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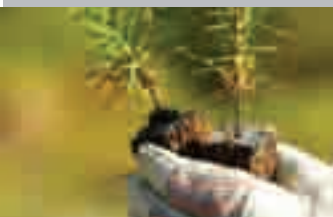
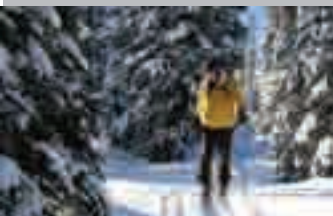
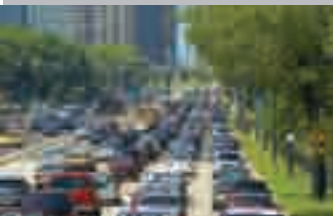
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Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems

Final Report, Synthesis and Assessment Product 4.6
Report by the U.S. Climate Change Science Program
and the Subcommittee on Global Change Research

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July 2008

Members of Congress:

On behalf of the National Science and Technology Council, the U.S. Climate Change Science Program (CCSP) is pleased to transmit to the President and the Congress this Synthesis and Assessment Product (SAP), *Analyses of the Effects of Global Change on Human Health and Welfare and Human Systems*. This is part of a series of 21 SAPs produced by the CCSP aimed at providing current assessments of climate change science to inform public debate, policy, and operational decisions. These SAPs are also intended to help the CCSP develop future program research priorities. This SAP is issued pursuant to Section 106 of the Global Change Research Act of 1990 (Public Law 101-606).

The CCSP's guiding vision is to provide the Nation and the global community with the science-based knowledge needed to manage the risks and capture the opportunities associated with climate and related environmental changes. The SAPs are important steps toward achieving that vision and help to translate the CCSP's extensive observational and research database into informational tools that directly address key questions being asked of the research community.

This SAP focuses on the effects of global change on human health and welfare and human systems. It was developed with broad scientific input and in accordance with the Guidelines for Producing CCSP SAPs, the Federal Advisory Committee Act, the Information Quality Act, Section 515 of the Treasury and General Government Appropriations Act for fiscal year 2001 (Public Law 106-554), and the guidelines issued by the Environmental Protection Agency pursuant to Section 515.

We commend the report's authors for both the thorough nature of their work and their adherence to an inclusive review process.

Sincerely,

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This report has been peer reviewed in draft form by individuals identified for their diverse perspectives and technical expertise. The expert review and selection of reviewers followed the Office of Management and Budget's Information Quality Bulletin for Peer Review. The purpose of this independent review is to provide candid and critical comments that will assist the Climate Change Science Program in making this published report as sound as possible and to ensure that the report meets institutional standards. The peer review comments, draft manuscript, and response to the peer review comments are publicly available at: www.climatechange.gov/Library/sap/sap4-6/default.php.

Environmental Protection Agency Internal Reviewers

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Finally, we are indebted to the thoughtful review provided by a Federal Advisory Committee convened by the U.S. Environmental Protection Agency to provide an independent expert review of the SAP 4.6. The HICCAC panel met in October 2007 to discuss their findings and recommendations for the report. Following extensive revisions to the report, the HICCAC reconvened by teleconference in January 2008 to review the authors' response to comments. The panel's review of the report has contributed to a markedly improved document.

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Summary

It has been an honor and a pleasure to work with all of the people named above as well as the many colleagues we have encountered in the process of preparing this report. We hope that this document will be a positive step forward in our efforts to assess the impacts of climate change on human systems and to evaluate opportunities for adaptation.

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For Chapter 2:

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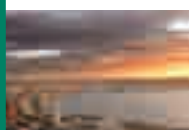
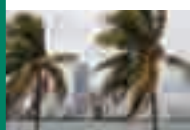
Wilbanks, T.J., P. Kirshen, D. Quattrochi, P. Romero-Lankao, C. Rosenzweig, M. Ruth, W. Solecki, and J. Tarr, 2008: Effects of Global Change on Human Settlements. In: Analyses of the effects of global change on human health and welfare and human systems. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Gamble, J.L. (ed.), K.L. Ebi, F.G. Sussman, T.J. Wilbanks, (Authors)]. U.S. Environmental Protection Agency, Washington, DC, USA, p. 89–109.

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