Fifth National Climate Assessment

Focus on Compound Events

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Authors and Contributors

Federal Coordinating Lead Author

Allison R. Crimmins, US Global Change Research Program

Chapter Lead Author

Deepti Singh, Washington State University Vancouver

Technical Contributors

Justin M. Pflug, University of Maryland, College Park, Earth System Science Interdisciplinary Center

Patrick L. Barnard, US Geological Survey

Jennifer F. Helgeson, National Institute of Standards and Technology

Andrew Hoell, NOAA Physical Sciences Laboratory

Fayola H. Jacobs, University of Minnesota

Michael G. Jacox, NOAA Southwest Fisheries Science Center and NOAA Physical Sciences Laboratory

Alessandra Jerolleman, Jacksonville State University

Michael F. Wehner, Lawrence Berkeley National Laboratory

Review Editor

Alton P. Williams, University of California, Los Angeles

Cover Art

Lisa Harrington

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Focus on Compound Events

Climate change is increasing the chances of multiple climate hazards occurring simultaneously or consecutively across the US and its territories. Such interactions between multiple hazards across space or time, known as compound events, exacerbate the societal and ecosystem impacts of individual hazards and hinder the ability of communities, particularly frontline communities, to respond and cope. Therefore, infrastructure design, planning, governance, and disaster preparedness for compound events are critical for building resilient systems.

What Are Compound Events?

Compound events result from the occurrence of multiple climate drivers or hazards either in an individual location or across multiple locations that, when combined, have greater impacts than isolated hazards on ecosystems, water resources, public health, energy infrastructure, transportation, food systems, and interconnected societal networks, often straining disaster response.[1,2,3] Compound events can also result from the intersection of climate hazards with other environmental hazards like pollution, non-climate hazards such as wars and pandemics, or socioeconomic stressors like poverty and lack of adequate housing that disproportionately impact overburdened communities, thereby deepening existing societal inequities (e.g., KMs 5.2, 18.2, 20.1, 23.1, 27.1, 29.2). Compound events are broadly categorized as:

- **Multivariate**: co-occurring hazards in a location, such as simultaneous precipitation deficits and extreme heat that contributed to the severe Pan-Caribbean 2013–2016 drought[4]
- **Temporally compounding**: successive hazards in a location, such as destructive wildfires in 2017 followed by heavy rainfall on burned landscapes in January 2018 that resulted in mudslides and debris flows, damaging ecosystems and infrastructure (KMs 3.5, 5.2, 6.1, 27.2)
- **Spatially compounding**: similar or disparate hazards occurring simultaneously or within a short time window in multiple locations that are connected by physical processes or complex human and natural systems, such as simultaneous megafires across multiple western states and record back-to-back Atlantic hurricanes in 2020 that caused unprecedented demand on federal emergency response resources (Figure F1.1)[5]
- **Preconditioned**: extreme events superimposed on long-term trends, such as higher sea levels, heavier precipitation, and/or changing storm seasonality causing more frequent and severe coastal flooding (KMs 4.2, 9.1, 30.1),[6,7] like during Hurricane Florence (2018) in the Southeast (KM 22.1),[8] Typhoon Surigae (2021) in Palau, and Typhoon Merbok (2022) in Alaska (KM 29.1)[9]
- **Complex events**: non-climatic stressors that exacerbate climate hazards, such as COVID-19, which exacerbated climate-driven food, water, and livelihood insecurities facing Tribes, Indigenous Peoples, and other frontline communities (KMs 5.2, 16.1; Focus on COVID-19 and Climate Change)

Recent Events

Compound events have resulted in multiple recent disasters across several US states. The following examples illustrate their cascading societal impacts (Figure F1.1):

- **Heat, drought, and wildfires**: A series of compound events between 2020 and 2021 stressed communities and ecosystems across the western US and caused economic damages exceeding $38.5 billion (in 2022 dollars; KMs 27.2, 28.1, 28.2, 28.4).[10] In 2020, co-occurring heat and drought caused concurrent destructive fires across California, Oregon, and Washington11 that resulted in infrastructure and property damage and human fatalities, threatened access to energy and water supplies, and strained firefighting resources.[10] Millions of residents were exposed to harmful pollutants in wildfire smoke, affecting public health and worsening COVID-19 related mortality.[12,13,14] Drought persisted into 2021 and amplified the record-breaking Northwest heatwave,[15] killing over 229 people in the US. Co-occurring heat, drought, low streamflow, and low tides in 2021 triggered toxic algal blooms and mass die-offs of shellfish and low survival of salmon, species important to Indigenous communities and the West Coast economy (KM 27.2; Figure 10.2).[16] West Coast crab fishery revenue losses were exacerbated by management actions implemented during earlier marine heatwaves.[17]
- **Compound flooding**: Back-to-back storms affected the Northeast in 2021, resulting in 55 deaths and more than $21.4 billion (in 2022 dollars) in damages (KM 21.1). On August 22, Hurricane Henri brought intense rainfall to the Northeast (7 inches in New York City, including 2 inches in one hour in Central Park) that caused $749 million (in 2022 dollars) in damages despite mild winds. On August 29, Hurricane Ida, which made landfall as a Category 4 in Louisiana, moved northeast, and delivered record rainfall during September 1–2 to already-saturated Northeast soils, causing catastrophic flooding. This temporally compounding event was about 30 times more deadly and more damaging than Hurricane Henri alone, straining local governance and emergency management systems.[18]

Will Compound Events Increase with Climate Change?

