

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/306106658>

Climate Change, Effects

Chapter · January 2008

DOI: 10.4135/9781412963893.n129

CITATIONS

3

READS

4,986

1 author:



Nsikak Benson

Covenant University Ota Ogun State, Nigeria

70 PUBLICATIONS 415 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:



Sea-air fluxes of dimethyl sulfide in the equatorial Gulf of Guinea (Atlantic Ocean) based on VG-CL technique [View project](#)



MARSHES: Microplastic Pollution Research in Southeast Atlantic Marine Ecosystems [View project](#)

S. George Philander

GENERAL EDITOR

ENCYCLOPEDIA OF

Global Warming and Climate Change



ENCYCLOPEDIA OF

Global Warming and Climate Change



ENCYCLOPEDIA OF

Global Warming and Climate Change

S. George Philander
GENERAL EDITOR

VOLUMES 1 - 3



Los Angeles • London • New Delhi • Singapore

A SAGE Reference Publication

Copyright © 2008 by SAGE Publications, Inc.

All rights reserved. No part of this book may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying, recording, or by any information storage and retrieval system, without permission in writing from the publisher.

For information:



SAGE Publications, Inc.
2455 Teller Road
Thousand Oaks, California 91320
E-mail: order@sagepub.com

SAGE Publications Ltd.
1 Oliver's Yard
55 City Road
London EC1Y 1SP
United Kingdom

SAGE Publications India Pvt. Ltd.
B 1/ I 1 Mohan Cooperative Industrial Area
Mathura Road, New Delhi 110 044
India

SAGE Publications Asia-Pacific Pte. Ltd.
33 Pekin Street #02-01
Far East Square
Singapore 048763

Library of Congress Cataloging-in-Publication Data

Encyclopedia of global warming and climate change / S. George Philander.

p. cm.

Includes bibliographical references and index.

ISBN 978-1-4129-5878-3 (cloth)

1. Global warming--Encyclopedias. 2. Climatic changes--Encyclopedias.

I. Philander, S. George.

QC981.8.G56E47 2008

363.738'7403--dc22

2008006238

This book is printed on acid-free and recycled paper.

08 09 10 11 12 10 9 8 7 6 5 4 3 2 1

GOLSON BOOKS, LTD.

President and Editor	J. Geoffrey Golson
Creative Director	Mary Jo Scibetta
Managing Editor	Susan Moskowitz
Copyeditor	Mary Le Rouge
Layout Editors	Kenneth W. Heller
	Stephanie Larson
	Oona Hyla Patrick
Proofreaders	Deborah Green
	Summer G. Ventis
	Barbara Paris
Indexer	J S Editorial

SAGE REFERENCE

Vice President and Publisher	Rolf A. Janke
Project Editor	Tracy Buyan
Cover Production	Janet Foulger
Marketing Manager	Amberlyn Erzinger
Editorial Assistant	Michele Thompson
Reference Systems Manager	Leticia Gutierrez

Photo credits are on page I-79.



List of Articles

A

- Abrupt Climate Changes
- Adaptation
- Aerosols
- Afforestation
- Afghanistan
- Agriculture
- Agulhas Current
- Air Force, U.S.
- Alabama
- Alaska
- Alaska Climate Research Center
- Albania
- Albedo
- Algeria
- Alliance of Small Island States
- Alliance to Save Energy
- Alternative Energy, Ethanol
- Alternative Energy, Overview
- Alternative Energy, Solar
- Alternative Energy, Wind
- American Council for an Energy-Efficient Economy
- American Electric Power
- American Gas Association
- American Geophysical Union
- American Meteorological Society
- Andorra
- Angola
- Animals
- An Inconvenient Truth*
- Antarctic Circumpolar Current
- Antarctic Ice Sheets
- Antarctic Meteorology Research Center
- Anthropogenic Forcing
- Anticyclones
- Antigua and Barbuda
- Applied Energy Services, Inc.
- Arakawa, Akio
- Arctic Ocean
- Argentina
- Arizona
- Arkansas
- Armenia
- Arrhenius, Svante August
- Atlantic Ocean
- Atmosphere, Climate and Environment
Information Programme (UK)
- Atmospheric Absorption of Solar Radiation
- Atmospheric Boundary Layer
- Atmospheric Component of Models
- Atmospheric Composition
- Atmospheric Emission of Infrared Radiation
- Atmospheric General Circulation Models
- Atmospheric Research and Information Centre
- Atmospheric Vertical Structure
- Attribution of Global Warming
- Aurora
- Australia

