Monthly global temperature compared with preindustrial levels

1940s-60s 1970s 1980s 1990s 2000s 2010s 2020s +1.78°C +1.6°C 2023 +1.4° +1.2° +1.0 +0.8 Other years since 1940 +0.6° +0.4° +0.2° 0 -0.2° Jan. April July Oct.

2023 was the hottest year on record

The world has just experienced the hottest summer on record – by a significant margin



CNN — none

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y.google.com.

As heat waves continue to bake parts of the world, scientists are reporting that this blistering, deadly summer was the hottest on record - and by a significant margin.

June to August was the planet's warmest such period since records began in

Kevin Frayer/Getty Images

ern

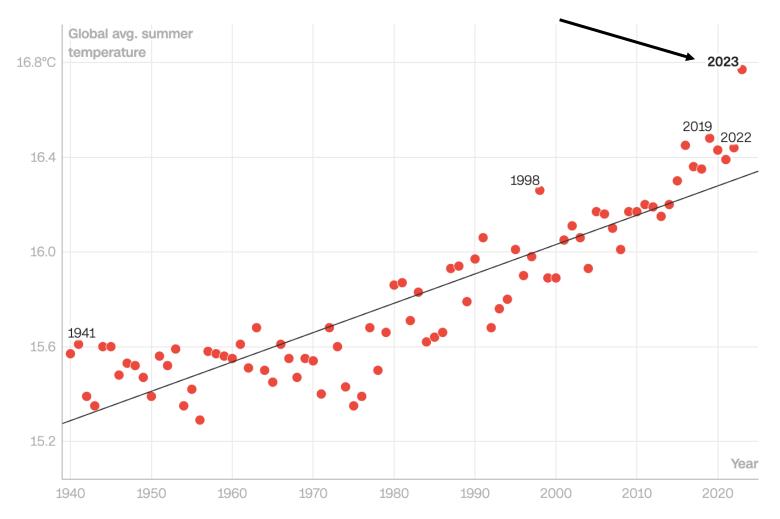
aters

Unstable Jet Stream – Extreme weather



This summer was the hottest on record — by a significant margin

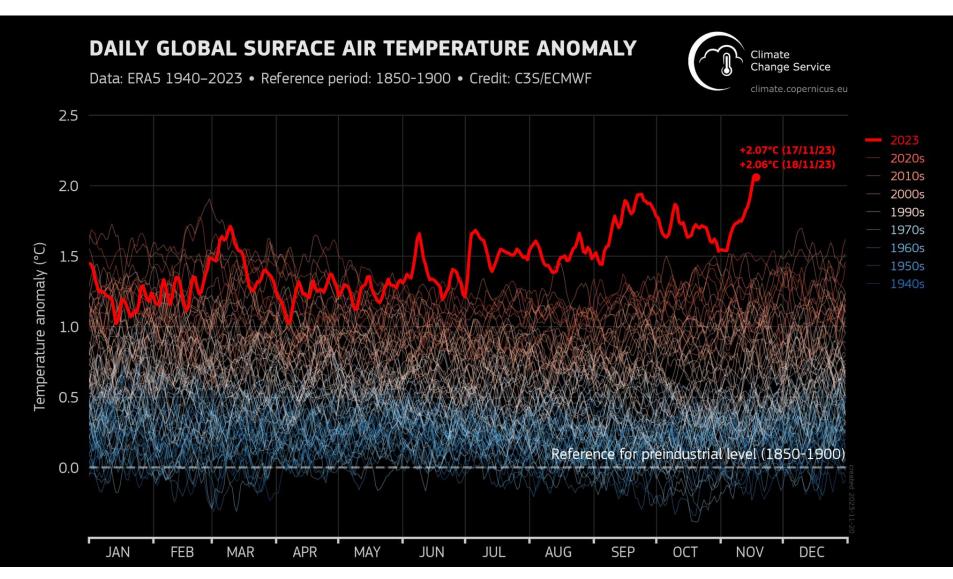
Summers have been trending hotter since at least the 1940s, and especially the past decade. Global temperature for June, July and August this year has surpassed that of summer 2019 — the previous record — by nearly a third of a degree Celsius.



Note: Summer temperature includes all days in June, July, and August.

Source: Copernicus Climate Change Service Graphic: Krystina Shveda, CNN

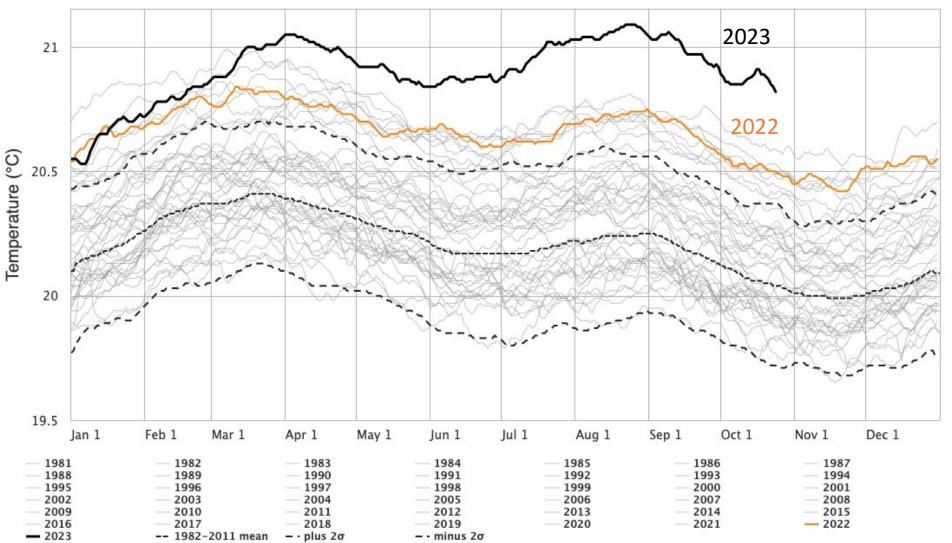
Global surface temperatures have set records virtually every day since mid-June



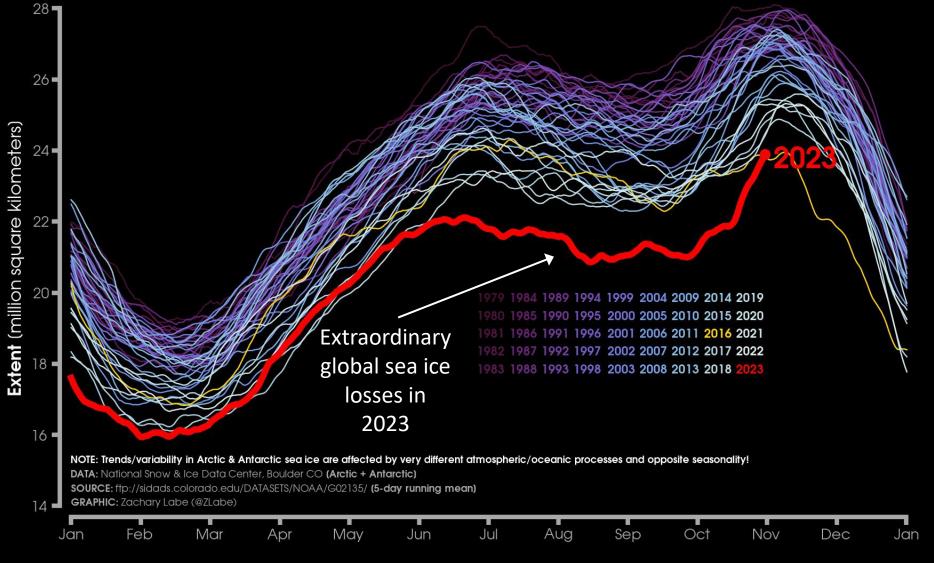
Since April, the hottest SSTs ever measured

