

# Aerosol Properties and Their Impacts on Climate

U.S. Climate Change Science Program (CCSP)  
5-Year Assessment Review

Synthesis and Assessment Product 2.3



# TABLE OF CONTENTS

<b>Executive Summary</b> .....	iii
--------------------------------	-----

## **Chapter I. Introduction**

1.1 Description of atmospheric aerosols.....	1
1.2 Climate effects of aerosols .....	2
1.2.1. Direct and indirect effects .....	3
1.2.2. Anthropogenic aerosol climate forcing.....	4
1.3 Reducing uncertainties in estimating aerosol climate effects.....	5
1.3.1. Synergy between observations and model.....	5
1.3.2. Estimates of emissions.....	6
1.3.3. Aerosol representation in GCMs .....	7
1.4 Contents of this report .....	8
<b>Inset 1:</b> Atmospheric and aerosol properties .....	10
<b>Inset 2:</b> Molecular and aerosol light interaction.....	11
<b>Inset 3:</b> Key properties in aerosol radiative forcing.....	12
<b>References</b> .....	13

## **Chapter II. In-Situ and Remote Sensing Measurements of Aerosol Properties, Burdens, and Radiative Forcing**

2.1 Introduction .....	18
2.2 Overview of aerosol measurement capabilities .....	18
2.2.1. Intensive field campaigns .....	18
2.2.2. Ground-based remote sensing and in-situ measurement networks.....	21
2.2.3. Satellite remote sensing.....	23
2.2.4. Synergy of measurements and model simulations.....	28
2.3 Assessments of aerosol characterization and climate forcing.....	29
2.3.1. The use of regional aerosol chemical and optical properties to improve model estimates of DRE and DCF...30	
2.3.2. Intercomparisons of satellite measurements and model simulation of aerosol optical depth.....	35
2.3.3. Remote sensing based estimates of aerosol direct radiative effect.....	37
2.3.4. Satellite based estimates of anthropogenic aerosol direct climate forcing.....	44
2.3.5. Remote sensing studies of aerosol-cloud interactions and indirect effects .....	46
2.4 Outstanding issues .....	48
2.4.1. Aerosol vertical distribution .....	48
2.4.2. Aerosol direct forcing over land .....	49

2.4.3. Aerosol absorption.....	49
2.4.4. Diurnal cycle.....	51
2.4.5. Aerosol-cloud interactions and indirect forcing .....	51
2.4.6. Long-term trends of aerosols and radiative fluxes .....	52
2.5 Concluding remarks .....	53
<b>References</b> .....	55
<b>Acronyms and Symbols</b> ..	71

### **Chapter III. Modeling the Effects of Aerosols on Climate**

3.1 Introduction.....	75
3.1.1. Calculating aerosol radiative forcing.....	76
3.1.2. Modeling aerosol direct radiative forcing.....	77
3.1.3. Modeling the aerosol indirect effect.....	82
3.2 Comparison of aerosol direct effect in observations and GCMs.....	84
3.2.1. The GISS model.....	84
3.2.2. The GFDL model.....	92
3.2.3. Model intercomparisons.....	94
3.2.4. Additional considerations.....	98
3.3 Comparison of the aerosol indirect effect in GCMs.....	100
3.3.1. Aerosol effects on clouds and radiation.....	100
3.3.2. Additional aerosol influences .....	104
3.3.3. Results based on high resolution modeling of aerosol- cloud interactions .....	104
3.4 Impacts of aerosols on model climate simulations .....	107
3.5 Implications of comparisons of modeled and observed aerosols for climate model simulations.....	110
<b>References</b> .....	110
<b>Appendix A.1</b> .....	115
<b>Appendix A.2</b> .....	117
<b>Appendix A.3</b> .....	120

### **Chapter IV. Way Forward**

4.1 Introduction.....	123
4.2 Requirements for future research – observations.....	124
4.2.1. In-situ measurements of aerosol properties and processes ..	124
4.2.2. Laboratory studies of aerosol evolution and properties .....	125
4.2.3. Surface- and satellite-based remote sensing.....	125
4.3 Requirements for future research - modeling .....	129
4.3.1. Required modeling improvements .....	129
4.3.2. Aerosol-climate modeling: the way forward .....	131
4.4 Concluding remarks .....	132
<b>References</b> .....	133