The Future of Atmospheric Chemistry Research

Remembering Yesterday, Understanding Today, Anticipating Tomorrow

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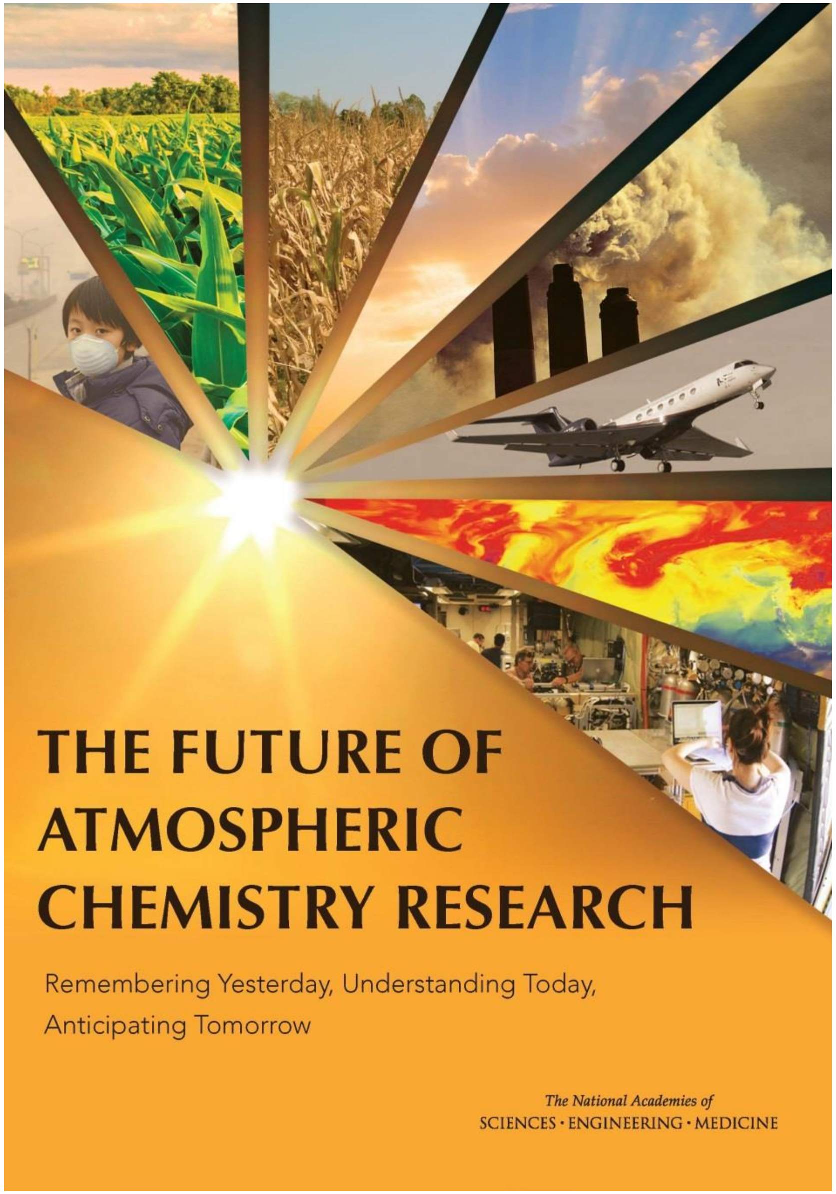

