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

Oberstdorf, Germany

Matthias Manuel / Alamy Stock Photo

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Corresponding author: Full Report: Jessica Blunden / jessica.blunden@noaa.gov
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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. 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 ~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.
Abida, A., Agence Nationale de l’Aviation Civile et de la Météorologie, Moroni, Union of the Comoros
Ades, Melanie, European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom
Adler, Robert, CMNS-Earth System Science Interdisciplinary Center, University of Maryland, College Park, Maryland
Adusumilli, Susheel, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California
Agyakwah, W., NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland
Ahmasuk, Brandon, Kawerak Inc., Nome, Alaska
Aldeco, Laura S., Servicio Meteorológico Nacional, Buenos Aires, Argentina
Alexe, Mihai, European Centre for Medium-Range Weather Forecasts, Bonn, Germany
Alfaro, Eric J., Center for Geophysical Research and School of Physics, University of Costa Rica, San José, Costa Rica
Allan, Richard P., Department of Meteorology and National Centre for Earth Observation, University of Reading, Reading, United Kingdom
Allgood, Adam, NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland
Alves, Lincoln M., Centro Nacional de Monitoramento e Alertas de Desastres Naturais CEMADEN, São Paulo, Brazil
Amador, Jorge A., Center for Geophysical Research and School of Physics, University of Costa Rica, San José, Costa Rica
Anderson, John, Hampton University, Hampton, Virginia
Andrade, B., Seychelles Meteorological Authority, Mahe, Seychelles
Anville, Orlane, National Research Institute for Agriculture, Food and Environment (INRAE), CARRET, Université Savoie Mont Blanc, Chambéry, France
Aono, Yasuyuki, Graduate School of Agriculture, Osaka Metropolitan University, Sakai, Japan
Arguez, Anthony, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Arosio, Carlo, University of Bremen, Bremen, Germany
Atkinson, C., Met Office Hadley Center, Exeter, United Kingdom
Augustine, John A., NOAA Global Monitoring Laboratory, Boulder, Colorado
Avalos, Grinia, Servicio Nacional de Meteorología e Hidrología del Perú, Lima, Perú
Azorin-Molina, Cesar, Centro de Investigaciones sobre Desertificación – Spanish National Research Council (CSIC-UV-GVA), Valencia, Spain
Backensto, Stacia A., National Park Service, Fairbanks, Alaska
Bader, Stephan, Federal Office of Meteorology and Climatology MeteoSwiss, Switzerland
Baez, Julian, Universidad Católica Nuestra Señora de la Asunción, Asunción, Paraguay
Baiman, Rebecca, Department of Atmospheric and Oceanic Sciences, University of Colorado Boulder, Boulder, Colorado
Ballinger, Thomas J., International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, Alaska
Banwell, Alison F., Earth Science Observation Center, Cooperative Institute for Research in Environmental Sciences (ESOC/CRES), University of Colorado Boulder, Boulder, Colorado
Bardin, M. Yu., Yu. A. Izrael Institute of Global Climate and Ecology, Russian Academy of Science, Moscow, Russia
Barichivich, Jonathan, Instituto de Geografía, Pontificia Universidad Católica de Valparaíso, Valparaíso, Chile; Laboratoire des Sciences du Climat et de l’Environnement (LSCE), LSCE/IPSL, CEA-CNRS-UVSQ, Gif-sur-Yvette, France
Barnes, John E., retired, NOAA Global Monitoring Laboratory, Boulder, Colorado
Barreira, Sandra, Argentine Naval Hydrographic Service, Buenos Aires, Argentina
Bartow-Gillies, Ellen, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Beading, Rebecca L., Department of Earth and Environmental Science, Temple University, Philadelphia, Pennsylvania
Beck, Hylke E., Physical Science and Engineering Division, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia
Becker, Emily J., University of Miami Rosenstiel School of Marine and Atmospheric Science, Miami, Florida
Bekele, E., NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland
Bellido, Guillem Martín, Instituto de Geografía, Pontificia Universidad Católica de Valparaíso, Valparaíso, Chile; Laboratoire des Sciences du Climat et de l’Environnement (LSCE), LSCE/IPSL, CEA-CNRS-UVSQ, Gif-sur-Yvette, France
Benedetti, Angela, European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom
Benestad, Rasmus, Norwegian Meteorological Institute, Oslo, Norway
Berne, Christine, Meteo France, Toulouse, France
Berner, Logan T., Northern Arizona University, Flagstaff, Arizona
Berner, Germar H., Biophysiological Instruments Inc., San Diego, California
Bhatt, Uma S., Geophysical Institute, University of Alaska Fairbanks, Fairbanks, Alaska
Bluh, MD A. E., NOAA/NWS Climate Prediction Center, Silver Spring, Maryland
Bigalke, Sii, Plant, Soils and Climate Department, Utah State University, Logan, Utah
Bilò, Tiago, Cooperative Institute for Marine and Atmospheric Studies, University of Miami, Miami, Florida; NOAA/OAR Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida
Bissolli, Peter, Deutscher Wetterdienst, WMO RA VI Regional Climate Centre Network, Offenbach, Germany
Bjerke Jarle, W., Department of Arctic Ecology, Norwegian Institute for Nature Research, Trondheim, Norway
Blagrove, Kevin, Department of Biology, York University, Toronto, Canada
Blake, Eric S., NOAA/NWS National Hurricane Center, Miami, Florida
Blenkinsop, Stephen, School of Engineering, Newcastle University, Newcastle-upon-Tyne, United Kingdom
Blunden, Jessica, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Bochňíček, Oliver, Slovak Hydrometeorological Institute, Bratislava, Slovakia
Bock, Olivier, Université Paris Cité, Institut de Physique du Globe de Paris, CNRS, IGN, F-75005 Paris, France; ENSG-Geomatique, IGN, F-77455 Marne-la-Vallée, France
Boden, Xavier, Laboratoire EDYTEM, CNRS/Université Savoie Mont-Blanc, Chambéry, France
Bosilovich, Michael, Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, Maryland
Boucher, Olivier, Sorbonne Université, Paris, France
Boyer, Tim, NOAA/NESDIS National Centers for Environmental Information, Silver Spring, Maryland
Buck, R., National Oceanic and Atmospheric Administration, Silver Spring, Maryland
Buchler, Dennis, University of Alabama in Huntsville, Huntsville, Alabama
Buehler, Stefan A., Universität Hamburg, Hamburg, Germany
Bukant, Brandon, NOAA/NWS Weather Forecast Office, Tyian, Guam
Calderón, Blanca, Center for Geophysical Research, University of Costa Rica, San José, Costa Rica
Editor and Author Affiliations (continued)