SST World (60S-60N)

Data Source: NOAA OISST V2.1 | ClimateReanalyzer.org, Climate Change Institute, University of Maine



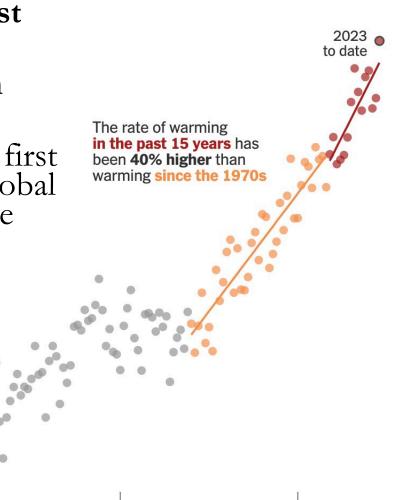




- The rate of global warming has **accelerated**
- Every month from June to November was the hottest ever recorded globally.
- 2023 may be **warmer than 1.5°C**

1850

 Nov 17&18 2023 were the first days on record to have a global average surface temperature above 2°C



2000

1950

Source: Berkeley Earth Land/Ocean Temperature Record

1900

Paris Agreement, 2015 United Nations Framework Convention on Climate Change

Stop global warming before 2°C (3.6°F)

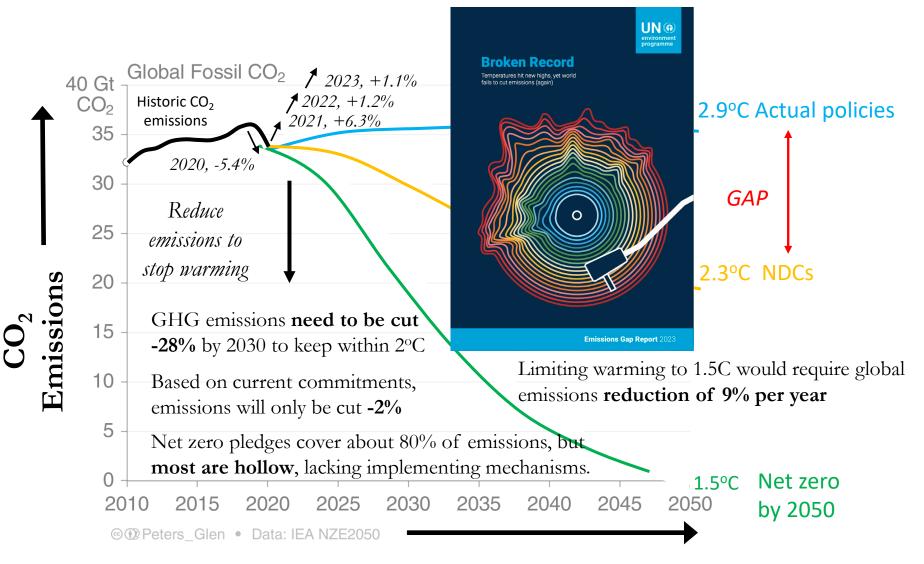
Pursue efforts to end warming before 1.5°C (2.7°F)

Nations Unies Conférence sur les Changements Climatiques 2015

COP21/CMP11



Progress on Stopping Warming at 1.5°C



Globally, Governments still plan to produce more than double the amount of fossil fuels in 2030 than would be consistent with stopping warming at 2°C

United Nations Environment Programme (2023). Emissions Gap Report 2023: Broken Record – Temperatures hit new highs, yet world fails to cut emissions (again). Nairobi. https://doi.org/10.59117/20.500.11822/43922.

Fate of anthropogenic CO₂ emissions (2010–2019)

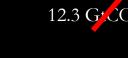


Sources = Sinks

35.3 GtCO₂/yr 88%0

18.9 GtCO₂/yr 47%/0





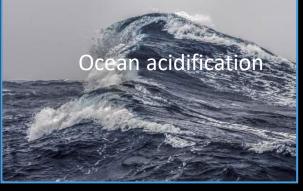
12%/0 4.7 GtCO₂/yr





(the difference between estimated sources & sinks)

3% -1.2 GtCO₂/yr 26% 10.4 GtCO₂/yr



Source: Friedlingstein et al 2023; Global Carbon Project 2023

- Plant *photosynthesis* removes CO_2 from the air
- Plant respiration releases CO₂ to the air
- Photosynthesis has a heat limit, past which:
 - Photosynthesis sharply declines
 - Respiration continues to increase
 - Carbon uptake by land plants is degraded
- With continued emissions,
 - Carbon uptake may be degraded nearly 50% as early as 2040
- This effect is not accounted for in National Policies

SCIENCE ADVANCES | RESEARCH ARTICLE

ENVIRONMENTAL STUDIES

How close are we to the temperature tipping point of the terrestrial biosphere?

Katharyn A. Duffy^{1,2}*, Christopher R. Schwalm^{2,3}, Vickery L. Arcus⁴ Liyin L. Liang^{4,5}, Louis A. Schipper⁴

The temperature dependence of global photosynthesis and respiration d While the land sink currently mitigates ~30% of anthropogenic carbon emi system service will persist and, more specifically, what hard temperature I Here, we use the largest continuous carbon flux monitoring network to cons temperature response curves for global land carbon uptake. We show that t quarter (3-month period) passed the thermal maximum for photosynthes temperatures, respiration rates continue to rise in contrast to sharply decl business-as-usual emissions, this divergence elicits a near halving of the lan

JOURNAL OF GEOPHYSICAL RESEARCH **Biogeosciences**

AN AGU JOURNAL

A Free Access

Are tropical forests near a high temperature threshold?

Christopher E. Doughty 🔀, Michael L. Goulden

First published: 17 October 2008 | https://doi.org/10.1029/2007/G000632 | Citations: 162

SECTIONS

👮 PDF 🔧 TOOLS

.... numerous studies

suggest that a variety

of ecosystems are

operating at or near

thermal thresholds."

Abstract

[1] We used leaf gas exchange, sap flow, and eddy covariance measurements to investigate whether high temperature substantially limits CO₂ uptake at the LBA (Large-scale Biosphere-Atmosphere) km-83 tropical forest site in Brazil. Leaf-leve temperature-photosynthesis curves, and comparisons of whole-canopy net ecos CO₂ exchange (NEE) with air temperature, showed that CO₂ uptake declined sha during warm periods. Observations of ambient leaf microclimate showed that le oscillate between two states: a cool, dimly lit stage and a hot, brightly illuminated where leaf temperatures are often greater than 35°C. The leaf-level rates of

"

photosynthesis decreased when shaded leaves (~ar μ mol m⁻² s⁻¹) were transferred into a prewa 38°C and 1000 μ mol m⁻² s⁻¹), coincide evaporative demand, and stomate calculated at 5-min intervals in followed extended cloudy pe temperature and evaporati The forest at km-83 appea CO₂ uptake drops sharply leaf temperature and leaf disproportionately to canop exchange is curtailed.

