STATE OF THE CLIMATE IN 2022

Special Supplement to the
Bulletin of the American Meteorological Society
Vol. 104, No. 9, September 2023

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

Oberstdorf, Germany

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How to cite this document:

Special Supplement to the Bulletin of the American Meteorological Society, Vol. 104, No. 9, September 2023 https://doi.org/10.1175/2023BAMSStateoftheClimate.1. Compiled by NOAA's National Centers for Environmental Information, *State of the Climate in 2022* is based on contributions from scientists from around the world. It provides a detailed update on global climate indicators, notable weather events, and other data collected by environmental monitoring stations and instruments located on land, water, ice, and in space.

Citing the complete report:

Blunden, J., T. Boyer, and E. Bartow-Gillies, Eds., 2023: "State of the Climate in 2022". Bull. Amer. Meteor. Soc., 104 (9), Si–S501 https://doi.org/10.1175/2023BAMSStateoftheClimate.1.

Corresponding author: Full Report: Jessica Blunden / jessica.blunden@noaa.gov

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 ∼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.

Editor and Author Affiliations (alphabetical by name)

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

Anneville, Orlane, National Research Institute for Agriculture, Food and Environment (INRAE), CARRTEL, 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/CIRES), University of Colorado Boulder, Boulder, Colorado

Bardin, M. Yu, Yu. A. Izrael Institute of Global Climate and Ecology, Institute of Geography, Russian Academy of Sciences, 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

Beadling, 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, Govern d’Andorra, Andorra la Vella, Andorra

Bellouin, Nicolas, University of Reading, Reading, United Kingdom

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

Bernhard, Germar H., Biospherical Instruments Inc., San Diego, California

Bhatt, Uma S., Geophysical Institute, University of Alaska Fairbanks, Fairbanks, Alaska

Bhuiyan, MD A. E., NOAA/NWS Climate Prediction Center, Silver Spring, Maryland

Bigalke, Siiri, Plant, Soils and Climate Department, Utah State University, Logan, Utah

Biló, 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

Blagrave, 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

Bochníček, 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-Géomatique, IGN, F-77455 Marne-la-Vallée, France

Bodin, 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

Bozkurt, Deniz, Department of Meteorology, University of Valparaíso, Valparaíso, Chile; Center for Climate and Resilience Research (CR)2, Santiago, Chile

Brettschneider, Brian, NOAA/NWS Alaska Region, Anchorage, Alaska

Bringas, Francis G., NOAA/OAR Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida

Bringas, Francis, NOAA/OAR Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida

Buechler, Dennis, University of Alabama in Huntsville, Huntsville, Alabama

Buehler, Stefan A., Universität Hamburg, Hamburg, Germany

Bukunt, Brandon, NOAA/NWS Weather Forecast Office, Tiyan, Guam

Calderón, Blanca, Center for Geophysical Research, University of Costa Rica, San José, Costa Rica

Editor and Author Affiliations (continued)

Camargo, Suzana J., Lamont-Doherty Earth Observatory, Columbia University, Palisades, New York

Campbell, Jayaka, Department of Physics, The University of the West Indies, Kingston, Jamaica

Campos, Diego, Dirección Meteorológica de Chile (DMC), Santiago, Chile

Carrea, Laura, Department of Meteorology, University of Reading, Reading, United Kingdom

Carter, Brendan R., Cooperative Institute for Climate, Ocean, and Ecosystem Studies, University of Washington, Seattle, Washington; NOAA/OAR Pacific Marine Environmental Laboratory, Seattle, Washington

Cetinić, Ivona, NASA Goddard Space Flight Center, Greenbelt, Maryland; Morgan State University, Baltimore, Maryland

Chambers, Don P., College of Marine Science, University of South Florida, St. Petersburg, Florida

Chan, Duo, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts

Chandler, Elise, Bureau of Meteorology, Melbourne, Australia

Chang, Kai-Lan, Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, Colorado; NOAA Chemical Sciences Laboratory, Boulder, Colorado

Chen, Hua, Nanjing University of Information Science and Technology, Nanjing, China

Chen, Lin, Institute for Climate and Application Research (ICAR)/KLME/ILCEC/CIC-FEMD, Nanjing University of Information Science and Technology, Nanjing, China

Cheng, Lijing, International Center for Climate and Environment Sciences, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

Cheng, Vincent Y. S., Environment and Climate Change Canada, Toronto, Ontario, Canada

Chomiak, Leah, Cooperative Institute for Marine and Atmospheric Studies, University of Miami; NOAA/OAR Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida; Rosenstiel School of Marine, Atmospheric, and Earth Science, University of Miami, Miami, Florida

Christiansen, Hanne H., Geology Department, University Centre in Svalbard, Longyearbyen, Norway

Christy, John R., University of Alabama in Huntsville, Huntsville, Alabama

Chung, Eui-Seok, Korea Polar Research Institute, Incheon, South Korea

Ciasto, Laura M., NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland

Clarke, Leonardo, Department of Physics, The University of the West Indies, Kingston, Jamaica

Clem, Kyle R., School of Geography, Environment and Earth Sciences, Victoria University of Wellington, Wellington, New Zealand

Clingan, Scott, Cooperative Institute for Research in the Earth Sciences, NOAA Global Monitoring Laboratory, Boulder, Colorado

