

STATE OF THE CLIMATE IN 2022



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Cover Credit:

Climate Change - Skiing and snowboarding during Winter Holidays in the Bavarian Alps around Oberstdorf.

Oberstdorf, Germany

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STATE OF THE CLIMATE IN 2022

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Abstract

—J. BLUNDEN, T. BOYER, AND E. BARTOW-GILLIES

Earth's global climate system is vast, complex, and intricately interrelated. Many areas are influenced by global-scale phenomena, including the "triple dip" La Niña conditions that prevailed in the eastern Pacific Ocean nearly continuously from mid-2020 through all of 2022; by regional phenomena such as the positive winter and summer North Atlantic Oscillation that impacted weather in parts the Northern Hemisphere and the negative Indian Ocean dipole that impacted weather in parts of the Southern Hemisphere; and by more localized systems such as high-pressure heat domes that caused extreme heat in different areas of the world. Underlying all these natural short-term variabilities are long-term climate trends due to continuous increases since the beginning of the Industrial Revolution in the atmospheric concentrations of Earth's major greenhouse gases.

In 2022, the annual global average carbon dioxide concentration in the atmosphere rose to 417.1 ± 0.1 ppm, which is 50% greater than the pre-industrial level. Global mean tropospheric methane abundance was 165% higher than its pre-industrial level, and nitrous oxide was 24% higher. All three gases set new record-high atmospheric concentration levels in 2022.

Sea-surface temperature patterns in the tropical Pacific characteristic of La Niña and attendant atmospheric patterns tend to mitigate atmospheric heat gain at the global scale, but the annual global surface temperature across land and oceans was still among the six highest in records dating as far back as the mid-1800s. It was the warmest La Niña year on record. Many areas observed record or near-record heat. Europe as a whole observed its second-warmest year on record, with sixteen individual countries observing record warmth at the national scale. Records were shattered across the continent during the summer months as heatwaves plagued the region. On 18 July, 104 stations in France broke their all-time records. One day later, England recorded a temperature of 40°C for the first time ever. China experienced its second-warmest year and warmest summer on record. In the Southern Hemisphere, the average temperature across New Zealand reached a record high for the second year in a row. While Australia's annual temperature was slightly below the 1991–2020 average, Onslow Airport in Western Australia reached 50.7°C on 13 January, equaling Australia's highest temperature on record.

While fewer in number and locations than record-high temperatures, record cold was also observed during the year. Southern Africa had its coldest August on record, with minimum temperatures as much as 5°C below normal over Angola, western Zambia, and northern Namibia. Cold outbreaks in the first half of December led to many record-low daily minimum temperature records in eastern Australia.

The effects of rising temperatures and extreme heat were apparent across the Northern Hemisphere, where snow-cover extent by June 2022 was the third smallest in the 56-year record, and the seasonal duration of lake ice cover was the fourth shortest since 1980. More frequent and intense heatwaves contributed to the second-greatest average mass balance loss for Alpine glaciers around the world since the start of the record in 1970. Glaciers in the Swiss Alps lost a record 6% of their volume. In South America, the combination of drought and heat left many central Andean glaciers snow free by mid-summer in early 2022; glacial ice has a much lower albedo than snow, leading to accelerated heating of the glacier. Across the global cryosphere, permafrost temperatures continued to reach record highs at many high-latitude and mountain locations.

In the high northern latitudes, the annual surface-air temperature across the Arctic was the fifth highest in the 123-year record. The seasonal Arctic minimum sea-ice extent, typically reached in September, was the 11th-smallest in the 43-year record; however, the amount of multiyear ice—ice that survives at least one summer melt season—remaining in the Arctic continued to decline. Since 2012, the Arctic has been nearly devoid of ice more than four years old.

In Antarctica, an unusually large amount of snow and ice fell over the continent in 2022 due to several landfalling atmospheric rivers, which contributed to the highest annual surface mass balance, 15% to 16% above the 1991–2020 normal, since the start of two reanalyses records dating to 1980. It was the second-warmest year on record for all five of the long-term staffed weather stations on the Antarctic Peninsula. In East Antarctica, a heatwave event led to a new all-time record-high temperature of -9.4°C — 44°C above the March average—on 18 March at Dome C. This was followed by the collapse of the critically unstable Conger Ice Shelf. More than 100 daily low sea-ice extent and sea-ice area records were set in 2022, including two new all-time annual record lows in net sea-ice extent and area in February.