Austria
Automobiles
Aviation
Azerbaijan

B

Bahamas
Bahrain
Bangladesh
Barbados
Belarus
Belgium
Belize
Benguela Current
Benin
Berlin Mandate
Bhutan
Biogeochemical Feedbacks
Biology
Biomass
Blizzards
Bolin, Bert
Bolivia
Bosnia and Herzegovina
Botany
Botswana
BP
Brazil
Broecker, Wallace
Brunei Darussalam
Bryan, Kirk
Bryson, Reid
Budyko, Mikhail
Bulgaria
Burkina Faso
Burundi
Bush (George H.W.) Administration
Bush (George W.) Administration

C

California
California Institute of Technology
Cambodia
Cameroon
Canada
Canadian Association for Renewable
Energies
Cantor Fitzgerald EBS
Cape Verde
Capitalism
Carbon Cycle

Carbon Dioxide
Carbon Emissions
Carbon Footprint
Carbon Permits
Carbon Sequestration
Carbon Sinks
Cenozoic Era
Center for Clean Air Policy
Center for Energy Efficiency
Center for International Climate and
Environment Research
Center for International Environmental
Law
Center for Ocean-Atmospheric Prediction
Studies
Center for Science and Environment (India)
Central African Republic
Chad
Chamberlin, Thomas C.
Chaos Theory
Charney, Jule Gregory
Chemistry
Chile
China
Clean Air Act, U.S.
Clean Development Mechanism
CLIMAP Project
Climate
Climate Action Network
Climate Change, Effects
Climate Change Knowledge Network
Climate Cycles
Climate Feedback
Climate Forcing
Climate Impacts LINK Project
Climate Models
Climate Sensitivity and Feedbacks
Climate Thresholds
Climate Zones
Climatic Data, Atmospheric Observations
Climatic Data, Cave Records
Climatic Data, Historical Records
Climatic Data, Ice Observations
Climatic Data, Instrumental Records
Climatic Data, Lake Records
Climatic Data, Nature of the Data
Climatic Data, Oceanic Observations
Climatic Data, Proxy Records
Climatic Data, Reanalysis
Climatic Data, Sea Floor Records
Climatic Data, Sediment Records

Climatic Data, Tree Ring Records
Climatic Research Unit
Clinton Administration
Cloud Feedback
Clouds, Cirrus
Clouds, Cumulus
Clouds, Stratus
Coal
Colombia
Colorado
Colorado Climate Center
Colorado State University
Columbia University
Comoros
Compliance
Computer Models
Condensation
Congo
Congo, Democratic Republic of
Connecticut
Conservation
Convection
Cooperative Institute for Arctic Research
Coriolis Force
Cornell University
Costa Rica
Côte d'Ivoire
Cretaceous Era
Croatia
Croll, James
Cuba
Culture
Current
Cyclones
Cyprus
Czech Republic

D

David Suzuki Foundation
Deforestation
Delaware
Denmark
Department of Defense, U.S.
Department of Energy, U.S.
Department of State, U.S.
Desertification
Desert Research Institute
Deserts
Detection of Climate Changes
Developing Countries
Diseases

Djibouti
Doldrums
Dominica
Dominican Republic
Doris Duke Charitable Foundation
Drift Ice
Drought
Dynamical Feedbacks

E

Earth's Climate History
Earthshine
East Timor
Ecological Footprint
Economics, Cost of Affecting Climate Change
Economics, Impact From Climate Change
Ecosystems
Ecuador
Edison Electric Institute
Education
Egypt
Ekman Layer
El Niño and La Niña
El Salvador
Emissions, Baseline
Emissions, Cement Industry
Emissions, Trading
Energy
Energy, Renewable
Energy Balance Models
Energy Efficiency
Environmental and Societal Impacts Group
Environmental Defense
Environmental Development Action in the
Third World
Environmental Financial Products, LLC
Environmental History
Environmental Law Institute
Environmental Protection Agency (EPA)
Equatorial Countercurrent
Equatorial Guinea
Equatorial Undercurrent
Eritrea
Estonia
Ethics
Ethiopia
European Commission
European Union
Evaporation and Transpiration
Evaporation Feedbacks
Evolution of the Atmosphere

F

FEEM (Italy)
Fiji
Finland
Floods
Florida
Florida International University
Florida State University
Food Miles
Food Production
Foraminifera
Forced Climate Variability
Forests
Foundation for International Environmental
 Law and Development
Fourier, Joseph
Framework Convention on Climate Change
France
Friends of the Earth

G

Gabon
Gaia Hypothesis
Gambia
Geography
Geophysical Fluid Dynamics Laboratory
Georgia (Nation)
Georgia (U.S. State)
Geospatial Technology
Germany
Ghana
Glaciers, Retreating
Glaciology
Global Atmospheric Research Program (GARP)
Global Environment Facility (GEF)
Global Industrial and Social Progress Research
 Institute (GISPRI)
Globalization
Global Warming
Goddard Institute for Space Studies
Gore, Albert, Jr.
Greece
Green Buildings
Green Cities
Green Design
Green Homes
Greenhouse Effect
Greenhouse Gases
Greenland Cores
Greenland Ice Sheet
Greenpeace International