Coelho, Caio A.S., Centro de Previsão do Tempo e Estudos Climáticos/National Institute for Space Research, Center for Weather Forecasts and Climate Studies, Cachoeira Paulista, Brazil

Cohen, Judah L., Atmospheric and Environmental Research, Lexington, Massachusetts

Coldewey-Egbers, Melanie, DLR (German Aerospace Center) Oberpfaffenhofen, Germany

Colwell, Steve, British Antarctic Survey, Cambridge, United Kingdom

Cooper, Owen R., Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, Colorado; NOAA Chemical Sciences Laboratory, Boulder, Colorado

Cornes, Richard C., National Oceanography Centre, Southampton, United Kingdom

Correa, Kris, Servicio Nacional de Meteorología e Hidrología del Perú, Lima, Perú

Costa, Felipe, Centro Internacional para la Investigación del Fenómeno de El Niño (CIIFEN), Guayaquil, Ecuador

Covey, Curt, Lawrence Livermore National Laboratory, Livermore, California

Coy, Lawrence, Science Systems and Applications, Inc., Lanham, Maryland; NASA Goddard Space Flight Center, Greenbelt, Maryland

Créatux, Jean-François, LEGOS (CNES/CNRS/IRD/UPS), University of Toulouse, Toulouse, France

Crhova, Lenka, Czech Hydrometeorological Institute, Prague, Czech Republic

Crimmins, Theresa, USA National Phenology Network, School of Natural Resources and the Environment, University of Arizona, Tucson, Arizona

Cronin, Meghan F., NOAA/OAR Pacific Marine Environmental Laboratory, Seattle, Washington

Cropper, Thomas, National Oceanography Centre, Southampton, United Kingdom

Crotwell, Molly, Cooperative Institute for Research in the Earth Sciences, NOAA Global Monitoring Laboratory, Boulder, Colorado

Culpepper, Joshua, Department of Biology, York University, Toronto, Canada

Cunha, Ana P., Centro Nacional de Monitoramento e Alertas de Desastres Naturais CEMADEN, São Paulo, Brazil

Cusicanqui, Diego, Université Grenoble Alpes, Institut de Géosciences de l'Environnement (IGE), Grenoble, France

Datta, Rajashree T., Department of Atmospheric and Oceanic Sciences, University of Colorado Boulder, Boulder, Colorado

Davis, Sean M., NOAA Chemical Sciences Laboratory, Boulder, Colorado

De Bock, Veerle, Royal Meteorological Institute of Belgium (KMI), Brussels, Belgium

de Jeu, Richard A. M., Planet Labs, Haarlem, The Netherlands

De Laat, Jos, Royal Netherlands Meteorological Institute (KNMI), DeBilt, The Netherlands

Decharme, Bertrand, Centre National de Recherches Météorologiques, Météo-France/CNRS, Toulouse, France

Degenstein, Doug, University of Saskatchewan, Saskatoon, Canada

Delaloye, Reynald, Department of Geosciences, University of Fribourg, Fribourg, Switzerland

Demircan, Mesut, Turkish State Meteorological Service, Igdir, Türkiye

Derksen, Chris, Climate Research Division, Environment and Climate Change Canada, Toronto, Canada

Deus, Ricardo, Portuguese Sea and Atmosphere Institute, Lisbon, Portugal

Dhurmea, K. R., Mauritius Meteorological Service, Vacoas, Mauritius

Diamond, Howard J., NOAA/OAR Air Resources Laboratory, College Park, Maryland

Dirkse, S., Namibia Meteorological Service, Windhoek, Namibia

Divine, Dmitry, Norwegian Polar Institute, Fram Centre, Tromso, Norway

Dokulil, Martin T., Research Institute for Limnology, University of Innsbruck, Mondsee, Austria

Donat, Markus G., Barcelona Supercomputing Centre, Barcelona, Spain; Catalan Institution for Research and Advanced Studies (ICREA), Barcelona, Spain

Dong, Shenfu, NOAA/OAR Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida

Dorigo, Wouter A., TU Wien, Department of Geodesy and Geoinformation, Vienna, Austria

Drost Jensen, Caroline, Danish Meteorological Institute, Copenhagen, Denmark

Druckenmiller, Matthew L., National Snow and Ice Data Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado

Drumond, Paula, Portuguese Sea and Atmosphere Institute, Lisbon, Portugal

du Plessis, Marcel, Department of Marine Sciences, University of Gothenburg, Gothenburg, Sweden

Dugan, Hilary A., Center for Limnology, University of Wisconsin-Madison, Madison, Wisconsin

Dulamsuren, Dashkhuu, Institute of Meteorology, Hydrology and Environment, National Agency for Meteorology, Ulaanbaatar, Mongolia

Dunmire, Devon, Department of Atmospheric and Oceanic Sciences, University of Colorado Boulder, Boulder, Colorado

Dunn, Robert J. H., Met Office Hadley Centre, Exeter, United Kingdom

Durre, Imke, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina

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 Chereque, Alesksandra, Department of Physics, University of Toronto, Toronto, Canada

ElKharrim, 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

Fausto, Robert S., Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark

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

Fioletov, 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

Füllekrug, 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

Garg, Jay, Science Systems and Applications Inc., Hampton, Virginia

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

Gilson, 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

Grooß, 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

Hamlington, Benjamin D., Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, Virginia

