IN THE CIRCUIT COURT OF THE STATE OF OREGON

FOR THE COUNTY OF MULTNOMAH

COUNTY OF MULTNOMAH, Plaintiff, v. EXXON MOBIL CORP., SHELL PLC, F.K.A. ROYAL DUTCH SHELL PLC, SHELL U.S.A., INC., EQUILON ENTERPRISES LLC DBA SHELL OIL PRODUCTS US, BP PLC, BP AMERICA, INC., BP PRODUCTS NORTH AMERICA, INC., CHEVRON CORP., CHEVRON U.S.A., INC., CONOCOPHILLIPS, MOTIVA ENTERPRISES, LLC, OCCIDENTAL PETROLEUM F.K.A. ANADARKO PETROLEUM CORP., SPACE AGE FUEL, INC., VALERO ENERGY CORP., TOTALENERGIES MARKETING USA F.K.A. TOTAL SPECIALTIES USA, INC., MARATHON OIL COMPANY, MARATHON OIL CORP., MARATHON PETROLEUM CORP., KOCH INDUSTRIES, INC., AMERICAN PETROLEUM INSTITUTE, WESTERN STATES PETROLEUM ASSOCIATION, MCKINSEY & COMPANY, INC., MCKINSEY HOLDINGS, INC., NW NATURAL F.K.A. NORTHWEST NATURAL GAS COMPANY, OREGON INSTITUTE OF SCIENCE AND MEDICINE and DOES 1-250 INCLUSIVE, Defendants.	Case No. 23CV25164 **DECLARATION OF DANIEL L. SWAIN, PH.D** Hon. Benjamin Souede

I, Daniel L. Swain, Ph.D., hereby declare under penalty of perjury the following:

1. I am over the age of 21 and am competent to be a witness in this action.

2. My name is Daniel Swain, Ph.D. I am a climate scientist and currently employed as an Associate Scientist with the University of California (UC), with a dual appointment in UC Agriculture and Natural Resources as well as within UCLA's Institute of the Environment and Sustainability and am also a Research Fellow within the Capacity Center for Weather and Climate Extremes at the National Science Foundation National Center for Atmospheric Research. I have not been convicted of a felony. I have specific knowledge and experience that qualifies me to provide expert opinions in this matter.

3. I have prepared the following report, "**Recent Pacific Northwest extreme events, attribution to anthropogenic climate change, and potential links to specific emitters"** for use in this above captioned matter. A true and correct copy of my April 17, 2025 report which includes my opinions is attached hereto as Exhibit 1.

4. I hereby adopt and incorporate my report into this declaration as though it was set forth in full herein. My professional services have been performed using the degree of care and skill ordinarily exercised. All opinions in this report are my opinions to a reasonable degree of scientific certainty.

I hereby declare that the above statement is true to the best of my knowledge and belief, and that I understand it is made for use as evidence in court and is subject to penalty for perjury.

Daniel L. Swain, Ph.D.

EXHIBIT 1

Recent Pacific Northwest extreme events, attribution to anthropogenic climate change, and potential links to specific emitters

Report by Daniel L. Swain, Ph.D.

April 17, 2025

1. Table of Contents

2. Introduction

2.1 *Professional qualifications relevant to this report*

<u>2.1.1 *Relevant Knowledge, Skills, Training, and Experience*</u>

In my capacity as a climate scientist, I study atmospheric and Earth system processes relevant to extreme events–including those responsible for floods, droughts, and wildfire, as well as other natural hazards–and how they may be changing due to global warming. I am currently employed as an Associate Scientist with the University of California (UC), with a dual appointment in UC Agriculture and Natural Resources as well as within UCLA's Institute of the Environment and Sustainability, and am also a Research Fellow within the Capacity Center for Weather and Climate Extremes at the National Science Foundation National Center for Atmospheric Research. I also serve as an external advisor on extreme weather, climate, and wildfire-related topics to multiple private companies. In this report, I offer evidence-based professional assessments and opinions in my capacity as an independent expert; statements herein are not intended to suggest endorsement by my employers or other private entities with which I engage.

I am formally trained in both atmospheric science–including the physics and thermodynamics related to extreme weather processes–as well as broader Earth system science, including the dynamic interactions between the Earth's atmosphere, oceans, biosphere, and land surface. I received a Bachelor of Science degree in Atmospheric Science from the University of California, Davis in 2011, a Ph.D. in Earth System Science from Stanford University in 2016, and completed my postdoctoral training at the University of California, Los Angeles between 2016 and 2018.

My research has historically encompassed topics related to extreme weather and related natural hazards (including wildfire) and how these phenomena may be changing in a warming climate. My primary geographic focus in these research efforts is the western United States, although much of my work is global in scope. I have authored numerous publications published in peer-reviewed journals (40 in total, 16 lead-author, with several additional publications in various stages of preparation as of this writing), which have collectively been cited over 7,000 times since 2014. I engage extensively with the public on weather, climate, and wildfire-related issues, and have given over 600 interviews to a combination of television, radio, and print news media outlets as well as over 65 invited or keynote lectures over the past 5 years. Upon invitation, I have also offered expert testimony on similar topics to various legislative and government entities, including the State of California, federal agencies, and the U.S Executive Branch (i.e., The White House).

2.1.2 *Educational Background*

- Postdoctoral Fellowship, University of California, Los Angeles (2016-2018)
- Ph.D., Earth System Science, Stanford University (2016)
- B.S. (Highest Honors), Atmospheric Science, University of California, Davis (2011)

2.1.3 *Professional Experience/Academic Appointments*

- Climate Scientist (Associate Researcher), University of California Agriculture and Natural Resources & UCLA Inst. of Environment and Sustainability (Jul 2024-present)
- Climate Scientist (Assistant Researcher), UCLA Inst. of Environment and Sustainability (Sep 2018-Jul 2024)
- Research Fellow, Capacity Center for Climate and Weather Extremes, National Science Foundation National Center for Atmospheric Research (Sep. 2018-present)
- Postdoctoral Fellow, UCLA Inst. of Environment and Sustainability (Sep. 2016- Sep. 2018)

2.1.4 *Selected Publications of Particular Relevance*

- **Swain, D. L.**, Singh, D., Touma, D. & Diffenbaugh, N. S. Attributing extreme events to climate change: a new frontier in a warming world. *One Earth* **2**, 522–527 (2020).

- **Swain, D. L.**, Prein, A. F., Abatzoglou, J. T., Albano, C. M., Brunner, M., Diffenbaugh, N. S., Singh, D., Skinner, C. B. & Touma, D. Hydroclimate volatility on a warming Earth. *Nat. Rev. Earth Environ.* **6**, 35–50 (2025).
- **Swain, D. L.**, Abatzoglou, J. T., Kolden, C. A., Shive, K. L., Kalashnikov, D. A., Singh, D. & Smith, E. K. Climate change is narrowing and shifting prescribed fire windows in the western United States. *Commun. Earth Environ.* **4**, 340 (2023).
- Diffenbaugh, N. S., Singh, D., Mankin, J. S., Horton, D. E., **Swain, D. L.**, Touma, D., Charland, A. E., Liu, Y., Haugen, M., Tsiang, M. & Rajaratnam, B. Quantifying the influence of global warming on unprecedented extreme climate events. *Proc. Natl Acad. Sci. USA* **114**, 4881–4886 (2017).
- Goss, M., **Swain, D. L.**, Abatzoglou, J. T., Sarhadi, A., Kolden, C. A., Williams, A. P. & Diffenbaugh, N. S. Climate change is increasing the risk of extreme autumn wildfire conditions across California. *Environ. Res. Lett.* **15**, 094016 (2020).

(*Please also see attached curriculum vitae for additional publications.*)

2.1.5 *Professional Organizations*

- Member, American Meteorological Society (AMS) (2007-present)
- Member, American Geophysical Union (AGU) (2010-present)
- Member, American Assn. for the Advancement of Science (AAAS) (2017-present)

2.1.6 *Selected Academic and Professional Recognitions*

- National Science Foundation/Univ. of Texas DesignSafe Award (co-recipient, 2023)
- National Academy of Sciences Kavli Fellow (2019)
- Award for Scholarly & Research Achievement, Stanford Univ. (2016)
- College Medal, College of Agricultural & Environmental Sciences, Univ. of California, Davis (2011)
- Departmental Citation, Atmospheric Science, University of California, Davis (2011)

2.2 *Overview of topical focus of and basis for report*

In this report, I summarize and synthesize the evidence relevant to determining whether human-caused (i.e., anthropogenic and predominantly caused by the burning of fossil fuels) climate change influenced the likelihood of occurrence and/or severity of several specific extreme meteorological events that affected northwestern Oregon (including Multnomah County) between 2014 and the present. Additionally, I offer an evidence-based opinion, to a reasonable degree of scientific certainty, regarding whether these same specific events can, at least in part, be linked to the actions of specific entities that caused fossil fuel-derived greenhouse gases to be emitted into the atmosphere prior to their occurrence.

At the end of each subsection pertaining to specific events, I include a one-sentence summary statement as to whether, in my professional opinion and on the basis of the available scientific evidence, anthropogenic climate change has increased the likelihood and/or severity of each such event. For the purpose of these determinations, I consider the likelihood and severity of each event occurring "as observed"–i.e., using the actual sequence of events that was reported in popular media and/or scientific/government reports as a basis for defining the assessed characteristics and severity. In the section discussing the potential linkage between the actions of specific emitters and the likelihood, severity, or adverse impacts associated with the specific extreme meteorological events, I use both existing estimates of absolute and relative contributions as well as my expert assessment pertaining to the event-by-event attributions to arrive at an overall conclusion.

2.3 *A note regarding confidence and/or likelihood claims in this report*

Throughout this report, I have broadly aligned my own likelihood statements with the thresholds set forth by the Intergovernmental Panel on Climate Change (IPCC), which are described in detail by Mastrandrea et al. 2010 and adopted in successive IPCC reports up through the present. The terminology briefly summarized below is, wherever possible, intended to assign semi-quantitative bounds to the degree of scientific confidence regarding specific claims. For the purposes of this report, these likelihood statements are made on the basis of the full breadth of evidence available–including existing peer reviewed studies, analysis of publicly-available data, and my own professional judgment and synthesis taking into account both the volume and quality of evidence.

In this report:

- "Virtually certain" corresponds to > 99% likelihood
- "Very likely" corresponds to > 90% likelihood
- "Likely" corresponds to > 66% likelihood
- "More likely than not" corresponds to > 50% likelihood
- "About as likely as not" corresponds to 33-66% likelihood
- "Unlikely" corresponds to < 33% likelihood
- "Very unlikely" corresponds to < 10% likelihood
- "Exceptionally unlikely" corresponds to < 1% likelihood

2.4 *Executive summary of findings*

Anthropogenic climate change likely increased the likelihood and intensity of all three extreme events affecting Multnomah County assessed in this report–including the record-breaking June 2021 record-breaking heatwave, the summer drought conditions at various points between 2010 and 2023, and the severe September 2020 wildfire smoke pollution episode. In the specific case of the exceptional 2021 heat event, it is virtually certain that anthropogenic climate change worsened the severity of the event and associated adverse societal impacts.

Separately, it is very likely that the historical and ongoing actions by the specific greenhouse gas emitters named in this document–including fossil fuel extraction, processing, distribution, and eventual combustion following sale–have directly increased the cumulative concentration of greenhouse gases in Earth's atmosphere, contributing to the magnitude of observed planetary warming (i.e., anthropogenic climate change).

Thus, by contributing to the total amount of global warming over this period, it is therefore also very likely that the actions by these specific emitters increased the likelihood and severity of the above-mentioned events in the Pacific Northwest. ***Accordingly, it is very unlikely that these events would have occurred, when and as they did, but for the large observed***

increase in climate-warming greenhouse gas emissions–including those directly resulting from the actions of these specific emitters. Additionally, it is virtually certain that further warming–caused, in part, by historical and ongoing actions by these emitters–will continue to increase the future likelihood and intensity of extreme heat, drought, and wildfire events of similar or greater severity to those considered in this report.

3. Brief overview of greenhouse gas emissions, extreme events, and climate change

3.1 *The cumulative effect of greenhouse gas emissions upon climate*

There is essentially universal scientific consensus, drawing upon multiple independent lines of evidence, that the Earth's climate has warmed as a direct result of the rapid accumulation of greenhouse gases (primarily carbon dioxide and methane) in the atmosphere due to human activities (IPCC, 2023). In recent decades, the vast majority (greater than 85%) of cumulative anthropogenic emissions have been caused by the combustion of fossil fuels; even over centuries, the contribution by fossil fuels remains, by far, the single most important source (comprising over 66% of cumulative anthropogenic emissions since the mid-1700s, with the remainder primarily stemming from emissions caused by land use change; Friedlingstein et al. 2022). Thus, the definitive majority of observed anthropogenic global warming can itself ultimately be linked to fossil fuels–with the proportional role of fossil fuels becoming progressively larger since the mid 20th century.

An individual molecule of carbon dioxide emitted into the atmosphere will only remain there for around 5 years (i.e., has an approximately 5 year residence time). However, an emitted quantity of carbon dioxide will exert a warming influence on the Earth's climate for far longer–generally for centuries thereafter (i.e., has a multi-centennial adjustment time (Solomon et al. 2010)). This is because the amount of global warming depends on the total atmospheric concentration of greenhouse gases–not the length of time any particular molecule remains there. The biological, geological, and chemical processes that collectively comprise the Earth's "carbon cycle" operate slowly–generally over decades, centuries, and millennia–and slowly regulate the equilibrium level of greenhouse gases in the atmosphere such that when a specific carbon dioxide molecule exits the atmosphere, it is quickly replaced by another. Ultimately, this means that carbon dioxide emitted through human activities even a century ago continues to exert a climate-warming influence today, and will continue to do so well into the future (Solomon et al. 2010).

The difference between carbon dioxide's short residence time but long adjustment time, and its implications for long-term climate warming stemming from historical emissions decades in the past, can be visualized using a simple analogy that helps to illustrate this "stock versus flow" problem.

Consider a bathtub, initially filled halfway to the upper rim, with new water flowing into the tub via the faucet above and water simultaneously exiting the tub via a drain below. In this analogy, the water flowing into the tub via the faucet is akin to the sum of both natural and human (anthropogenic) emission of greenhouse gases, the water flowing out of the tub via the drain is akin to greenhouse gases exiting the atmosphere via the (natural) carbon cycle, and the overall water level in the tub is akin to the total concentration of greenhouse gases in the atmosphere (and thus analogously proportional to overall planetary warming potential). If the water flow from the faucet exceeds the water flow from the drain, the water level in the tub will rise–analogous to rising concentrations of greenhouse gases on Earth–even though many of the individual water molecules initially contributed by the faucet will have exited via the drain. If one is concerned about water spilling out of the tub, it is the overall water level that matters–and thus the imbalance between the rate of filling and draining.

This analogy is intended to illustrate the case of anthropogenic global warming, caused by the substantive and growing imbalance between stocks and flows of carbon. Here, it is the overall accumulation of greenhouse gases in the atmosphere that fundamentally drives warming–and subsequently causes increases in many types of extreme weather and weather-related events by altering the thermodynamics and dynamics of the Earth's global climate system.

One important corollary to the bathtub analogy: should one wish to understand how close the tub is to overflowing, it is not sufficient to consider only the recent rate of water inflow. To do so, an observer would also need to know the cumulative (net) amount of water that had been in the tub prior to the moment of inquiry. Likewise, in a climate change context, it is not sufficient to consider only recent greenhouse gas emissions; instead, to fully account for the cumulative effect of all historical emissions on the level of warming or the frequency/intensity of extreme events, it is critical to also account for the net increase in greenhouse gas concentrations that occurred prior to the time of inquiry (and in the case of anthropogenic climate change, the time horizon of relevance extends back to the 1800s for some emissions sources).