Grenada
Gross National Product
Gross Primary Production
Guatemala
Guinea
Guinea-Bissau
Gulf Stream
Guyana

H

Hadley, George
Hadley Circulation
Haiti
Hansen, James
Harvard University
Hawaii
Health
Heat, Latent
Heat, Sensible
Heinz Center
Historical Development of Climate Models
History of Climatology
History of Meteorology
Holocene Era
Honduras
Hot Air
Hungary
Hurricanes and Typhoons
Hydrofluorocarbons
Hydrological Cycle

I

Ice Ages
Ice Albedo Feedback
Ice Component of Models
Iceland
Idaho
Idaho State Climate Services
Illinois
Impacts of Global Warming
India
Indiana
Indiana University
Indian Ocean
Indonesia
Industrialization
Institute of Energy Economics (Argentina)
Intergovernmental Panel on Climate Change (IPCC)
Internal Climate Variability
International Council of Scientific Unions (ICSU)
International Energy Agency (IEA)

International Geophysical Year (IGY)
 International Geosphere-Biosphere Program
 (IGBP)
 International Institute for Sustainable Development
 (IISD)
 International Research Institute for Climate
 Prediction
 International Solar Energy Society (ISES)
 International Union of Geodesy and Geophysics
 (IUGG)
 Intertropical Convergence Zone
 Iowa
 Iowa State University
 Iran
 Iraq
 Ireland
 Israel
 Italy

J

Jamaica
 Japan
 Jet Streams
 Johns Hopkins University
 Joint Institute for the Study of the Atmosphere
 and Ocean (JISAO)
 Jordan
 Jurassic Era

K

Kansas
 Kazakhstan
 Keeling, Charles David
 Kentucky
 Kenya
 Kiribati
 Korea, North
 Korea, South
 Kuroshio Current
 Kuwait
 Kyoto Mechanisms
 Kyoto Protocol
 Kyrgyzstan

L

Land Component of Models
 Land Use
 Laos
 Latvia
 LDEO Climate Modeling Group
 Lebanon

Lesotho
 Liberia
 Liechtenstein
 Life Cycle Analysis
 Lindzen, Richard
 Lithuania
 Little Ice Age
 Lorenz, Edward
 Louisiana
 Louisiana State University
 Luxembourg

M

Macedonia (FYROM)
 Madagascar
 Maine
 Malawi
 Malaysia
 Maldives
 Mali
 Malta
 Manabe, Syukuro
 Marine Mammals
 Marshall Institute
 Marshall Islands
 Maryland
 Massachusetts
 Massachusetts Institute of Technology
 Mauritania
 Mauritius
 Maximum Sustainable Yield
 Measurement and Assessment
 Media, Books and Journals
 Media, Internet
 Media, TV
 Meridional Overturning Circulation
 Mesosphere
 Mesozoic Era
 Methane Cycle
 Mexico
 Michigan
 Micronesia
 Midwestern Regional Climate Center
 Milankovitch, Milutin
 Milankovitch Cycles
 Minnesota
 Mississippi
 Mississippi State University
 Missouri
 Mixed Layer
 Modeling of Ice Ages

Modeling of Ocean Circulation
Modeling of Paleoclimates
Moldova
Monaco
Mongolia
Monsoons
Montana
Montreal Protocol
Morocco
Movements, Environmental
Mozambique
Munk, Walter
Myanmar

N

Namibia
National Academy of Sciences, U.S.
National Aeronautics and Space Administration
(NASA)
National Association of Energy Service Companies
(NAESCO)
National Center for Atmospheric Research
(NCAR)
National Oceanic and Atmospheric Administration
(NOAA)
National Science Foundation
Natsource
Natural Gas
Natural Resources Defense Council (NRDC)
Nauru
Navy, U.S.
Nebraska
Needs and Wants
Nepal
Netherlands
Net Primary Production
Nevada
New Hampshire
New Jersey
New Mexico
New Mexico Climate Center
New York
New Zealand
Nicaragua
Niger
Nigeria
Nitrous Oxide
Nongovernmental Organizations (NGOs)
North Atlantic Oscillation
North Carolina
North Dakota

Norway
Nuclear Power

O

Ocean Component of Models
Oceanic Changes
Oceanography
OECD Annex 1 Expert Group on the UNFCCC
OECD Climate Change Documents
Office of Naval Research
Ohio
Ohio State University
Oil, Consumption of
Oil, Production of
Oklahoma
Oman
Orbital Parameters, Eccentricity
Orbital Parameters, Obliquity
Orbital Parameters, Precession
Oregon
Oregon Climate Service
Oregon State University
Organisation for Economic Co-operation and
Development (OECD)
Oxygen Cycle