Hanna, Edward, Department of Geography and Lincoln Climate Research Group, Lincoln, United Kingdom

Hanssen-Bauer, Inger, Norwegian Meteorological Institute, Oslo, Norway

Harnos, 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

Hirschi, 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 Council Centre of Excellence for Climate Extremes, University of Tasmania, Hobart, Tasmania

Holmes, Robert M., Woodwell Climate Research Center, Falmouth, Massachusetts

Holzworth, Robert, University of Washington, Seattle, Washington

Hrbáček, 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

Editor and Author Affiliations (continued)

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

Ialongo, 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

Johns, W., Rosenstiel School of Marine, Atmospheric, and Earth Science, University of Miami, Miami, Florida

Johnsen, Bjørn, Norwegian Radiation and Nuclear Safety, Østerås, Norway

Johnson, Bryan, NOAA/OAR Earth System Research Laboratory, Global Monitoring Division, Boulder, Colorado; University of Colorado Boulder, Boulder, Colorado

Johnson, Gregory C., NOAA/OAR Pacific Marine Environmental Laboratory, Seattle, Washington

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.

Jumaux, 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 Météorologie Nationale Maroc, Rabat, Morocco

Kaiser, Johannes W., SatFire Kaiser, Hofheim am Taunus, Germany

Kaler, Robb S.A., U.S. Fish and Wildlife Service, Alaska Region, Anchorage, Alaska

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 Fazl, 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, Piarco, Trinidad

Khan, Valentina, Hydrometcenter 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, CIRES, 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 Meteorología e Hidrología del Perú, Lima, Perú

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

Leuliette, Eric, NOAA/NWS NCWCP Laboratory for Satellite Altimetry, College Park, Maryland

Leung, Kinson 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)

Likso, Tanja, Croatian Meteorological and Hydrological Service, Zagreb, Croatia

Lin, I-I., National Taiwan University, Taipei, Taiwan

Lindsey, Jackie, Coastal Observation and Seabird Survey Team, University of Washington, Seattle, Washington

Liu, Yakun, Massachusetts Institute of Technology, Cambridge, Massachusetts

Locarnini, Ricardo, NOAA/NESDIS National Centers for Environmental Information, Silver Spring, Maryland

Loeb, Norman G., NASA Langley Research Center, Hampton, Virginia

Loomis, Bryant D., NASA Goddard Space Flight Center, Greenbelt, Maryland

Lorrey, Andrew M., National Institute of Water and Atmospheric Research, Ltd., Auckland, New Zealand

Loyola, Diego, DLR (German Aerospace Center) Oberpfaffenhofen, Germany

Lu, Rui, Nanjing University of Information Science and Technology, Nanjing, China

Lumpkin, Rick, NOAA/OAR Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida

Luo, Jing-Jia, Institute for Climate and Application Research, Nanjing University of Information Science and Technology, Nanjing, China

Luojus, Kari, Arctic Research Centre, Finnish Meteorological Institute, Helsinki, Finland

Lyman, John M., Cooperative Institute for Marine and Atmospheric Research, University of Hawaii, Honolulu, Hawaii; NOAA/OAR Pacific Marine Environmental Laboratory, Seattle, Washington

Maberly, Stephen C., UK Centre for Ecology & Hydrology, Lancaster, United Kingdom

Macander, Matthew J., ABR Inc., Fairbanks, Alaska

MacFerrin, Michael, Earth Science and Observation Center, CIRES, University of Colorado, Boulder, Colorado

MacGilchrist, Graeme A., University of St. Andrews, St Andrews, United Kingdom; Princeton University, Princeton, New Jersey

MacLennan, Michelle L., Department of Atmospheric and Oceanic Sciences, University of Colorado Boulder, Boulder, Colorado

Madelon, Remi, CESBIO, Université de Toulouse, CNES/CNRS/INRAe/IRD/UPS, Toulouse, France

Magee, Andrew D., Centre for Water, Climate and Land, School of Environmental and Life Sciences, University of Newcastle, Callaghan, Australia

Magnin, Florence, Laboratoire EDYTEM, CNRS/Université Savoie Mont-Blanc, Chambéry, France

Mamen, Jostein, Norwegian Meteorological Institute, Oslo, Norway

Mankoff, Ken D., Business Integra, New York, New York; NASA Goddard Institute for Space Studies, New York, New York

Manney, Gloria L., NorthWest Research Associates, Socorro, New Mexico

Marcinonienė, Izolda, Lithuanian Hydrometeorological Service, Vilnius, Lithuania

Marengo, Jose A., Centro Nacional de Monitoramento e Alertas de Desastres Naturais CEMADEN, São Paulo, Brazil

Marjan, Mohammadi, Iran National Climate and Drought Crisis Management, National Meteorology Organization, Tehran, Iran

Martínez, Ana E., National Meteorological Service of Mexico, Mexico City, Mexico

Massom, Robert A., Australian Antarctic Division, Australian Antarctic Program Partnership (AAPP) and Australian Centre for Excellence in Antarctic Science (ACEAS), Tasmania, Australia

Matsuzaki, Shin-Ichiro, National Institute for Environmental Studies, Tsukuba, Japan