Across the world's oceans, global mean sea level was record high for the 11th consecutive year, reaching 101.2 mm above the 1993 average when satellite altimetry measurements began, an increase of 3.3 ± 0.7 over 2021. Globally-averaged ocean heat content was also record high in 2022, while the global sea-surface temperature was the sixth highest on record, equal with 2018. Approximately 58% of the ocean surface experienced at least one marine heatwave in 2022. In the Bay of Plenty, New Zealand's longest continuous marine heatwave was recorded.

A total of 85 named tropical storms were observed during the Northern and Southern Hemisphere storm seasons, close

to the 1991–2020 average of 87. There were three Category 5 tropical cyclones across the globe—two in the western North Pacific and one in the North Atlantic. This was the fewest Category 5 storms globally since 2017. Globally, the accumulated cyclone energy was the lowest since reliable records began in 1981. Regardless, some storms caused massive damage. In the North Atlantic, Hurricane Fiona became the most intense and most destructive tropical or post-tropical cyclone in Atlantic Canada’s history, while major Hurricane Ian killed more than 100 people and became the third costliest disaster in the United States, causing damage estimated at \$113 billion U.S. dollars. In the South Indian Ocean, Tropical Cyclone Batsirai dropped 2044 mm of rain at Commerson Crater in Réunion. The storm also impacted Madagascar, where 121 fatalities were reported.

As is typical, some areas around the world were notably dry in 2022 and some were notably wet. In August, record high areas of land across the globe (6.2%) were experiencing extreme drought. Overall, 29% of land experienced moderate or worse categories of drought during the year. The largest drought footprint in the contiguous United States since 2012 (63%) was observed in late October. The record-breaking megadrought of central Chile continued in its 13th consecutive year, and 80-year record-low river levels in northern Argentina and Paraguay disrupted fluvial transport. In China, the Yangtze River reached record-low values. Much of equatorial eastern

Africa had five consecutive below-normal rainy seasons by the end of 2022, with some areas receiving record-low precipitation totals for the year. This ongoing 2.5-year drought is the most extensive and persistent drought event in decades, and led to crop failure, millions of livestock deaths, water scarcity, and inflated prices for staple food items.

In South Asia, Pakistan received around three times its normal volume of monsoon precipitation in August, with some regions receiving up to eight times their expected monthly totals. Resulting floods affected over 30 million people, caused over 1700 fatalities, led to major crop and property losses, and was recorded as one of the world’s costliest natural disasters of all time. Near Rio de Janeiro, Brazil, Petrópolis received 530 mm in 24 hours on 15 February, about 2.5 times the monthly February average, leading to the worst disaster in the city since 1931 with over 230 fatalities.

On 14–15 January, the Hunga Tonga-Hunga Ha'apai submarine volcano in the South Pacific erupted multiple times. The injection of water into the atmosphere was unprecedented in both magnitude—far exceeding any previous values in the 17-year satellite record—and altitude as it penetrated into the mesosphere. The amount of water injected into the stratosphere is estimated to be 146 ± 5 Terragrams, or $\sim 10\%$ of the total amount in the stratosphere. It may take several years for the water plume to dissipate, and it is currently unknown whether this eruption will have any long-term climate effect.

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STATE OF THE CLIMATE IN 2022

INTRODUCTION

T. Boyer, E. Bartow-Gillies, J. Blunden, and R. J. H. Dunn



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Self portrait: Traveling of a lone tourist in the snowy Carpathians among wild forests and fields, during a strong storm with a winter thunderstorm against the backdrop of mountains.