P

Pacific Ocean
Pakistan
Palau
Paleoclimates
Paleozoic Era
Panama
Papua New Guinea
Paraguay
Penguins
Penn State University
Pennsylvania
Perfluorocarbons
Peru
Peruvian Current
Pew Center on Global Climate Change
Philippines
Phillips, Norman
Phytoplankton
Plants
Pleistocene Era
Pliocene Era
Poland
Polar Bears
Policy, International

Policy, U.S.
 Pollution, Air
 Pollution, Land
 Pollution, Water
 Population
 Portugal
 Precambrian Era
 Precautionary Principle
 Precipitation
 Preparedness
 Princeton University
 Public Awareness

Q

Qatar
 Quaternary Era

R

Radiation, Absorption
 Radiation, Infrared
 Radiation, Long Wave
 Radiation, Microwave
 Radiation, Short Wave
 Radiation, Ultraviolet
 Radiative Feedbacks
 Rain
 Rainfall Patterns
 Refugees, Environmental
 Regulation
 Religion
 Renewable Energy Policy Project (REPP)
 Resources
 Resources for the Future (RFF)
 Revelle, Roger
 Rhode Island
 Richardson, Lewis Fry
 Risk
 Romania
 Rossby, Carl-Gustav
 Royal Dutch/Shell Group
 Royal Meteorological Society
 Russia
 Rwanda

S

Saint Kitts and Nevis
 Saint Lucia
 Saint Vincent and the Grenadines
 Salinity
 Samoa
 San Marino

São Tomé and Príncipe
 Saudi Arabia
 Schneider, Stephen H.
 Scripps Institute of Oceanography
 Sea Ice
 Sea Level, Rising
 Seasonal Cycle
 Seawater, Composition of
 Senegal
 Serbia and Montenegro
 Seychelles
 Sierra Leone
 Simulation and Predictability of Seasonal and
 Interannual Variations
 Singapore
 Singer, S. Fred
 Slovakia
 Slovenia
 Smagorinsky, Joseph
 Snowball Earth
 Social Ecology
 Soil Organic Carbon
 Soils
 Solar Energy Industries Association
 (SEIA)
 Solar Wind
 Solomon Islands
 Somalia
 Somali Current
 South Africa
 South Carolina
 South Dakota
 Southern Ocean
 Southern Oscillation
 Spain
 Species Extinction
 Sri Lanka
 Stanford University
 Stockholm Environment Institute (SEI)
 Stommel, Henry
 Stratopause
 Stratosphere
 Sudan
 Sulphur Dioxide
 Sulphur Hexafluoride
 Sunlight
 Suriname
 Sustainability
 Sverdrup, Harald Ulrik
 Swaziland
 Sweden

Switzerland

Syria

T

Tajikistan

Tanzania

Tata Energy Research Institute (TERI)

Technology

Tennessee

Tertiary Climate

Texas

Thailand

Thermocline

Thermodynamics

Thermohaline Circulation

Thermosphere

Thunderstorms

Togo

Tonga

Toronto Conference

Tourism

Trade Winds

Transportation

Trexler and Associates, Inc.

Triassic Period

Trinidad and Tobago

Tropopause

Troposphere

Tsunamis

Tunisia

Turkey

Turkmenistan

Tuvalu

Tyndall, John

U

Uganda

Ukraine

UN Conference on Trade and Development/Earth
Council Institute: Carbon Market Program

United Arab Emirates

United Kingdom

United Nations

United Nations Development Programme (UNDP)

United Nations Environment Programme (UNEP)

United States of America

University Corporation for Atmospheric Research

University Corporation for Atmospheric Research
Joint Office for Science Support

University of Alaska

University of Arizona

University of Birmingham

University of California, Berkeley

University of Cambridge

University of Colorado

University of Delaware

University of East Anglia

University of Florida

University of Hawaii

University of Illinois

University of Kentucky

University of Leeds

University of Maine

University of Maryland

University of Miami

University of Michigan

University of Nebraska

University of New Hampshire

University of Oklahoma

University of Reading

University of St. Gallen (Switzerland)

University of Utah

University of Washington

Upwelling, Coastal

Upwelling Equatorial

Uruguay

U.S. Global Change Research Program

Utah

Utah Climate Center

Uzbekistan

V

Validation of Climate Models

Vanuatu

Venezuela

Vermont

Vermont Law School

Vienna Convention

Vietnam

Villach Conference

Virginia

Volcanism

Von Neumann, John

Vostok Core

W

Walker, Gilbert Thomas

Walker Circulation

Washington

Washington, Warren

Waves, Gravity

Waves, Internal

Waves, Kelvin
Waves, Planetary
Waves, Rossby
Weather
Weather World 2010 Project
Western Boundary Currents
Western Regional Climate Center
West Virginia
Wind-Driven Circulation
Winds, Easterlies
Winds, Westerlies
Wisconsin
Woods Hole Oceanographic Institution
World Bank
World Business Council for Sustainable
Development
World Climate Research Program