May, Linda, UK Centre for Ecology & Hydrology, Edinburgh, United Kingdom

Mayer, Michael, University of Vienna, Vienna, Austria; European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom

Mazloff, Matthew R., Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California

McAfee, Stephanie A., Department of Geography, University of Nevada Reno, Reno, Nevada

McBride, C., Climate Service, South African Weather Service, Pretoria, South Africa

McCabe, Matthew F., Climate and Livability Initiative, Division of Biological and Environmental Sciences and Engineering, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

McClelland, James W., Marine Biological Laboratory, Woods Hole, Massachusetts

McPhaden, Michael J., NOAA/OAR Pacific Marine Environmental Laboratory, Seattle, Washington

McVicar, Tim R., CSIRO Environment, Canberra, Australia; Australian Research Council Centre of Excellence for Climate Extremes, Sydney, Australia

Mears, Carl A., Remote Sensing Systems, Santa Rosa, California

Meier, Walter N., National Snow and Ice Data Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado

Mekonnen, A., North Carolina A&T University, Greensboro, North Carolina

Menzel, Annette, Ecoclimatology, Department of Life Science Systems, TUM School of Life Sciences, Technical University of Munich, Freising, Germany; Institute for Advanced Study, Technical University of Munich, Garching, Germany

Merchant, Christopher J., Department of Meteorology, University of Reading, Reading, United Kingdom

Merrifield, Mark A., Cooperative Institute for Marine and Atmospheric Research, University of Hawaii, Honolulu, Hawaii

Meyer, Michael F., United States Geological Survey, Madison, Wisconsin

Meyers, Tristan, National Institute of Water and Atmospheric Research, Ltd. (NIWA), Auckland, New Zealand

Mikolajczyk, David E., Antarctic Meteorological Research and Data Center, Space Science and Engineering Center, University of Wisconsin-Madison, Madison, Wisconsin

Miller, John B., NOAA Global Monitoring Laboratory, Boulder, Colorado

Miralles, Diego G., Hydro-Climate Extremes Lab (H-CEL), Ghent University, Ghent, Belgium

Misevicius, Noelia, Instituto Uruguayo de Meteorología, Montevideo, Uruguay

Mishonov, Alexey, Earth System Science Interdisciplinary Center/Cooperative Institute for Satellite Earth System Studies Maryland, University of Maryland, College Park, Maryland; NOAA/NESDIS National Centers for Environmental Information, Silver Spring, Maryland

Mitchum, Gary T., College of Marine Science, University of South Florida, St. Petersburg, Florida

Moat, Ben I., National Oceanography Centre, Southampton, United Kingdom

Moesinger, Leander, TU Wien, Vienna, Austria

Moise, Aurel, Centre for Climate Research Singapore, Meteorological Service Singapore, Singapore

Molina-Carpio, Jorge, Universidad Mayor de San Andrés, La Paz, Bolivia

Monet, Ghislaine, Université Savoie Mont Blanc, INRAE, CARRTEL, Chambéry, France

Montzka, Stephan A., NOAA Global Monitoring Laboratory, Boulder, Colorado

Moon, Twila A., National Snow and Ice Data Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado

Moore, G. W. K., University of Toronto Mississauga, Mississauga, Canada

Mora, Natali, Center for Geophysical Research, University of Costa Rica, San José, Costa Rica

Morán, Johnny, Centro Internacional para la Investigación del Fenómeno de El Niño (CIIFEN), Guayaquil, Ecuador

Morehen, Claire, Environment and Climate Change Canada, Vancouver, British Columbia, Canada

Morice, Colin, Met Office Hadley Centre, Exeter, United Kingdom

Mostafa, A. E., Department of Seasonal Forecast and Climate Research, Cairo Numerical Weather Prediction, Egyptian Meteorological Authority, Cairo, Egypt

Mote, Thomas L., University of Georgia, Athens, Georgia

Mrekaj, Ivan, Technical University in Zvolen, Zvolen, Slovakia

Mudryk, Lawrence, Climate Research Division, Environment and Climate Change Canada, Toronto, Canada

Editor and Author Affiliations (continued)

Mühle, Jens, AGAGE, Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California

Müller, Rolf, Forschungszentrum 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

Nicolas, Julien P., European Centre for Medium-Range Weather Forecasts, Bonn, Germany

Nieto, Juan J., Centro Internacional para la Investigación del Fenómeno de El Niño (CIIFEN), 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 Science Observation Center, Cooperative Institute for Research in Environmental Sciences (ESOC/CIRES), University of Colorado Boulder, Boulder Colorado

Oikawa, 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

Pasch, 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

Pelto, Mauri S., Nichols College, Dudley, Massachussetts

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 (DIOTG), 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), Jyvaskyla, Finland

Purkey, 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 Meteorología, 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 Meteorológica 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

Robjhon, M., NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland

Rocha, Willy, Servicio Nacional de Meteorologia e Hidrologia, Bolivia

Rodell, 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)

Romanovsky, Vladimir E., Geophysical Institute, University of Alaska Fairbanks, Fairbanks, Alaska; Earth Cryosphere Institute, Tyumen Science Center, Tyumen, Russia