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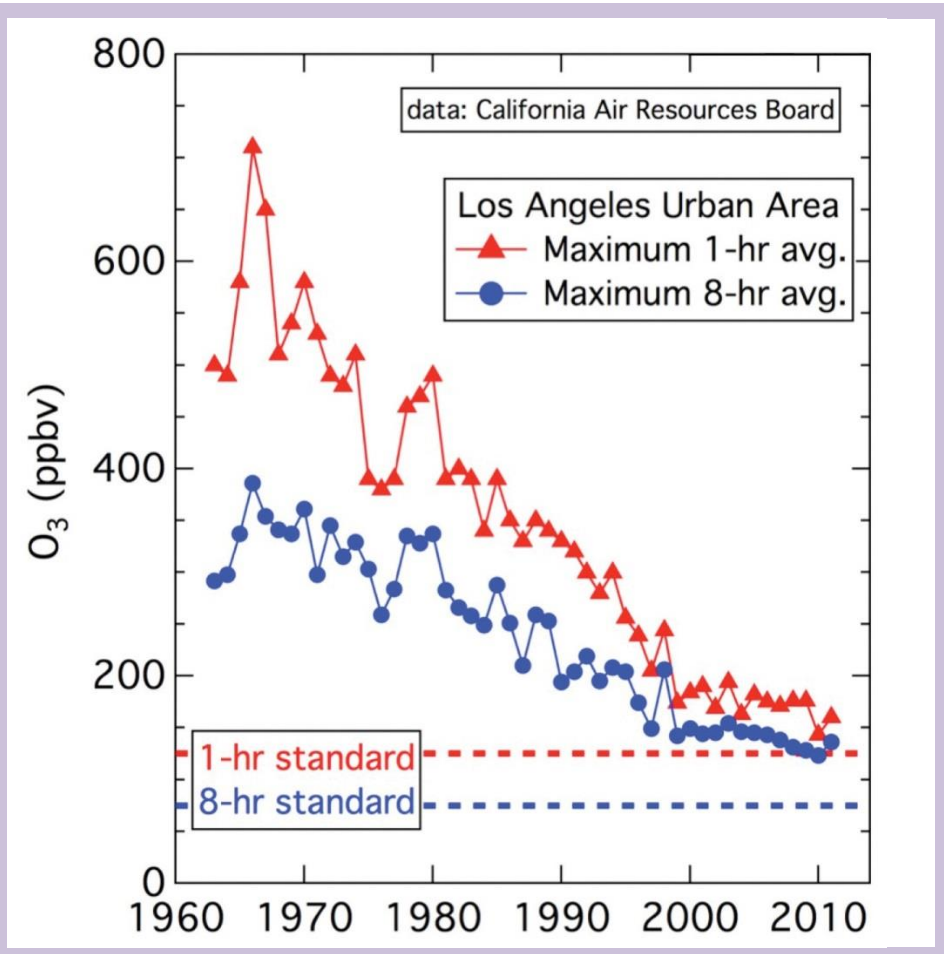
Atmospheric Chemistry Research

- Field of atmospheric chemistry research
  - Chemical composition of the atmosphere
  - Chemical transformations within the atmosphere
  - Exploring how air composition responds to human and natural inputs
- Atmosphere – “common air that bathes the globe”