World Health Organization
World Meteorological
Organization
World Resources Institute
World Systems Theory
Worldwatch Institute
World Weather Watch
World Wildlife Fund
Wyoming

Y

Yemen
Younger Dryas

Z

Zambia
Zimbabwe

Climate Change, Effects

CLIMATE CHANGE IS commonly used to describe any systematic alteration or statistically significant variation in either the average state of the climate elements such as precipitation, temperature, winds, or pressure; or in its variability, sustained over a finite time period (decades or longer). It can be referred to as the long-term change in global weather patterns, associated especially with increases in temperature, precipitation, and storm activity.

These inconsistencies in climate systems are a potential consequence of the greenhouse effect by greenhouse gases (GHGs). Examples of greenhouse gases include: carbon dioxide (CO_2), methane (CH_4), dinitrogen monoxide or nitrous oxide (N_2O), halocarbon gases such as trichlorofluorocarbon (CFCl_3) and dichlorofluorocarbon (CF_2Cl_2), water (H_2O), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). The atmospheric concentrations of these gases have been increasing, due to anthropogenic activities.

Climate change is attributed directly or indirectly to anthropogenic activities that impact the natural composition of the global climate elements. It may also be a result of natural external forcing, such as changes in Earth's orbital variables, or solar emission, and other natural internal processes of the Earth's climate system. The relative influences of external anthropogenic and natural factors on climate can be broadly compared, using the concept of radiative forcing. Radiative forcing simply refers to the process that disrupts the infrared radiation balance between incoming solar radiation from the Sun and the outgoing radiation from the Earth. A positive radiative forcing primarily results in the relative warming of the Earth's surface and is due to increasing levels of GHGs. A negative radiative forcing, which can arise from an increase in some types of aerosols, tends to bring about the cooling of the Earth's surface.

Changes in orbital variables, solar output, or explosive volcanic activity, are natural external factors that can also cause radiative forcing. The systematic account of these climate-forcing agents and their differences over a timescale is required to understand past climate changes in the context of natural variations, and to predict the nature of future climate changes.

The effects of climate change include variations in biospheric ambient temperature, which could lead

to heat stress, change in rainfall patterns, sea-level rise, saltwater intrusion, loss of biodiversity, drought, habitat loss, and freshwater depletion and pollution. In most cases, climate change has been used interchangeably with global warming, and the greenhouse effect. However, in recent accepted usage, climate change only connotes any change or changes in modern climate systems, whether due to natural variability or as a result of human-caused activity, including an increase over a period of time of the average temperature of the Earth's atmosphere and oceans, known as global warming.

The United Nations Framework Convention on Climate Change (UNFCCC) has adopted the phrase *climate variability* for non-human mediated changes in climate elements. Climate variability is usually natural in origin, resulting primarily from slight variations in the complex processes that drive the movement of heat and mass between the atmosphere, the marine aquatic ecosystems, and the land surfaces. For example, the El Niño–Southern Oscillation (ENSO) is caused by weakening trade winds in the southern part of the Pacific Ocean, and has consistently affected regional variations of precipitation and temperature over much of the tropics, subtropics, and some mid-latitude areas, leading to warmer episodes in these areas. Trade winds carry warmer air west, which leads to rising sea temperatures and increased precipitation.

According to reports by the Intergovernmental Panel on Climate Change (IPCC), human beings are altering the Earth's natural climate system. Evidence indicates that human-induced climate change, if allowed to continue unabated, could have profound consequences for the economy and the quality of life of future generations. Fossil fuel consumption, which has been steadily increasing since the pre-industrial period, is causing an overall increase in concentrations of atmospheric GHGs, especially CO_2 .

Current research indicates that radiative forcing driven by greenhouse gases is the primary cause of global warming. According to these studies, GHGs traps the Sun's heat energy and compels a redistribution of the trapped radiation available near the Earth's surface, thus regulating the Earth's temperature. GHGs, especially CO_2 , are the major non-climate factors driving climate change. The continuous build-up of these gases is expected to cause

significant changes in climatic conditions over the next century.

WATER RESOURCES AND TEMPERATURE RISE

Researchers around the globe have found that climate change is likely to impact water resources depletion and pollution significantly. There have been observed changes in surface temperature, rainfall, evaporation, and extreme events since the beginning of the 20th century. The atmospheric concentration of CO₂ has increased from about 280 parts per million by volume (ppmv) to about 369 ppmv, and the global temperature of the Earth has increased by about 0.6 degrees C. The present CO₂ concentration has not been exceeded during the past 420,000 years and likely not during the past 20 million years. The current rate of atmospheric CO₂ level increase is unprecedented during at least the past 20,000 years. About 75 percent of the anthropogenic emissions of CO₂ to the atmosphere during the past 20 years is attributed to fossil fuel burning. The rest is predominantly due to land-use change, especially deforestation.