Ronchail, Josyane, Laboratoire LOCEAN-IPSL, Paris, France

Rosencrans, Matthew, NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland

Rosenlof, Karen H., NOAA Chemical Sciences Laboratory, Boulder, Colorado

Rösner, Benjamin, Laboratory for Climatology and Remote Sensing, Faculty of Geography, University of Marburg, Marburg, Germany

Rösner, Henrieke, Humboldt University, Berlin, Germany

Rozanov, Alexei, University of Bremen, Bremen, Germany

Rozkošný, Jozef, Slovak Hydrometeorological Institute, Bratislava, Slovakia

Rubek, Frans, Danish Meteorological Institute, Copenhagen, Denmark

Rusanovskaya, Olga O., Irkutsk State University, Institute of Biology, Irkutsk, Russia

Rutishauser, This, Swiss Academy of Sciences (SCNAT), Bern, Switzerland

Sabeerali, C. T., India Meteorological Department, Ministry of Earth Sciences, Pune, India

Salinas, Roberto, Dirección de Meteorología e Hidrología / Dirección Nacional de Aeronáutica Civil, Asunción, Paraguay

Sánchez-Lugo, Ahira, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina

Santee, Michelle L., NASA Jet Propulsion Laboratory, Pasadena, California

Santini, Marcelo, Laboratory of Ocean and Atmosphere Studies (LOA), Earth Observation and Geoinformatics Division (DIOTG), National Institute for Space Research (INPE), São José dos Campos, Brazil

Sato, Katsunari, Japan Meteorological Agency, Tokyo, Japan

Sawaengphokhai, Parnchai, Science Systems and Applications, Inc. (SSAI), Hampton, Virginia

Sayouri, A., Direction de la Météorologie Nationale Maroc, Rabat, Morocco

Scambos, Theodore, Earth Science Observation Center, Cooperative Institute for Research in Environmental Sciences (ESOC/CIRES), University of Colorado Boulder, Boulder, Colorado

Schenzinger, Verena, Medical University of Innsbruck, Innsbruck, Austria

Schimanke, Semjon, Swedish Meteorological and Hydrological Institute, Norrköping, Sweden

Schlegel, Robert W., Laboratoire d'Océanographie de Villefranche, Sorbonne Université, CNRS, Villefranche-sur-mer, France

Schmid, Claudia, NOAA/OAR Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida

Schmid, Martin, Eawag, Swiss Federal Institute of Aquatic Science and Technology, Surface Waters - Research and Management, Kastanienbaum, Switzerland

Schneider, Udo, Global Precipitation Climatology Centre, Deutscher Wetterdienst, Offenbach, Germany

Schreck, Carl J., North Carolina State University, North Carolina Institute for Climate Studies, Cooperative Institute Satellite Earth System Studies, Asheville, North Carolina

Schultz, Cristina, Northeastern University, Boston, Massachusetts

Science Systems and Applications Inc., Lanham, Maryland

Segele, Z. T., NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland

Sensoy, Serhat, Turkish State Meteorological Service, Ankara, Türkiye

Serbin, Shawn P., Brookhaven National Laboratory, Upton, New York

Serreze, Mark C., National Snow and Ice Data Center, University of Colorado, Boulder, Colorado

Setiawan, Amsari Mudzakir, Division for Climate Variability Analysis, BMKG, Jakarta, Indonesia

Sezaki, Fumi, Japan Meteorological Agency, Tokyo, Japan

Sharma, Sapna, Department of Biology, York University, Toronto, Canada

Sharp, Jonathan D., Cooperative Institute for Climate, Ocean, and Ecosystem Studies, University of Washington, Seattle, Washington; NOAA/OAR Pacific Marine Environmental Laboratory, Seattle, Washington

Sheffield, Gay, Alaska Sea Grant, Marine Advisory Program, University of Alaska Fairbanks, Nome, Alaska

Shi, Jia-Rui, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts

Shi, Lei, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina

Shiklomanov, Alexander I., University of New Hampshire, Durham, New Hampshire; Arctic and Antarctic Research Institute, St. Petersburg, Russia

Shiklomanov, Nikolay I., Department of Geography, George Washington University, Washington, DC

Shimaraeva, Svetlana V., Irkutsk State University, Institute of Biology, Irkutsk, Russia

Shukla, R., NOAA/NWS National Centers for Environmental Prediction Climate Prediction Center, College Park, Maryland

Siegel, David A., University of California, Santa Barbara, Santa Barbara, California

Silow, Eugene A., Irkutsk State University, Institute of Biology, Irkutsk, Russia

Sima, F., Division of Meteorology, Department of Water Resources, Banjul, The Gambia

Simmons, Adrian J., European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom

Smeed, David A., National Oceanography Centre, Southampton, United Kingdom

Smith, Adam, NOAA/NESDIS National Centers for Environmental Information, Asheville, North Carolina

Smith, Sharon L., Geological Survey of Canada, Natural Resources Canada, Ottawa, Canada

Soden, Brian J., University of Miami, Miami, Florida

Sofieva, Viktoria, FMI (Finnish Meteorological Institute), Helsinki, Finland

Souza, Everaldo, Federal University of Pará (UFPA), Belém, Brazil

Sparks, Tim H., Poznań University of Life Sciences, Poznań, Poland

Spence-Hemmings, Jacqueline, Meteorological Service, Jamaica, Kingston, Jamaica

Spencer, Robert G. M., Florida State University, Tallahassee, Florida

Spillane, Sandra, Climate Services Division, Met Éireann, The Irish Meteorological Service, Dublin, Ireland