1. Introduction

[2] Researchers have hypothesized that increasing

on tropical forest production [Clark, 2004], resulting in a positive reglobal climate change [Cox et al., 2000]. High temperatures reduce CO2 uptake by C through reversible, short-term increases in photorespiration, respiration and stoma closure, and, in extreme cases, irreversible damage to biochemical machinery [Berr Björkman, 1980]. Increases in temperature that increase photorespiration, total ecc respiration, or the incidence of stomatal closure would be expected to decrease tro forest primary production. The Amazon Forest contains 93 (±23) PgC (1015 g) of live aboveground, and tropical forest accounts for at least 30% of global terrestrial prim

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Temperate and Tropical Forest Canopies are Already Functioning beyond Their Thermal Thresholds for Photosynthesis

u¹, Sasha C. Reed², Tana E. Wood³ and Molly A. Cavaleri^{1,*}

ECOLOGY

Forest Resources & Environmental Science, Michigan Technological University, 1400 Townsend Dr., n, MI 49931, USA; acmau@mtu.edu

logical Survey, Southwest Biological Science Center, 2290 S. West Resource Blvd, Moab, UT 84532,





No evidence of canopy-scale leaf thermoregulation to cool leaves below air temperature across a range of forest ecosystems

ENVIRONMENTAL SCIENCES

Christopher J. Still^{0,1} ¹, Gerald Page^{b,,} ¹, Bharat Rastogi^{d,e}, Daniel M. Griffith^{3,1} , Donald M. Aubrecht^{g,h}, Youngil Kim¹, Sean P. Burns^{1,4} Chad V. Hanson^a, Hyojung Kwon^a, Linnia Hawkins^a, Frederick C. Meinzer¹, Sanna Sevanto^m, Dar Robertsⁿ, Mike Goulden^o, Stephanie Pau^o, Matteo Detto^{9,r}, Brent Helliker⁶, and Andrew D. Richardson^{8,h}

Edited by James Clark, Duke University, Durham, NC: received March 31, 2022; accepted June 28, 2022

Understanding and predicting the relationship between leaf temperature (T_{leaf}) and air Understanding and protocols and the second maintained near photosynthetic temperature optimis and below damgging temperature thresholds. Specifically, leaves should cool below T_{ine}, relationships and substantial carbon uptake when leaves are cooler than air. This hypothesis implies that climate varning will be mitigated by a compensatory leaf cooling response. A leave uncertainty is understanding whether such thermoregulatory behavior occurs in natural forest canopies. We present an unprecedented set of growing season canopy-level leaf temperature (Tca data measured with thermal imaging at multiple well-instrumented forest sites in and Central America. Our data do not support the limited homeothe canopy leaves are warmer than air during most of the day and mid to late afternoon, leading to T_{can}/T_{air} slopes >1 or. We find that the majority of ecosystem photosynthesi air. Using energy balance and ce leaf-air couplin es are warmer we show that key leaf relationship. Canopy struc-

Significance

MDPI

Leaf temperature has long been recognized as important for plant function, and climate warming may lead to outsized impacts or leaf temperature and function. This includes carbon assimilation s numerous studies suggest that a variety of ecosystems are operating at or near thermal thresholds. However sustained high-frequency measurements of canopy-scale leaf temperature across a range of ecosystems and conditions are rare. We show that davtime canopy leaf temperatures do not cool below air as predicted by the leaf homeothermy hypothesis. Leaves are typically warmer than air and the magnitude of this departure varies with leaf size and canopy structure. Almost all ecosyst photosynthesis occurs when leaf temperature exceeds air temperature. Future warming is unlikely to be mitigated by leaf cooling.

Author contribution: C.J.S. D.M.A., Y.K., S.P.B., C.Y.H., H.K., M.G., S.P., M.D., F.H., and A.D.R. collered data: G.P., B.R., D.M.G., D.M.A., Y.K., and S.P.B., repared data: C.J.S., G.P., B.R., D.M.G., S.P.B., L.H., F.C.M., S.S., D.R., M.G., S.P., M.D., B.H., and A.D.R. analyzed data: C.J.S. wrote the paper: and C.J.S. G.P., B.R., D.M.G., D.M., Y.K., S.P.S., CVH, H.X., L.H., F.C.M., S.S., D.M., M.G., S.P., M.D., B.H., and A.D.R. assisted with editing the manuscipt.

The authors declare no competing interest

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(CC BY-NC-ND). ¹To whom corre chris.still@oregor instate.edi

This article contains supporting info

Published September 12, 2022

Its influence spans from enzymatic reactions to ale species distributions. Temperature is also a of the concern about the impact of climate d by the pervasive influence of temperature on long been recognized as important for plant ly influences photosynthesis, respiration (1–4), of T_{loaf} in different habitats are also affected by latitude. A global meta-analysis of leaf size in relabund that large leaves occur preferentially in warm tions affecting selection for maximum possible leaf The temperature of leaves is, therefore, of fundamental on, productivity, and distribution. g appreciation of variation in Tleaf and its critical control on

plant and ecosystem function. Several studies document temperature positive net photosynthesis at leaf and canopy scales, with evidence that urrent temperatures are approaching or surpassing such thresholds, particularly in tropical forests (7-10). This has large implications for forest carbon balance and the global carbon cycle. If tropical canopy photosynthesis declines with increasing temperature while respiration continues to increase, then the strength of the carbon sink in the tropics will be reduced. The temperature sensitivity of leaf respiration-and its acclimation to rising temperature—underlines the importance of accurate T_{leaf} measurements and models for predicting carbon fluxes (4, 11-13). Finally, the increasing prevalence of heat extremes and heat waves resulting from climate warming (14, 15) has heightened interest in how ecosystems respond to such events, in particular, how leaves can avoid heat stress and mortality (16). Thus, understanding Tlat variations and controls

cuture climate warming is likely pacts on forest carbon cycling and

othermy | photosynthesis | leaf trait: tal control on biological systems and processes at



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Original Content from

PUBLISHED 19 May 2020

Article

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Climate and Atmo SCIENCE ADVANCES | RESEARCH ARTICLE

CLIMATOLOGY

ARTICLE OPEN Business-as-usual heatwaves in the I

George Zittis ^[0][™], Panos Hadjinicolao Levent Kurnaz 07,8, Grigory Nikulin9, A Rashyd Zaaboul¹² and Jos Lelieveld

Global climate projections suggest a (MENA). To assess regional impacts, a downscaling studies, which has been Index and a comprehensive ensemb indicate that in the second half of the events involve excessively high temp potentially life-threatening for huma could be exposed to annually recurr population (>90%) will live in urban npj Climate and Atmospheric Science

INTRODUCTION

The manifestation of human-induced Mediterranean region, including the Mir (MENA), is expected to become partic 21st century¹. Climate projections, eve gas emission pathways, indicate signif warming, in addition to less robust be precipitation^{2,3}. The regional warming differential seasonal response with a m increase projected for the boreal summe the year⁴. As a result of the rising wa heatwaves can be expected to increase and duration 5-8. The observed trends i rate the model simulations and the tra conditions, which started in the 1980s9 The potential intensification of heatw hot and arid MENA environment is negative impacts on human health^{18,1} and energy nexus^{21,22}, and many other s example, heat stress can cause su productivity²³ and may also be linked to Livestock in the MENA region will al majority of the camel, cattle, and goat areas of high vulnerability25. Regarding health, in particular, exposure to elevat to heat cramps, heat syncope, heat exi especially among the elderly and conditions, such as cardiovascular an Under high greenhouse gas emiss

¹Climate and Atmosphere Research Center (CARE-C Abdulaziz University, Jeddah, Saudi Arabia. 3Euro ⁵University Mohammed VI Polytechnic, Ben Guerir, I Arts, Bogazici University, Istanbul, Turkey. 8Center Hydrological Institute, Norrköping, Sweden. 10Der Engineering, King Abdullah University of Science Atmospheric Chemistry, Max Planck Institute for Cl

Deadly heat waves projected in the densely populated agricultural regions of South Asia

Eun-Soon Im,¹* Jeremy S. Pal,²* Elfatih A. B. Eltahir^{3†}

The risk associated with any climate change impact reflects intensity of natural hazard and level of human vulnerability. Previous work has shown that a wet-bulb temperature of 35°C can be considered an upper limit on human survivability. On the basis of an ensemble of high-resolution climate change simulations, we project that extremes of wet-bulb temperature in South Asia are likely to approach and, in a few locations, exceed this critical threshold by the late 21st century under the business-as-usual scenario of future greenhouse gas emissions. The most intense hazard from extreme future heat waves is concentrated around densely populated agricultural regions of the Ganges and Indus river basins. Climate change, without mitigation, presents a serious and unique risk in South Asia, a region inhabited by about one-fifth of the global human population, due to an unprecedented combination of severe natural hazard and acute vulnerability.