The globally averaged surface temperature is projected to increase by 1.4 to 5.8 degrees C 1990–2100. The global mean sea level has risen by 4–8 in. (10–20 cm.). The average global surface temperature is projected to increase by 1.4–3.0 degrees C 1990–2100 for low-emission scenarios, and 2.5–5.8 degrees C for higher emission scenarios of greenhouse gases in the atmosphere. Over the same period, associated rise in global mean sea level is projected between 1.3–13.6 sq. in. (9–88 sq. cm.).

A number of researchers have reported the impact of climate-change scenarios on hydrology of various basins and regions; they project that increasing temperature and decline in rainfall may reduce net recharge and affect freshwater resources. Human-caused influences are expected to follow a steady growth trend in the future; climate modifications caused by anthropogenic radiative forcing are considered to be more permanent than those caused by natural variability factors.

According to the Intergovernmental Panel on Climate Change (IPCC), since the Industrial Revolution began in the mid-16th century, CO₂ levels in the atmosphere have increased by 35 percent and the atmospheric concentration of CH₄ has increased by 1060 parts per billion (151 percent) and will continue

to increase. The present CH₄ concentration has not been exceeded during the past 420,000 years. The inter-annual growth in CH₄ level slowed and became significantly variable in the 1990s, compared with the 1980s. It has been suggested that a significant ratio of the current CH₄ emissions are anthropogenic rather than natural. The anthropogenic sources of methane include the consumption of fossil fuels, cattle, paddy rice fields, and landfills. Recent studies have indicted carbon monoxide (CO) emissions as a cause of increasing atmospheric CH₄ concentration.

In addition, the emissions of persistent GHGs such as CO₂, N₂O, PFCs, and SF₆ could continue to have long-term impacts on atmospheric composition, radiative forcing, and climate elements. This could imply that anthropogenic climate change may persist for a long time to come. The enhanced atmospheric concentrations of GHGs are implicated as the primary cause of global warming.

Recent findings by the IPCC indicate that the atmospheric concentration of CO₂ in 2005 was 375 ppm compared to the pre-industrial levels of 280 ppm. This has contributed to the increase in the Earth's surface temperature by 0.6 degrees C (one degree F). Worldwide measurements of sea level have demonstrated a rise of about 0.56 ft. (0.17 m.) during the 20th century. The world's glaciers have, over time, receded steadily and Arctic sea ice extent has steadily shrunk by 2.7 percent per decade since 1978.

Glaciers are an intriguing part of the Earth's natural environment and have been identified as one of the significant and sensitive indicators of climate change. Their size, lifespan, and timescale information of accumulation and ablation, or growth and collapse (glacier retreat) are primarily attributed to change in climate elements such as temperature, precipitation, wind speed, humidity, and solar radiation.

Increased surface temperatures of the Earth are causing glaciers to melt faster than winter snows can replenish them. Melting sea ice may eventually lead to global changes in water resources and circulation, and melting ice could speed up warming of the Arctic because water absorbs much more heat than ice. Extreme and ongoing declines in the thickness and extent of Arctic sea ice will pose enormous consequences for the Arctic population, their ecosystems, and coastal evolution. As the glaciers shrink, a greater portion of the Earth's water will enter the liquid phase

and becomes available to the oceans and the atmosphere. This will ultimately result in a increased volume of water in the oceans, which could lead to a significant rise in sea level.

IMPACTS OF SEA-LEVEL RISE

During the 20th century, the sea level rose by 4–8 in. (10–20 cm.) primarily as a result of melting glacier ice and thermal expansion of warmer ocean water. It has been predicted that sea level rise will be even greater as the oceans warm along with the rest of the Earth. This is due to the fact that water expands as its temperature increases. Climate change models have predicted that a global mean sea level rise as much as 33 in. (85 cm.) is expected during the 21st century. Accelerated global sea-level rise is expected to have far-reaching and dramatic impacts in vulnerable regions of the Earth where subsidence and erosion challenges already exist. Rising seawaters are already submerging, for example, coastal wetlands and mangroves in southern Florida, and approximately one million acres of Louisiana wetlands have become open water since the mid 20th century.

Sea-level rise has the potential of causing increases in the intrusion of saltwater into coastal aquifers. Shallow islands, and coastal aquifers supporting human use (such as those in Long Island, New York, and central California) could be at greatest risk. Rising sea level has also contributed to increased mortality of trees in coastal areas of Louisiana and southern Florida, where saltwater has already intruded into the groundwater on which trees depend.

