona on the leeward side and Kapoho in the southeast.

"A mile and a half of reef on the eastern side of Lisianski Island is essentially dead"

(900 miles northwest of Oahu) Courtney Couch, Hawaii Institute of Marine Biology
Not all reefs that bleach die, but mortality of bleached reefs can be 50% or more

A reef in American Samoa
Mapping the Global Coral Reef Bleaching Crisis

The longest and most widespread global coral bleaching event on record began in 2014, causing reefs near at least 38 countries and island groups to turn ghost white—and in some cases killing them. The bleaching is ongoing, triggered by high ocean temperatures, and scientists say 38 percent of reefs have already been impacted. The Great Barrier Reef and reefs around Kiribati are among the hardest hit. The worst is likely yet to come for the Caribbean and Florida.

 SOURCES: "Global Coral Bleaching 2014-2017" report by C.M. Eakin et al.; NOAA/Bernardo Vargas-Ángel; XL Catlin Seaview Survey; InsideClimate News research

PAUL HORN / InsideClimate News
In 2015-2017, the Great Barrier Reef experienced its worst bleaching event on record
Bleaching during the 2015-2016 El Niño was severe and, for the first time, continued into the non-El Niño year of 2017
https://www.facebook.com/chasingcoral/videos/1776577129313083/
High ocean temperatures killed roughly 30% of the Great Barrier Reef corals in 2016 alone (Hughes et al., 2018, Nature)

“the interval between recurrent bouts of coral bleaching is too short for a full recovery...tropical sea surface temperatures are warmer now during current La Niña conditions than they were during El Niño events three decades ago. Consequently, as we transition to the Anthropocene, coral bleaching is occurring more frequently in all El Niño–Southern Oscillation phases, increasing the likelihood of annual bleaching in the coming decades.” (Hughes et al., 2018, Science)
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Ocean Acidification and Carbonate Chemistry
Causes skeletal loss in corals and other marine organisms

As CO$_2$ in the atmosphere increases from the burning of fossil fuels, the oceans become more acidic

Chemical reactions:

- $CO_2$ (g) + $H_2$O (l) $\rightarrow$ $CO_2$$_{aq}$ (aq)
- $CO_2$$_{aq}$ + $H_2$O (l) $\rightarrow$ $H_2$CO$_3$ (aq)
- $H_2$CO$_3$ (aq) $\rightarrow$ $HCO_3^-$ + $H^+$
- $HCO_3^-$ + $H^+$ $\rightarrow$ $CO_3^{2-}$ + $H^+$
- $CaCO_3$ (s) $\rightarrow$ $CO_3^{2-}$ + $H_2$O (l)

Chemical species:
- Carbonic acid $H_2$CO$_3$
- Bicarbonate $HCO_3^-$
- Carbonate $CO_3^{2-}$
- Alkalinity $Mg^{2+}$, $Na^+$, $K^+$, $Ca^{2+}$
- Photosynthesis
- Respiration
- Calcification
- Dissolution
Tropical cyclones/typhoons (hurricanes)

Hurricane tracks from a global climate model

Future: less hurricanes but the ones that form will likely be more intense
What about sea level rise?

Two factors can cause sea level to rise:

1. thermal expansion of warmer water
2. additional water added to the oceans from melting land ice (glaciers and ice sheets);

(sea ice is shrinking but that doesn’t add to sea level rise)
What if you live on an atoll like this one? (Tetiaroa, highest point above sea level: 6 feet)
You’d better worry about land glaciers, Greenland and Antarctica!
Sea level rise over the past 50 years or so (about 8”) is already causing coastal and beach erosion, increased tidal flooding, and more severe storm surge flooding; in the future sea level rise could submerge entire atolls making them uninhabitable.

Coastal flooding on Funafuti Atoll (top) and Tarawa Atoll (bottom)
Melting all of the current Greenland ice sheet would result in a sea-level rise of about 6.5 meters (about 20 feet); melting all of the West Antarctic ice sheet would result in a sea-level rise of about 8 meters (about 25 feet).

This is not likely to happen, but accelerated melting of the Greenland ice sheet has already been observed.

**how much will melt and how fast?**
Greenland

Melting on the lower parts of the surface, icebergs calve off from ice sheet edges into ice fjords and the sea

Equilibrium line

Snow accumulation

Ice sheet

Ice flow

Iceberg calving

Ablation

Ocean

Bedrock
Antarctica
Ice shelves, with subglacial melting. Icebergs calve off from ice shelves
Due to our lack of knowledge of ice sheet disintegration processes, we still cannot definitively answer the questions “how much and how fast?” Some estimates go as high as 3 feet of sea level rise or more by 2100.
Much of West Antarctica is below sea level; if warming ocean water penetrates under the ice and starts melting it, the West Antarctic Ice Sheet could become unstable and disintegrate more rapidly—we have very little information on whether that has occurred before or could occur now.
Earth System models

simulate this:

with this:

Components of atmosphere, ocean, land surface processes, sea ice, ice sheets (sea level rise), ocean biogeochemistry (ocean acidification), atmospheric chemistry (air pollution)
¼ degree (grid points every 25 km) time slice simulation representative of present-day climate run with an INCITE allocation at Argonne
Access and Analysis of Earth System Model output

Current phase of CMIP6 expected to produce 10 petabytes of model data; 33 modeling groups from 16 countries.

Data access via web portals:
- obs4MIPs
- ana4MIPs
- ESGF
- ESMValTool
- PCMDI Metrics Package (PMP)

Well-Established Analysis
Sharing of Diagnostic Code
Guidance and support from CMIP Panel,
WGNE/WGCM Climate Model Metrics Panel and, CMIP6-Endorsed MIPs
Summary:
Future threats to physical system in Pacific region related to increasing CO$_2$ from burning of fossil fuels:

1. Warming ocean temperatures produce more intense El Niño impacts (droughts, floods, extreme heat, coral bleaching)
2. Ocean acidification
3. Fewer total tropical cyclones/typhoons but more intense
4. Sea level rise
5. Earth System Models are tools to quantify possible future risks; large data volumes and distributed analysis via the Earth System Grid Federation