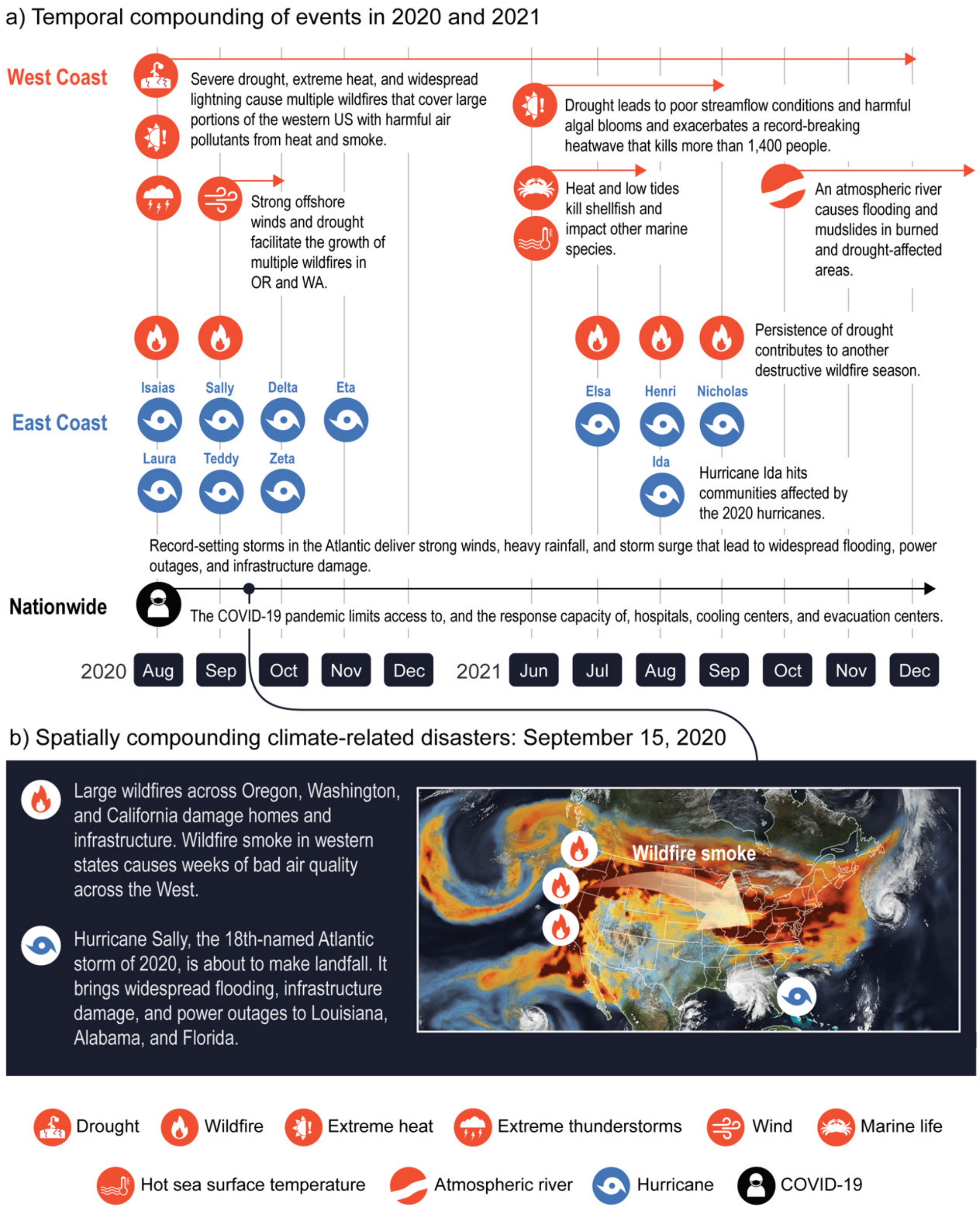
Compound events are expected to become more frequent with continued climate change (e.g., KMs 2.2, 9.1). The increasing frequency and severity of climate hazards such as extreme heat, heavy precipitation, and severe storms are projected to increase the chances of 1) a sequence of hazards occurring within a short time span and 2) simultaneous independent events in a location or multiple locations. For instance, increasing swings from dry-to-wet extremes in western states and Pacific Islands will increase the chances of intense rains on parched or recently burned landscapes, increasing risks of postfire flash flooding, debris flow, and contaminated drinking water supplies (KMs 4.2, 30.1).[19,20,21] Climate change is also expected to alter the physical drivers of compound events. For instance, more frequent extreme La Niñas[22] would simultaneously elevate the risk of western US droughts and back-to-back severe Atlantic hurricanes, increasing the chances of compounding disasters similar to the 2020 season (Figure F1.1).[23,24] Changes in weather patterns such as more frequent atmospheric high-pressure systems could increase the risk of co-occurring heat, drought, and marine heatwaves.[25,26]

How Can We Adapt?