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1. INTRODUCTION

T. Boyer, E. Bartow-Gillies, J. Blunden, and R. J. H. Dunn

The year 2022 was marked by unusual (though not unprecedented) disruptions in the climate system. The first was the third successive year of below-average temperatures in the tropical Pacific. A “triple-dip” La Niña nearly continuous from August 2020 through the end of 2022 marked the first such occurrence in the twenty-first century. Note that the triple-dip La Niña should not be confused with the double-dip La Niña described in the *State of the Climate 2021*, as the double-dip referred to the short interruption between two La Niña events in 2021 which was the only break in the triple-dip period. Descriptions of the large-scale characteristics of the triple-dip La Niña are found in Chapters 2 (Global Climate) and 3 (Global Ocean). The El Niño–Southern Oscillation phenomena, of which the triple-dip La Niña is an anomalous manifestation, has major short-term influence on the climate system. The specific details of the effects of the triple-dip La Niña on other aspects of the climate system are found throughout the report. A perspective of the triple-dip La Niña and its implications for long-term climate are discussed in a sidebar of Chapter 3.

The second unusual event was the extraordinary amount of precipitation over Antarctica in 2022, which led to a record-high annual surface mass balance (since 1980) and the first net positive annual ice-sheet mass balance on the continent since satellite measurements began in 1993. The heavy precipitation was closely tied to an unusually high number of atmospheric rivers over the continent, which carry moisture over Antarctica that mainly falls as snow. March precipitation totals in the Wilkes and Adelie regions were particularly high, estimated to exceed 300% of the 1991–2020 climatological mean. While an increase in ice-sheet mass in Antarctica has positive implications for global continental water storage and hence lessening sea-level increase, atmospheric rivers also have a large impact on surface melt and ice-sheet stability. Surface melt in turn has an impact on ‘firn’, the underlying layer of recrystallized snow from previous years. Firn density is an important factor in determining how surface melt water flows on and within ice shelves, which can reduce glacial stability and lead to their breakup and collapse. There was also record-low sea ice surrounding Antarctica in 2022, and on the eastern Antarctic Peninsula which allowed large swells to reach the coast and caused a breakout of fast ice that contributed to an acceleration of upstream glaciers. The complex interactions of climate factors on the Antarctic continent are discussed in Chapter 6, with particulars in the two sidebars: 1) The Antarctic heatwave of March 2022 and 2) Larsen-B fast ice breakout and glacier response.

A third event in 2022 was the eruption of the Hunga Tonga–Hunga Ha’apai underwater volcano (HTHH) in January. This eruption propelled immense amounts of water vapor (50 Tg to 150 Tg, upwards of 10% of the total stratospheric water vapor burden) and other gases into the stratosphere, with a plume higher than any previous eruption in the satellite era. Implications of the eruption, detailed in a sidebar and elsewhere in Chapter 2, include increased stratospheric aerosols and observations of cool stratospheric temperatures outside normal ranges with correspondingly anomalous winds. Long-term effects on tropospheric temperatures and the Antarctic ozone hole remain to be seen. The HTHH eruption also had an effect on our ability to make observations. For example, as detailed in Chapter 3, the calculation of ocean carbon biomass from satellite measurements has been greatly affected by the amount of sulfate aerosols injected by the HTHH eruption.

Another instance of volcanic activity, though not of the scale of HTHH, but with significant effects on the climate observing system, was the eruption of Mauna Loa in late November 2022. This eruption and subsequent lava flow shut down access and power to the NOAA Mauna Loa Observatory (featured on the cover of Chapter 8, Datasets), interrupting one of the longest time series for a variety of atmospheric variables, including atmospheric carbon dioxide (CO₂) levels. After a 10-day interruption, NOAA's CO₂ measurements were transferred to the University of Hawaii's Maunakea Observatories. The Mauna Loa CO₂ time series is an invaluable monitor of the changes in our climate system (as detailed in Chapter 2). This serves as a reminder of the importance of long-term continuous time series in our understanding of Earth's climate system and the importance of continuing such time series.

All the above singular events, along with the status of essential climate variables (ECVs) and their implications for Earth's climate system are detailed in the *State of the Climate 2022* due to the persistent dedication of the chapter editors and section authors—this year 576 authors from 66 different countries, including Andorra and Namibia for the first time. A distillation of the state of the climate for 2022 in the context of long-term trends and variability of selected essential climate variables is found in the 36 panels of Plate 1.1. The *State of the Climate* report continues to advance toward a more comprehensive survey of essential climate variables (ECVs). A new section on lightning (Chapter 2, Global Climate) documents global distributions in this ECV. A new section on Arctic Precipitation (Chapter 5, the Arctic) adds regional insight into the precipitation ECV.