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INTRODUCTION

The risk of human illness and mortality increases in hot and humid weather associated with heat waves. Sherwood and Huber (1) proposed the concept of a human survivability threshold based on wetbulb temperature (TW). TW is defined as the temperature that an air parcel would attain if cooled at constant pressure by evaporating water within it until saturation. It is a combined measure of temperature [that is, dry-bulb temperature (T)] and humidity (Q) that is always less than or equal to T. High values of TW imply hot and humid conditions and vice versa. The increase in TW reduces the differential between human body skin temperature and the inner temperature of the human body, which reduces the human body's ability to cool itself (2). Because normal human body temperature is maintained within a very narrow limit of ±1°C (3), disruption of the body's ability to regulate temperature can immediately impair physical and cognitive functions (4). If ambient air TW exceeds 35°C (typical human body skin temperature under warm conditions), metabolic heat can no longer be dissipated. Human exposure to TW of around 35°C for even a few hours will result in death even for the fittest of humans under shaded, well-ventilated conditions (1). While TW well below 35°C can pose dangerous conditions for most humans, 35°C can be considered an upper limit on human survivability in a natural (not air-conditioned) environment. Here, we consider maximum daily TW values averaged over a 6-hour window (TW_{max}), which is considered the maximum duration fit humans can survive at 35°C.

HISTORICAL DISTRIBUTION OF MAXIMUM WET-BULB TEMPERATURE

According to the global historical reanalysis for modern record (1979-2015) (5), the largest TW_{max} rarely exceeds 31°C in the current climate. However, three extensive regions, where values exceed 28°C, are observed: southwest Asia around the Persian/Arabian Gulf and Red Sea. South Asia in the Indus and Ganges river valleys, and eastern China

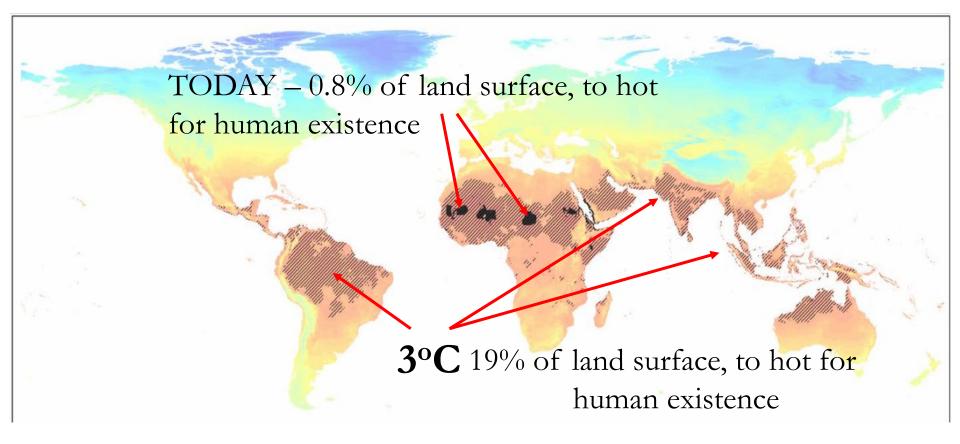
¹Division of Environment and Sustainability, Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Kowloon, Hong Kong. ²Department of Civil Engineering and Environmental Science, Loyola Marymount University, Los Angeles, CA 90045, USA. ³Ralph M. Parsons Laboratory, Massachusetts Institute of Technology, Cambridge, MA 02139, USA. *These authors contributed equally to this work. +Corresponding author. Email: eltahir@mit.edu

(Fig. 1). To identify the precise reasons for high TW, individual studies need to be performed because of each region's unique geography and climate. The underlying reasons why southwest Asia stands out are discussed by Pal and Eltahir (6), who concluded that future TWmax around the Persian/Arabian Gulf region is likely to exceed the TW threshold for human survivability by the end of the century under a business-as-usual (BAU) scenario of atmospheric greenhouse gas (GHG) concentrations. In summer 2015, TW in the Bandar Mahshahr, Iran Persian/Arabian Gulf, reached nearly 35°C, suggesting that the threshold may be breached sooner than projected (7). In this study, we shift our attention to the region of South Asia, here defined as Pakistan, Nepal, India, Bangladesh, and Sri Lanka. The northern part of this region is the second hottest after southwest Asia but is more expansive when considering the land area affected.

Heat waves and their impacts on human health are combined consequences of high dry-bulb temperatures and humidity (that is, high TW) and the vulnerability of the population. Many previous studies have investigated the impacts of anthropogenic climate change on heat waves and human health (8, 9). However, it is not until more recently that the combined effects of temperature and humidity have been more commonly considered. For example, the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (10) when making projections about future heat waves only considers T. However, the latest IPCC report (11) does consider the combined effects of T and Q when considering working conditions, which are projected to worsen considerably in many regions (12, 13). In addition, studies that include the combined effects at a global scale are largely based on output from climate models with resolutions on the order of 100 to 200 km (1, 14). Studies that are based on higher-resolution simulations are generally focused on North America and Europe (15, 16). However, the most detrimental human impacts of climate change on heat waves could potentially be those in developing nations because of the vulnerability of their populations. In much of India and Pakistan, an apparent rising trend in the frequency of deadly heat waves has been observed (17-19). For example, severe heat waves resulting in thousands of deaths to humans and livestock were reported around Odisha (eastern India) in 1998, Andhra Pradesh in 2003, and Ahmadabad and other parts of Gujarat (western India) in 2010 (20). In particular, the fifth deadliest heat wave in recorded history (21) affected large parts of India and Pakistan, claiming around

Warming on Land

1 billion displaced for every 1°C of additional global warming



Xu, C., et al. (2020) Future of the human climate niche, PNAS, May 2020, 201910114; DOI:10.1073/pnas.1910114117

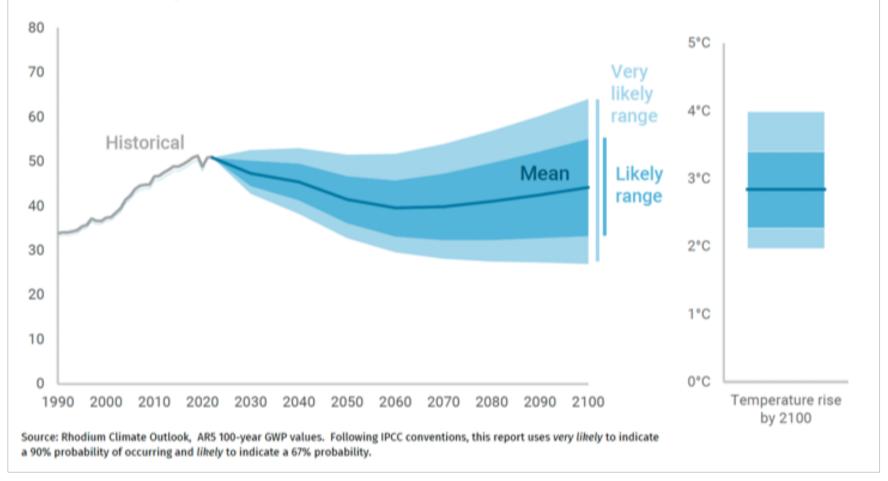
After 200 yrs of fossil fuel expansion we are at a turning point in the global energy system

- World spent \$1.8 trillion transitioning to clean power last year, more than spent producing oil & gas.
- Rooftop solar grew nearly 50% globally last year
- 2020 1 in 25 cars sold was electric
- 2023 1 in 5 cars sold was electric
- Global energy demand growth will now "almost entirely be met by renewables" IEA
- Economic growth no longer requires rising emissions
- However, Ambition needs to accelerate
 - We are headed for a long plateau of continued emissions
 - In 2022 solar and wind produced 12% of global electricity.
 - By 2030 this must increase to 41% of global electricity (to be on track for net-zero by 2050).