Dutton, Geoff, Cooperative Institute for Research in the Earth Sciences, NOAA Global Monitoring Laboratory, Boulder, Colorado
Duveiller, Gregory, Max Planck Institute for Biogeochemistry, Jena, Germany
Ekici, Mithat, Turkish State Meteorological Service, Ankara, Türkiye
Elias Cheque, Aleksandra, Department of Physics, University of Toronto, Toronto, Canada
El Kharrim, M., Direction de la Météorologie Nationale Maroc, Rabat, Morocco
Epstein, Howard E., University of Virginia, Charlottesville, Virginia
Espinoza, Jhan-Carlo, Université Grenoble Alpes, Institut des Géosciences de l’Environnement, IRD, CNRS, Grenoble INP, Grenoble, France
Estilow, Thomas W., Rutgers University, Piscataway, New Jersey
Estrella, Nicole, Ecoclimatology, Department of Life Science Systems, TUM School of Life Sciences, Technical University of Munich, Freising, Germany
Fauchereau, Nicolas, National Institute of Water and Atmospheric Research, Ltd., Auckland, New Zealand
Feely, Richard A., NOAA/OAR Pacific Marine Environmental Laboratory, Seattle, Washington
Fenimore, Chris, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Fereday, David, Met Office Hadley Centre, Exeter, United Kingdom
Fettweis, Xavier, University of Liège, Belgium
Fiorettov, Vitali E., Environment and Climate Change Canada, Toronto, Canada
Flemming, Johannes, European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom
Fogarty, Chris, Canadian Hurricane Centre, Environment and Climate Change Canada, Dartmouth, Nova Scotia, Canada
Fogt, Ryan L., Department of Geography, Ohio University, Athens, Ohio
Forbes, Bruce C., Arctic Centre, University of Lapland, Rovaniemi, Finland
Foster, Michael J., Cooperative Institute for Meteorological Satellite Studies, Space Science and Engineering Center, University of Wisconsin-Madison, Madison, Wisconsin
Franz, Bryan A., NASA Goddard Space Flight Center, Greenbelt, Maryland
Freeman, Natalie M., Department of Atmospheric and Oceanic Sciences, University of Colorado Boulder, Boulder, Colorado
Fricker, Helen A., Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California
Frith, Stacey M., Science Systems and Applications, Inc, Lanham, Maryland; NASA Goddard Space Flight Center, Greenbelt, Maryland
Froidevaux, Lucien, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California
Frost, Gerald V. (JJ), ABR Inc., Fairbanks, Alaska
Fuhrman, Steven, NOAA/NWS NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland
Fülekrug, Martin, University of Bath, Bath, United Kingdom
Ganter, Catherine, Bureau of Meteorology, Melbourne, Australia
Gao, Meng, NASA Goddard Space Flight Center, Greenbelt, Maryland
Gardner, Alex S., NASA Jet Propulsion Laboratory, Pasadena, California
Garforth, Judith, Woodland Trust, Grantham, United Kingdom
Gerland, Sebastian, Norwegian Polar Institute, Fram Centre, Tromso, Norway
Gibbes, Badin, School of Civil Engineering, The University of Queensland, Brisbane, Australia
Gille, Sarah T., Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California
Gillson, John, Scripps Institution of Oceanography, University of California San Diego, La Jolla, California
Gleason, Karin, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Gobron, Nadine, European Commission Joint Research Centre, Ispra, Italy
Goetz, Scott J., Northern Arizona University, Flagstaff, Arizona
Goldenberg, Stanley B., NOAA/OAR Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida
Goni, Gustavo, NOAA/OAR Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida
Goodman, Steven, Thunderbolt Global Analytics, Huntsville, Alabama
Goto, Atsushi, World Meteorological Organization, Geneva, Switzerland
Groß, Jens-Uwe, Forschungszentrum Jülich, Jülich, Germany
Gruber, Alexander, TU Wien, Department of Geodesy and Geoinformation, Vienna, Austria
Gu, Guojun, CMNS-Earth System Science Interdisciplinary Center, University of Maryland, College Park, Maryland
Guard, Charles “Chip” P., Tropical Weather Sciences, Sinajana, Guam
Hagos, S., Pacific Northwest National Lab, Department of Energy, Richland, Washington
Hahn, Sebastian, TU Wien, Department of Geodesy and Geoinformation, Vienna, Austria
Haimberger, Leopold, University of Vienna, Vienna, Austria
Hall, Bradley D., NOAA Global Monitoring Laboratory, Boulder, Colorado
Hannam, Daniel S., NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland
Harris, Ian, National Centre for Atmospheric Science (NCAS), University of East Anglia, Norwich, United Kingdom; Climatic Research Unit, School of Environmental Sciences, University of East Anglia, Norwich, United Kingdom
He, Qiong, Earth System Modeling Center, Nanjing University of Information Science and Technology, Nanjing, China
Heim, Richard R. Jr., NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Hellström, Sverker, Swedish Meteorological and Hydrological Institute, Norrköping, Sweden
Hemming, Deborah L., Met Office Hadley Centre, Exeter, United Kingdom; Birmingham Institute of Forest Research, Birmingham University, Birmingham, United Kingdom
Hendricks, Stefan, Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany
Hicks, J., NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland
Hidalgo, Hugo G., Center for Geophysical Research and School of Physics, University of Costa Rica, San José, Costa Rica
