

<https://doi.org/10.5194/essd-2019-183>
Preprint. Discussion started: 10 October 2019
© Author(s) 2019. CC BY 4.0 License.





2 Pierre Friedlingstein¹, Matthew W. Jones², Michael O’Sullivan¹, Robbie M. Andrew³, Judith
3 Hauck⁴, Glen P. Peters³, Wouter Peters^{5,6}, Julia Pongratz^{7,8}, Stephen Sitch⁹, Corinne Le Quéré²,
4 Dorothee C. E. Bakker², Josep G. Canadell¹⁰, Philippe Ciais¹¹, Rob Jackson¹², Peter Anthoni¹³,
5 Leticia Barbero^{14,15}, Ana Bastos⁷, Vladislav Bastrikov¹¹, Meike Becker^{16,17}, Laurent Bopp¹⁸, Erik
6 Buitenhuis², Naveen Chandra¹⁹, Frédéric Chevallier¹¹, Louise P. Chini²⁰, Kim I. Currie²¹, Richard
7 A. Feely²², Marion Gehlen¹¹, Dennis Gilfillan²³, Thanos Gkritzalis²⁴, Daniel S. Goll²⁵, Nicolas
8 Gruber²⁶, Sören Gutekunst²⁷, Ian Harris²⁸, Vanessa Haverd¹⁰, Richard A. Houghton²⁹, George
9 Hurtt²⁰, Tatiana Ilyina⁸, Atul K. Jain³⁰, Emilie Joetzjer³¹, Jed O. Kaplan³², Etsushi Kato³³, Kees
10 Klein Goldewijk^{34,35}, Jan Ivar Korsbakken³, Peter Landschützer⁸, Siv K. Lauvset^{36,17}, Nathalie
11 Lefèvre³⁷, Andrew Lenton^{38,39}, Sebastian Lienert⁴⁰, Danica Lombardozi⁴¹, Gregg Marland²³,
12 Patrick C. McGuire⁴², Joe R. Melton⁴³, Nicolas Metzler³⁷, David R. Munro⁴⁴, Julia E. M. S. Nabel⁸,
13 Shin-Ichiro Nakaoka⁴⁵, Craig Neill³⁸, Abdirahman M. Omar^{36,17}, Tsuneo Ono⁴⁶, Anna Peregón¹¹,
14 Denis Pierrot^{14,15}, Benjamin Poulter⁴⁷, Gregor Rehder⁴⁸, Laure Resplandy⁴⁹, Eddy Robertson⁵⁰,
15 Christian Rödenbeck⁵¹, Roland Séférian⁵², Jörg Schwinger^{36,17}, Naomi Smith^{5,53}, Pieter P. Tans⁵⁴,
16 Hanqin Tian⁵⁵, Bronte Tilbrook^{38,56}, Francesco N Tubiello⁵⁷, Guido R. van der Werf⁵⁸, Andrew J.
17 Wiltshire⁵⁰, Sönke Zaehle⁵¹

¹ College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter EX4 4QF, UK

² Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich Research Park, Norwich NR4 7TJ, UK

³ CICERO Center for International Climate Research, Oslo 0349, Norway

⁴ Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Postfach 120161, 27515 Bremerhaven, Germany

⁵ Wageningen University, Environmental Sciences Group, P.O. Box 47, 6700AA, Wageningen, The Netherlands

⁶ University of Groningen, Centre for Isotope Research, Groningen, The Netherlands

⁷ Ludwig-Maximilians-Universität Munich, Luisenstr. 37, 80333 München, Germany

⁸ Max Planck Institute for Meteorology, Hamburg, Germany

⁹ College of Life and Environmental Sciences, University of Exeter, Exeter EX4 4RJ, UK

¹⁰ CSIRO Oceans and Atmosphere, GPO Box 1700, Canberra, ACT 2601, Australia

¹¹ Laboratoire des Sciences du Climat et de l’Environnement, Institut Pierre-Simon Laplace, CEA-CNRS-UVSQ, CE Orme des Merisiers, 91191 Gif sur Yvette Cedex, France

¹² Department of Earth System Science, Woods Institute for the Environment, and Precourt Institute for Energy, Stanford University, Stanford, CA 94305–2210, United States of America

¹³ German Helmholtz Association in its ATMO programme

¹⁴ Cooperative Institute for Marine and Atmospheric Studies, Rosenstiel School for Marine and Atmospheric Science, University of Miami, Miami, FL 33149, USA

¹⁵ National Oceanic & Atmospheric Administration/Atlantic Oceanographic & Meteorological Laboratory (NOAA/AOML), Miami, FL 33149, USA

¹⁶ Geophysical Institute, University of Bergen, Bergen, Norway

¹⁷ Bjerknes Centre for Climate Research, Allégaten 70, 5007 Bergen, Norway

¹⁸ Laboratoire de Météorologie Dynamique, Institut Pierre-Simon Laplace, CNRS-ENS-UPMC-X, Département de Géosciences, Ecole Normale Supérieure, 24 rue Lhomond, 75005 Paris, France

¹⁹ Earth Surface System Research Center (ESS), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokohama, 236-0001, Japan