Spillane, Sandra, Met Éireann, Dublin, Ireland

Sreejith, O. P., India Meteorological Department, Ministry of Earth Sciences, Pune, India

Srivastava, A. K., India Meteorological Department, Pune, India

Stackhouse Jr., Paul W., NASA Langley Research Center, Hampton, Virginia

Stammerjohn, Sharon, Institute of Arctic and Alpine Research, University of Colorado Boulder, Boulder, Colorado

Stauffer, Ryan, NASA Goddard Space Flight Center, Greenbelt, Maryland

Steinbrecht, Wolfgang, DWD (German Weather Service), Hohenpeissenberg, Germany

Steiner, Andrea K., Wegener Center for Climate and Global Change, University of Graz, Graz, Austria

Stella, Jose L., Servicio Meteorológico Nacional, Buenos Aires, Argentina

Stephenson, Tannecia S., Department of Physics, The University of the West Indies, Kingston, Jamaica

Stradiotti, Pietro, TU Wien, Department of Geodesy and Geoinformation, Vienna, Austria

Strahan, Susan E., University of Maryland, Baltimore County, Baltimore, Maryland; NASA Goddard Space Flight Center, Greenbelt, Maryland

Streletskiy, Dmitry A., George Washington University, Washington DC

Surendran, Divya E., India Meteorological Department, Ministry of Earth Sciences, Pune, India

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., Irkutsk State University, Institute of Biology, Irkutsk, Russia

Tobin, Skie, Bureau of Meteorology, Melbourne, Australia

Tømmervik, Hans, Arctic Department, Norwegian Institute for Nature Research, Tromsø, Norway

Tourpali, Kleareti, Aristotle University, Thessaloniki, Greece

Trescilo, 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

Triñanes, Joaquin A., 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 Meerbeeck, 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

Weber, Mark, University of Bremen, Bremen, Germany

Webster, Melinda, University of Washington, Seattle, Washington

Wehrlé, 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

Widlansky, 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, Dedi, Environmental and Climate Sciences Department, Brookhaven National Laboratory, Upton, New York; Department of Ecology and Evolution, Stony Brook University, Stony Brook, New York

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, Peiqun, 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, 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

STATE OF THE CLIMATE IN 2022

INTRODUCTION

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

Special Online Supplement to the *Bulletin of the American Meteorological Society* Vol. 104, No. 9, September, 2023

https://doi.org/10.1175/2023BAMSStateoftheClimate_Intro.1

Corresponding author: Jessica Blunden / jessica.blunden@noaa.gov

STATE OF THE CLIMATE IN 2022

Introduction

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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.

How to cite this document:
Introduction is one chapter from the *State of the Climate in 2022* annual report and is available from https://doi.org/10.1175/2023BAMSStateoftheClimate_Intro.1. Compiled by NOAA's National Centers for Environmental Information, *State of the Climate in 2022* is based on contributions from scientists from around the world. It provides a detailed update on global climate indicators, notable weather events, and other data collected by environmental monitoring stations and instruments located on land, water, ice, and in space. The full report is available from https://doi.org/10.1175/2023BAMSStateoftheClimate.1.

Citing the complete report:
Blunden, J., T. Boyer, and E. Bartow-Gillies, Eds., 2023: "State of the Climate in 2022". Bull. Amer. Meteor. Soc., 104 (9), Si–S501 https://doi.org/10.1175/2023BAMSStateoftheClimate.1.

Citing this chapter:
Boyer, T., E. Bartow-Gillies, J. Blunden, and R J. H. Dunn, 2023: Introduction [in "State of the Climate in 2022"]. Bull. Amer. Meteor. Soc., 104 (9), S1–S10, https://doi.org/10.1175/2023BAMSStateoftheClimate_Intro.1.

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.