Hirsch, Martin, ETH Zurich, Department of Environmental Systems Science, Zürich, Switzerland
Ho, Shu-peng (Ben), Center for Satellite Applications and Research, NOAA, College Park, Maryland; Remote Sensing Systems, Santa Rosa, California
Hobbs, W., Australian Antarctic Program Partnership, Institute for Marine and Antarctic Studies; Australian Research Centre Council of Excellence for Climate Extremes, University of Tasmania, Hobart, Tasmania
Holmes, Robert M., Woodwell Climate Research Center, Falmouth, Massachusetts
Holsworth, Robert, University of Washington, Seattle, Washington
Hrůšaček, Filip, Department of Geography, Masaryk University, Brno, Czech Republic
Hu, Guojie, Cryosphere Research Station on Qinghai-Tibet Plateau, Northwestern Institute of Eco-Environment and Resources, CAS, Beijing, China
Hu, Zeng-Zhen, NOAA/NWS Climate Prediction Center, College Park, Maryland
Huang, Boyin, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Huang, Hongjie, Nanjing University of Information Science and Technology, Nanjing, China
Hurst, Dale F., Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, Colorado; NOAA Global Monitoring Laboratory, Boulder, Colorado
Ilango, Iolanda, Finnish Meteorological Institute, Helsinki, Finland
Inness, Antje, European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom
Isaksen, Ketil, Norwegian Meteorological Institute, Oslo, Norway
Ishii, Masayoshi, Department of Atmosphere, Ocean and Earth System Modeling Research, Meteorological Research Institute, Japan Meteorological Agency, Tsukuba, Japan
Jadra, Gerardo, Instituto Uruguayo de Meteorología, Montevideo, Uruguay
Jevrejeva, Svetlana, National Oceanography Centre, Liverpool, United Kingdom
John, Viju O., EUMETSAT, Darmstadt, Germany
Jones, Philip D., Climatic Research Unit, School of Environmental Sciences, University of East Anglia, Norwich, United Kingdom
Jones, Timothy, Coastal Observation and Seabird Survey Team, University of Washington, Seattle, Washington
Josey, Simon A., National Oceanography Centre, Southampton, United Kingdom
Jumaa, G., Meteo France, Direction Interregionale Pour L'Ocean Indien, Reunion
Junod, Robert, Earth System Science Center (ESSC), University of Alabama in Huntsville, Huntsville, Alabama
Kääb, Andreas, Department of Geosciences, University of Oslo, Norway
Kabidi, K., Direction de la Meteorologie Nationale Maroc, Rabat, Morocco
Kaiser, Johannes W., SatFire Kaiser, Hofheim am Taunus, Germany
Kaleschke, Lars, Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany
Kaufmann, Viktor, Institute of Geodesy, Working Group Remote Sensing and Photogrammetry, Graz University of Technology, Graz, Austria
Kazemi, Amin Fazli, Iran National Climate and Drought Crisis Management, National Meteorology Organization, Tehran, Iran
Keller, Linda M., Antarctic Meteorological Research and Data Center, Space Science and Engineering Center, University of Wisconsin-Madison, Madison, Wisconsin
Kellerer-Pirklbauer, Andreas, Institute of Geography and Regional Science, Cascade – The Mountain Processes and Mountain Hazards Group, University of Graz, Graz, Austria
Kendon, Mike, Met Office National Climate Information Centre, Exeter, United Kingdom
Kennedy, John, Met Office Hadley Centre, Exeter, United Kingdom
Kent, Elizabeth C., National Oceanography Centre, Southampton, United Kingdom
Kerr, Kenneth, Trinidad and Tobago Meteorological Service, Port of Spain, Trinidad
Khan, Valentina, Hydrometeorology Center of Russia, WMO North Eurasia Climate Center, Moscow, Russia
Khiem, Mai Van, Vietnam National Center for Hydro-Meteorological Forecasting, Vietnam Meteorological and Hydrological Administration, Hanoi, Vietnam
Kidd, Richard, EODC GmbH, Vienna, Austria
Kim, Mi Ju, Climate Change Monitoring Division, Korea Meteorological Administration, Seoul, South Korea
Kim, Seong-Joong, Korea Polar Research Institute, Incheon, South Korea
Kipling, Zak, European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom
Klotzbach, Philip J., Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado
Knaff, John A., NOAA/NESDIS Center for Satellite Applications and Research, Fort Collins, Colorado
Koppa, Akash, Hydro-Climate Extremes Lab (H-CEL), Ghent University, Ghent, Belgium
Korshunova, Natalia N., All-Russian Research Institute of Hydrometeorological Information, World Data Center, Obninsk, Russia
Kraemer, Benjamin M., University of Konstanz, Konstanz, Germany
Kramarova, Natalya A., NASA Goddard Space Flight Center, Greenbelt, Maryland
Kruger, A. C., Climate Service, South African Weather Service, Pretoria, South Africa
Kruger, Andries, Climate Service, South African Weather Service, Pretoria, South Africa
Kumar, Arun, NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland
L’Heureux, Michelle, NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland
La Fuente, Sofia, Dundalk Institute of Technology, Dundalk, Ireland
Laas, Alo, Estonian University of Life Sciences, Tartumaa, Estonia
Labe, Zachary M., Princeton University, Princeton, New Jersey
Lader, Rick, International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, Alaska
Lakatos, Mónika, Climatology Unit, Hungarian Meteorological Service, Budapest, Hungary
Lakkala, Kaisa, Finnish Meteorological Institute, Sodankylä, Finland