3.2 *High magnitude of observed and projected changes in Earth history context*

As of this writing (in April 2025), the Earth has warmed by around 1.3°C (2.3°F) on a global mean 20-year moving average basis (i.e., as defined in Intergovernmental Panel on Climate Change (IPCC) reports) relative to the "pre-industrial" era (mid-1800s) baseline period, though 2023 and 2024 both featured a period of accelerated warming that brought temperatures near or above 1.5°C (2.7°F) relative to that benchmark (Bevacqua et al. 2025). The enormous significance of planetary temperature variations on the order of several degrees might not be immediately obvious to some observers, but to put these numbers into a contextually appropriate Earth history perspective: the Earth's average temperature at the peak of the last ice age ~20,000 years ago, when ice sheets thousands of feet thick covered vast expanses of North America, Europe, and Asia (including where cities like Chicago and New York now stand), was only around 6°C (10.8°F) cooler than today's (Tierney et al. 2020). Moreover, the rapid observed rate of warming over the past ~150 years, caused overwhelmingly by the accumulation of heat-trapping greenhouse gases resulting from human activities, is unprecedented in the last 24,000 years (Osman et al. 2021).

3.3 *Scientific basis for attributing individual extreme events to climate change*

"Global warming" is generally defined as an increase in Earth's average surface temperature (i.e., the mean value of the near surface-level air temperature over all land, oceans, and ice sheets). “Climate change,” a term which is sometimes used interchangeably with “global warming” (including, often, in scientific settings), is perhaps more accurately described as a broader umbrella term encompassing various and complex changes in the Earth’s climate system that can arise from an increase in the Earth’s mean temperature (including changes to wind and precipitation patterns, and thus the occurrence of events like floods, droughts, various types of storms, and wildfires). Thus, when discussing climate change, I am referring to a range of atmospheric and Earth system phenomena that extend well beyond global mean temperature.

Over the past 15-20 years (following seminal work by Stott et al. 2004), a relatively new subfield of atmospheric and climate science–known as “extreme event attribution–has rapidly emerged, with over 1,800 scientific publications using or mentioning such methods as of April 2025 (per a Google Scholar search). The primary aim of this line of inquiry is to assess whether specific observed extreme meteorological events (including, for example, instances of highly anomalous temperature or precipitation) and/or their secondary hazards (including, for example, droughts, floods, or wildfires) were more (or less) likely to occur, and/or more (or less) intense, due to the anthropogenic global warming that has occurred to date.

While various investigators have used a wide range of specific approaches to conduct extreme event attribution studies (using some combination of Earth observational data and physics-based numerical modeling), they generally share a common overall epistemology: In essentially all cases, scientists attempt to compare the real-world climate (including the considerable and growing human influence due to anthropogenic greenhouse gas emissions) to a counterfactual climate (absent human influence, and thus without the effect of anthropogenic greenhouse gas emissions (Swain et al. 2020)). If the likelihood and/or magnitude of the specific extreme event in question is discernibly higher (i.e., to a statistically high degree of scientific confidence) in the real-world (human-influenced) climate than in the counterfactual (non human-influenced) climate, an affirmative climate attribution claim can be made (i.e., that anthropogenic climate change increased event likelihood and/or magnitude (Diffenbaugh 2020)).

In the following section of this report (Section 4), I discuss the potential influence of climate change on three specific extreme events occurring in the Pacific Northwest and affecting

Multnomah County in Oregon. To arrive at specific conclusions, I draw (primarily) upon a wide and continuously expanding body of existing peer-reviewed scientific research, including some studies that use extreme event attribution approaches, and (secondarily) upon publicly available climate data. In some instances, I draw inferences from fundamental and well-understood principles of atmospheric and climate science–synthesizing extant peer-reviewed reports, historical climate observations, and my own domain expertise–to offer assessments to a reasonable degree of scientific certainty.

4. Specific Pacific Northwest extreme events under consideration

4.1 *"Record-shattering" extreme heatwave/"heat dome," June 2021*

4.1.1 *Overview of the event*

From June 25 to July 7 2021, an extraordinarily extreme heat event occurred across a broad portion of the northwestern United States and western Canada. The event brought the hottest temperatures ever observed across nearly the entire region by a wide margin, with some locations exceeding previous all-time record high temperatures by 10°F or more (Philip et al. 2022; Figure 1).

Portland, OR (which is located in Multnomah County) was one of the many cities that experienced record-shattering temperatures during this event. The city, which is located at the northern end of the Willamette Valley in the far northwestern part of the state, had never experienced a temperature greater than 107°F. On June 26, the temperature in Portland climbed to 108°F–setting a new all-time record for any calendar month. Then, on June 27th, the temperature rose further to 112°F–breaking the all-time record set the previous day–and even higher on the 28th to an astonishing 117°F. The June 28th value was fully 10°F hotter than any previous observed temperature prior to June 2021–representing a heatwave much more severe than any previous ones in living memory.

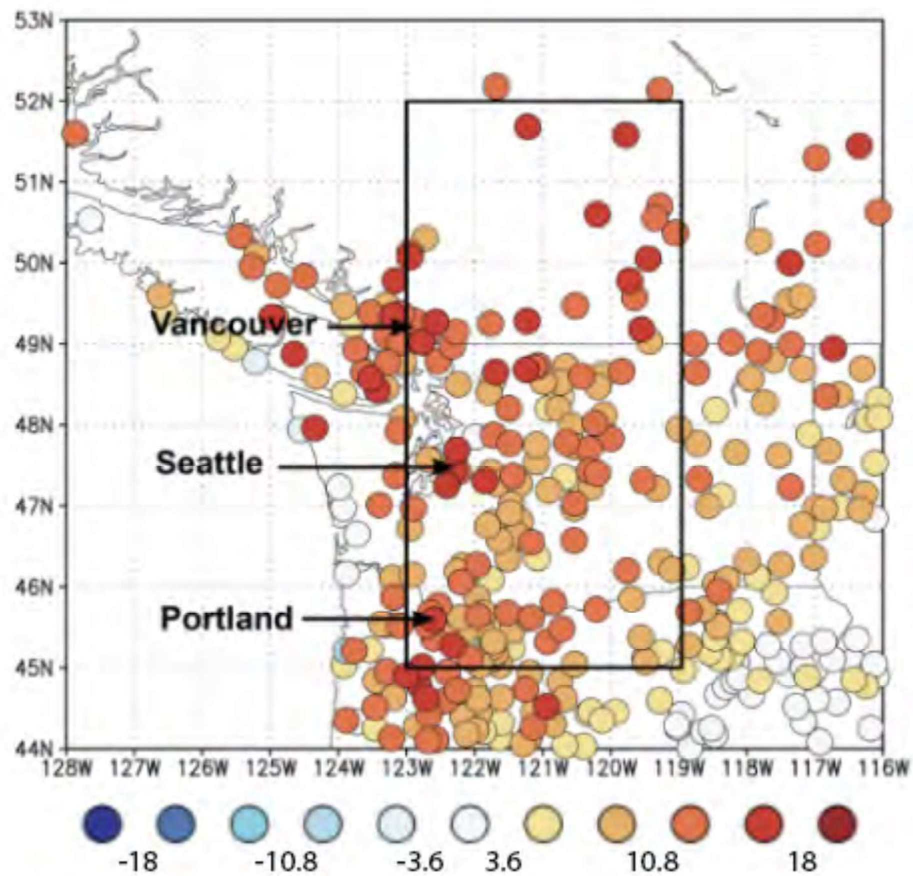
Heatwave impacts were widespread and severe. Conservatively, around 1,000 people are believed to have died as a result of the heatwave across the Pacific Northwest and Western Canada, including around 100 people in Oregon, in addition to widespread reports of heat-related illness and morbidity including a nearly 70-fold increase in hospital emergency department visits across the Pacific Northwest during this period. Damage to transportation infrastructure, including buckled roadways and rail lines, were reported in many areas. Mass mortality of various species in coastal marine and riverine ecosystems was reported, as well as damage to both commercial agricultural crops as well as urban forest and parkland (White et al. 2023).

4.1.2 *Assessing potential links to anthropogenic climate change*

The record-shattering 2021 Pacific Northwest heat event spurred a flurry of scientific research into the character and context of the event, including the potential role of anthropogenic climate change. Many of these studies have focused on different aspects of the event itself, from its proximal meteorological origins to its broader links to long-term climate trends. Generally, however, there is agreement from among these studies that the extreme event was proximally caused by the persistence and in-situ strengthening of a highly anomalous region of atmospheric high pressure over the region that lasted for nearly 2 weeks. (Such high pressure systems are sometimes referred to as “blocking ridges,” “blocking high pressure systems,” or colloquially “heat domes” due to their propensity to shield a broad area from clouds or precipitation by shifting the storm track away for days to weeks at a time.)

This blocking high pressure system was generated, in part, due to unusually substantial storm activity in the subtropical West Pacific Ocean. Though this storm activity was located thousands of miles away from the Pacific Northwest, it generated a longitudinal sinusoidal wave pattern known as Rossby wave train (McKinnon and Simpson 2022), which modified the upper-atmospheric wind patterns in such a way that favored the initial development of the blocking high pressure system. Then, the active storm corridor between the western subtropical Pacific allowed for a persistent band of clouds and precipitation–including a very elongated and anomalously strong warm season “atmospheric river” (Mo et al. 2022)–to form along a frontal band.

Figure 1.



Map depicting the margin by which peak temperatures during the summer 2021 Pacific Northwest extreme heat event exceeded the average "hottest temperature of the year" during the historical period at specific weather observation locations (units: °F).
Adapted from Philip et al. 2022.

This atmospheric river made landfall in southeastern Alaska (Figure 2), just to the northwest of the primary heatwave region, and deposited unusually warm and moist air at upper levels of the atmosphere. This, in turn, led to significant latent heating of the ambient upstream airmass (i.e., heat release that occurs when water vapor condenses into a cloud and subsequently falls out as precipitation) upwind of the high pressure system in the days preceding the peak of the heatwave.

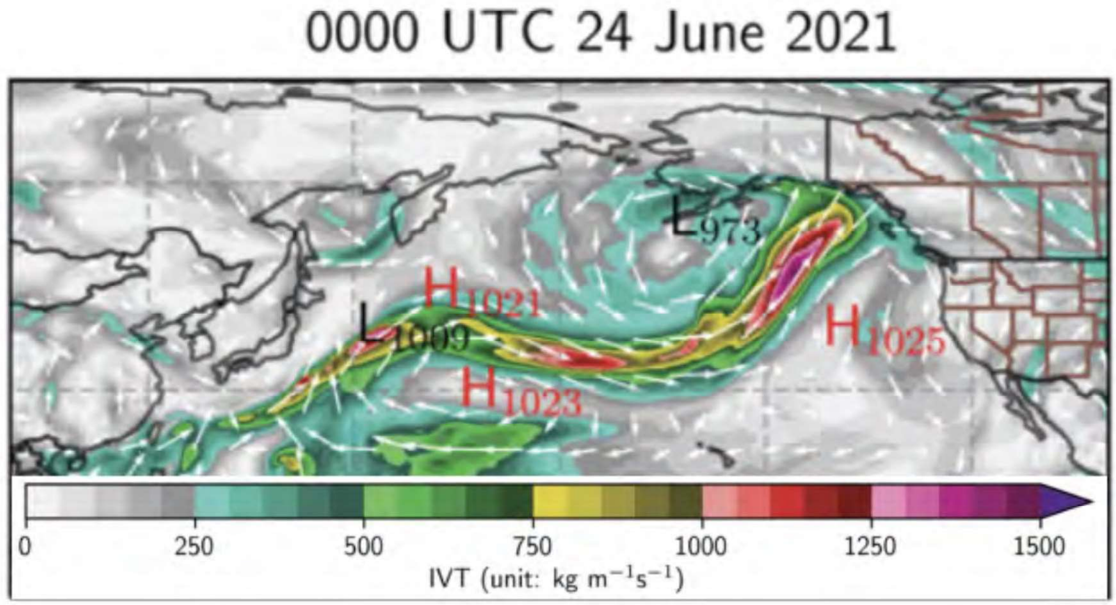
This moisture, however, was not substantial enough to cause significant cloud cover or precipitation within areas affected by the high pressure system itself. Instead, the injection of additional moisture and latent heat air that was later entrained into the high pressure system aided in its initial intensification (Schumacher et al. 2022). Strong downward motion of the air within the high pressure system (i.e., "subsidence" of the airmass causing compressional heating) then led to further warming as well as significant drying of the air as it descended toward the surface over the Pacific Northwest (Figure 3). As the heatwave persisted, the hot temperatures and low humidity at ground level contributed to desiccation of the soils throughout the region–amplifying the heatwave even further by allowing a progressively greater proportion of the sun's energy to heat the ground and lower atmosphere instead of evaporating soil moisture (i.e., increasing the ratio of sensible to latent heating; Schumacher et al. 2022). The soil moisture drying effect–part of a self-reinforcing "vicious cycle feedback"—became increasingly intense as the heatwave persisted beyond its first week (Bartusek et al. 2022).

Additionally, the advection (i.e., "transport") of anomalously hot air from nearby regions also experiencing unusually dry soil conditions is a known mechanism for heatwave intensification and was indeed evident during this specific June 2021 event, contributing to its severity (Li et al. 2024); this phenomenon is expected to increasingly contribute to extreme temperate latitude heatwaves as global temperatures rise (Schumacher et al. 2019).

In this way, the extraordinary Pacific Northwest heatwave of 2021 was likely amplified (initially) by 1) the transport of unusual warm and moist subtropical air into the Pacific Northwest (Figure 2); then, 2) by strong downward motion within the anomalously strong high pressure system (Figure 3); and, finally, 3) by the progressive depletion of soil moisture within the heatwave region, which allowed strong sunlight just after the summer solstice to heat the lower atmosphere even further.

In the paragraphs that follow, I assess the potential climate change contribution to each of these individual contributors.

Figure 2.

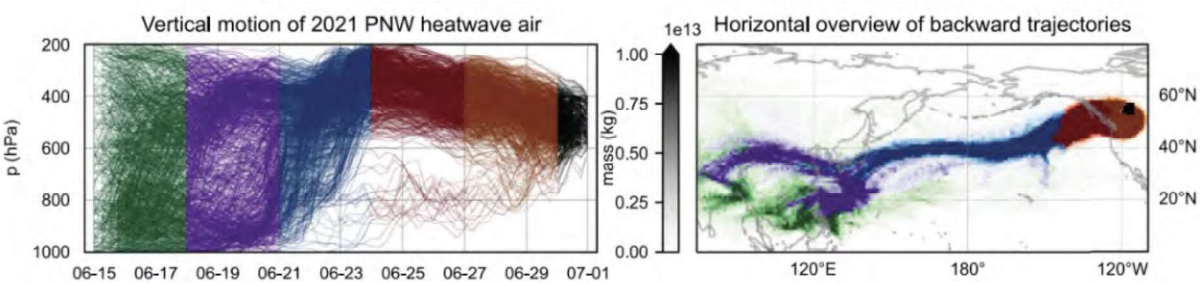


Map depicting the atmospheric river storm, extending for thousands of miles eastward over the North Pacific Ocean, that contributed to the intensity of the June 2021 extreme heat event in the Pacific Northwest via latent heating in the upstream airmass. Adapted from Mo et al. 2022.

Baseline warming likely contributed around 2.7°F to the magnitude of the heatwave (Bartusek et al. 2022, McKinnon and Simpson et al. 2022; Figure 4), and nonlinear interactions—primarily associated with land surface-atmosphere interactions involving soil moisture (~3.6-5.4°F contribution; Bartusek et al. 2022, Li et al. 2024) and upstream latent heating in the tropics (~2.7-3.6°F contribution; Schumacher et al. 2022)—together likely contributed an additional 6.3-9.0°F increment of warming. While essentially 100% of the baseline warming can be attributed to human-caused (anthropogenic) warming, there is less certainty regarding what portion of the further non-linear amplification of this event due to increased sensible heating of the lower atmospheric due to low soil moisture and/or increased latent heating upstream was caused by anthropogenic warming.

Nonetheless, to a reasonable degree of scientific certainty, a substantial portion of the cumulative nonlinear effect (via local land-atmosphere coupling and geographically distant upstream latent heating) can itself be linked to background warming and drying of this region during the early summer period. I therefore offer physically-based estimates of the portion of these nonlinear heatwave contributors that are associated with anthropogenic climate change. Planetary warming of approximately 2.3°F had occurred by 2021, which is associated with an approximately 10% increase in the intensity of evaporation and precipitation (and thus latent heating) over tropical ocean regions due to fundamental thermodynamic effects associated with the increasing amount of water vapor that air can hold as temperatures warm (Trenberth et al. 2003, Swain et al. 2025). (The true effect may be greater for extreme warm season events, but I use a conservative estimate in this context (Fowler et al. 2021)). 10% of the estimated 2.7-3.6°F upstream latent heating effect yields an anthropogenic climate change contribution of around 0.3°F (0.27-0.36°F).