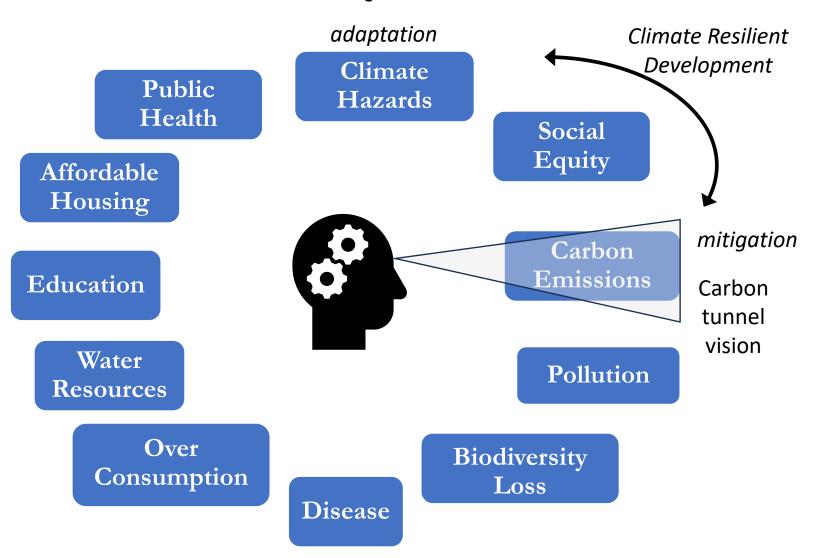
https://www.businessgreen.com/news/4061209/extraordinary-iea-heralds-energy-crisis-'historic-point-renewables?utm_campaign=Carbon%20Brief%20Daily%20Briefing&utm_content=20221206&utm_medium=email&utm_source=Revue%20Daily

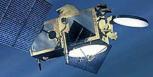
FIGURE 1 Global greenhouse gas emissions and temperature rise

Net emissions including removals (billion metric tons of CO2-equivalent)