Lam, Hoang Phuc, Vietnam National Center for Hydro-Meteorological Forecasting, Vietnam Meteorological and Hydrological Administration, Hanoi, Vietnam
Lan, Xin, CIERES, University of Colorado Boulder & NOAA Global Monitoring Laboratory, Boulder, Colorado
Landschützer, Peter, Flanders Marine Institute, InnovaOcean Campus, Ostend, Belgium
Landsea, Chris W., NOAA/NWS National Hurricane Center, Miami, Florida
Lang, Timothy, NASA Marshall Space Flight Center, Huntsville, Alabama
Lankhorst, Matthias, Scripps Institution of Oceanography, University of California San Diego, La Jolla, California
Lantz, Kathleen O., NOAA Global Monitoring Laboratory, Boulder, Colorado
Lara, Mark J., University of Illinois at Urbana-Champaign, Urbana, Illinois
Lavado-Casimiro, Waldo, Servicio Nacional de Meteorologia e Hidrologia del Peru, Lima, Peru
Lavers, David A., European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom
Lazzara, Matthew A., Department of Physical Sciences, School of Arts and Sciences, Madison Area Technical College, Madison, Wisconsin
Kellerer-Pirklbauer, Andreas, Institute of Geography and Regional Science, Cascade – The Mountain Processes and Mountain Hazards Group, University of Graz, Graz, Austria
Kendon, Mike, Met Office National Climate Information Centre, Exeter, United Kingdom
Kennedy, John, Met Office Hadley Centre, Exeter, United Kingdom
Kent, Elizabeth C., National Oceanography Centre, Southampton, United Kingdom
Kerr, Kenneth, Trinidad and Tobago Meteorological Service, Port of Spain, Trinidad
Khan, Valentina, Hydrometeorology Center of Russia, WMO North Eurasia Climate Center, Moscow, Russia
Khiem, Mai Van, Vietnam National Center for Hydro-Meteorological Forecasting, Vietnam Meteorological and Hydrological Administration, Hanoi, Vietnam
Kidd, Richard, EODC GmbH, Vienna, Austria
Kim, Mi Ju, Climate Change Monitoring Division, Korea Meteorological Administration, Seoul, South Korea
Kim, Seong-Joong, Korea Polar Research Institute, Incheon, South Korea
Kipling, Zak, European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom
Klotzbach, Philip J., Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado
Knaff, John A., NOAA/NESDIS Center for Satellite Applications and Research, Fort Collins, Colorado
Koppa, Akash, Hydro-Climate Extremes Lab (H-CEL), Ghent University, Ghent, Belgium
Korshunova, Natalia N., All-Russian Research Institute of Hydrometeorological Information, World Data Center, Obninsk, Russia
Kraemer, Benjamin M., University of Konstanz, Konstanz, Germany
Kramarova, Natalya A., NASA Goddard Space Flight Center, Greenbelt, Maryland
Kruger, A. C., Climate Service, South African Weather Service, Pretoria, South Africa
Kruger, Andries, Climate Service, South African Weather Service, Pretoria, South Africa
Kumar, Arun, NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland
L’Heureux, Michelle, NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland
La Fuente, Sofia, Dundalk Institute of Technology, Dundalk, Ireland
Laas, Alo, Estonian University of Life Sciences, Tartumaa, Estonia
Labe, Zachary M., Princeton University, Princeton, New Jersey
Lader, Rick, International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, Alaska
Lakatos, Mónika, Climatology Unit, Hungarian Meteorological Service, Budapest, Hungary
Lakkala, Kaisa, Finnish Meteorological Institute, Sodankylä, Finland
Lam, Hoang Phuc, Vietnam National Center for Hydro-Meteorological Forecasting, Vietnam Meteorological and Hydrological Administration, Hanoi, Vietnam
Lan, Xin, CIERES, University of Colorado Boulder & NOAA Global Monitoring Laboratory, Boulder, Colorado
Landschützer, Peter, Flanders Marine Institute, InnovOcean Campus, Ostend, Belgium
Landsea, Chris W., NOAA/NWS National Hurricane Center, Miami, Florida
Lang, Timothy, NASA Marshall Space Flight Center, Huntsville, Alabama
Lankhorst, Matthias, Scripps Institution of Oceanography, University of California San Diego, La Jolla, California
Lantz, Kathleen O., NOAA Global Monitoring Laboratory, Boulder, Colorado
Lara, Mark J., University of Illinois at Urbana-Champaign, Urbana, Illinois
Lavado-Casimiro, Waldo, Servicio Nacional de Meteorologia e Hidrologia del Peru, Lima, Peru
Lavers, David A., European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom
Lazzara, Matthew A., Department of Physical Sciences, School of Arts and Sciences, Madison Area Technical College, Madison, Wisconsin; Antarctic Meteorological Research and Data Center, Space Science and Engineering Center, University of Wisconsin-Madison, Madison, Wisconsin
Leblanc, Thierry, Jet Propulsion Laboratory, California Institute of Technology, Wrightwood, California
Lee, Tsz-Cheung, Hong Kong Observatory, Hong Kong, China
Leibensperger, Eric M., Department of Physics and Astronomy, Ithaca College, Ithaca, New York
Lennard, Chris, Department of Environmental and Geographical Science, University of Cape Town, Cape Town, South Africa
Leuillette, Eric, NOAA/NWS NCCP Laboratory for Satellite Altimetry, College Park, Maryland
Leung, Kinison H. Y., Environment and Climate Change Canada, Toronto, Ontario, Canada
Lieser, Jan L., Australian Bureau of Meteorology and Institute for Marine and Antarctic Studies (IMAS), University of Tasmania, Hobart, Australia
Editor and Author Affiliations (continued)