The layout of this Supplement is similar to previous years. Following this introduction (Chapter 1), Chapter 2 catalogs global climate, Chapter 3 the oceans, Chapter 4 the tropics, Chapters 5 and 6 the high latitudes (Arctic and Antarctic, respectively), and Chapter 7 other specific regions of the globe (North America, Central America/Caribbean, South America, Africa, Europe, Asia, and Oceania). Finally, Chapter 8 is a listing of many (though not all) datasets used in the various sections of the *State of the Climate in 2022* and a link to dataset access and further information. Datasets are listed by chapter. Most of the datasets are readily downloadable by the reader who would like to reproduce the results found in the *State of the Climate* report or investigate further.

GLOBAL AVERAGE TEMPERATURE
The Jan-Dec 2022 average global surface temperature was among the sixth highest since global records began in the mid- to late-1800s.

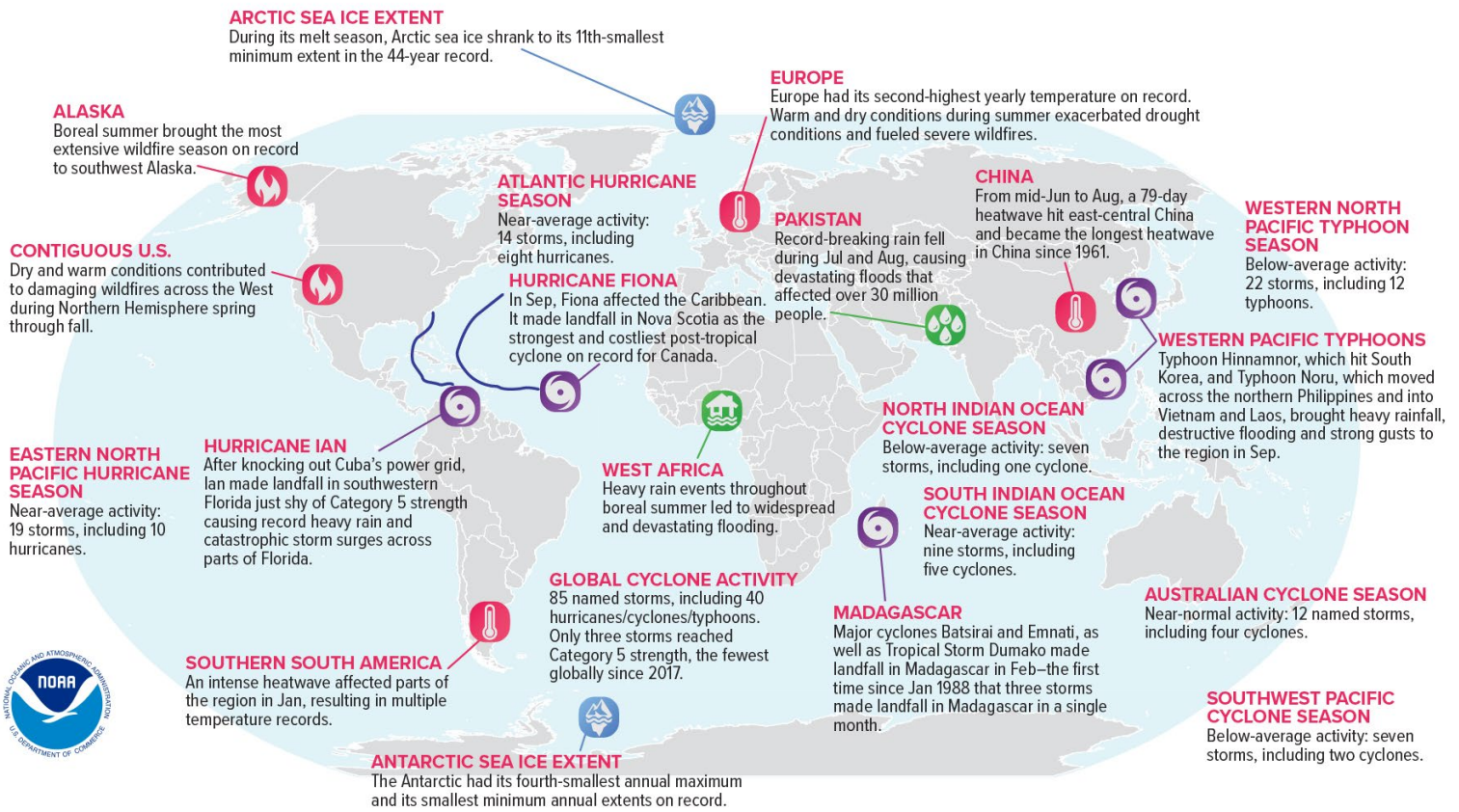
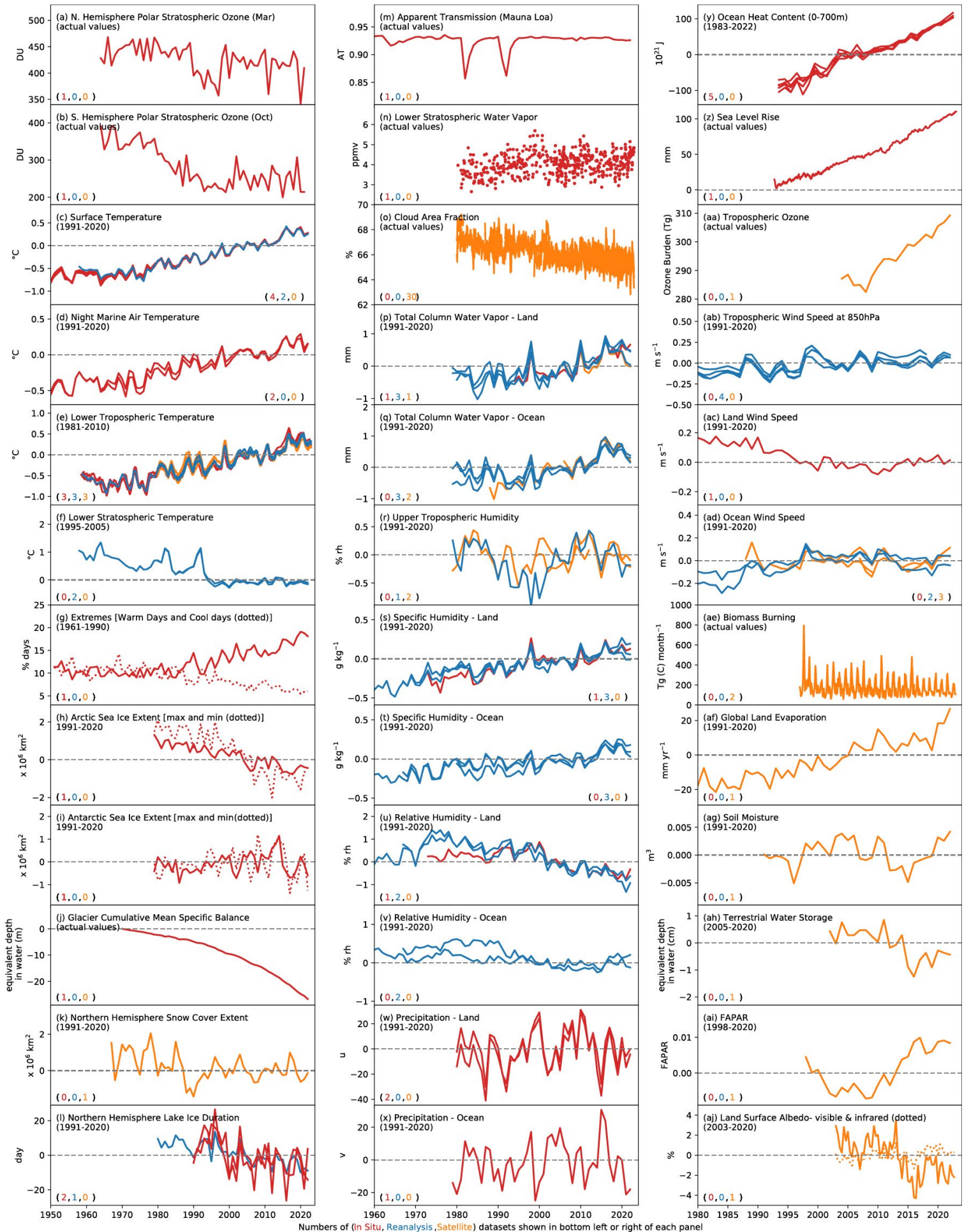


Fig. 1.1. Geographical distribution of selected notable climate anomalies and events in 2022.