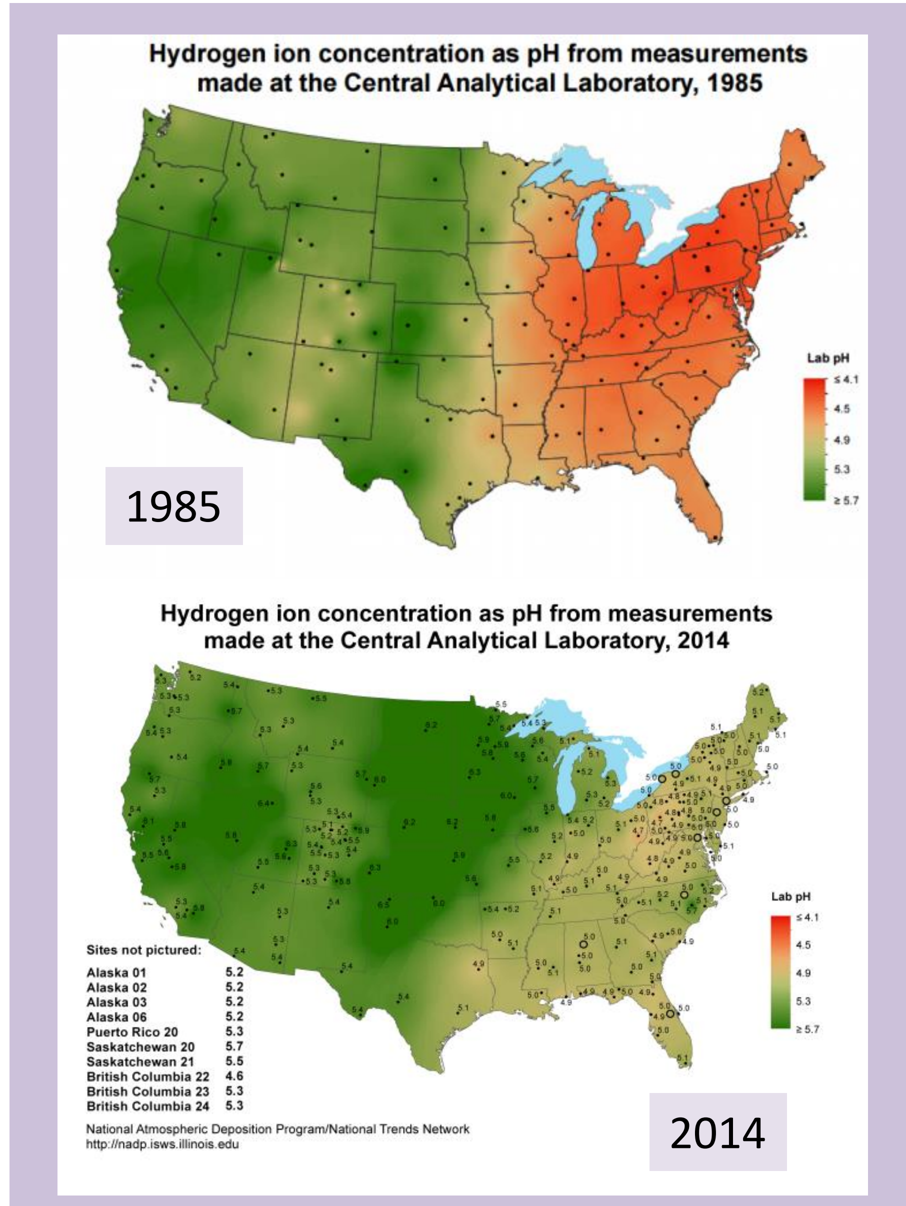
Success Story: Urban Smog

- Urban air pollution pervasive problem by mid-20th century
- Scientists determined vehicle emissions were major contributor
  - Photolysis of mixture of hydrocarbons and nitrogen oxides → ozone
- Scientific understanding helped inform policy decisions
  - Clean Air Act and amendments
- Decreased levels of air pollutants in many areas



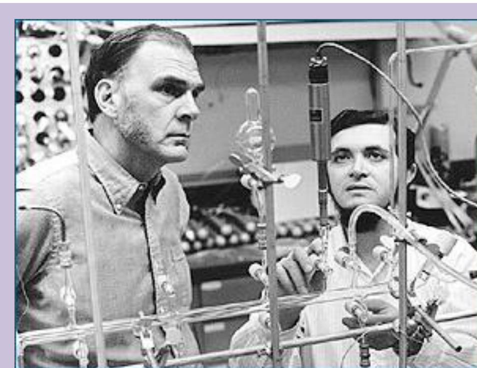
Success Story: Acid Deposition

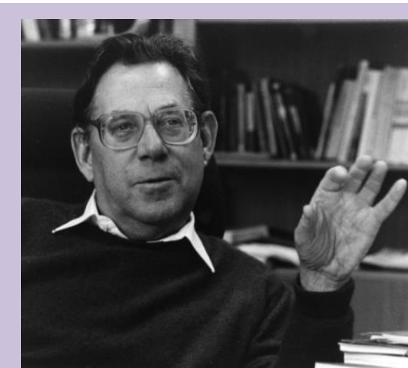
- Crop damage, “dead” lakes, etc. observed in mid-20th century
- Scientists determined nitrogen and sulfur oxides from power plants lead to “acid rain”
- Scientific understanding helped inform policy decisions
  - Clean Air Act led to reduced NOx and SOx
- Less acid deposition across US