Mühl, Jens, AGAGE, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California
Müller, Rolf, Forschungsanstalt Jülich, Jülich, Germany
Nance, David, Cooperative Institute for Research in the Earth Sciences, NOAA Global Monitoring Laboratory, Boulder, Colorado
Nash, Eric R., Science Systems and Applications, Inc., Lanham, Maryland; NASA Goddard Space Flight Center, Greenbelt, Maryland
Nerem, R. Steven, Colorado Center for Astrodynamics Research, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, Colorado
Newman, Paul A., NASA Goddard Space Flight Center, Greenbelt, Maryland
Parrington, Mark, European Centre for Medium-Range Weather Forecasts, Bonn, Germany
Nieto, Juan J., Centro Internacional para la Investigación de El Niño (CIFEN), Guayaquil, Ecuador
Noetzli, Jeannette, WSL Institute for Snow and Avalanche Research SLF, Davos-Dorf, Switzerland; Climate Change, Extremes and Natural Hazards in Alpine Regions Research Center CERC, Davos Dorf, Switzerland
Noll, Ben, National Institute of Water and Atmospheric Research, Auckland, New Zealand
Norton, Taylor, Antarctic Meteorological Research and Data Center, Space Science and Engineering Center, University of Wisconsin-Madison, Madison, Wisconsin
Nyland, Kelsey E., Department of Geography, George Washington University, Washington, DC
O’Keefe, John, The Harvard Forest, Harvard University, Petersham, Massachusetts
Ochwat, Naomi, Earth System Observation Center, Cooperative Institute for Research in Environmental Sciences (ESOC/CRES), University of Colorado Boulder, Boulder Colorado
Okawa, Yoshinori, Tokyo Climate Center, Japan Meteorological Agency, Tokyo, Japan
Okunaka, Yuka, Tokyo Climate Center, Japan Meteorological Agency, Tokyo, Japan
Osborn, Timothy J., Climatic Research Unit, School of Environmental Sciences, University of East Anglia, Norwich, United Kingdom
Overland, James E., NOAA Pacific Marine Environmental Laboratory, Seattle, Washington
Park, Taejin, NASA Ames Research Center, Mountain View, California; Bay Area Environmental Research Institute, Mountain View, California
Parrington, Mark, European Centre for Medium-Range Weather Forecasts, Bonn, Germany
Parrish, Julia K., Coastal Observation and Seabird Survey Team, University of Washington, Seattle, Washington
Pastor, Richard J., NOAA/NWS National Hurricane Center, Miami, Florida
Pascual Ramírez, Reynaldo, National Meteorological Service of Mexico, Mexico City, Mexico
Pellet, Cécile, Department of Geosciences, University of Fribourg, Fribourg, Switzerland
Peltola, Mauri S., Nichols College, Dudley, Massachusetts
Perčec Tadić, Melita, Croatian Meteorological and Hydrological Service, Zagreb, Croatia
Perovich, Donald K., University of Dartmouth, Hanover, New Hampshire
Petersen, Guðrún Nína, Icelandic Meteorological Office, Reykjavik, Iceland
Petersen, Kyle, Cooperative Institute for Research in the Earth Sciences, NOAA Global Monitoring Laboratory, Boulder, Colorado
Petropavlovskikh, Irina, NOAA/OAR Earth System Research Laboratory, Global Monitoring Division, Boulder, Colorado; University of Colorado Boulder, Boulder, Colorado
Petty, Alek, NASA Goddard Space Flight Center, Greenbelt, Maryland
Pezza, Alexandre B., Greater Wellington Regional Council, Wellington, New Zealand
Pezzi, Luciano P., Laboratory of Ocean and Atmosphere Studies (LOA), Earth Observation and Geoinformatics Division (DIOGT), National Institute for Space Research (INPE), São José dos Campos, Brazil
Phillips, Coda, Cooperative Institute for Meteorological Satellite Studies, Space Science and Engineering Center, University of Wisconsin-Madison, Madison, Wisconsin
Phoenix, Gareth K., University of Sheffield, Sheffield, United Kingdom
Pierson, Don, Department of Ecology and Genetics, Uppsala University, Uppsala, Sweden
Pinto, Izidine, Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands
Pires, Vanda, Portuguese Sea and Atmosphere Institute, Lisbon, Portugal
Pitts, Michael, NASA Langley Research Center, Hampton, Virginia
Po-Chedley, Stephen, Lawrence Livermore National Laboratory, Livermore, California
Pogliotti, Paolo, Environmental Protection Agency of Valle d’Aosta, Saint-Christophe, Italy
Poinar, Kristin, University at Buffalo, Buffalo, New York
Polvani, Lorenzo, Columbia University, New York, New York
Preimesberger, Wolfgang, TU Wien, Department of Geodesy and Geoinformation, Vienna, Austria
Price, Colin, Tel Aviv University, Tel Aviv, Israel
Pulkkanen, Merja, Finnish Environment Institute (SYKE), Jyväskylä, Finland
Porkey, Sarah G., Scripps Institution of Oceanography, University of California San Diego, La Jolla, California
Qiu, Bo, Department of Oceanography, University of Hawaii at Manoa, Honolulu, Hawaii
Quisbert, Kenny, Servicio Nacional de Meteorología e Hidrología de Bolivia, La Paz, Bolivia
Quispe, Willy R., Servicio Nacional de Meteorología e Hidrología de Bolivia, La Paz, Bolivia
Rajeevan, M., Ministry of Earth Sciences, New Delhi, India
Ramos, Andrea M., Instituto Nacional de Meteorologia, Brasilia, Brazil
Randel, William J., National Center for Atmospheric Research, Boulder, Colorado
Rantanen, Mika, Finnish Meteorological Institute, Helsinki, Finland
Raphael, Marilyn N., Department of Geography, University of California, Los Angeles, Los Angeles, California
Reagan, James, NOAA/NESDIS National Centers for Environmental Information, Silver Spring, Maryland
Recalde, Cristina, NOAA/NWS National Centers for Environmental Prediction, Climate Prediction Center, College Park, Maryland
Reid, Phillip, Australian Bureau of Meteorology and Australian Antarctic Program Partnership (AAPP), Hobart, Australia
Rémy, Samuel, HYGEOS, Lille, France
Reyes Kohler, Alejandra J., Dirección de Meteorologia de Chile, Santiago de Chile, Chile
Ricciardulli, Lucrezia, Remote Sensing Systems, Santa Rosa, California
Richardson, Andrew D., School of Informatics, Computing, and Cyber Systems, Flagstaff, Arizona; Center for Ecosystem Science and Society, Northern Arizona University, Flagstaff, Arizona
Ricker, Robert, NORCE Norwegian Research Centre, Tromso, Norway
Robinson, David A., Rutgers University, Piscataway, New Jersey
Robijn, M., NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland
Rocha, Willy, Servicio Nacional de Meteorologia e Hidrologia, Bolivia
Roddell, Matthew, Earth Sciences Division, NASA Goddard Space Flight Center, Greenbelt, Maryland
Rodriguez Guisado, Esteban, Agencia Estatal de Meteorología, Madrid, Spain
Rodriguez-Fernandez, Nemesio, CESBIO, Université de Toulouse, CNES/CNRS/INRAe/IRD/UPS, Toulouse, France
Editor and Author Affiliations (continued)