Figure 3.



Times series plots depicting the initial upward and later downward motion of the air that would later become entrained by the persistent and extreme high pressure system that precipitated the historic 2021 heat event as it moved from the subtropical western Pacific Ocean to the Pacific Northwest interior. Adapted from Schumacher et al. 2022.

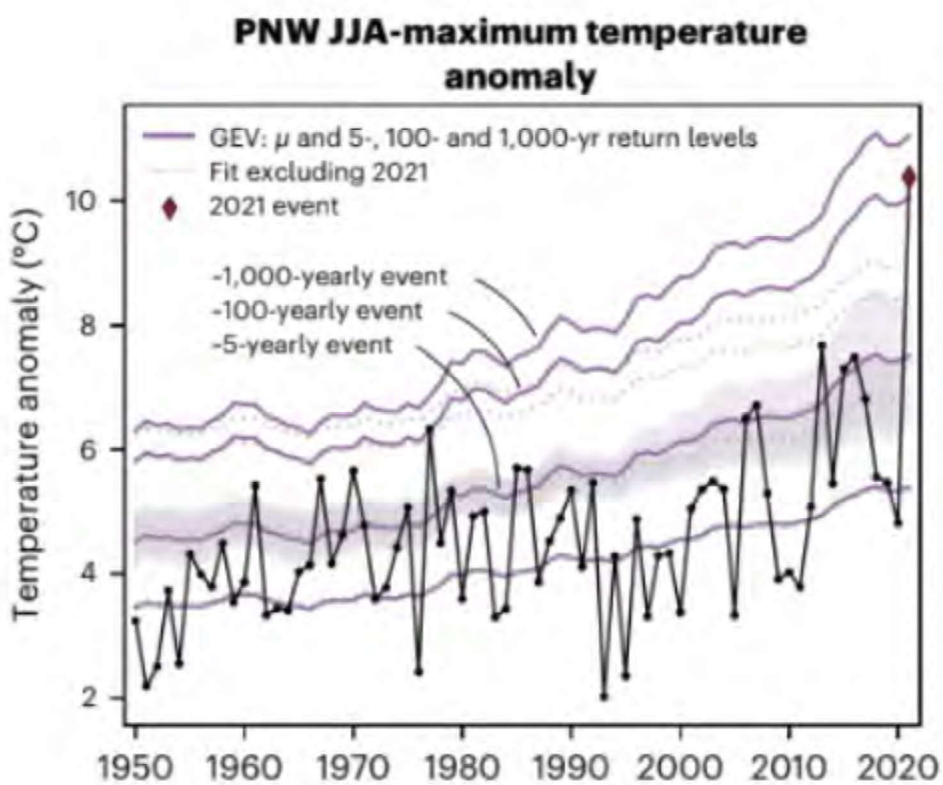
Additionally, Zhuang et al. 2021 indicated that around 66% of the observed increase in evaporative demand (i.e., "atmospheric thirstiness" that contributes to surface soil desiccation as measured by the vapor pressure deficit (VPD)) in Oregon can be attributed to human-caused warming, and Hawkins et al. 2022 found that extreme (95th percentile) VPD events in western Oregon in recent decades were around 50% higher than in counterfactual climate without human influence. (Bartusek et al. 2022 and others have noted that the effect may be considerably larger than this typical value during the most extreme events.) Further, there is direct evidence that the persistent and anomalous atmospheric high pressure system that preceded the peak of the heatwave caused strong soil moisture drying, "preconditioning" the region to subsequently experience a record-breaking heat event in the days that followed (Li et al. 2024). Thus, I estimate that the anthropogenic contribution to the nonlinear amplification of the 2021 event due to land surface/soil moisture-driven feedbacks is around 40-50% of the total estimated value of 3.6-5.4°F, or a further ~2°F (1.4-2.7°F).

To summarize: I estimate the combined effects from anthropogenic climate change upon the extreme June 2021 heat event in the Pacific Northwest to be approximately +2.7°F from baseline warming, +2.0°F from the anthropogenic component of regional-scale soil moisture feedbacks, and +0.3°F from the anthropogenic component of upstream latent heating in the tropics–suggesting a total anthropogenic contribution on the order of approximately 5°F. Given that the overall magnitude of the regionally-averaged multi-day heat anomaly was +18-23°F (depending on methodology, definition, and dataset used), this indicates that anthropogenic climate change was responsible for approximately 22-28% of the overall magnitude of the event as observed. Notably, this estimate is consistent with recent research suggesting that the most extremely hot temperatures should generally be expected to increase at approximately double the local warming rate of mean temperatures in moist mid-latitude regions (Zhang and Booz, 2023).

On the basis of the above, I find that it is *virtually certain* that anthropogenic climate change made the observed heat event at least 2.7°F hotter than it otherwise would have been (due to the linear background warming trend alone), and *likely* that anthropogenic climate change made the observed heat event at least 5°F hotter than it would otherwise would have been (inclusive of both the anthropogenic linear warming as well as anthropogenically-influenced nonlinear effects, as discussed above).

Critical to note, in this context, is that even seemingly modest increases in temperature can strongly affect the societal and environmental adverse effects of such events. A historically severe heatwave during the summer of 2003, for instance, was responsible for tens of thousands (~70,000) deaths across Europe (Robine et al. 2008); recent research (Callahan et al. 2025) suggests that at a level of ~1.5°C (2.7°F) of global mean warming, the additional physiologic heat stress from anthropogenic warming during a similar event could cause ~15,000 additional excess deaths in a single week (and a level of ~3°C (5.4°F) of global warming, ~30,000 additional excess deaths). While the death toll resulting from the June 2021 event in the Pacific Northwest was likely lower than during the 2003 European event due to differences in demographics and other background factors, the cumulative death toll across Oregon, Washington, and British Columbia was nonetheless confirmed to be (at least) in the hundreds and estimated to be (more likely than not) in excess of 1,000 people (including over 50 deaths in Multnomah County ((Popovich, N. & Choi-Schagrin, 2021))–making it among, if not singularly, the deadliest weather event(s) on record in this region.

Figure 4.



Time series plot showing the observed (black line) and climate model projected (purple lines, each representing a different level of event rarity) maximum summer (June-August) temperatures across the Pacific Northwest. June 2021 event is denoted by a purple diamond. Adapted from Bartusek et al. 2022.

Additional analysis has been conducted and published in the peer-reviewed literature strongly and directly indicating that anthropogenic climate change has greatly increased the *likelihood* of the observed 2021 extreme heat event unfolding as it did (in addition to its severity, as discussed above). Several independent research groups have come to qualitatively similar conclusions in this regard (e.g., Bartusek et al. 2022, McKinnon and Simpson et al. 2022, Dong et al. 2023). Although there is uncertainty regarding the actual baseline occurrence or rarity of record-shattered heat event of similar magnitude in this region, there is unanimity amongst all available formal estimates that anthropogenic climate change has transformed such an event from one that was "virtually impossible" or at least exceptionally rare (expected to occur only once per 10,000-100,000 years, or even less often, in an unchanging climate) to one that is now possible in the present climate (once per ~200-1,000 years)—representing an (at least) 100-fold increase in the estimated in likelihood of the event (as it occurred) taking place in 2021.

Multiple studies also indicate that relatively modest additional warming–comparable to what will likely occur by 2050 on a moderate emissions trajectory (i.e., ~2°C (3.6°F) on a global mean basis)–is expected to further increase the likelihood of a 2021-like event to such an extent that similar events would occur with notable regularity (i.e., every 10-20 years within the next 30 years (Bartusek et al. 2022, Dong et al. 2023, Philip et al. 2022)). *Altogether, this suggests that anthropogenic climate change has already increased the likelihood a 2021-level event occurring as observed by a factor of ~100 (i.e., by ~10,000%) or more, and continued warming will increase future likelihood by a further factor of 10 (i.e., by an additional 1000%) over the next 30 years when global mean warming reaches ~2°C (3.6°F).*

4.1.3 *Summary Statement*

It is virtually certain that anthropogenic climate change increased the likelihood and severity of the June 2021 extreme heat event, and it is also virtually certain that continued climate change will further increase the likelihood and severity of similar (or worse) events over the next 30 years. Thus, it is exceptionally unlikely that this event would have occurred when and as it did but for anthropogenic climate change.

4.2 *Summer drought conditions in the early 21 century*

4.2.1 *Overview of the event*

Severe multi-year drought conditions developed across much of Oregon beginning in 2013 and initially peaking in severity in 2015, particularly during the warm season (summer) months, but with additional peaks in 2018, 2021, and most recently 2023. Despite brief seasonal to annual-scale interludes where drought conditions have lessened in severity and/or briefly disappeared by some metrics, the Willamette Valley has experienced drought conditions more often than not between 2013 and 2023, with historically unprecedented short-term drought conditions occurring at times over this interval (Figure 5). Drought impacts have been widespread though varied in time and space, ranging from hydrologic (affecting streamflow in area rivers and ecosystems/fisheries) to agricultural (affecting both commercial cropland as well as urban parkland and open spaces) and beyond. Additionally, these drought conditions likely also predisposed the region to increased wildfire activity and more extreme summer heatwaves, both of which co-occurred with drought conditions at multiple points during this period.

4.2.2 *Assessing potential links to anthropogenic climate change*

For the purposes of this assessment, drought is defined as an anomalous deficit in the amount of water present in soils and/or streamflow relative to typical conditions in a specific location at a particular time of year. Such unusually dry conditions are generally brought about by some combination of unusually low precipitation, unusually high temperatures, and/or unusually low snowpack accumulations.

The Pacific Northwest generally and northwestern Oregon in particular is expected to experience large and sustained increases in temperature throughout the calendar year (Fleishman 2023) due to anthropogenic climate change. The observed historical and projected future increases in temperature are contributing to increased "evaporative demand" by the atmosphere (Figure 6)–increasing the propensity for existing water in the soil (when/where it is available), bodies of water, and plants to re-enter the atmosphere through evaporation (Albano et al. 2022) as warmer air acts like a progressively larger “sponge” (Swain et al. 2025). This is directly related to the increased vapor pressure deficit discussed in previous sections. Multnomah County specifically has warmed by around 2.5°F degrees overall in the past century, which has directly driven an increase in evaporative demand in this region (Zhuang et al. 2021).

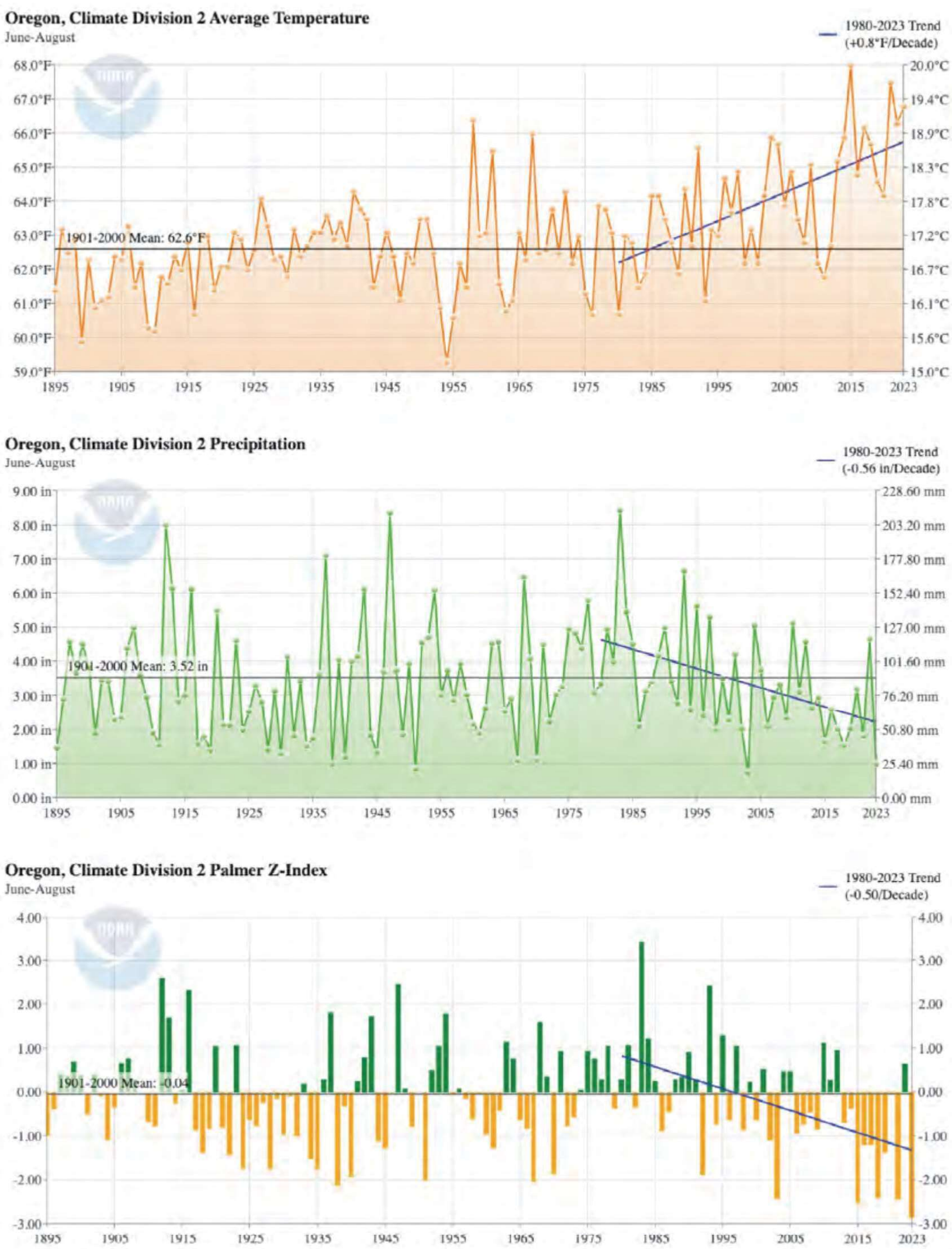
Indeed, the Pacific Northwest region in general and northwestern Oregon specifically has a relatively moist climate, characterized by cool, wet winters and comparatively warm, dry summers–characteristics that make the region particularly susceptible to the effects of increasing evaporative demand. Places with relatively wet background climates, like western Oregon, have experienced accelerated soil drying in recent decades (Qing et al. 2023), which has been directly tied to increasing temperatures via rising atmospheric evaporative demand (Figure 6). Increases in the rates of soil drying have also been implicated in the rise in rapidly-emerging and temperature-driven “flash droughts” in recent years, which is expected to be another signature of the increasing evaporative demand (vapor pressure deficit) in many regions (Yuan et al. 2023).

Precipitation changes in the Pacific Northwest due to climate change are more spatially and temporally complex than those in temperature. Overall annual average precipitation is expected to increase modestly in most areas (most substantially in winter), but this coincides with a projected *decrease* in precipitation specifically during the summer months (thereby amplifying the preexisting “wet winter/drier summer” seasonal cycle (Rupp et al. 2017)). While decreases in annual average precipitation across the Pacific Northwest are not anticipated due to anthropogenic climate change, modest projected decreases in *summer precipitation* in conjunction with the more certain and likely larger contribution of increasing evaporative demand due to anthropogenic climate change will likely, nonetheless, increase drought risk. Notably, both of these factors (i.e., decreased seasonal precipitation and increased evaporative demand) would be most relevant to drought conditions occurring in the warm season months. These predictions are broadly borne out in observations (Figure 5). Between 1980 and 2022, Multnomah County experienced no substantial trend in *annual average* precipitation (-0.1 inches per decade) but did experience a notable decrease in *summer* (June-August) precipitation (-0.56 inches per decade), and evaporative demand has also increased (as further quantified below).