Plate 1.1. (Next page) Global (or representative) average time series for essential climate variables through 2019. Anomalies are shown relative to the base period in parentheses although base periods used in other sections of the report may differ. The numbers in the parentheses in the lower left or right side of each panel indicate how many in situ (red), reanalysis (blue), and satellite (orange) datasets are used to create each time series in that order. (a) NH polar stratospheric ozone (Mar); (b) SH polar stratospheric ozone (Oct); (c) surface temperature; (d) night marine air temperature; (e) lower-tropospheric temperature; (f) lower-stratospheric temperature; (g) extremes (warm days [solid] and cool days [dotted]); (h) Arctic sea-ice extent (max [solid]) and min [dotted]); (i) Antarctic sea-ice extent (max [solid] and min [dotted]); (j) glacier cumulative mean specific balance; (k) NH snow-cover extent; (l) NH lake ice duration; (m) Mauna Loa apparent transmission; (n) lower-stratospheric water vapor; (o) cloud area fraction; (p) total column water vapor – land; (q) total column water vapor – ocean; (r) upper-tropospheric humidity; (s) specific humidity – land; (t) specific humidity – ocean; (u) relative humidity – land; (v) relative humidity – ocean; (v) precipitation – land; (x) precipitation – ocean; (y) ocean heat content (0 m–700 m); (z) sea-level rise; (aa) tropospheric ozone; (ab) tropospheric wind speed at 850 hPa; (ac) land wind speed; (ad) ocean wind speed; (ae) biomass burning; (ae) global land evaporation; (af) soil moisture; (ag) terrestrial groundwater storage; (ah) fraction of absorbed photosynthetically active radiation (FAPAR); (ai) land surface albedo – visible (solid) and infrared (dotted).



Essential Climate Variables

—T. BOYER, E. BARTOW-GILLIES, J. BLUNDEN, AND R.H. DUNN

The following variables are considered fully monitored in this report, in that there are sufficient spatial and temporal data, with peer-reviewed documentation to characterize them on a global scale:

- Surface atmosphere: air pressure, precipitation, temperature, water vapor, wind speed and direction
- Upper atmosphere: Earth radiation budget, temperature, water vapor, wind speed and direction, lightning
- Atmospheric composition: carbon dioxide, methane and other greenhouse gases, ozone
- Ocean physics: ocean surface heat flux, sea ice, sea level, surface salinity, sea-surface temperature, subsurface salinity, subsurface temperature, surface currents, surface stress
- Ocean biogeochemistry: ocean color
- Ocean biogeosystems: plankton
- Land: albedo, river discharge, snow

The following variables are considered partially monitored, in that there is systematic, rigorous measurement found in this report, but some coverage of the variable in time and space is

lacking due to observing limitations or availability of data or authors:

- Atmospheric composition: aerosols properties, cloud properties, precursors of aerosol and ozone
- Ocean physics: subsurface currents
- Ocean biogeochemistry: inorganic carbon
- Land: above-ground biomass, anthropogenic greenhouse gas fluxes, fire, fraction of absorbed photosynthetically active radiation, glaciers, groundwater, ice sheets and ice shelves, lakes, permafrost, soil moisture
- Surface atmosphere: surface radiation budget

The following variables are not yet covered in this report, or are outside the scope of it.

- Ocean physics: sea state
- Ocean biogeochemistry: nitrous oxide, nutrients, oxygen, transient tracers
- Ocean biogeosystems: marine habitat properties
- Land: anthropogenic water use, land cover, land surface temperature, latent and sensible heat fluxes, leaf area index, soil carbon

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