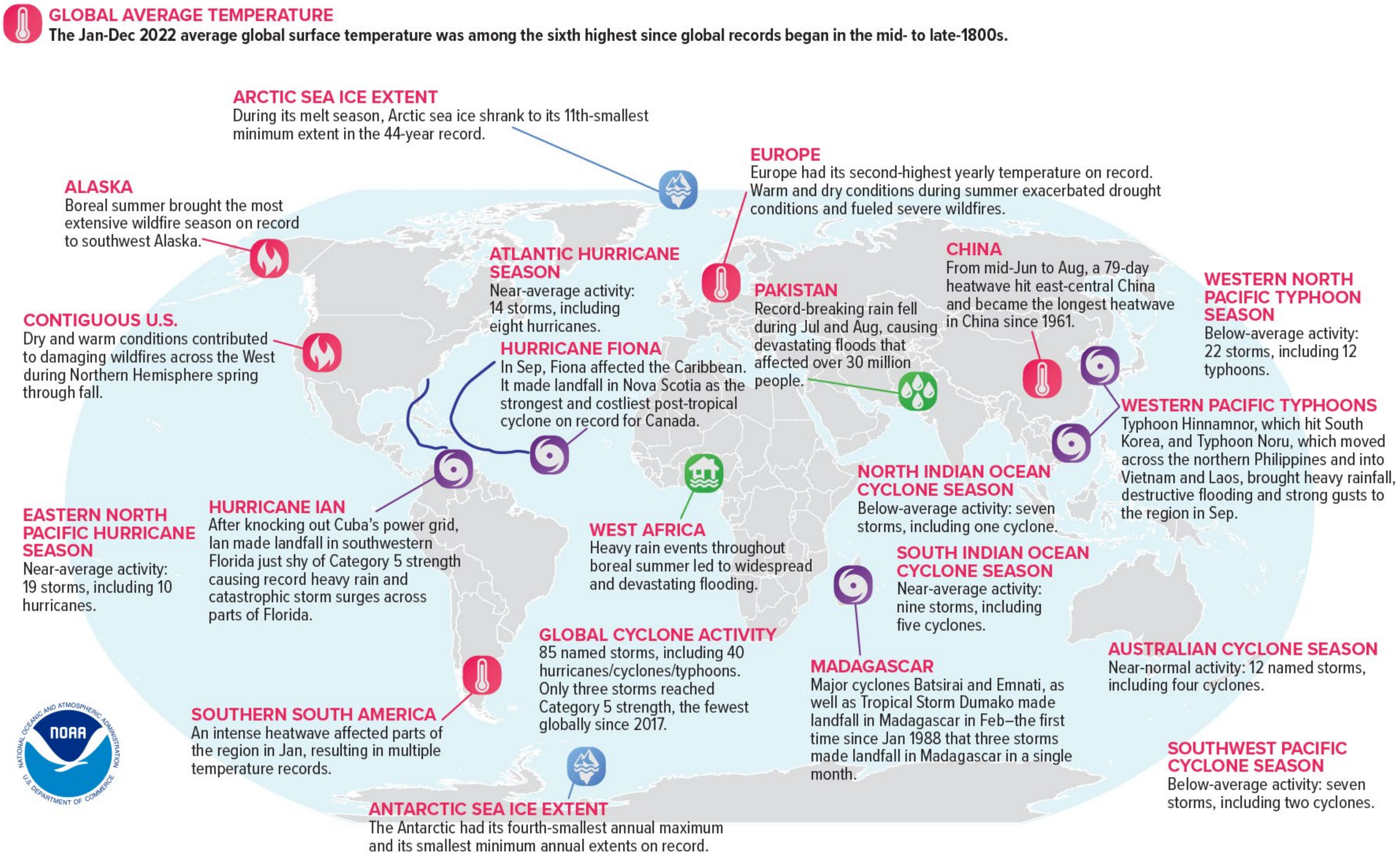
The second unusual event was the extraordinary amount of precipitation over Antarctica in 2022, which led to a record-high annual surface mass balance (since 1980) and the first net positive annual ice-sheet mass balance on the continent since satellite measurements began in 1993. The heavy precipitation 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 '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 (CO_2) levels. After a 10-day interruption, NOAA's CO_2 measurements were transferred to the University of Hawaii's Maunakea Observatories. The Mauna Loa CO_2 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.

ARCTIC SEA ICE EXTENT
During its melt season, Arctic sea ice shrank to its 11th-smallest minimum extent in the 44-year record.

EUROPE
Europe had its second-highest yearly temperature on record. Warm and dry conditions during summer exacerbated drought conditions and fueled severe wildfires.

ALASKA
Boreal summer brought the most extensive wildfire season on record to southwest Alaska.

ATLANTIC HURRICANE SEASON
Near-average activity: 14 storms, including eight hurricanes.

CHINA
From mid-Jun to Aug, a 79-day heatwave hit east-central China and became the longest heatwave in China since 1961.

WESTERN NORTH PACIFIC TYPHOON SEASON
Below-average activity: 22 storms, including 12 typhoons.

PAKISTAN
Record-breaking rain fell during Jul and Aug, causing devastating floods that affected over 30 million people.

CONTIGUOUS U.S.
Dry and warm conditions contributed to damaging wildfires across the West during Northern Hemisphere spring through fall.

HURRICANE FIONA
In Sep, Fiona affected the Caribbean. It made landfall in Nova Scotia as the strongest and costliest post-tropical cyclone on record for Canada.

WESTERN PACIFIC TYPHOONS
Typhoon Hinnamnor, which hit South Korea, and Typhoon Noru, which moved across the northern Philippines and into Vietnam and Laos, brought heavy rainfall, destructive flooding and strong gusts to the region in Sep.

NORTH INDIAN OCEAN CYCLONE SEASON
Below-average activity: seven storms, including one cyclone.

EASTERN NORTH PACIFIC HURRICANE SEASON
Near-average activity: 19 storms, including 10 hurricanes.

HURRICANE IAN
After knocking out Cuba's power grid, Ian made landfall in southwestern Florida just shy of Category 5 strength causing record heavy rain and catastrophic storm surges across parts of Florida.

WEST AFRICA
Heavy rain events throughout boreal summer led to widespread and devastating flooding.

SOUTH INDIAN OCEAN CYCLONE SEASON
Near-average activity: nine storms, including five cyclones.

GLOBAL CYCLONE ACTIVITY
85 named storms, including 40 hurricanes/cyclones/typhoons. Only three storms reached Category 5 strength, the fewest globally since 2017.