Additionally, the Pacific Northwest has experienced multiple “snow droughts” in the past decade (e.g., Marlier et al. 2017). A snow drought occurs when overall soil moisture and streamflow are near average but (mainly high elevation/mountain) snowpack is substantially below average. Such a condition can arise when precipitation is near to above average but temperatures are substantially warmer than average, causing precipitation to fall as rain rather than snow and preventing snow accumulation and/or accelerating melting of existing snowpack. Although snow drought conditions do not immediately lead to the full suite of societal or environmental impacts associated with “traditional” drought, low mountain snowpack can still result in substantially decreased soil moisture and streamflow in these areas during the warm season (summer and autumn) months that follow–and can accelerate the development of anomalously dry conditions if atmospheric factors are otherwise favorable. Indeed, Pacific Northwest snow drought conditions in the mid 2010s–which contributed to unusually low summer soil moisture and subsequently to increased wildfire activity–are thought to be representative of conditions that will become much more common in this region as a result of anthropogenic climate change (Marlier et al. 2017).

Using data from NOAA’s temperature, precipitation, and drought database (Figure 5), I have conducted a brief analysis of observed trends in NOAA’s Willamette Valley climate division (which includes nearly all of the city of Portland and most of Multnomah County). Between 1980 and 2023–a 43 year period–summer (June-August) precipitation declined by -0.56 inches per decade (meaning that by 2023 the average summer received around 2.5 inches less rainfall than in the decades previous). Summer temperature increased by 0.8°F per decade (with a cumulative rise of 3.2°F) over the same period. Additionally, a key indicator of short-term drought (the standardized Palmer Z-Index) increased sharply over these same decades, reaching a point beginning in 2013 during which a majority (9 of 11) of all summer values were substantially negative (i.e., indicative of drought). Also, all of the most strongly negative Z-Index values (i.e., the most severe short-term drought conditions) in the period of record (1895-2023) occurred after 2013. 2015 exhibited the lowest Z-Index values on record to date at that point, though that record has since been surpassed by even drier conditions in summer 2023.

Figure 5.



Time series plots depicting historically observed summer (Jun-Aug) temperatures (top), summer precipitation (middle), and summer drought severity (as measured by the normalized Palmer Index; bottom). In each plot, linear trends for the period 1980-2023 are shown. Data via NOAA's "Climate at a Glance" portal.

This analysis demonstrates that the NOAA climate region encompassing most of the population in Multnomah County has experienced both a strong warming trend and a strong drying trend (from a net water balance perspective) during the summer months (Figure 5). This observed increase in historically unprecedented summer warmth and dryness has unfolded in the absence of a meaningful long-term trend in overall annual precipitation (although precipitation in the summer months specifically has indeed decreased).

On their own, these observational data cannot be used to make a formal attribution statement regarding the potential role of anthropogenic climate change. Observed trends represent the net effect of both natural and human-caused climatic changes over the period in question, and targeted studies are required to determine the relative proportion of each. However, when considered in the context of the large volume of existing published scientific literature suggesting a) very strong evidence for increases in summer temperature and b) moderately strong evidence for decreases in summer precipitation in this region and c) moderately strong evidence for increases in overall summer aridity in this region caused by anthropogenic climate change, the NOAA observational data (Figure 5) helps tie together disparate threads in a manner that indicates a probable human fingerprint upon increasingly frequent and severe summer droughts in the Willamette Valley–including recent record-breaking drought conditions.

Collectively, this body of direct and indirect evidence indicates a substantial likelihood that the observed increase in temperature and atmospheric evaporative demand, themselves caused primarily by anthropogenic climate change, have increased the likelihood and severity of summertime droughts in this region. The observed decrease in summer precipitation has likely amplified this effect.

4.2.3 *Summary Statement*

It is likely that anthropogenic climate change increased the likelihood and severity of the observed summer drought conditions between 2015 and 2023. Thus, it is unlikely that this event would have occurred when and as it did but for anthropogenic climate change.

4.3 *Severe and prolonged wildfire smoke pollution episode, September 2020*

4.3.1 *Overview of the event*

Multnomah County and much of the Pacific Northwest has been severely affected by multiple episodes of severe air pollution due to smoke emitted by wildfires at multiple points in recent years, but the most intense, disruptive, and damaging of these episodes was arguably that which unfolded during September 2020. During this event, a sequence of three distinct periods of significant weather conditions that unfolded over several weeks interacted with antecedent anomalously warm and dry climate conditions to produce a catastrophic wildfire and subsequent smoke pollution event. Air pollution in Portland and surrounding areas reached dangerously high levels during this event–the worst on record for the city–with regional air quality briefly becoming the worst in any major city on Earth at that point in time. Air pollution levels in Portland reached “hazardous” levels constituting public health “emergency” conditions, affecting all members of the population (not just those considered vulnerable) on five separate days during the event (Oregon Department of Air Quality, 2023).

First, a period of extremely hot and dry weather dried out regional vegetation in the weeks leading up to the period of most extreme smoke pollution. This, in conjunction with preexisting drought conditions, preconditioned the vegetation at landscape scale to become unusually dry and thus unusually flammable–both making new wildfire ignitions more likely and increasing the potential intensity and volume of smoke generated by any of these potential fires.

Second, an extreme “east wind” event (characterized by powerful offshore winds, blowing from more arid inland regions westward toward moister forested regions and associated with very low atmospheric humidity) occurred across western Oregon. These strong winds caused both existing and new wildfires to spread rapidly, including some in heavily forested areas with little recent fire history (Hawkins et al. 2022). In a handful of cases, these wildfires moved into populated areas and also consumed small towns and subdivisions–causing historic destruction and at least 11 deaths. An extremely large volume of smoke, primarily generated by the combustion of vegetation including coniferous forests but with contributions also from burning homes, commercial structures, vehicles, and any number of hazardous materials that are ordinarily found in such environments, began to accumulate over Oregon and extended across many adjacent states and regions.

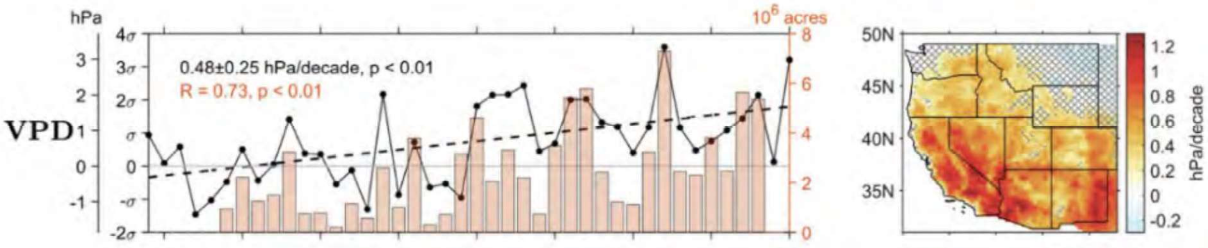
Third, a stable weather pattern–characterized by an atmosphere without precipitation, significant winds, or upward vertical motion–followed the east wind event. Such patterns are known meteorologically as “air stagnation events” because they prevent the movement of air pollutants (including both gaseous and particulate types) out of a given area, trapping them near the surface and allowing them to accumulate in the air that people and animals breathe. In this instance, the air stagnation event co-occurred with a historic wildfire smoke emission episode, and the result was a prolonged period of extremely high smoke-derived particulate matter (PM 2.5) pollution throughout much of Oregon and including the highly populated Portland metropolitan area, which was positioned directly downwind of some of the densest wildfire smoke plumes.

4.3.2 *Assessing potential links to anthropogenic climate change*

Above, I have described a sequence of three specific weather events that interacted with a climate change-altered baseline to yield the observed conditions and ultimately the extreme wildfire smoke episode of September 2020. Now, I examine each element of this sequence (as well as the background state) to assess the potential role of anthropogenic climate change.

As discussed in greater detail in earlier sections of this report, there is an overwhelming amount of evidence (i.e., it is virtually certain) that anthropogenic climate change has increased the likelihood and severity of heatwaves, both broadly in a global context and specifically in western Oregon (e.g., Philip et al. 2022; Bartusek et al. 2022; Figure 4). Additionally, there is strong evidence that anthropogenic climate change has increased the likelihood and severity of the atmospheric vapor pressure deficit (Zhuang et al. 2021; Albano et al. 2022; Figure 6) and soil moisture drought conditions in western Oregon in the summer months specifically (Figure 5).

Figure 6.



Left: Time series plot depicting observed increases in the vapor pressure deficit (VPD) over the Western United States. Right: Map plot depicting observed historical increases in VPD over the same period used in the time series plot at left. Adapted from Zhuang et al. 2021.

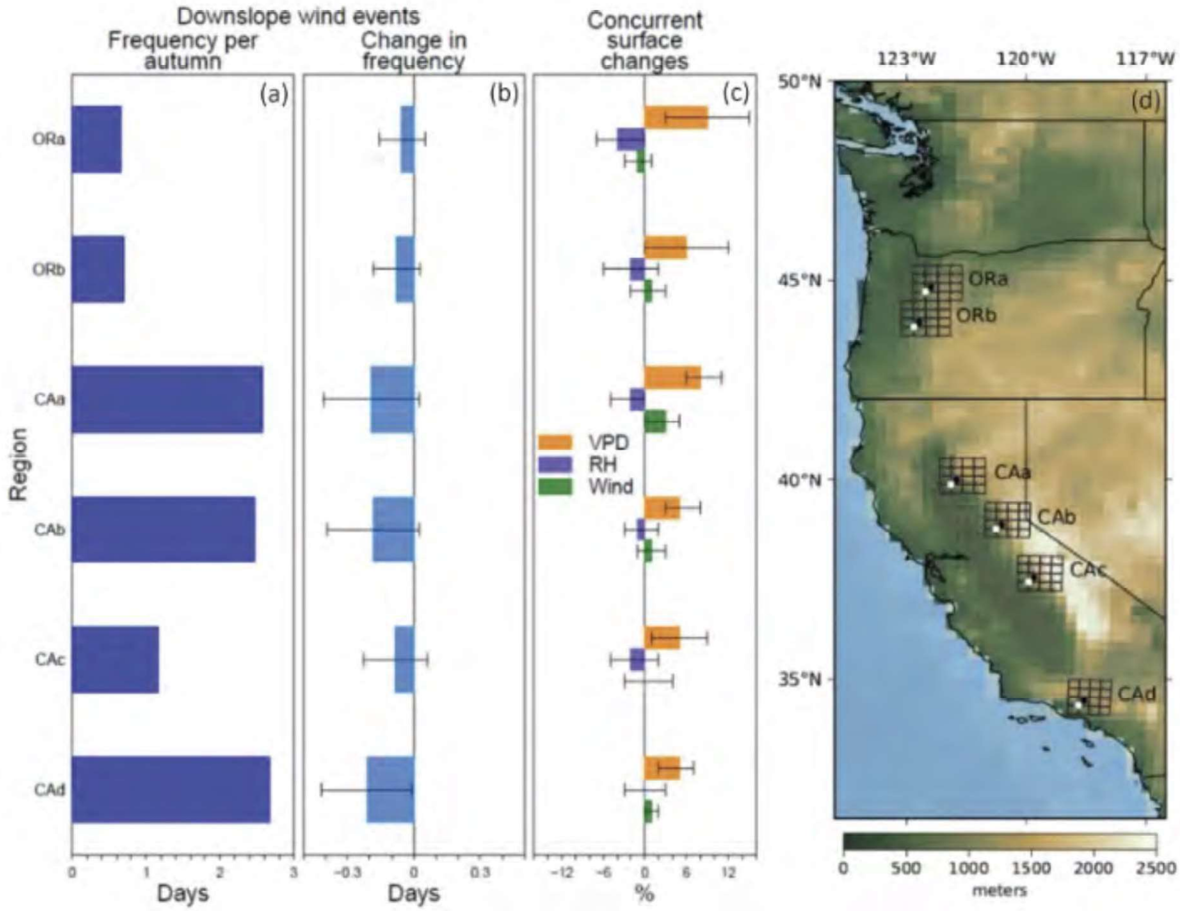
In addition to the evidence derived from existing research exploring links between the general conditions favorable for extreme wildfires in the Pacific Northwest and their links to anthropogenic climate change, research specifically focused on the 2020 wildfire events in Oregon also supports the conclusion that the unusually dry vegetation preconditions leading up to the event and low atmospheric humidity during the wildfire outbreak itself were amplified by anthropogenic climate change (Hawkins et al. 2022; Figure 7). Thus, I find that it is overall very likely that anthropogenic climate change substantially contributed to the unusually dry vegetation conditions (caused, in turn, by unusually low precipitation and high temperatures) that preceded and ultimately facilitated and/or amplified the wildfire smoke event.

Unusually dry vegetation and ambient air were not the sole contributors to the extreme wildfire event, however. With respect to the extreme east (offshore) wind event that helped propel the wildfires in question, there is relatively limited evidence available to make an assessment. However, the handful of relevant peer-reviewed studies available at the time of this writing suggest that climate change may slightly *decrease* the frequency of offshore wind events in Oregon in the future–which, on its own, would likely have a slight mitigating effect on wildfire extent and/or severity (Figure 7). However, because there is a limited amount of scientific evidence pointing in either direction (either from a process-based modeling perspective or from meteorological theory), and because those studies which are available suggest that the overall effect on strong east winds in this region is likely small, I am not able to make an assessment regarding whether historical climate change had substantially affected the likelihood or severity of such extreme wind events as of 2020. Thus, I find that anthropogenic climate change is about as likely as not to have influenced the occurrence of strong and dry east winds as coincided with this event–representing a neutral attribution statement due to limited evidence and high uncertainty.

I also note, however, that Hawkins et al. 2022 found that the net effect of anthropogenic warming on extreme fire weather conditions during autumn in western Oregon (i.e., the combined effect of warmer temperatures, substantial decreases in atmospheric humidity/increased evaporative demand, and small decreases in the frequency/strength of strong east wind events) was to substantially increase the occurrence of high-end fire weather events overall. In other words: the larger net effect of warming temperatures and drying vegetation/air outweighed the potential partial offsetting effect of slightly weaker east wind events in this context.

Additionally, recent research directly attributes more than a third (~37%) of cumulative forest area burned in the Western U.S. and southwestern Canada (including Washington and Oregon, which comprise the primary regions contributing to extreme smoke pollution events in Multnomah County) to the cumulative greenhouse gas emissions from a list of specific companies and large emitters (Figure 9; Dahl et al. 2023). The causal mechanism involved is the increased "atmospheric thirstiness" (here quantified as the vapor pressure deficit) that results directly from rising air temperatures in the absence of a compensating increase in relative humidity; nearly half (~48%) of the observed vapor pressure deficit increase, which in turn made forests drier and more flammable, is directly attributed to these major carbon emitters (Dahl et al. 2023).

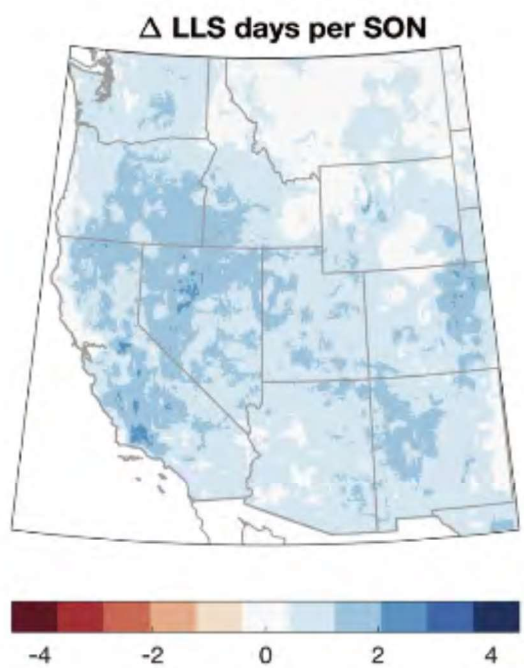
Figure 7.



Panels a) and b) depict projected historical changes in the frequency of autumn "offshore wind" events along different portions of the West Coast of the United States. Panel c) depicts projected historical changes in the intensity of offshore wind events in addition to trends in autumn relative humidity (RH) and vapor pressure deficit (VPD). Apparent are small decreases in the magnitude and frequency of offshore winds but substantial increases in the VPD in western Oregon. Adapted from Hawkins et al. 2022.