Other impacts associated with sea-level rise include changes in salinity distribution in estuaries, altered coastal circulation patterns, destruction of transportation infrastructure in low-lying areas, and increased pressure on coastal levee systems. Atlantic and Gulf Coast shorelines will be especially vulnerable to long-term sea-level rise, as well as any increase in the frequency of storm surges or hurricanes. Most erosion events on these coasts are the results of storms, and the slope of these areas is so vulnerable and gentle that a small rise in sea level may produce a large inland shift of the shoreline. This increases the threats to coastal development, transportation, freshwater aquifers, infrastructure, and fisheries. These impacts can adversely affect the quality of water resources. Moreover, the potential negative impli-

cations of climate change for water quality include reductions in stream flows, increased storm surges, and higher water temperatures. An increase in the number of intense precipitation days could lead to increases in the variety of agricultural and municipal polluting substances being washed into rivers, estuaries, streams, and lakes, and sea-level rise would contribute to saltwater intrusion into rivers, estuaries, and coastal aquifers.

FRESHWATER SUPPLY ISSUES

Global climate change will have major impacts on freshwater ecosystems. This will affect availability, as well as quality, distribution, and form. In certain regions, where stream flow and precipitation increase, flooding could threaten the structure and functions of aquatic systems, leading to increased pollution of freshwater ecosystems, especially in areas where human-mediated activities might have altered the landscape. The impacts of climate change on the Earth's freshwater resources have the potential of affecting international relations, especially at continental or country borders, where shared wetlands can generate local and international political and geographical disputes.

Impacts of climate change on water resources will have a wide range of consequences for coastal ecosystems. The health of the Earth's ecosystems will be affected by changes in the quality and quantity of freshwater runoff into coastal wetlands, higher water temperatures, extreme runoff rates or altered timing, and the ability of watersheds to assimilate pollutants and wastes.

Global climatic changes could pose a serious demand on the water supply. In most regions of the world where there are observed and projected declines in per capita average of annual freshwater availability, coupled with attendant population growth, the possibility of increased demand for water will likely lead to increased withdrawal of water, which will invariably reduce the recharging time of the water tables. These changes may influence a wide range of water-system components, including reservoir operations, water quality, hydroelectric generation, and navigation. In some regions, where large volumes of water are channeled for non-consumptive purposes such as agriculture demand, particularly for irrigation, water supply will be particularly sensitive to climate conditions;



Predicted mean sea-level rise of as much as 33 in. in the 21st century threatens fragile shorelines such as this one in Florida.

demand for irrigation water tends to increase as conditions become hotter and drier. A possible change in field-level climate may result in altering the timing of, and need for, irrigation.

In-stream water uses such as hydroelectric power generation, navigation, recreation, and ecosystem maintenance are also sensitive to changes in the quantity, quality, and timing of runoff stemming from greenhouse warming. Potential negative implications of climate change include reductions in dilution flows, increased storm surges, and higher water temperatures. Low flows in many rivers will lead to increases in salinity levels to downstream water users.

On the other hand, higher flows could help reduce some water quality concerns. Warmer water could threaten aquatic life directly, as cool-water habitats disappear, and indirectly, as dissolved oxygen levels decline with higher temperatures. An increase in days with more intense precipitation could increase the agricultural and urban pollutants washed into streams and lakes, further reducing oxygen levels. Heavy rainfall is primarily responsible for soil erosion, leaching of agricultural chemicals, and runoff of urban and livestock wastes and nutrients into water bodies.

CHANGING ECOSYSTEMS AND WEATHER

Another possible effect associated with climate change is the potential danger it holds for marine ecosystems. As the sea-level rises, coupled with increased warming of the ocean waters, marine biodiversity will be further threatened by the myriad impacts on all marine ecosystems, from tropical coral reefs (especially in

the Maldives), to polar ecosystems. Coral reefs are already under severe stress from human activities, and have experienced unprecedented increases in the extent of coral bleaching, emergent coral diseases, and widespread die-offs. Damages to coral reefs lead to depletion of important habitat for fish food.

Changes in ocean temperatures, currents, and net productivity will affect the distribution, abundance, assemblages, and productivity of marine populations, with unpredictable consequences to marine ecosystems and fisheries. As the Earth's surface temperature warms, species may either migrate to a cooler, more suitable habitat, or die. Species that are particularly vulnerable to climate change effects include polar animals, such as seals, penguins, and polar bears, coral reefs, and many other endangered animal and plant species.

Climate change has the potential to alter the hydrologic cycle. In many regions of the world, global climate change will have significant effects on precipitation and evapotranspiration. Heavier rainfall could lead to flooding in many regions as warmer temperatures speed up the hydrologic cycle. Flood frequencies in some areas are likely to change. In northern latitudes and snowmelt-driven basins, floods may become more frequent, although the increase in flooding for any given climate scenario is uncertain and impacts will vary among basins.