²⁰ Department of Geographical Sciences, University of Maryland, College Park, Maryland 20742, USA

²¹ NIWA / UoO Research Centre for Oceanography, PO Box 56, Dunedin 9054, New Zealand

²² Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration, 7600 Sand Point Way NE, Seattle, WA 98115-6349, USA



-
- ²³ Research Institute for Environment, Energy, and Economics, Appalachian State University, Boone, North Carolina, USA
- ²⁴ Flanders Marine Institute (VLIZ), InnovOceanSite, Wandelaarkaai 7, 8400 Ostend, Belgium
- ²⁵ Lehrstuhl für Physische Geographie mit Schwerpunkt Klimaforschung, Universität Augsburg, Augsburg, Germany
- ²⁶ Environmental Physics Group, ETH Zürich, Institute of Biogeochemistry and Pollutant Dynamics and Center for Climate Systems Modeling (C2SM)
- ²⁷ GEOMAR Helmholtz Centre for Ocean Research Kiel, Düsterbrookweg 20, 24105 Kiel, Germany
- ²⁸ NCAS-Climate, Climatic Research Unit, School of Environmental Sciences, University of East Anglia, Norwich Research Park, Norwich, NR4 7TJ, UK
- ²⁹ Woods Hole Research Center (WHRC), Falmouth, MA 02540, USA
- ³⁰ Department of Atmospheric Sciences, University of Illinois, Urbana, IL 61821, USA
- ³¹ Centre National de Recherche Meteorologique, Unite mixte de recherche 3589 M t o- France/CNRS, 42 Avenue Gaspard Coriolis, 31100 Toulouse, France
- ³² Department of Earth Sciences, University of Hong Kong, Pokfulam Road, Hong Kong
- ³³ Institute of Applied Energy (IAE), Minato-ku, Tokyo 105-0003, Japan
- ³⁴ PBL Netherlands Environmental Assessment Agency, Bezuidenhoutseweg 30, P.O. Box 30314, 2500 GH, The Hague, the Netherlands
- ³⁵ Faculty of Geosciences, Department IMEW, Copernicus Institute of Sustainable Development, Heidelberglaan 2, P.O. Box 80115, 3508 TC, Utrecht, Netherlands
- ³⁶ NORCE Norwegian Research Centre, NORCE Climate, Jahnebakken 70, 5008 Bergen, Norway
- ³⁷ LOCEAN/IPSL laboratory, Sorbonne Université, CNRS/IRD/MNHN, Paris, France
- ³⁸ CSIRO Oceans and Atmosphere, Hobart, TAS, Australia
- ³⁹ Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Tasmania
- ⁴⁰ Climate and Environmental Physics, Physics Institute and Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland
- ⁴¹ National Center for Atmospheric Research, Climate and Global Dynamics, Terrestrial Sciences Section, Boulder, CO 80305, USA
- ⁴² Department of Meteorology, Department of Geography & Environmental Science, National Centre for Atmospheric Science, University of Reading, Reading, UK,
- ⁴³ Climate Research Division, Environment and Climate Change Canada, Victoria, BC, Canada
- ⁴⁴ Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO, USA
- ⁴⁵ Center for Global Environmental Research, National Institute for Environmental Studies (NIES), 16-2 Onogawa, Tsukuba, Ibaraki, 305-8506, Japan
- ⁴⁶ Japan Fisheries Research and Education Agency, 2-12-4 Fukuura, Kanazawa-Ku, Yokohama 236-8648, Japan
- ⁴⁷ NASA Goddard Space Flight Center, Biospheric Sciences Laboratory, Greenbelt, Maryland 20771, USA
- ⁴⁸ Leibniz Institute for Baltic Sea Research Warnemuende (IOW), Seestrasse 15; 18119 Rostock, Germany
- ⁴⁹ Princeton University, Department of Geosciences and Princeton Environmental Institute, Princeton, NJ, USA
- ⁵⁰ Met Office Hadley Centre, FitzRoy Road, Exeter EX1 3PB, UK
- ⁵¹ Max Planck Institute for Biogeochemistry, P.O. Box 600164, Hans-Knöll-Str. 10, 07745 Jena, Germany
- ⁵² CNRM (Météo-France/CNRS)-UMR 3589
- ⁵³ ICOS Carbon Portal, Lund University, Lund, Sweden
- ⁵⁴ National Oceanic & Atmospheric Administration, Earth System Research Laboratory (NOAA/ESRL), Boulder, CO 80305, USA



18 ⁵⁵ International Center for Climate and Global Change Research, School of Forestry and Wildlife
Sciences, Auburn University, 602 Dugan Drive, Auburn, AL 36849, USA

19 ⁵⁶ Australian Antarctic Partnership Program, University of Tasmania, Hobart, Australia

20 ⁵⁷ Statistics Division, Food and Agriculture Organization of the United Nations, Via Terme di
Caracalla, Rome 00153, Italy

21 ⁵⁸ Faculty of Science, Vrije Universiteit, Amsterdam, The Netherlands

22

Correspondence: Pierre Friedlingstein (p.friedlingstein@exeter.ac.uk)

23