With respect to the air stagnation event that followed the extreme fire weather and actual wildfire events: there is considerable evidence that anthropogenic climate change is increasing the frequency and severity of air stagnation events, both regionally within western Oregon and more broadly (Swain et al. 2023). In many regions (Horton et al. 2014), anthropogenic climate change is expected to increase the occurrence and severity of air stagnation events (which can lead to severe air pollution episodes when pollutants are present). It does so by increasing vertical stability of the atmosphere, which creates an increasingly prevalent and strong “lid” that prevents pollutants from escaping vertically, and by altering wind and precipitation patterns in ways that prevent pollutants from dispersing horizontally or being “rained out” of the atmosphere, respectively. Multiple existing studies indicate that anthropogenic climate change will substantially increase the number of air stagnation days in Pacific Northwest and western Oregon specifically (Swain et al. 2023; Horton et al. 2014; Figure 8).

Figure 8.



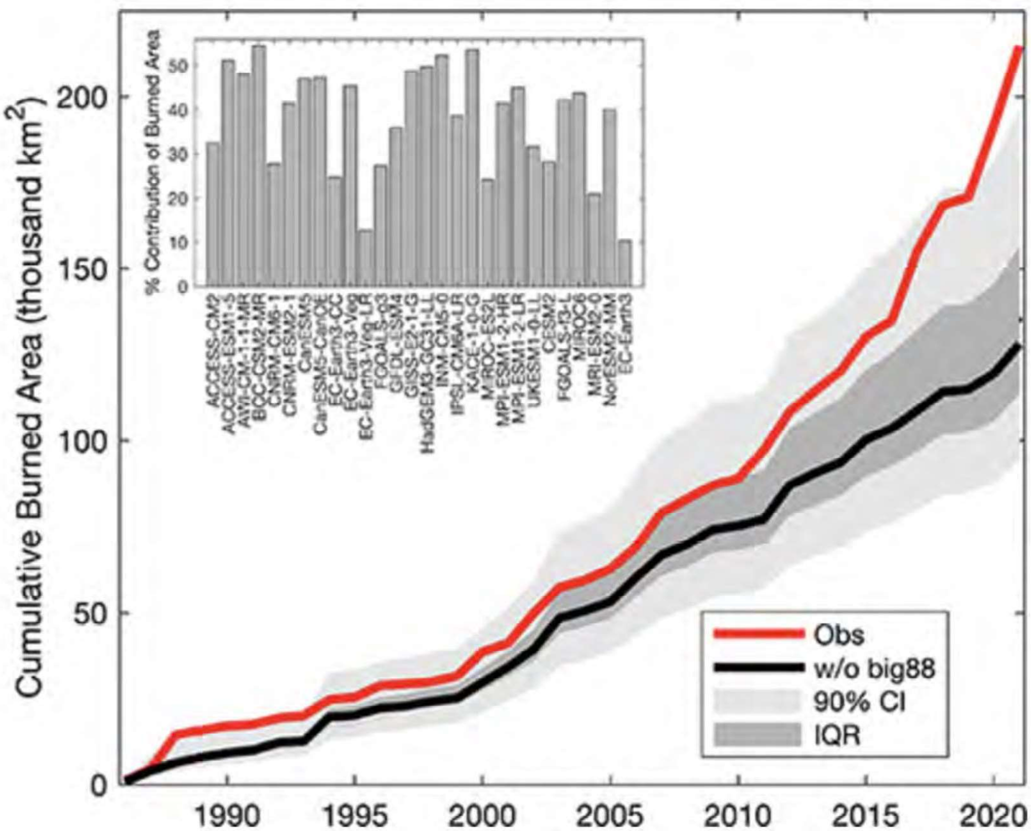
Projected change in low-level “air stagnation days” (LLS) during autumn (Sep-Nov) for 2021-2060 relative to 1981-2020. Adapted from Swain et al. 2023.

Additionally, there is a rapidly growing body of research indicating that Western U.S. wildfires have already yielded large increases in the frequency and magnitude of extreme particulate matter air pollution episodes (Xie et al. 2022; Kalashnikov et al. 2022)–even to the extent that they have reversed regional improvements in air quality stemming from the implementation of the modern Clean Air Act in 1970 (McClure and Jaffe 2018). Similarly, studies show that multiple specific events in the past decade–including the September 2020 event that affected both western Oregon and the Western U.S. more broadly–are representative of the kind of increasing episodic wildfire smoke-driven air pollution extremes (Kalashnikov et al. 2022) that can be expected in a warming climate in which wildfire-derived particulate emissions could potentially triple on medium-to-high warming trajectories (Xie et al. 2022). Other non-climate factors are of course important in understanding the escalating degree of wildfire activity and subsequent smoke emissions in the Western U.S., but the role of anthropogenic climate change itself as a substantial aggravating factor is now clear.

Finally, recent work has suggested that both wildfire intensity and wildfire emissions (including smoke pollution) from temperate forests in Europe and North America (including those in and surrounding Multnomah County) rose dramatically between 2001 and 2023; anthropogenic climate change-linked increases in extreme fire weather conditions were identified as the primary cause (Jones et al. 2024). Indeed, these global findings drawn from recent observations are broadly consistent with future projections that fine particulate matter pollution from wildfires in the Pacific Northwest (including Oregon) specifically may triple by the late 21 century even assuming greenhouse gas emissions are significantly reduced (Xie et al. 2022). Even more directly relevant to the question at hand: Xie et al. 2022 find that historically severe wildfire-generated air pollution extremes similar to those which occurred in 2017-2020 in the Pacific Northwest could eventually occur as often as every 2-5 years with continued warming.

One recent study that specifically considered the role of anthropogenic climate change in worsening wildfire-related particulate air pollution over the contiguous United States found that ~15,000 smoke pollution-related deaths were attributable to climate warming between 2006-2020 (Law et al. 2025)–with 34% of the total attributable deaths occurring in 2020 alone (partly associated with the September 2020 Oregon wildfires). Notably, 10 of the most affected counties in the contiguous United States (from a mortality perspective) were located in Oregon, and in some portions of the state up to 60% of the total particulate matter (smoke) pollution volume over this period was attributable to anthropogenic climate change.

Figure 9.



Time series plot showing the cumulative burned forested area in the western United States and southwestern Canada (including Washington and Oregon). The black curve shows the estimated forest area that would have burned but for the emissions from specific major carbon emitters, and the red curve shows the estimated area that burned due to the warming effects of actual emissions. Adapted from Dahl et al. 2022.

In light of this evidence, I find that is overall “likely” that anthropogenic climate change increased the likelihood and severity of the severe wildfire smoke air pollution episode that affected Oregon in September 2020–primarily due to links to the antecedent warmth and dryness that increased vegetation flammability as well as links to atmospheric conditions favorable for the air stagnation event that followed.

This finding is consistent with existing studies that strongly indicate increases in Pacific Northwest wildfire activity and severity due to a warming climate–primarily caused by increasing vegetation aridity due to rising temperatures and subsequently increased evaporative demand (e.g., Abatzoglou and Williams 2016; Halofsky et al. 2020; Dahl et al. 2023)

4.3.3 *Summary Statement*

It is likely that anthropogenic climate change increased the likelihood and severity of the September 2020 extreme smoke pollution event. Thus, it is unlikely that this event would have occurred when and as it did but for anthropogenic climate change.

4.4 *Are these estimates in this report conservative in light of emerging evidence?*

Additionally, there is emerging scientific evidence that changes in atmospheric circulation (i.e., large-scale wind patterns) due to anthropogenic warming might actually bring about an even greater increase in the types of extreme meteorological events discussed in this report. I include the following to emphasize that in some cases the attribution claims above may be considered a "lower bound" on the magnitude of the actual influence of anthropogenic climate change, *though none of the information below has factored into my formal assessments above nor into my specific attribution likelihood statements*. Three key physical processes and considerations relevant to this additional discussion are enumerated below.

4.4.1 *Are unusually persistent atmospheric patterns increasing in summer?*

Several recent scientific studies have suggested that the jet stream–the high velocity air current in the upper atmosphere that helps determine the path that storms take in the Earth's temperature latitudes–may be shifting during Northern Hemisphere summer in ways that favor persistent weather patterns (Mann et al. 2018, He et al. 2023). In technical terms, this hypothesis involves the increased persistence and self-reinforcing amplification of certain types of horizontally-oriented (i.e., in a latitude and longitude sense) sinusoidal waves in the Earth's atmosphere when mid-latitude jet-stream winds are weaker but subpolar and subtropical jet stream winds are stronger than usual–causing waves of a particular size to become "trapped" and undergo resonant amplification. (A visual analogy of resonant wave amplification would be a person pushing a child on a playground swing at just the right moment to force them ever higher with each successive iteration.) Recent research suggests that such patterns may be occurring more frequently and with increased amplitude, specifically during the summer months, due to climate change (Mann et al. 2018, He et al. 2023).

Such changes are hypothesized to favor increasingly persistent and slow-moving high and low pressure systems, the former of which would be associated with increasingly prolonged and intense "heat domes" similar to the one observed in the Pacific Northwest during June 2021 (Li et al. 2024) and which have been explicitly tied to other extreme heat events globally in the past decade (Petoukhov et al. 2016). In fact, recent research has explicitly indicated that such a process was in play during (or just prior to) the 2021 extreme heat event across the Pacific Northwest, and contributed to its severity (Li et al. 2024).

The degree of scientific confidence remains relatively low with respect to this particular mechanism, but if future research and observations continue to suggest its existence then observed historical and future increasing trends in extreme summer heatwaves in places including northwestern Oregon have likely been *underestimated*.

4.4.2 *Are climate models underestimating increases in atmospheric dryness?*

Evidence has recently grown that climate model projections may be overestimating the increase in absolute atmospheric humidity that is likely to occur over many continental (land) areas on Earth. In a warming climate, *absolute* humidity has previously been projected to increase nearly everywhere (including land and ocean areas), coincident with slight decreases in *relative* humidity over many land areas (Zhou et al. 2023) and substantial increases in the vapor pressure deficit (i.e., the difference between how much water vapor could potentially be contained by the air, if fully saturated, and the amount that is actually present (Yuan et al. 2019;

Li et al. 2023)). However, real world observations suggest that absolute humidity over land has actually *decreased* instead of increasing over the past several decades (Simpson et al. 2024)—accentuating increasing evaporative demand beyond projections in some regions. The specific causes are not entirely clear, but recent research indicates that this may be due to certain changes in atmospheric wind patterns and/or relationships between the land surface, vegetation, and the atmosphere that are not fully or correctly represented in these projections.

4.4.3 *Will extreme heatwaves increase non-linearly in a warming climate?*

There is also emerging evidence that the magnitude and frequency of extreme heat events will, in general, increase considerably faster than average temperatures over most continental regions. Zhang and Boos 2023 find that, due to fundamental constraints on how the vertical structure of the atmosphere adjusts to surface warming, the most extreme heat events in the global temperature latitudes (which encompass the Pacific Northwest) will increase about twice as fast as average temperatures. Low soil moisture conditions, as were observed during the June 2021 event, allow extreme heatwaves locally to approach theoretical maximum temperatures. Additionally, relatively moist regions that are at least occasionally subjected to droughts or prolonged heatwaves (like the Pacific Northwest) appear to be especially susceptible to experiencing rapidly-evolving "flash droughts" (Yuan et al. 2023) that deplete soil moisture more rapidly (Qing et al. 2023), which would allow temperatures to approach their theoretical local maxima at a particular level of long-term warming (Zhang and Booz 2023).

The degree of scientific confidence remains relatively low with respect to this mechanism, as well. However, if future research and observations continue to indicate that real-world absolute humidity is indeed increasing less than previously expected in a warming climate, and evaporative demand more than previously expected, this would suggest that existing estimates of the degree to which climate change has worsened droughts and extreme wildfire burning conditions and will continue to do so moving forward have likely been *underestimated.*

I present these three emerging hypothesis not as direct evidence of the mechanisms of influence of climate change on the three specific Pacific Northwest/Oregon extreme events of interest, but instead to offer insights into where ongoing and future research is headed in the next 1-3 years and also a qualitative sense of the sign of uncertainties that exist in this space (i.e., whether the formal estimates above are more likely to be over- or under-estimates of the true influence).

5. Role of Specific Emitters

5.1 *Linking fractional cumulative emissions to specific climate change impacts*

In the context of 20th and 21st century climate change, the overall warming effect per increment of increasing greenhouse gas concentrations is approximately linear at global scales (Allen et al. 2009). This can be measured in units of degrees of global warming per unit of carbon emitted, which is commonly known as the transient climate response to cumulative carbon dioxide emissions (TCRE; Gillett et al. 2013). There may be deviations from linearity in some contexts, especially at higher levels of warming (when self-reinforcing climate system and carbon cycle feedbacks can be triggered (e.g., Nicholls et al. 2020), but previous research has shown the TCRE to be approximately constant across a range of background conditions–even when accounting for various climate feedbacks and the Earth's dynamic carbon cycle response (Matthews et al. 2009). For this reason, it is scientifically reasonable (and common practice in the field) to view greenhouse gas concentrations and global warming as two axes along a "dose-response" curve, wherein a given increment of increase in cumulative concentration yields a predictable increment of global warming (MacDougall et al. 2015).

This approach can simplify interpretation of fractional contribution by different emitters, at different points in time, to the overall level of observed warming: At a given level of global warming, caused by an approximately known total cumulative amount of cumulative anthropogenic emissions, the fractional contribution by specific emitters to the total warming is approximately equivalent to their respective proportional contributions to the total anthropogenic emissions to date.

When it comes to the influence of global warming to individual temperature and precipitation-related extreme events, which often intensify at a predictable but not always linear rate (sometimes exhibiting, for instance, a non-linear “percent per degree of warming” scaling, as discussed in Section 4 (e.g., Bartusek et al. 2022, Pendergrass et al. 2019), the total contribution by specific emitters can still reasonably be considered proportional to their historical cumulative fractional contribution to total global warming. This is because, despite nonlinearities that might exist in the response of extreme events to climate change overall, any given increment of historical greenhouse gas accumulation comprises a “foundation” on which all future emissions (and their associated adverse effects), whether by the same or other emitters, stand atop. Additionally, and as discussed at greater length in Section 3.1, historical emissions attributable to specific emitters–even decades to a century or more in the past–are still relevant to climate change and extreme events occurring at present due to the long (multiple centuries to millennia-long) adjustment period required for the Earth’s carbon cycle to reach equilibrium.

5.2 *Significance of actions by specific emitters to observed Pacific Northwest events*

Any entity that contributed to the cumulative global greenhouse gas accumulation in the Earth’s atmosphere prior to the dates in question, and thus to the overall level of planetary warming at that point in time, would have contributed to the likelihood of occurrence and/or severity of various extreme weather and weather-related events. Previous scientific analysis has demonstrated that specific and identifiable major carbon emitters were collectively responsible for a majority of the total historical observed increase in global atmospheric carbon dioxide concentration, as well as a large portion (up to 50%) of the observed increase in specific climate-change related phenomena (Ekwurzel et al. 2017).

I have been asked to evaluate whether the historical greenhouse gas emissions from a list of specific companies may have contributed to the likelihood of occurrence or observed magnitude of the three specific Pacific Northwest extreme events discussed in Section 3. This list of companies includes: BP, Chevron Corp., ConocoPhillips; ExxonMobil., Koch Industries, Marathon Oil, Marathon Petroleum, Motiva Enterprises, Northwest Natural, Occidental

Petroleum (including Anadarko), Shell, Space Age Fuel, TotalEnergies USA, and Valero Energy.

The first step in this process is to assess whether the companies enumerated above are responsible for a portion of total cumulative anthropogenic greenhouse gas emissions historically, and therefore also for a portion of the observed increases in atmospheric greenhouse gas concentrations–which are the primary cause of observed global warming and subsequently of increases in certain types of extreme events.

In this section of the assessment, I have used information obtained from R. Heede, including existing peer-reviewed scientific publications (cited where relevant), personal communication directly with Mr. Heede, and a new report by Mr. Heede (Heede 2025) that is intended to serve as an update to previous peer reviewed publications (including Heede 2014a, with methods therein being comprehensively described in Heede 2014b) by assessing contributions by additional companies and over a longer time horizon using a process similar to and consistent with the existing peer-reviewed methodology.