Suslova, Anya, Woodwell Climate Research Center, Falmouth, Massachusetts
Svendby, Tove, Norwegian Institute for Air Research, Kjeller, Norway
Sweet, William, NOAA/NOS Center for Operational Oceanographic Products and Services, Silver Spring, Maryland
Takahashi, Kiyotoshi, Tokyo Climate Center, Japan Meteorological Agency, Tokyo, Japan
Takemura, Kazuto, Tokyo Climate Center, Japan Meteorological Agency, Tokyo, Japan
Tank, Suzanne E., University of Alberta, Edmonton, Canada
Taylor, Michael A., Department of Physics, The University of the West Indies, Kingston, Jamaica
Tedesco, Marco, Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York; NASA Goddard Institute of Space Studies, New York, New York
Thackeray, Stephen J., UK Centre for Ecology and Hydrology, Lancaster, United Kingdom
Thiaw, W. M., NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland
Thibert, Emmanuel, Université Grenoble Alpes, INRAE, CNRS, IRD, Grenoble INP, IGE, Grenoble, France.
Thoman, Richard L., International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, Alaska
Thompson, Andrew F., California Institute of Technology, Pasadena, California
Thompson, Philip R., Cooperative Institute for Marine and Atmospheric Research, University of Hawaii, Honolulu, Hawaii
Tian-Kunze, Xiangshan, Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany
Timmermans, Mary-Louise, Yale University, New Haven, Connecticut
Timofeyev, Maxim A., Irsutsk State University, Institute of Biology, Irkutsk, Russia
Tobin, Skye, Bureau of Meteorology, Melbourne, Australia
Tommervik, Hans, Arctic Department, Norwegian Institute for Nature Research, Tromsø, Norway
Tourpali, Klearali, Aristotle University, Thessaloniki, Greece
Trescolio, Lidia, State Hydrometeorological Service, Chisinau, Republic of Moldova
Tretiakov, Mikhail, Arctic and Antarctic Research Institute, St. Petersburg, Russia
Trewin, Blair C., Australian Bureau of Meteorology, Melbourne, Australia
Trinh, Hoa, Laboratory of Systems, Technological Research Institute, Universidad de Santiago de Compostela, Campus Universitario Sur, Santiago de Compostela, Spain; Cooperative Institute for Marine and Atmospheric Studies, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida; NOAA/OAR Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida
Trotman, Adrian, Caribbean Institute for Meteorology and Hydrology, Bridgetown, Barbados
Truchelut, Ryan E., WeatherTiger, Tallahassee, Florida
Trusel, Luke D., Pennsylvania State University, University Park, Pennsylvania
Tye, Mari R., National Center for Atmospheric Research, Boulder, Colorado
van der A, Ronald, Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands
van der Schalie, Robin, Planet Labs, Haarlem, The Netherlands
van der Schrier, Gerard, Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands
Van Meerbeek, Cedric J., Caribbean Institute for Meteorology and Hydrology, Bridgetown, Barbados
van Vliet, Arnold J.H., Environmental Systems Analysis Group, Wageningen University and Research, The Netherlands
Vazife, Ahad, Iran National Climate and Drought Crisis Management, National Meteorology Organization, Tehran, Iran
Verburg, Piet, National Institute of Water and Atmospheric Research, Wellington, New Zealand
Vernier, Jean-Paul, NASA Langley Research Center, Hampton, Virginia
Vimont, Isaac J., NOAA Global Monitoring Laboratory, Boulder, Colorado
Virts, Katrina, University of Alabama in Huntsville, Huntsville, Alabama
Vivero, Sebastián, Department of Geosciences, University of Fribourg, Fribourg, Switzerland
Volkov, Denis L., Cooperative Institute for Marine and Atmospheric Studies, University of Miami; NOAA/OAR Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida
Vömel, Holger, Earth Observing Laboratory, National Center for Atmospheric Research, Boulder, Colorado
Vose, Russell S., NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Walker, Donald (Skip) A., Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, Alaska
Walsh, John E., International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, Alaska
Wang, Bin, School of Ocean and Earth Science and Technology, Department of Meteorology, University of Hawaii; International Pacific Research Center, Honolulu, Hawaii
Wang, Hui, NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland
Wang, Muyin, NOAA Pacific Marine Environmental Laboratory, Seattle, Washington; Cooperative Institute for Climate, Ocean, and Ecosystem Studies, University of Washington, Seattle, Washington
Wang, Ray H. J., Georgia Institute of Technology, Atlanta, Georgia
Wang, Xinyue, National Center for Atmospheric Research, Boulder, Colorado
Wanninkhof, Rik, NOAA/OAR Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida
Warnock, Taran, University of Saskatchewan, Saskatoon, Canada
Webber, Mark, University of Bremen, Bremen, Germany
Webster, Melinda, University of Washington, Seattle, Washington
Wehrli, Adrian, University of Zürich, Zürich, Switzerland
Wen, Caihong, NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland
Westberry, Toby K., Oregon State University, Corvallis, Oregon
Widiansky, Matthew J., Cooperative Institute for Marine and Atmospheric Research, University of Hawaii, Honolulu, Hawaii
Wiese, David N., Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California
Wild, Jeannette D., ESSIC/University of Maryland, College Park, Maryland; NOAA NESDIS/STAR, College Park, Maryland
Wille, Jonathan D., Institute for Atmospheric and Climate Science, ETH Zürich, Zürich, Switzerland; Institut des Géosciences de l’Environnement, CNRS/UGA/IRD/G-INP, Saint Martin d’Hères, France
Willems, An, Royal Meteorological Institute of Belgium (KMI), Brussels, Belgium
Willett, Kate M., Met Office Hadley Centre, Exeter, United Kingdom
Williams, Earle, Massachusetts Institute of Technology, Cambridge, Massachusetts
Willis, J., Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California
Wong, Takmeng, NASA Langley Research Center, Hampton, Virginia
Wood, Kimberly M., Department of Geosciences, Mississippi State University, Mississippi State, Mississippi
Woolway, Richard Iestyn, School of Ocean Sciences, Bangor University, Menai Bridge, Anglesey, Wales
Xie, Ping-Ping, NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland
Yang, Daqing, National Hydrology Research Centre, Environment Canada, Saskatoon, Canada
Editor and Author Affiliations (continued)