Over the past century, it is estimated that there has been a 5–10 percent increase in precipitation. Climate-induced changes in hydrology will affect the magnitude, frequency, and cost of extreme events, which have the greatest economic and social impact on humans. Flooding, the most costly and destructive natural disaster, is becoming a common and extreme event as a result of climate-induced variations. Severe weather events are becoming more common and extreme, as well.

Climate change researchers have indicated that the number and strength of anthropogenic-induced climate extreme events such as storms, hurricanes, typhoons, floods, and tornadoes have increased over the past 10–20 years. For example, a record breaking 28 tropical storms hit the United States in 2005, alone. All these phenomena are traceable to variations in radiative forcing brought about by anthropogenic GHGs in the atmosphere. Increases in precipitation and runoff are likely to intensify the stresses

on streams, lakes, bays, estuaries, and rivers in some regions of the world by strengthening the transport of nutrients and contaminants loading to coastal ecosystems. Higher latitudes are more likely to receive increased precipitation and runoff, while lower latitudes are more likely to experience decreased runoff.

Regions with snowfall, such as the Rocky Mountains and Sierra Nevada, California, will experience seasonal shifts in runoff, with increases in winter and early spring runoff, decreases in late spring and summer runoff, and possible increased flood intensities. The frequency and severity of droughts could increase in some areas as a result of a decrease in total rainfall, more frequent dry spells, and greater evapotranspiration.

HEALTH ISSUES

Several health challenges can be linked to global climate change. According to IPCC scientists, a climate-induced warmer world could lead to a number of health problems. These health challenges include increased global distribution of tropical diseases, such as malaria and dengue, heat stress, hunger-related ailments, and injuries and drowning associated with increased storm frequency and intensity.

Africa, for example, is expected to be at risk from increased incidence of vectorborne diseases. A warmer Africa has the potential of opening up new areas for malaria, and altered temperature and rainfall patterns in the continent could lead to increased incidence of yellow fever, dengue fever, onchocerciasis, and trypanosomiasis. In the Middle East and Asia, heat stress, which will affect human comfort levels, and the possible spread of vectorborne diseases will likely result from climate-induced changes. In general, decreases in freshwater availability would lead to indirect impacts on human health.

SEE ALSO: Climate; Climate Models; Diseases; Floods; Health; Hurricanes and Typhoons; Salinity; Sea Level, Rising; Weather.

BIBLIOGRAPHY. D.M. Allen, D.C. Mackie, and M. Wei, "Groundwater and Climate Change: A Sensitivity Analysis for the Grand Forks Aquifer, Southern British Columbia, Canada," *Hydrogeology Journal* (v.12/2, 2004); N.S. Christensen et al., "Effects of Climate Change on the Hydrology and Water Resources of the Colorado River Basin," *Climatic Change* (v.62/1–3, 2004); K.D. Frederick and P.H. Gleick,

Water and Global Climate Change: Potential Impacts on U.S. Water Resources (Pew Center on Global Change, 1999); J.T. Houghton, et al., eds., *Climate Change, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge University Press, 2001); Irin News, www.irinnews.org (cited July 2007); R.K. Mall et al., "Water Resources and Climate Change: An Indian Perspective," *Current Science* (v.90/12, 2006); K.L. Martinez and D.R. Maidment, *Assessing the Impacts of Climate Change on Water Resources for the Edwards Aquifer* (Center for Research in Water Resources, 1998); M.M.Q. Mirza, R.A. Warrick, and N.J. Ericksen, "The Implications of Climate Change on Floods of the Ganges, Brahmaputra and Meghna Rivers in Bangladesh," *Climate Change* (v.57/3, 2003).

NSIKAK BENSON
COVENANT UNIVERSITY

Climate Change Knowledge Network

THE CLIMATE CHANGE Knowledge Network (CCKN) was established in 1998, to enhance cooperation between developed and developing countries on research related to climate change. The network aims to make knowledge about climate change available to all countries of the world. The collaborative efforts encouraged by the network strive to disseminate knowledge on climate change and to make such knowledge relevant for the international policy process. The network includes 12 core member institutions in Senegal, Zimbabwe, the United States, Canada, Brazil, Argentina, China, India, Norway, the Netherlands, and Sweden. The governments of Canada, the United States, and Norway support its activities.

The aims of the network are to promote more sustainable and equitable climate change management through research and communication on issues such as the Kyoto Protocol, to develop a dialogue between developed and developing countries for a better understanding of the global effects of climate change, and to help each member institution to increase its capacity to propose regional policies about climate change. The network promotes international negotiations that make explicit connections between