This information suggests that a reasonable, and likely conservative (lower-bound), estimate of the total contribution by the companies named above to the observed increase in fossil-fuel derived carbon dioxide emissions between 1965 and 2022 is greater than 15% of the total global amount, and to the observed overall increase in total cumulative greenhouse gas emissions (inclusive of all anthropogenic sources between 1965 and 2022) is greater than 10% of the total global amount (Heede 2025; Table 1). This topline estimate is based on a (70.4%) scaling factor used to convert the fraction of fossil fuel-derived carbon dioxide emissions (as reported in Table 1) to the fraction of total global greenhouse gas emissions (as originally reported in Grasso and Heede (2023) for the 1988-2018 period).

Table 1.

Company	Product sales 1950-2022 $MtCO_2$	Percent of global fossil fuel emissions %	Product sales 1965-2022 $MtCO_2$	Percent of global fossil fuel emissions %
BP	25,092	1.68%	24,585	1.79%
Chevron	21,807	1.46%	20,739	1.51%
ConocoPhillips	17,833	1.19%	16,901	1.23%
ExxonMobil	74,036	4.96%	65,596	4.78%
Koch Industries	2,284	0.15%	2,284	0.17%
Marathon	9,803	0.66%	9,603	0.70%
Motiva	1,263	0.08%	1,263	0.09%
Occidental	4,241	0.28%	3,835	0.28%
Shell	54,086	3.63%	49,993	3.64%
TotalEnergies	11,178	0.75%	11,178	0.81%
Valero	6,918	0.46%	6,918	0.50%
Total selected companies	**228,540**	**15.31%**	**212,896**	**15.51%**
Global fossil fuel emissions	**1,493,015**		**1.372,459**	

Contribution by specific companies to total cumulative global fossil fuel emissions since the mid 20th century, individually and in aggregate. Note that this table excludes emissions prior to 1965, and may underestimate the relative contributions due to data unavailability for some emitters. The data represented here includes emissions from production-based emissions generally from 1950 onward, with estimated contributions from refinery output and product sales from as early as 1965 onward but with considerable variability due to lack of data availability. Table reproduced directly from Heede 2025 report (referenced as Table 5 therein; Climate Accountability Institute).

Additionally, cumulative lifetime contributions to the total greenhouse gas accumulation burden as of 2022 are likely to be larger than noted here, as a notable additional volume of such emissions occurred prior to the assessment period (i.e., prior to 2010 for Northwest Natural and Space Age Fuel, and prior to 1965 for others listed) for many of these entities but are still relevant to the question of causation of observed global warming and associated extreme events. Additionally, there is some scope of further greenhouse gas emissions by these companies that is not reflected in Heede 2025 due to a lack of publicly available data (especially for Northwest Natural and Space Age Fuel prior to 2010 and other companies prior to ~1965). Fuller access to this information could yield a more accurate, and likely higher, estimate of the proportional contribution by these specific companies to the total global greenhouse gas burden. Between 2010 and 2022, Northwest Natural and Space Age Fuel Inc. were each individually among the top fossil fuel emitters in the State of Oregon (Table 8 in Heede 2025).

In Section 3, I offer evidence-based assessments that historical anthropogenic global warming is virtually certain to have increased the likelihood and magnitude of the unprecedented 2021 Pacific Northwest heatwave, and also likely to have increased the likelihood and magnitude of both recent severe drought conditions in the Pacific Northwest and the severe 2020 wildfire smoke pollution episode in the same region. In this section, I offer evidence that the cumulative historical greenhouse gas emissions generated or caused by the companies named above are, in turn, responsible for a substantial portion of observed historical anthropogenic global warming. *To a reasonable degree of scientific certainty, therefore, the actions by the named companies are also responsible for a proportion of the increased likelihood of occurrence, and observed magnitude/severity, of the extreme heat, drought, and wildfire-related events described in this report.*

5.3 *Summary Statement*

It is very likely that the historical actions by the specific emitters listed in this document—namely, fossil fuel extraction, processing, distribution, and eventual combustion resulting in cumulative increases in atmospheric greenhouse gas concentrations, and thus climate warming–increased the likelihood and severity of the above-mentioned extreme meteorological events in the Pacific Northwest, and thereby also contributed to the adverse effects that resulted from them. Accordingly, it is very unlikely that these events would have occurred, when and as they did, but for the large observed increase in climate-warming greenhouse gas emissions–including those directly resulting from the actions of these specific emitters.

6. Conclusions

6.1 *Overall Assessment*

In my professional opinion, it is likely that anthropogenic climate change increased both the likelihood of occurrence, as well as the intensity, of all three Pacific Northwest extreme meteorological events in question. The level of confidence in the underlying individual attribution statements is "virtually certain" for the exceptional Pacific Northwest heatwave in June 2021, and "likely" for both summer drought conditions earlier in the decade and the extreme smoke-related air pollution episode stemming from September 2020 wildfires.

Additionally, it is very likely that the actions of the specific greenhouse gas emitters named in this document contributed to the likelihood and severity of these three extreme meteorological events to a degree that is, at a minimum, proportional to their known share of total cumulative global anthropogenic greenhouse gas emissions between 1965 and 2022 (and likely higher, due to additional emissions prior to 1965 and incomplete data for the 1965-2022 period). This suggests that a portion of the adverse effects associated with these events, which included considerable physical and economic harm, can reasonably be attributed to the historical actions by these specific companies, and therefore would have been unlikely to occur when and as they did but for these actions.

Further consideration of the future frequency and severity of extreme heat, wildfire smoke, and summer drought events in the Pacific Northwest region (including Multnomah County) indicates that large further increases in risk from such events is "very likely" to "virtually certain" (depending on the time horizon and specific event type). The frequency and severity of extreme heatwaves and extreme wildfire burning conditions, in particular, are expected to increase rapidly due to further climate warming, with historically rare or unprecedented heat and wildfire events potentially recurring multiple times per decade. This suggests that quantified adverse consequences and damages, to date, likely represent a small fraction of potential future damages from comparable or worse anthropogenic climate change-amplified events in future years.

7. Signature and declarations

7.1 *Statement of Truth*

I confirm that the contents of this report are true to the best of my knowledge and belief.

7.2 *Signature*

Daniel Swain, Ph.D. Date: April 17, 2025

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Selected honors and awards

"Future Perfect 50" List, Vox Media	2024
DesignSafe Dataset Award (co-recipient with Xingying Huang), NSF/Univ. of Texas, Austin	2023
Deseret Magazine "Most Important Changemaker in the West"	2022
Vice Magazine "Human of the Year"	2020
National Academy of Sciences Kavli Fellow	2019
NatureNet Postdoctoral Fellowship, The Nature Conservancy/University of California	2016-2018
ARCS Fellowship, Achievement Rewards for College Scientists Foundation	2015-2016
Switzer Environmental Fellowship, Robert and Patricia Switzer Foundation	2015-2016
Graduate Student Award for Scholarly & Research Achievement, Stanford University	2015
Centennial Teaching Assistant Award, School of Earth Sciences, Stanford University	2013
College Medal, College of Agricultural & Environmental Sciences, Univ. of California, Davis	2011
Departmental Citation, Atmospheric Science, University of California, Davis	2011

Grants and external funding

Principal Investigator, Tilia Fund Climate Communication Grant 2024-2029
Award total: ~$275,000

Co-Investigator, Aon Reinsurance Solutions grant, "Future Fire Weather Scenarios," 2023-2025
Award total: $20,000 (UCLA portion)

Co-Principal Investigator, The Nature Conservancy of California grant, "Climate Science and Managing Nature to Minimize the Damage of Extreme Events," **Award total: $450,410** 2018-2024

Co-Principal Investigator, National Science Foundation Prediction of and Resilience against Extreme Events (NSF PREEVENTS) Program, Track 2: "COEXIST: COnnected EXtremes In Space and Time," Award ID: 1854761, **Award total: $345,446** (UCLA portion) 2019-2024

Principal Investigator, California Department of Water Resources grant: "Developing plausible extreme storm and flood scenarios for disaster resilience planning and emergency response exercises in California," **Award total: $140,000** 2021-2023

Principal Investigator, Yuba Water Agency grant: "Developing California Megastorm Scenarios for ARkStorm 2.0," **Award total: $60,000** 2021-2022

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21. Abatzoglou, J., Smith, C., **Swain, D.L.**, Ptak, T., and C. Kolden. Population exposure to pre-emptive de-energization aimed at averting wildfires in Northern California. *Environmental Research Letters*, 15, 094046, doi: 10.1088/1748-9326/aba135, 2020. 2020

20. ***Goss, M., **Swain, D.L., Sarhadi, A., Kolden, C.A., Abatzoglou, J.T., Williams, A.P., and N.S. Diffenbaugh. Climate change is increasing the risk of extreme autumn wildfire conditions across California. *Environmental Research Letters*, 15 (9), 094016, doi: 10.1088/1748-9326/ab83a7, 2020. 2020
[***Named "Best Article of 2020" by Environmental Research Letters Editorial Board (2020); IOP Publishing Top Cited Paper Award (2023)]***

19. Huang, X., **Swain, D.L.**, and A. Hall. Large ensemble downscaling of extreme atmospheric River storms in California reveals large increase in fine-scale precipitation. *Science Advances*, 6, eaba1323, doi: 10.1126/sciadv.aba1323, 2020. 2020

18. Brunner, M.I., Gilleland, E., Wood, A., **Swain, D.L.**, and M. Clark. Spatial dependence of floods shaped by spatiotemporal variations in meteorological and land-surface processes. *Geophysical Research Letters, 47,* e2020GL088000*,* doi: 10.1029/2020GL088000, 2020. 2020

17. †Swain, D.L., Singh, D., Touma, D., and N.S. Diffenbaugh. Attributing extreme events to climate change: A new frontier in a warming world. *One Earth*, 2, 522-527, doi: 10.1016/j.oneear.2020.05.011, 2020. 2020

16. Huang, X., **Swain, D.L.**, Walton, D.B., Berg, N., Stevenson, S., and A. Hall, Simulating and Evaluating Atmospheric River-Induced Precipitation Extremes along the U.S. Pacific Coast: Case Studies from 1980-2017. *Journal of Geophysical Research: Atmospheres,* 125, e2019JD031554, doi: 10.1029/2019JD031554, 2020. 2020

15. Gibson, P.B., Waliser, D.E., Guan, B., DeFlorio, M.J., and **D.L. Swain**. Ridging associated with drought in western and southwestern United States: characteristics, trends and predictability. 2020

Journal of Climate, 33, 2485-2408, doi: 10.1175/JCLI-D-19-0439.1, 2020.

14. Gonzales, K.R., **Swain, D.L.**, Barnes, E.A., K. Nardi, and N.S. Diffenbaugh. Recent warming of landfalling atmospheric rivers along the West Coast of the United States. *Journal of Geophysical Research: Atmospheres,* 124, 6810-6826, doi: 10.1029/2018JD029860, 2019. 2019

13. †Swain, D.L., 2019. Is society ready for precipitation whiplash?, In: "Toward a Resilient Global Society: Air, Sea Level, Earthquakes, and Weather." *Earth's Future*, 7, 854-864, doi: 10.1029/2019EF001242, 2019. 2019

12. Thackeray, C.W., A.M. DeAngelis, A. Hall, **D.L. Swain**, and X. Qu. On the Connection Between Global Hydrologic Sensitivity and Regional Wet Extremes. *Geophysical Review Letters,* 45, doi: 10.1029/2018GL079698, 2018. 2018

11. Touma, D., A. M. Michalak, **D.L. Swain**, and N.S. Diffenbaugh. Characterizing the spatial characteristics of extreme precipitation over the United States. *Journal of Climate,* 31, 8023-8037, doi: 10.1175/JCLI-D-18-0019.1, 2018. 2018

10. *Swain, D.L., B. Langenbrunner, J.D. Neelin, and A. Hall. Increasing precipitation volatility in twenty-first-century California. *Nature Climate Change,* 8, 427-433, doi: 10.1038/s41558-018-0140-y., 2018. 2018

9. Swain, D.L., D. Singh, D.E. Horton, J.S. Mankin, T. Ballard, and N.S. Diffenbaugh. Remote linkages to anomalous winter atmospheric ridging over the northeastern Pacific. *Journal of Geophysical Research: Atmospheres*, 122, 12,194-12,209, doi: 10.1002/2017JD026575, 2017. 2017

8. ***Diffenbaugh, N.S., Singh, D., Mankin, J.S., Charland, A., Horton, D.E., Haugen, M., **Swain, D.L., Rajaratnam, B., and Touma, D. Quantifying the influence of global warming on unprecedented extreme climate events. *Proceedings of the National Academy of Sciences*, 114, 4881-4886, doi: 10.1073/pnas.1618082114, 2017. 2017

7. Singh, D., **D. L. Swain**, J.S. Mankin, D.E. Horton, L.N. Thomas, B. Rajaratnam, and N.S. Diffenbaugh. Recent amplification of the North American winter temperature dipole. *Journal of Geophysical Research: Atmospheres*, 121, 9911-9928, doi: 10.1002/2016JD025116, 2016. 2016

6. Swain, D. L., Horton, D.E., Singh, D., and N.S. Diffenbaugh. Trends in atmospheric patterns conducive to seasonal precipitation and temperature extremes in California. *Science Advances*, 2, e1501344, doi: 10.1126/sciadv.1501344, 2016. 2016

5. Swain, **D.L.,** Lebassi-Habtezion, B., and N.S. Diffenbaugh. Evaluation of non-hydrostatic simulations of Northeast Pacific atmospheric rivers and comparison to in-situ observation. *Monthly Weather Review*, 143, 3556-3569, doi: 10.1175/MWR-D-15-0079.1, 2015. 2015

4. ***Horton, D.E., N.C. Johnson, D. Singh, **D.L. Swain, B. Rajaratnam and N.S. Diffenbaugh. Contribution of changes in atmospheric circulation patterns to extreme temperature trends. *Nature*, 522, 465–469, doi: 10.1038/nature14550, 2015. 2015

3. ***Diffenbaugh, N.S., **D.L. Swain and D. Touma. Anthropogenic warming has increased drought risk in California. 112, 3931-3936, *Proceedings of the National Academy of Sciences*, doi: 10.1073/pnas.1422385112, 2015. 2015

2. †Swain, D.L. A tale of two California droughts: Lessons amidst record warmth and 2015

dryness in a region of complex physical and human geography. *Geophysical Research Letters*, doi:10.1002/2015GL066628, 2015.

1. *Swain, D.L., M. Tsiang, M. Haugen, D. Singh, A. Charland, B. Rajaratnam and N.S. Diffenbaugh. The extraordinary California drought of 2013-2014: character, context, and the role of climate change [in "Explaining Extremes of 2013 from a Climate Perspective"]. *Bulletin of the American Meteorological Society*, 95 (9), S3–S7, 2014. 2014

*** = Essential Science Indicators (ISI) Highly Cited Paper**

++ = Equal contributions/co-first authorship

† = Perspective, commentary, opinion piece, or subject matter primer

Publications in progress

Camponuri, S.K., A.K. Heaney, G.S. Cooksey, D.J. Vugia, **D.L. Swain**, J. Balmes, J.V. Remais, and J.R Head. "Recent and forecasted increases in coccidioidomycosis incidence in California linked to swings in precipitation extremes" *(in review)*

Muñoz-Castro, E., Anderson, B.J., Astagneau, P.C., **Swain, D.L.**, Mendoza, P.A., and Brunner, M.I. "How well do hydrological models simulate streamflow extremes and drought-to-flood transitions?" *(in review)*

Science communication and public-facing science engagement

Author & founder, Weather West blog (www.weatherwest.com) 2006-Present
Write regular articles focusing on a wide range of California/western North America weather and climate topics; answer questions from public, decision-makers, and scientists regarding meteorology/climatology/general science/science policy. Strong emphasis on making scientific and technical topics accessible to a broad audience (>1 million visitors each year).