Low-income communities, communities of color, Tribes and Indigenous Peoples experience high exposure and vulnerability to climate hazards due to their proximity to hazard-prone areas, infrastructure deficits, limited disaster-management resources, and governance challenges, which are legacies of colonialism, redlining, and other discriminatory policies (KMs 4.2, 16.2, 18.2, 20.1).[27] Consequently, these communities could face higher risks through complex event outcomes, which can magnify existing disproportionate health risks (KM 15.2). Transformative, socially just adaptation approaches (KM 31.3), investment in emergency preparedness, and governance structures that account for the inequitable distribution of climate impacts can avoid further exacerbating such existing social disparities (KMs 12.4, 20.3, 31.2).[28,29,30] Incorporating compound event risks in infrastructure design standards and regulations, updating aging infrastructure, and planning at the community-level can improve climate resilience and protect against risks like displacement and gentrification.[28,31,32] Despite the availability of tools to evaluate infrastructure alternatives (e.g., Helgeson et al. 2020[33]), communities with limited adaptation resources face significant challenges in making such investments.

Resource allocation toward solutions that address multiple community resilience objectives can address some of these challenges.[34,35] For example, blue-green infrastructure—use of green-areas and water bodies in urban planning—and tidal marsh restoration can sequester greenhouse gas emissions and protect against floods while also providing ecosystem services like reducing heat and air pollution, creating recreational spaces, and advancing environmental justice in urban environments (KM 12.3).[36] Enhanced monitoring of adaptation actions, scenario planning activities (e.g., Gerlak et al. 2021[37]), and sharing best practices among stakeholders can alleviate planning challenges and improve management of the growing risk of compound events.

Compound Events



Compound events have amplifying impacts on ecosystems and human communities and affect their capacity to respond.

Figure F1.1. (**a**) The timeline shows temporally compounding events in 2020–2021 on the West and East Coasts and their cascading impacts on communities and ecosystems. (**b**) The satellite image shows simultaneous disasters—multiple wildfires in the US West and Hurricane Sally in the Southeast. The orange and red colors show wildfire smoke traveling across the US. Figure credit: Washington State University Vancouver. See figure metadata for additional contributors. Satellite image credit: Joshua Stevens, NASA Earth Observatory, using GEOS-5 data courtesy of NASA GSFC and VIIRS data courtesy of NASA EOSDIS/LANCE and GIBS/Worldview and the Suomi National Polar-orbiting Partnership.

Traceable Accounts

Description of Evidence Base and Research Gaps

There is broad agreement across the physical and social sciences and engineering communities that compound events are a growing threat to communities, sectors, emergency management, insurance companies, and interconnected societal systems. Recent studies have developed frameworks for studying compound events and quantified future changes in risks in several types of compound events such as hot and dry or hot and humid extremes, compound coastal and fluvial flooding, drought and marine heatwaves, marine heatwaves and ocean acidity extremes, and wildfires followed by heavy rainfall. Identification of various types of compound events has grown in recent years. Compound events are rare, and thus the short observational record for many climate variables limits the ability to quantify historical changes, characterize present-day probabilities, and evaluate the ability of climate models to simulate them. There are also gaps in the scientific understanding of the range of physical processes that lead to various types of compound events affecting many regions, communities, and sectors. Literature on their societal impacts is even more limited and challenging to quantify because compound events are still relatively rare and result from a complex set of factors. Together, these result in uncertainties and low confidence in estimates of projected changes in their risks.

Compound events span a wide variety of physical phenomena, societal impacts, and different research communities with different needs, requirements, and impacts. There is a diversity of definitions of compound events, and much of the literature consists of case studies. Compound events of multiple weather and climate variables are often treated by combining those variables into a single metric. For instance, the literature contains multiple formulations of the combined effect of high temperatures, humidity (or aridity), and winds (or stagnancy) on human health and fire risk. While such univariate formulations are more amenable to standard analysis techniques, the richness of the multivariate space can be lost. Advanced multivariate extreme statistical analysis tools have not seen widespread adoption by the scientific community. The recent development of large climate model ensembles combined with event identification analysis tools offers the opportunity to increase our understanding of the physical processes that lead to compound events and to evaluate their historical and future risks under different warming levels.

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