Sustainability Transition





Jason 3 2016

OSTM/Jason 2 2008

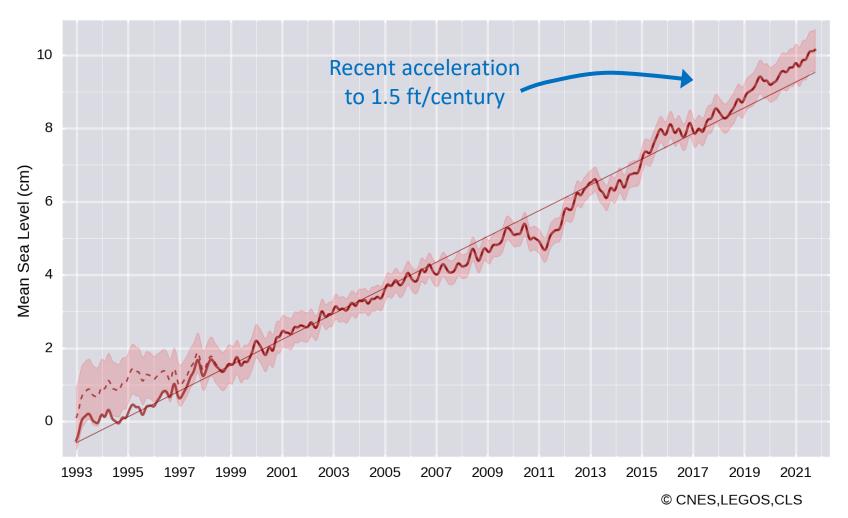


TOPEX/Poseidon 1992–2006

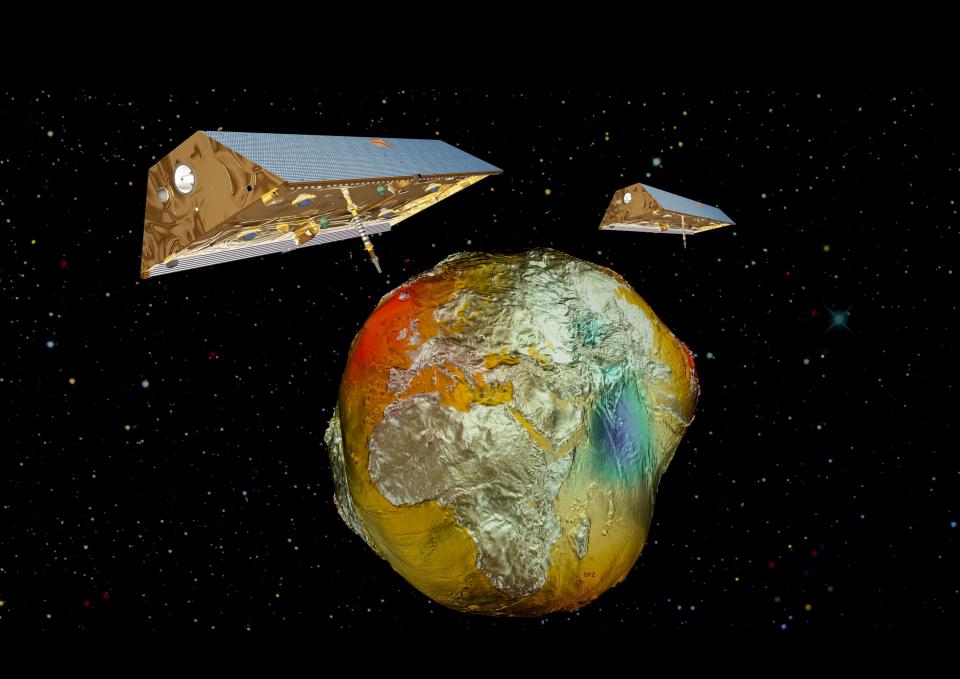
Global Mean Sea Level Rise

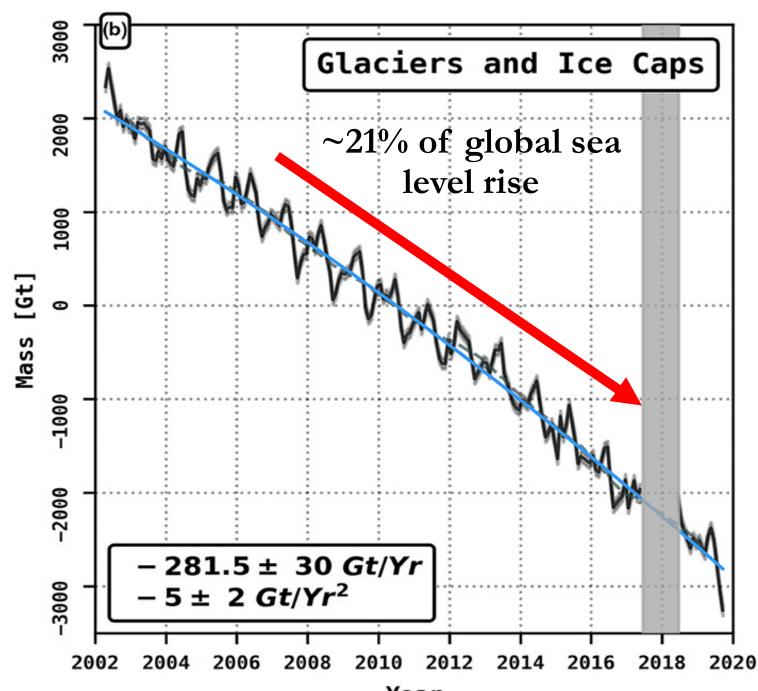
Latest MSL Measurement 15 October. 2021

1 foot per century Reference GMSL - corrected for GIA

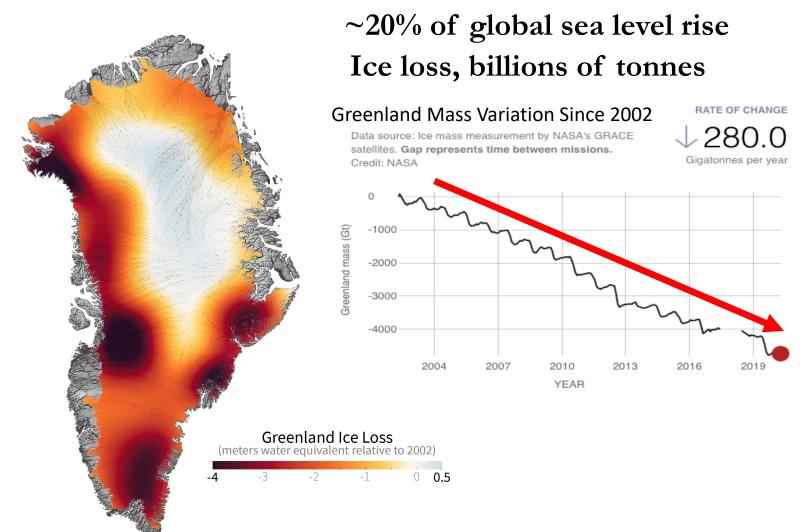


https://www.aviso.altimetry.fr/en/data/products/ocean-indicators-products/mean-sea-level.html



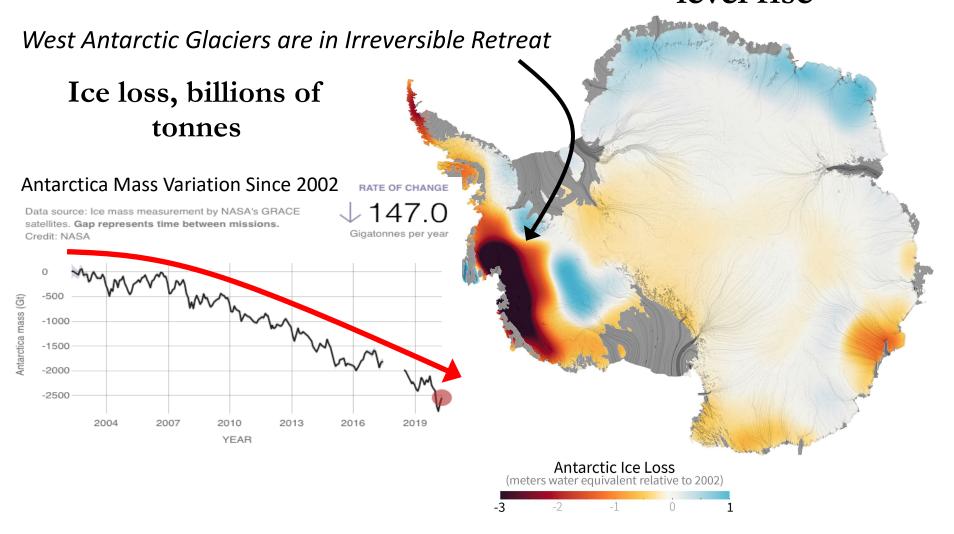


Greenland melting has quadrupled since 2010



Bevis, M. et al. (2019) Accelerating changes in ice mass within Greenland, and the ice sheets sensitivity to atmospheric forcing. PNAS, 116, 1934-1939. King, M.D., *et al.* (2020) Dynamic ice loss from the Greenland Ice Sheet driven by sustained glacier retreat. *Commun Earth Environ* **1**. https://doi.org/10.1038/s43247-020-0001-2

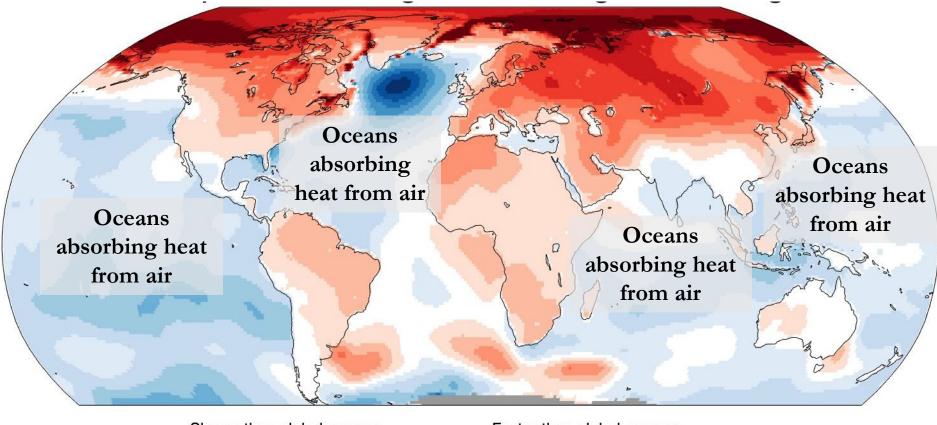
Antarctic ice melt has tripled since 2010 ~9% of global sea level rise

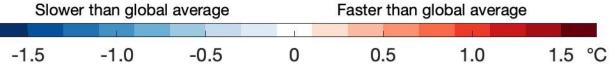


The IMBIE team (2018) Mass Balance of the Antarctic Ice Sheet, Nature, 558, pages219–222, https://doi.org/10.1038/s41586-018-0179-y

Temperature change relative to global average

Thermal expansion ~38% of SLR





Groundwater Depletion ~10%

IPCC, 2021 Assessment Report 6

Sea level is committed to rise for centuries to millennia due to continuing deepocean warming and ice-sheet melt and will remain elevated for thousands of years (high confidence). [AR6 WGI SPM p.21 B.5.4]

> Global mean sea level will rise by about - 6.5 to 10 ft at 1.5°C - 6.5 to 20 ft at 2°C ...and will continue to rise over subsequent millennia

IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., et al. (eds.)]. In Press.