Climate, weather, wildfire, and Earth science engagement via social media 2014-Present
Weather, climate, Earth science, and public policy discussion and outreach via Twitter as @Weather_West (>10 million views each year) and on YouTube (@WeatherWest) as well as Bluesky, Threads, & Mastodon. Daily direct engagement with public, scientists, wildland firefighters, water managers, local & regional government, and local to international policymakers.

Weather, climate, wildfire, and Earth science media liaison 2013-present
Frequent, sustained engagement with local, national, and international news media on weather & climate-related issues. >250 interviews each year (>1,500 news media interviews cumulatively since 2018) with a wide range of outlets:

Newspaper: New York Times, Washington Post, USA Today, Wall Street Journal, Bloomberg, Los Angeles Times, San Francisco Chronicle, Sacramento Bee & dozens of local/regional papers

Long-form/magazine: Time, The Economist, Newsweek, The Atlantic, Wired, Scientific American, Popular Science, National Geographic, Rolling Stone, Vogue, Outside Magazine, Sunset Magazine, Bay Nature Magazine, Mother Jones, among many others

Radio: NPR/Science Friday (and numerous local affiliates), BBC World Service, ABC & CBS national radio (and local affiliates), plus hundreds of local stations

Television: CNN, ABC, NBC, PBS, BBC, CBC, Al Jazeera, HBO, public television in 15+ countries, Democracy Now, numerous documentaries, plus over 100 different local stations

Web outlets: Vox, Axios, Slate Magazine, Vice Magazine, Buzzfeed, Mashable, The Verge, & many others

Climate/weather-focused: The Weather Channel, Climate Central, Climate Nexus, InsideClimate News, Covering Climate Now, Wunderground, The Weather Network, Fox Weather

Podcasts: American Adapts (Doug Parsons), Science+Story (Bob Lalasz), Factually (Adam Conover, 3x), Water Talk, The Flakes (OpenSnow), Growing the Valley (UC Extension), TBD (Slate Magazine, 3x), Nova (PBS), Climate Crisis (Yahoo News, 2x), What Is California? (Stu VanAirsdale), Abwaan Chronicles, Fifth and Mission (SF Chronicle, 3x), The Lookout (Zeke Lunder), Capital Considerations (Wilmington Trust, 2x), The Weather Geeks (The Weather Channel, x2) The Civil Engineering Podcast, In the Bubble (Andy Slavitt), Against the Odds (Wondery), NPR (Short Wave), ClimateBreak (UC Berkeley), GeoTrek (Hal Needham), Across the Sky, TILclimate Podcast (MIT), The Assignment (CNN/Audie Cornish), Union of Concerned Scientists Podcast (Jess Phoenix), The Everything Story (Jillian Goodman), SnowBrains (Miles Clark), A Song Called Life (Osi Atikpoh), WebMD Health Discovered Podcast, EarthSky (Dave Adalian), Climate Chat (Dan Miller), Star Talk (Neil deGrasse Tyson), California Sun (Jeff Schechtman), Who What Why (Jeff Schechtman), Living on Earth (NPR), The Climate Dispatch (Sierra Club), Last Born (Patrick Farnsworth)

Science writing and film production for broad audiences

Scientific and Technical Advisor, "Climate Extremes: At The Abyss?" Documentary film; release date 10/25/2024. — 2024

Swain, D.L. Extreme Weather Page-A-Day Calendar 2025: A Year of Fire Tornadoes, Atmospheric Rivers, and Other Wild Weather Events. Workman Publishing Company, ISBN-9781523525317, 6 August 2024. — 2024

Swain, D.L. Extreme Weather Page-A-Day Calendar 2024: A Year of Fire Tornadoes, Atmospheric Rivers, and Other Wild Weather Events. Workman Publishing Company, ISBN-9781523520886, 8 August 2023. — 2023

Swain, D.L. "The Deadly Dynamics of Colorado's Marshall Fire," *Outside Magazine*, 11 January 2022. — Jan. 2022

Swain, D.L., Kolden, C., and J. Abatzoglou, "The era of megafires: the crisis facing California and what will happen next," perspective in *The Guardian*, 08 August 2018. — Aug. 2018

Swain, **D.L.**, *Outside Magazine* & KQED Public Media contributor, various articles — 2015-2016

Public policy engagement

Peer-reviewed works cited 425 times across 328 policy documents (per Sage PolicyProfiles) — 2014-present

Member, Scientific Advisory Committee for the Delta Stewardship Council's Delta Science Program — 2021-present

Member, Public Policy Institute of California Water Policy Research Network — 2018-present

Invited Presentation, U.S. Dept. of Agriculture Firescope predictive services committee — Apr. 2025

Invited Seminar, National Park Service Climate Change Response Program — Feb. 2025

Invited Presentation, White House Office of Science and Technology Policy (OSTP) & U.S. Global Change Research Program delivered to U.S. Subcommittee on Global Change Research (SGCR) and the U.S. Subcommittee on Climate Services — Jan. 2025

Expert Testimony, Public Hearing on Climate Action, City of Hayward/Climate Protection and Restoration Initiative Public, Hayward, CA*. — Aug. 2024

Invited Panelist, White House Council of Economic Advisers Roundtable on Climate Risk Modeling, The White House, Washington, D.C. — Sep. 2023

Expert Testimony, Hearing on California's Preparedness for and Response to Extreme Atmospheric River Incidents, California Assembly Joint Hearing by Committee on Emergency, Committee on Utilities and Energy, & Committee on Water, Parks, and Wildlife — Feb. 2023

Invited Panelist, California Governor's Office of Planning and Research (OPR) Roundtable On Water Management and California's 5th Climate Change Assessment — Sep. 2022

Invited Expert, science briefing on extreme heat and climate change, office staff of U.S. Senator Alex Padilla — Sep. 2022

Invited Panelist, California Senate Democratic Caucus panel on climate change — Mar. 2022

Invited Panelist, Climate Change Town Hall meeting hosted by California State Senator Mike McGuire — Oct. 2021

Invited Expert, science briefing on extreme atmospheric rivers, climate change, and flood risk in California, United States Representative Terrance John Cox — Jul. 2020

Invited Expert, science briefing on weather extremes and climate change, United States Senator Sheldon Whitehouse — Oct. 2019

Invited scientific presentations

"Shifts in seasonality and increases in hydroclimate whiplash are increasing California wildfire risk," *California Fire Science Seminar Series*, California Fire Science Consortium/UC Berkeley* **(invited speaker)** — Feb. 2025

"Increasing hydroclimate whiplash in California: Implications for California's grasslands and shrublands," *Rustici Rangeland Science Symposium*, University of California, Davis, Davis, CA* **(invited speaker)** — Jan. 2025

"Increasing Hydroclimate Whiplash on a Warming Earth," *DAES/ASRC Joint Colloquium Series*, State University of New York, Albany (SUNY Albany) **(invited speaker)** — Oct. 2024

"An overview of ARkStorm 2.0 and its implications: California flood risk looms large in a warming climate," 2024 California Extreme Precipitation Symposium (CEPSYM), University of California, Davis, Davis, CA **(invited speaker)** — Jul. 2024

"Hydroclimate volatility on a warming Earth," *Earth Day Speaker Series*, National Science Foundation, Arlington, VA*** (invited speaker)** — Apr. 2024

"Increasing whiplash due to climate change: Perspectives on volatility in the hydrologic cycle (and beyond) in a warming world," *NASA Global Modeling and Assimilation Office (GMAO) Seminar Series on Earth System Science*, NASA Goddard Space Flight Center, Greenbelt, MD **(invited speaker)** — Mar. 2024

"Will increasing 'hydroclimate whiplash' in a warming climate amplify co-seismic hazards in California (and beyond)?" *USGS Northern California Earthquake Hazards Workshop*, Moffett Field, CA*** (invited keynote speaker)** — Jan. 2024

"ARkStorm 2.0: An extreme multi-week winter storm and flood scenario for California reimagined for the climate change era," *California Floodhub Discussion,* University of California Berkeley Center for Catastrophic Risk Management & California Department of Water Resources, Berkeley, CA*** (invited speaker)** — Nov. 2023

"Worse droughts, but also more severe floods: Increasing hydroclimate volatility in a warming California," *California Islands Climate Change Workshop*, *California Islands Symposium*, Ventura, CA* **(invited speaker)** — Nov. 2023

"Thinking (critically) about the most "extreme extremes" in a warming climate," *Sci Foo Camp 2023*, Googleplex, Mountain View, CA **(invited speaker and participant)** — Jul. 2023

"Increasing hydroclimate whiplash in a warming climate: Implications for the future of California water," *UC Davis Institute of the Environment Seminar*, University of California, Davis **(invited speaker)** — Apr. 2023

"Understanding extremes in a warming climate: On acknowledging uncertainty, embracing complexity, and asking societally relevant questions," *American Physical Society Annual Meeting*, Chicago, IL*** (invited speaker)** — Mar. 2022

"Rising California flood risk from stronger, wetter atmospheric rivers in a warming climate," *California Extreme Precipitation Symposium*, University of California, Davis*** (invited speaker)** — June 2021

"A worsening wildfire crisis in California and the broader West: The role of climate change," Cat Risk Management 2021 Conference, Reinsurance Association of America*** (invited speaker)** — Mar. 2021

"Sharpening seasonality and shifting hydrology: implications for wildfire and flood risk in a warming California," *Geological and Planetary Sciences Division Seminar*, California Institute of Technology, Pasadena, CA*** (invited speaker)** — Mar. 2021

"Climate communication in the Twitter era: Challenges, opportunities, and some personal reflection," *American Geophysical Union Fall Meeting*, San Francisco, CA*** (invited speaker)** — Dec. 2020

"Regional downscaling of large ensemble simulations as a tool for understanding changing hydroclimatic extremes in a warming climate," *CLIVAR Large Ensembles Workshop*, Boulder, CO **(invited speaker)** — Jul. 2019

"Hydroclimatic intensification in a warming world: is society ready for increasing precipitation whiplash?" *American Geophysical Union Fall Meeting*, Washington, D.C. **(invited speaker)** — Dec. 2018

"Thinking about climate risk in an era of extremes: California's increasingly wide swings between drought and flood," *Department of Geography Seminar*, University of California, Berkeley **(invited lecturer)** — Oct. 2018

"Atmospheric rivers as a scientific (and conversational) bridge between weather and climate," *International Atmospheric Rivers Conference*, Scripps Institute of Oceanography, La Jolla, CA **(invited speaker)** — Jun. 2018

"California's increasingly extreme climate future," Rusch Honors Colloquium, Viterbi School of Engineering, Univ. of Southern California, Los Angeles, CA **(invited lecturer)** — Nov. 2017

"Causes and impacts of climate change—a California perspective," Climate and Law Policy Seminar, UCLA School of Law, Los Angeles, CA **(invited lecturer)** — Sep. 2017

"Teleconnections and regional impacts under anthropogenic forcing" & "Global warming influence on extreme events," *US Climate Variability and Predictability Program (CLIVAR) Summit*, Baltimore, MD **(invited speaker and panelist)** — Aug. 2017

"Trends in persistent seasonal-scale atmospheric circulation patterns responsible for precipitation and temperatures extremes in California," *American Geophysical Union Fall Meeting*, San Francisco, CA **(invited speaker)** — Dec. 2015

"Drought causes," *American Geophysical Union Chapman Conf. on California Drought: Causes, Impacts, & Policy*, Univ. of California, Irvine **(invited speaker)** — Apr. 2015

"The extraordinary 2012-2015 drought in California and its context in a warming world," *Water Scarcity in the West: Past, Present, Future Conference*, Univ. of California, Davis **(invited speaker and panelist)** — Apr. 2015

"Persistent atmospheric patterns and the ongoing California drought: the role of the Ridiculously Resilient Ridge," *NASA Earth Science Seminar*, NASA Ames, Mountain View, CA **(invited speaker)** — Mar. 2015

"The extraordinary California drought of 2012-2015: Historical context and the role of climate change," PACLIM *Pacific Climate Workshop 2015*, Pacific Grove, CA **(invited speaker)** — Mar. 2015

"The extraordinary California drought of 2012-2015: Historical context and the role of climate change," *Atmosphere and Energy Departmental Seminar*, Stanford University, Stanford, CA **(invited speaker)** — Mar. 2015

Academic service activities and professional affiliations

Journal Manuscript Referee: *Geophysical Research Letters (29 reviews), Journal of Climate (14 reviews), Journal of Geophysical Research—Atmospheres (7 reviews), Environmental Research Letters (5 reviews), Science Advances (4 reviews), Proceedings of the National Academy of Sciences (5 reviews), Bulletin of the American Meteorological Society, (3 reviews), Climatic Change (2 reviews), International Journal of Climatology (2 reviews), Scientific Reports (2 reviews), Communications Earth and Environment (4 reviews), Advances in Water Resources (1 review), Earth's Future (1 review), Nature (1 review), Nature Climate Change (1 review), Nature Communications (1 review), PNAS Nexus (1 review)* — 2013-present

Ad Hoc Reviewer, NSF Climate and Large-scale Dynamics (CLD) Program — 2024

Expert External Reviewer, Corporation for Public Broadcasting, proposed PBSKIDS digital and broadcast content pertaining to weather/climate — 2024

External Reviewer, University of California personnel advancement dossiers — 2022

Associate Editor, *Frontiers in Climate*, Climate, Ecology, and People section — 2021-2022

Ad Hoc Reviewer, NSF Paleo Perspectives on Climate Change (P2C2) Program — 2021

Ad Hoc Reviewer, NSF Industry-University Research Partnerships — 2021

AGU Outstanding Student Presentation Award Judge, AGU Fall Meeting — 2024, 2019

Expert Reviewer, United Nations International Strategy for Disaster Reduction (UNISDR) Global Assessment Report on Disaster Risk Reduction (GAR) 2019 — 2019

Expert Reviewer, California's Fourth Climate Change Assessment — 2018

President, American Meteorological Society Student Chapter, UC Davis — 2009-2011

AGU Fall Meeting session co-convener: "Hydroclimate and Extremes in the Western United States in a Changing Climate," "Bridging the Gap from Climate to Extreme Weather: Observations, Theory and Modeling" (2019), "Tropical Cyclones in the Global Climate System" (2010) — 2024, 2019, 2010

Member, American Association for the Advancement of Science (AAAS) — 2017-present

Member, American Geophysical Union (AGU) — 2010-present

Member, American Meteorological Society (AMS) — 2007-present

Broader community engagement (including invited talks & events)

Invited Keynote Speaker: "Drier and Wetter in 21st Century California? Managing Increasing Hydroclimate Whiplash in a Warming World," Irvine Company Landscape Symposium, Irvine, CA — Apr. 2025

Invited Keynote Speaker: "Wildfire and climate change in California: Lessons from Los Angeles and other recent disasters," Special community event hosted by CA Wildfire and Forest Resilience Task Force, Climate and Wildfire Institute, and Marin Wildfire Prevention Authority, San Rafael, CA — Mar. 2025

Invited speaker: "What we know (and what we don't) about climate change in California," *Language of the Land Webinar*, Sonoma Land Trust* — Feb. 2025

Invited Speaker, "Climate change in California: Hotter with increasing hydroclimate whiplash," Alameda County Beekeepers Association Meeting, Alameda, CA* — Feb. 2025

Invited Keynote Speaker, "Drier *and* wetter in 21st century California? Managing increasing hydroclimate whiplash in a warming world," California Irrigation Institute Annual Conference, — Jan. 2025

Sacramento, CA

Invited Keynote Speaker, "Drier *and* wetter in 21st century California? Managing increasing hydroclimate whiplash in a warming world," California Irrigation Institute Annual Conference (Water: What's Your Next Move?), Sacramento, CA — Jan. 2025

Invited Opening Speaker, "The Science of Climate Change in California and beyond," Climate Health and Action Webinar Series, San Bernardino County Medical Society/ California Medical Association* — Sep. 2024

Invited Speaker, "Atmospheric Rivers, Heat Domes, and Hydroclimate Whiplash (Oh My!): How is it Playing Out Today?", Ursus Environmental Symposium, University of California, Los Angeles College of Social Sciences/Department of Geography* — Sep. 2024

Invited Guest and Speaker, "Recharging California - In Conversation with Dr. Daniel Swain," Public webinar hosted by Sustainable Conservation* — Sep. 2024