Yin, Xungang, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Yin, Ziqi, Department of Atmospheric and Oceanic Sciences, University of Colorado Boulder, Boulder, Colorado
Zeng, Zhenzhong, School of Environmental Science and Engineering, Southern University of Science and Technology, Shenzhen, China
Zhang, Huai-min, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Zhang, Li, NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland; ERT, Laurel, Maryland
Zhang, Peiquan, Beijing Climate Center, Beijing, China
Zhao, Lin, School of Geographical Sciences, Nanjing University of Information Science and Technology, Nanjing, China
Zhou, Xinjia, Center for Satellite Applications and Research, NOAA, College Park, Maryland
Zhu, Zhiwei, Nanjing University of Information Science and Technology, Nanjing, China
Ziemke, Jerry R., Goddard Earth Sciences Technology and Research, Morgan State University, Baltimore, Maryland; NASA Goddard Space Flight Center, Greenbelt, Maryland
Ziese, Markus, Global Precipitation Climatology Centre, Deutscher Wetterdienst, Offenbach, Germany
Zolkos, Scott, Woodwell Climate Research Center, Falmouth, Massachusetts
Zotta, Ruxandra M., TU Wien, Vienna, Austria
Zou, Cheng-Zhi, NOAA/NESDIS Center for Satellite Applications and Research, College Park, Maryland