AUSTRALIAN CYCLONE SEASON
Near-normal activity: 12 named storms, including four cyclones.

MADAGASCAR
Major cyclones Batsirai and Emnati, as well as Tropical Storm Dumako made landfall in Madagascar in Feb–the first time since Jan 1988 that three storms made landfall in Madagascar in a single month.

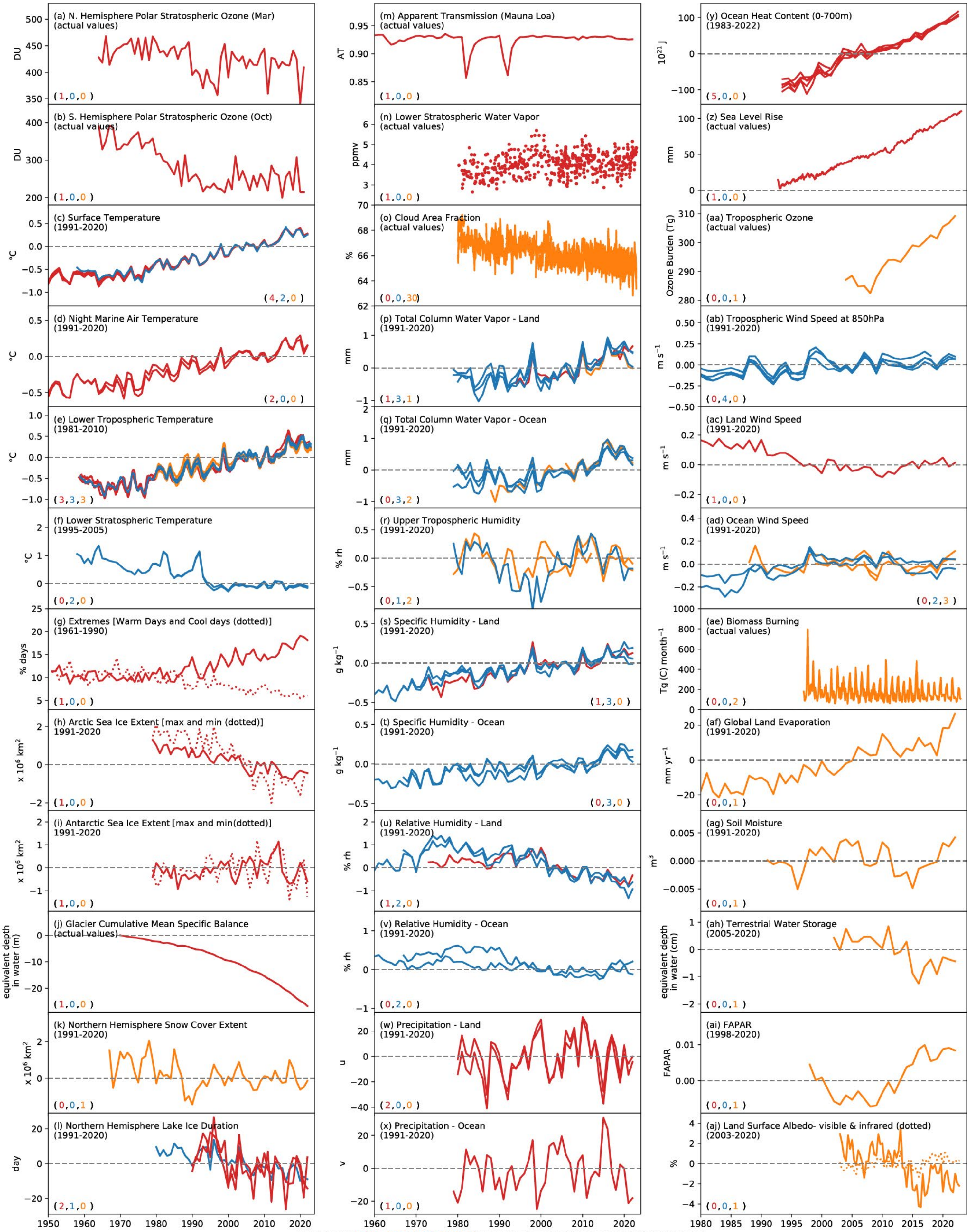
SOUTHERN SOUTH AMERICA
An intense heatwave affected parts of the region in Jan, resulting in multiple temperature records.

SOUTHWEST PACIFIC CYCLONE SEASON
Below-average activity: seven storms, including two cyclones.

ANTARCTIC SEA ICE EXTENT
The Antarctic had its fourth-smallest annual maximum and its smallest minimum annual extents on record.

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).



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

Acknowledgments

The editors thank the BAMS editorial staff, in particular Bryan Hanssen, who provided technical guidance, oversaw publication of the report, and continues to help us shepherd the report into a digital publishing era; Andrea Herbst, who provided peer review support; Nicole Rietmann, who oversaw the hundreds of citations and references this year; and the NCEI Graphics team for facilitating the construction of the report and executing the countless number of technical edits needed. We thank our technical editor, Lukas Noguchi, for his dedication and attention to detail. We also express our gratitude to Dr. Michael Alexander, who served for the third year as the AMS special editor for this report. Finally, we thank all of the authors and chapter editors who provide these valuable contributions each year, always with an aim to improve and expand their analyses for the readers.