Invited Speaker, "Wildfires and climate change in Northern California." Marin Wildfire Prevention Authority Ecologically Sound Practices Partnership (ESP) Meeting, San Rafael, CA — Jul. 2024

Invited Speaker, "Climate change in California: What we know, what we don't know, and what it all means for the Golden State." Stanford Alumni for Climate Action* — Apr. 2024

Invited Keynote Speaker, "Hydroclimate whiplash on a warming Earth." Operation Sierra Storm Conference 2024, South Lake Tahoe, CA — Jan. 2024

Invited Speaker, "*Twister* in 35mm: A post-screening conversation." *Beware the Elements: Natural Disasters on Film* series, Academy Museum of Motion Pictures, Los Angeles, CA — Jan. 2024

Invited Speaker, "Revisiting the ARkStorm 2.0 scenario in the context of an evolving El Niño event," FEMA Region 9 Climate Adaptation Seminar* — Sep. 2023

Invited Panelist, "Extreme weather events and their impact on urban, rural, working, and natural lands," TOGETHER Bay Area 2023 Spring Conference, Richmond, CA — May 2023

Invited Keynote Speaker, "California flood risk looms large as atmospheric rivers intensify in a warming climate," California Central Valley Flood Control Association Flood Forum 2023, Sacramento, CA — Apr. 2023

Invited Speaker, "The future of precipitation in California: A tale of water scarcity (but also overabundance) amid a warming climate," The Nature Conservancy Board Meeting, Santa Barbara, CA — Feb. 2023

Invited Speaker, "Weather extremes in a warming climate: Thoughts from a meteorologist-turned-climate scientist," Steamboat Weather Summit, Steamboat Springs, CO — Jan. 2023

Climate Feedback expert reviewer, assessing national/international media coverage on climate change and extreme weather as member of accredited fact-checking organization 2016-2022

Invited Speaker, "ARkStorm 2.0: A new and improved extreme storm and flood scenario for California in the climate change era," Federal Emergency Management Agency (FEMA) Region 9 Briefing* Oct. 2022

Invited Keynote Speaker, "In a warming climate, California flood risk looms large despite long-term aridification and worsening drought," California Department of Water Resources "Drought to Flood" Climate Change Symposium, Sacramento, CA* Oct. 2022

Invited Community Speaker, "California weather in the climate change era: A tale of increasing hydroclimate whiplash," Chan Zuckerberg Biohub Community Speaker Series, San Francisco, CA Sep. 2022

Invited Speaker, "California Weather, Climate & Its Extremes," Sustainable Silicon Valley Water & Sustainable Life (WET) Talk* July 2022

Invited Panelist, West Coast Climate Crisis Symposium, University of California, Los Angeles* June 2022

Invited Speaker, "California Wildfire in the Climate Change Era," Marin Wildfire Prevention Authority* May 2022

Invited Speaker, "Drought, flood, and precipitation whiplash in a warming California," The Metropolitan Water District of Southern California Water Dialogue* Mar. 2022

Invited Panelist, "California Dystopia: Understanding Climate Change and Social Collapse through Science Fiction," USC Visions and Voices: The Arts and Humanities Initiative, University of Southern California, Los Angeles, CA Mar. 2022

Invited Speaker and Panelist, "Hanging Ourselves Out to Dry or The Beginning of a New Beginning?" California Foundation on the Environment and the Economy Conference on California Water* Dec. 2021

Invited Speaker, California Water Action Collaboration Risk Discussion Session* Dec. 2021

Invited Keynote Speaker, "California water in an era of increasing climate complexity," California Water Policy Conference* Nov. 2021

Invited Speaker and Panelist, "Climate extremes and prediction in a warming California," Drought and Climate Forecasting Panel, California Legislative Staff Education Institute Virtual Meeting* Nov. 2021

Invited Panelist, "Making our water infrastructure climate-ready," California Water Policy Conference, Public Policy Institute of California* Nov. 2021

Invited Speaker and Panelist, "Climate extremes in a warming California," California Aug. 2021

Climate Safe Policy Summit*

Invited Speaker, "Warmer and wilder: Increasing water resource variability in a changing California," California Water Efficiency Partnership Annual Conference* Jun. 2021

Invited Plenary Speaker, "Hotter, drier, and longer: Shifting seasonality and fire season in California," The Nature Conservancy of California Leadership Meeting* Jun. 2021

Invited Speaker, "Wildfire, flood, and drought risk in a warming California," Bay Area Climate Adaptation Network Meeting* May 2021

Invited Speaker, "Climate change in California: A drier or wetter future—or…both?" 2021 Thelma Hansen Virtual Symposium, University of California Cooperative Extension* Apr. 2021

Invited Speaker, "Climate Change Issues Affecting Water Supply, Storage and Flood Control, and Endangered Species," California Water Law and Policy Conference 2021* Apr. 2021

Invited Speaker, "Increasing hydroclimate whiplash in California: Challenges (and opportunities) for wildfire and flood management," ARCS Foundation webinar* Apr. 2021

Invited Speaker, "Climate Change and Extreme Events in California," Northern California Science Writers Association virtual meeting* Mar. 2021

Invited Panelist, "Climate change in California and Nevada: Challenges and opportunities in an era of increasing variability," Operation Sierra Storm Broadcast Meteorology Virtual Conference* Jan. 2021

Invited Panelist, "A Meteorologist, a Seismologist, a Volcanologist, and a Decision-maker Walk into a Bar: Improving our own risk and impact communication by examining experiences from outside the weather, water, and climate enterprise," American Meteorological Society Annual Virtual Meeting* Jan. 2021

Invited Keynote Speaker, "Water woes in a warming California: Management challenges and opportunities in an era of increasing variability," Association of California Water Agencies (ACWA) Virtual Fall Meeting* Dec. 2020

Invited Speaker, "Fanning the Flames: The Reality of Climate Change and Wildfires in California," Nature Conservancy of California Webinar* Nov. 2020

Invited Keynote Speaker, "Climate Change in California: A Tale of Shifting Baselines, Sharpening Seasonality, and Increasing Precipitation Whiplash," Interagency Ecological Program Annual Workshop, Folsom, CA* Oct. 2020

Invited Panelist, "Early Career Leadership Academy Panel," American Meteorological Society* Oct. 2020

Invited Speaker, "Climate Change in California: Wetter wets, drier drys, and shifting seasonality," San Bernardino Valley Municipal Water District Board Engineering Workshop* Aug. 2020

Invited Panelist, "The Future of Wildfire, Climate Change, and Water in the West," California Grantmakers Association* July 2020

Invited Speaker, "Role of the scientist-communicator in an era of social media and climate change," The Nature Conservancy of California Webinar * Mar. 2020

Invited Speaker, "Climate change in California: A tale of fire and flood," Water Education Foundation "Water Leaders" Orientation, Sacramento, CA* Jan. 2020

Invited Speaker, "Wetter, drier, or both? Increasing hydroclimatic variability in 21st century California," University of California Agriculture & Natural Resources Water Strategic Initiative meeting, Davis, CA* May 2019

Invited Speaker, "Is California ready for increasing precipitation whiplash?," American River Operations Work Group meeting, Folsom, CA* May 2019

Invited Speaker, "Forces of Nature: H2-Uh-Oh," First Fridays event at Natural History Museum of Los Angeles, Los Angeles, CA May 2019

Invited Speaker, "The Wild West of Online Science Communication," University of Washington Program on Climate Change, Seattle, WA* Apr. 2019

Invited Panelist, "LA's New Abnormal: Megafires," UCLA Institute of the Environment and Sustainability & The Nature Conservancy, Los Angeles, CA Feb. 2019

Invited Speaker, "Fire & Water from the 30,000-Foot Level," Water Education Foundation "Water Leaders" Orientation, Sacramento, CA* Jan. 2019

Invited Keynote Speaker, "Drought, flood, and wildfire amidst increasing climate whiplash: the challenging road ahead for water management in the West," Water Education Foundation Water Summit, Sacramento, CA Sep. 2018

Invited Interactive Speaker, "Climate Change Cliff Notes," A Climate Series for the Ages, hosted by UCLA Institute of Environment and Sustainability & Natural History Museum of Los Angeles, Los Angeles, CA Oct. 2017

Invited Speaker, "Change in a land of extremes: what we know (and don't know) about California's climate future," Krotona Institute/Ojai Valley Conservancy, Ojai, California May 2017

Featured Speaker, Stanford Connects 2016: "The Rise of the Ridiculously Resilient Ridge and the Future of California Drought," Stanford University, Stanford, CA May 2016

Project Mentor, Stanford University course: "International Climate Negotiations (COP 21)" Dec. 2015

Invited Speaker, "Flood in a time of drought? Effects of a powerful El Niño in the midst of California's record dry spell," Association of Bay Area Governments, Oakland, CA Sep. 2015

Invited Speaker, "Climate Change in a Land of Extremes: Drought and Flood in California's Past, Present, and Future," U.S. National Park Service Parsons Memorial Lodge Lecture Series, Yosemite National Park, CA Aug. 2015

Invited Speaker and Panelist, "California Drought Panel," Water in the West/Woods Institute for the Environment, Stanford University, Stanford, CA Mar. 2015

Invited Panelist, "Earth Matters/A Matter of Degrees," Stanford Continuing Studies Program, Stanford University, Stanford, CA Feb. 2015

Invited Science Speaker, "Stanford to the Sea" Science Hike, "The Ridiculously Resilient Ridge in Context: Climate Variability of California's Past, Present, and Future," Bill Lane May 2014

Center for the American West, Stanford University, Stanford, CA

Invited Speaker and Panelist, "Current Drought: Causes, how bad is it, and will we see more?" University of California Drought Summit, California State Capitol, Sacramento, CA — Apr. 2014

Invited Speaker and Panelist, "The California Drought: Causes, Context, and Response," Bill Lane Center for the American West/Woods Institute for the Environment, Stanford University, Stanford, CA — Feb. 2014

Founder and leader, Aggie Forecasting Team at University of California, Davis — 2008-2011

Co-leader, Atmospheric Profiling & Stratospheric Photography Project, Univ. of Calif., Davis — 2009-2011

*Denotes remote participation via teleconference

Additional awards and recognitions

IOP Publishing Top Cited Paper Award (Goss et al. 2020)	2023
Environmental Research Letters Editorial Board "Best Article of 2020" (Goss et al. 2020)	2021
Finalist, AAAS Early Career Award for Public Engagement with Science	2018
"Must Follow" Social Media Meteorologist/Climatologist, Forbes Magazine	2016
Best Talk Award, Environmental Science, SES Research Review, Stanford University	2016
Oakland Museum of California "Agent of Change"	2015
"Ten under 30: Young leaders changing the American West," *High Country News*	2015
Fellow, Rising Environmental Leaders Program, Stanford Woods Inst. for the Environment	2013
"Research as Art" competition winner, School of Earth Sciences, Stanford University	2015, 2012
ThinkSwiss Award, Swiss National Science Foundation, "NCCR Climate Summer School," Grindelwald, Switzerland	2013
Winner, Prized Writing Competition, Scientific & Technical Writing, Univ. of California, Davis	2010, 2008
Guillermo Salazar Rodriguez Undergraduate Scholarship, American Meteorological Society	2010
Invitee, NCAR Undergraduate Leadership Workshop, Boulder, CO	2010
Regents Scholarship, University of California, Davis	2009-2011
UC Davis Integrated Studies Honors Program International Education Award	2008
UC Davis International Relations Study Abroad Award	2008
Edward Kraft Prize, University of California, Davis	2008
American Meteorological Society Undergraduate Scholarship	2007-2009
Henry A. Jastro Recruitment Scholarship, University of California, Davis	2007-2009
NASA Ames/AIAA Galileo Memorial Scholarship	2007

Additional professional experience

Teaching

Teaching Assistant, Department of Earth System Science, Stanford University 2013
Course: "Atmosphere, Ocean & Climate Dynamics: The Atmospheric Circulation."

Invited Guest Lecturer
University of California, Los Angeles 2016-2020
Courses: Advanced Topics in Environment and Sustainability; Climate Law and Policy; The Blue Planet: Introduction to Oceanography

Stanford University 2013-2023
Courses: Atmosphere, Ocean & Climate Dynamics I & II (ESS 246A & ESS 246B); Forecasting for Innovators (ME297); Stanford Pre-Collegiate Institutes

Academic Advisees
Eduardo Muñoz-Castro, Doctoral Student, Swiss Institute for Snow and Avalanche Research /ETH Zurich (Co-advised with Drs. Manuela Brunner & Bailey Anderson, ETH Zurich) 2024-Present

Dr. Jennifer Bukowski, Postdoctoral Researcher, Inst. Of Environ. & Sustainability, UCLA (Co-advised with Dr. James Done, NSF National Center for Atmospheric Research) 2021-2023

Additional publications

Non-peer reviewed reports
Persad, G.G., Partida, J.P.O., and **Swain, D.L.**, "Troubled Waters: Preparing for Climate Threats to California's Water System," *Union of Concerned Scientists*, 2020. 2020

Mount, J., **Swain, D.L.**, and P. Ullrich, "Just the Facts: Climate Change and California's Water," *Public Policy Institute of California*, 2019. 2019

Hanak, E. et al., "California's Water," *Public Policy Institute of California*, 2018. 2018

Mount, J. et al., "Managing Drought in a Changing Climate: Four Essential Reforms," *Public Policy Institute of California*, 2018. 2018

Additional scientific presentations

Oral presentations
"Clausius-Clapeyron as a potential framework for quantifying and attributing an increasingly broad range of extremes amid uncertainty in a warming climate," *American Geophysical Union Fall Meeting, Washington, D.C.* Dec. 2024

"Hydroclimate Volatility on a Warming Earth," *American Geophysical Union Fall Meeting, San Francisco, CA* Dec. 2023

"Climate change is narrowing and shifting windows favorable for prescribed fire in western United States," *American Geophysical Union Fall Meeting, Chicago, IL** Dec. 2022

"ARkStorm 2.0: Developing a new extreme atmospheric river storm scenario for 21st century California," *International Atmospheric Rivers Conference* (virtual meeting)* Oct. 2020

"Dynamics of and precursors to California megafloods, present and future," *American Meteorological Society Annual Meeting*, Phoenix, AZ Jan. 2019

"Increasing climate whiplash in 21st century California," *American Geophysical Union Fall Meeting*, New Orleans, LA — Dec. 2017

"California precipitation extremes in a warming world," *Sustainable LA Water Research Grand Challenge Research Symposium*, Los Angeles, CA — Nov. 2017

Poster presentations

"Is society ready for increasing climate whiplash?" *2019 Israeli-American Kavli Frontiers of Science Symposium*, Jerusalem, Israel — Sep. 2019

"Connections between the tropical Pacific Ocean, Arctic sea ice, and anomalous northeastern Pacific ridging," *American Geophysical Union Fall Meeting*, San Francisco, CA — Dec. 2016

"Character and causes of changing Pacific climate extremes: Special focus on the extraordinary 2012-2015 California drought," *Young Environmental Scholars Conference*, Stanford, CA — Dec. 2015

"The Extraordinary California Drought of 2013-2014: Character, Context, and the Role of Climate Change," *American Geophysical Union Fall Meeting*, San Francisco, CA — Dec. 2014

"The Extraordinary California Drought of 2013-2014: Character, Context, and the Role of Climate Change," *Graduate Climate Conference*, Seattle, WA — Nov. 2014

"The Extraordinary California Drought of 2013-2014: Character, Context, and the Role of Climate Change," *Fourth Workshop on understanding Climate Change from Data*, National Center for Atmospheric Research, Boulder, CO — Jun. 2014

"Evaluation of high-resolution simulations of Northeast Pacific atmospheric rivers," *American Geophysical Union Fall Meeting*, San Francisco, CA — Dec. 2013

"Mid-Latitude Precipitation Extremes: Latitudinal Linkages and Climate Change," *Swiss National Center for Competence in Research (NCCR Climate)*, Grindelwald, Switzerland — Sep. 2013

"High-resolution seasonal simulations of Northeast Pacific atmospheric rivers and comparison to in-situ observations," *American Geophysical Union Fall Meeting*, San Francisco, CA — Dec. 2012