Editorial and Production Team

Allen, Jessica, Graphics Support, Cooperative Institute for Satellite Earth System Studies, North Carolina State University, Asheville, North Carolina
Camper, Amy V., Graphics Support, Innovative Consulting and Management Services, LLC, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Haley, Bridgette O., Graphics Support, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Hammer, Gregory, Content Team Lead, Communications and Outreach, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Love-Brotak, S. Elizabeth, Lead Graphics Production, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Ohlmann, Laura, Technical Editor, Innovative Consulting and Management Services, LLC, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Noguchi, Lukas, Technical Editor, Innovative Consulting and Management Services, LLC, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Riddle, Deborah B., Graphics Support, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Veasey, Sara W., Visual Communications Team Lead, Communications and Outreach, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
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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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Citing the complete report:

Citing this chapter:
Editor and Author Affiliations (alphabetical by name)

Bartow-Gillies, Ellen, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Blunden, Jessica, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Boyer, Tim, NOAA/NESDIS National Centers for Environmental Information, Silver Spring, Maryland
Dunn, Robert J. H., Met Office Hadley Centre, Exeter, United Kingdom

Editorial and Production Team

Allen, Jessicca, Graphics Support, Cooperative Institute for Satellite Earth System Studies, North Carolina State University, Asheville, North Carolina
Camper, Amy V., Graphics Support, Innovative Consulting and Management Services, LLC, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Haley, Bridgette O., Graphics Support, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Hammer, Gregory, Content Team Lead, Communications and Outreach, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Love-Brotak, S. Elizabeth, Lead Graphics Production, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina

Ohlmann, Laura, Technical Editor, Innovative Consulting and Management Services, LLC, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Noguchi, Lukas, Technical Editor, Innovative Consulting and Management Services, LLC, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Riddle, Deborah B., Graphics Support, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
Veasey, Sara W., Visual Communications Team Lead, Communications and Outreach, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina
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 ‘firm’, 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.
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; (w) 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; (af) soil moisture; (ag) terrestrial groundwater storage; (ah) fraction of absorbed photosynthetically active radiation (FAPAR); (ai) land surface albedo – visible (solid) and infrared (dotted).
1. Introduction

Numbers of (In-Situ, Reanalysis, Satellite) datasets shown in bottom left or right of each panel.
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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