Sea level rise, an unstoppable reality

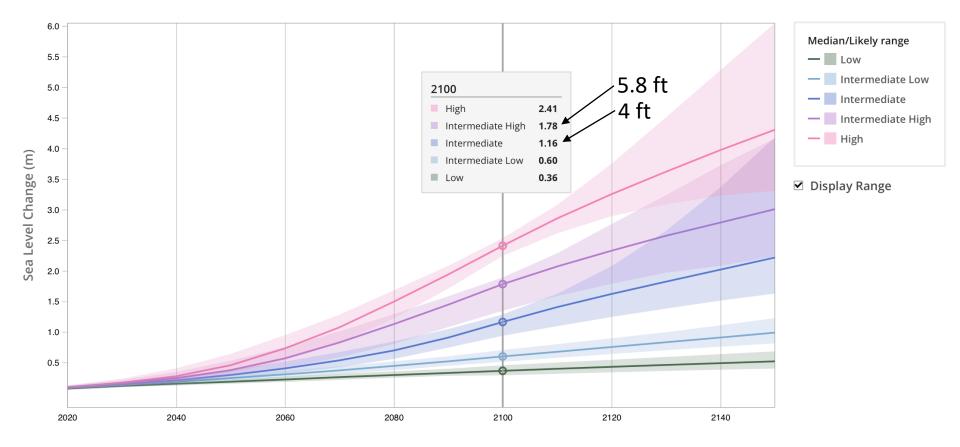
Photo, S. Habel

How high will sea level rise?

44A

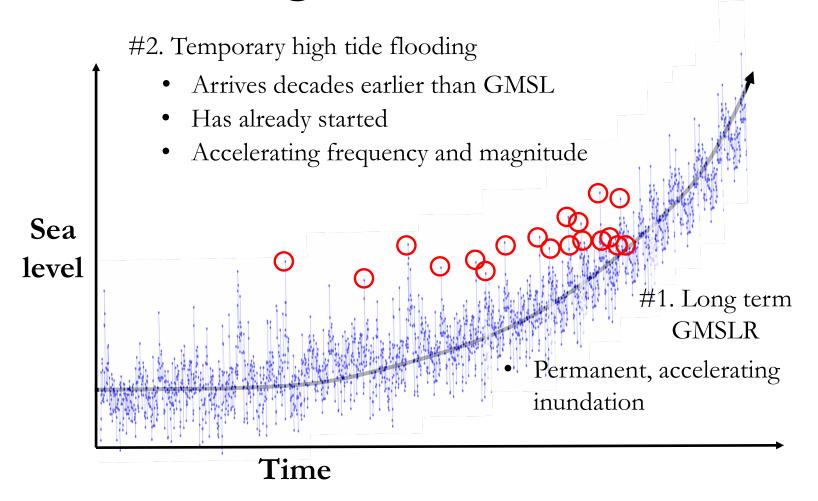
4

NOAA/NASA SLR Planning Scenarios Honolulu, Oahu



https://sealevel.nasa.gov/task-force-scenario-tool

SLR Flooding: Nuisance and Permanent



What are the impacts of SLR?

Ewa Beach – Wave Flooding, 1ft



Ewa Beach – Wave Flooding, 2-3ft



Ewa Beach – Wave Flooding, 4ft

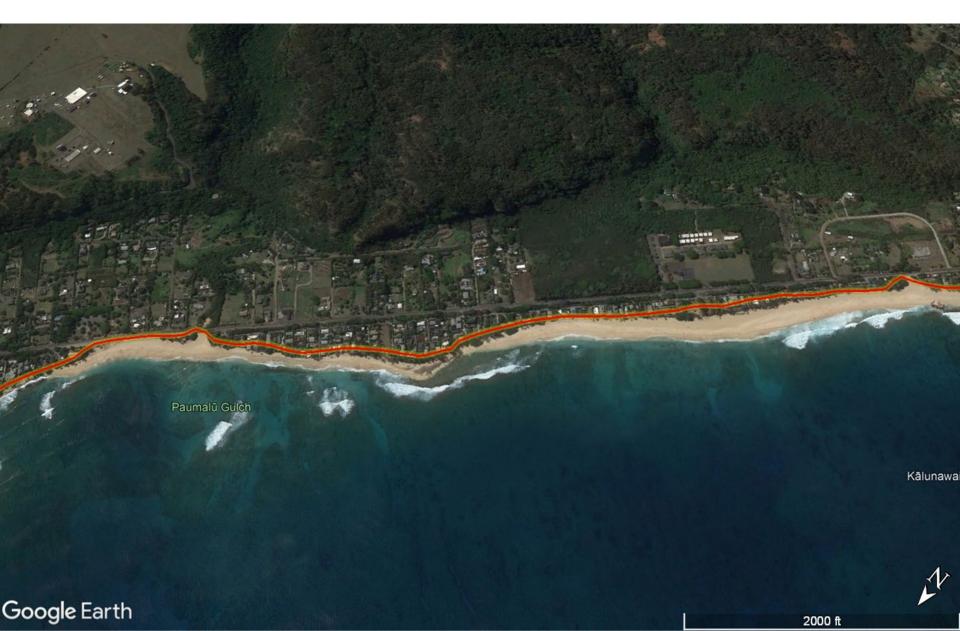


Sunset Beach – Coastal Erosion

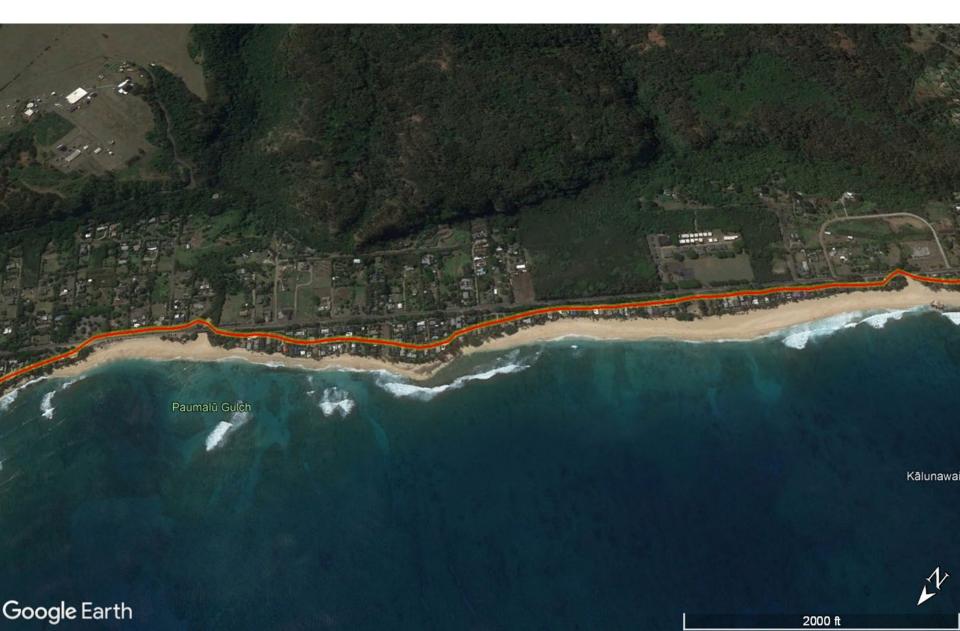
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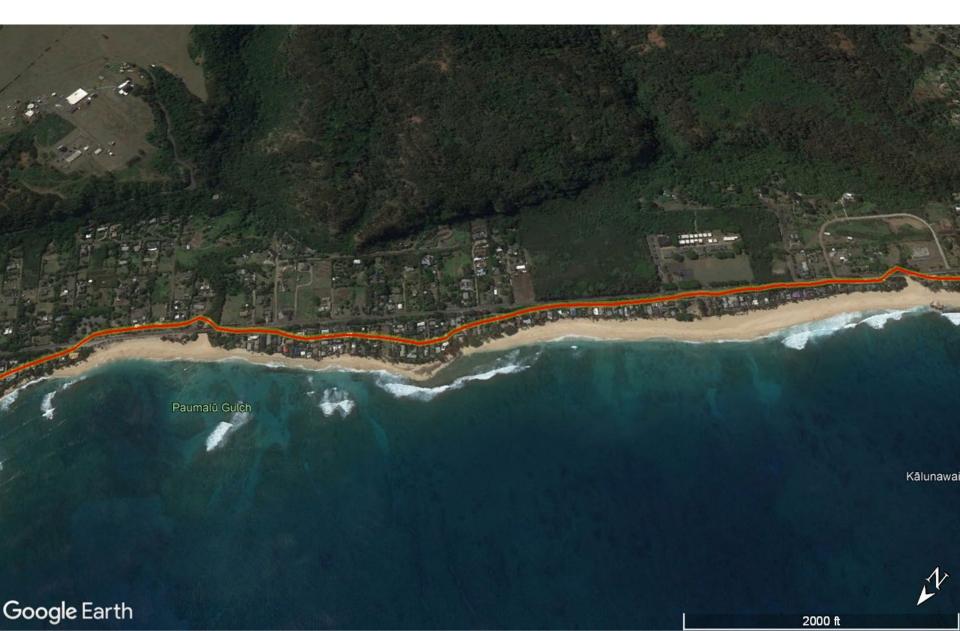
Sunset Beach – Coastal Erosion, 1 ft



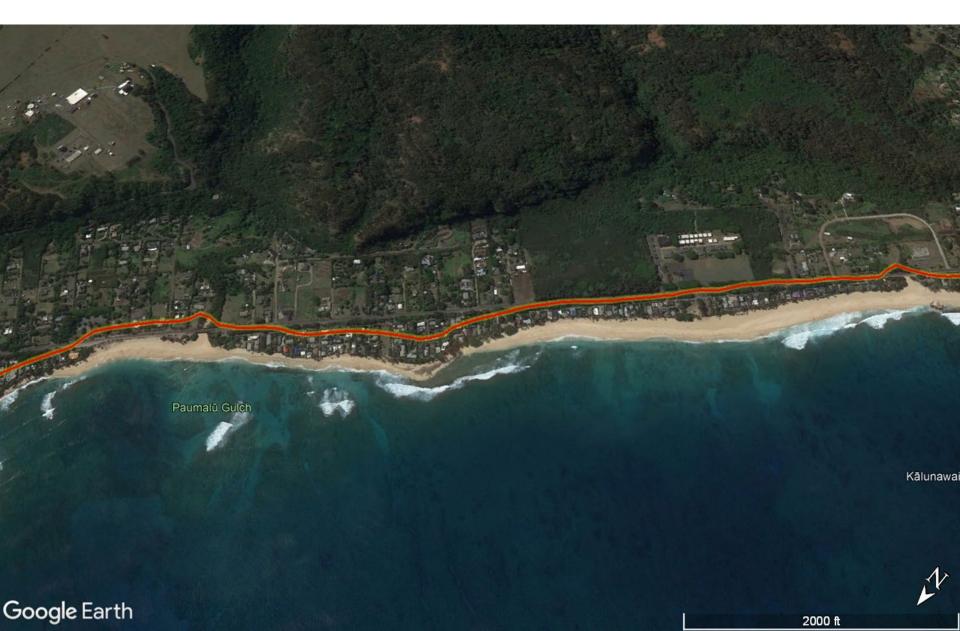
Sunset Beach – Coastal Erosion, 2 ft



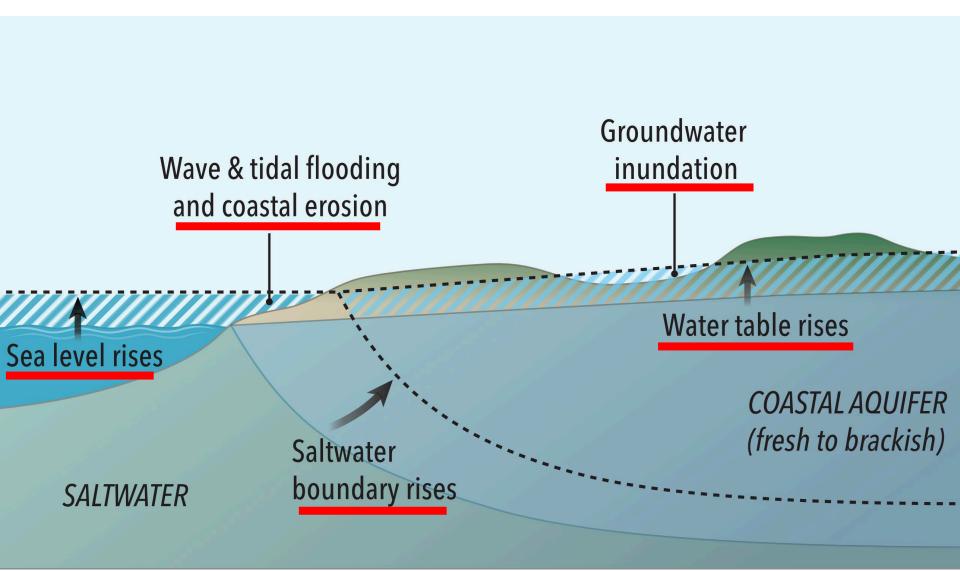
Sunset Beach – Coastal Erosion, 3 ft



Sunset Beach – Coastal Erosion, 4 ft



SLR Flooding

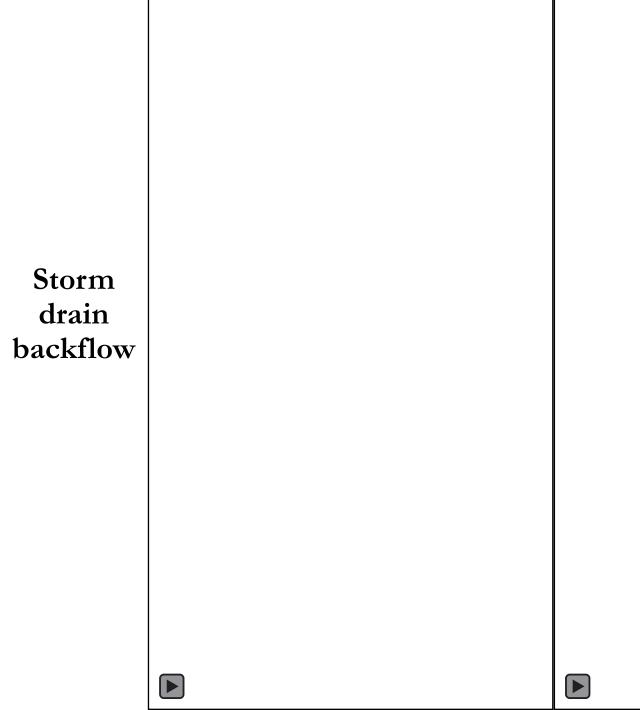


As sea level rises, so does the water table

SLR will bring polluted groundwater to the surface

Groundwater Pollution



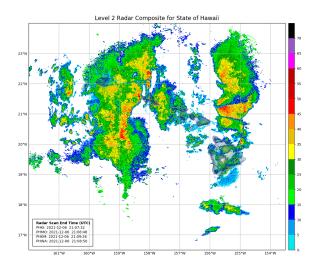


Rain + High Tide = Compound Flooding



Waikiki Dec. 5, 2021

- Sea level rise flooding today involves
 - Rain
 - Extreme tides
 - Onshore winds
 - Large waves



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Thank you for your time

https://www.wbsida.org/waikiki-beach-improvements

Rendering By Jonathan Quach, Inde

https://www.soest.hawaii.edu/crc/slr-viewer/index.php?map=kp