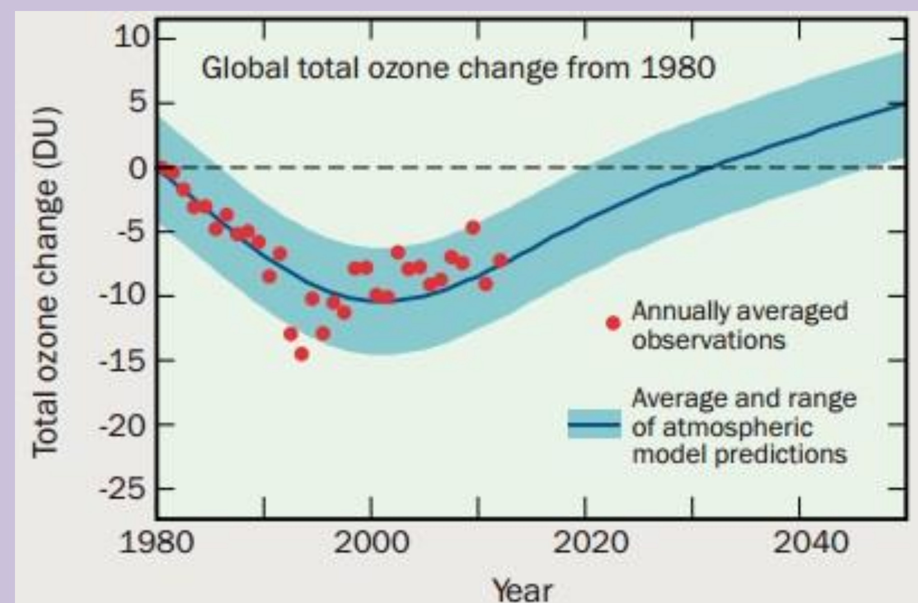


Success Story: Stratospheric Ozone

- Decreasing ozone leads to more skin cancer
- Scientists determined CFCs were source of chlorine to stratosphere
- Predictive modeling helped inform policy decisions
  - Montreal Protocol (1987) phased out CFCs
- Ozone layer now healing







Predictive Capability

Similar pattern to past examples

- Identify impacts of particular human activities
- Conduct fundamental research to understand drivers
- Integrate physical understanding with outcomes of potential policies into predictive framework
- Synthesize research for policy makers
  - Provide basis for informed choices

Predictive capability key step for science to inform policy choices

Examples

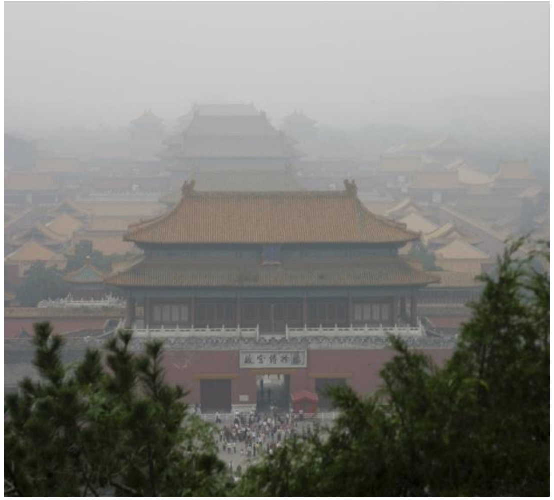
Understanding of acid chemistry allowed prediction that reducing NOx and SOx emissions from coal plants would reduce acid deposition

Integration of laboratory results into numerical models showed that reducing CFCs would reduce stratospheric ozone depletion

Atmospheric Chemistry Research Important to Today's Challenges

Examples

- Air quality in developing world
- Vehicle emissions
- Changing mix of energy sources



Need for improved predictive capability for new challenges

Changing World, Changing Atmosphere

- Global human population has grown
  - 6.1 billion to 7.1 billion in last 15 yrs
- 50%+ of population now lives in urban areas
- Increasing energy demands, industrial activities, and intensification of agricultural activities
  - →Rapidly changing emissions
  - →Enormous changes to Earth's atmosphere

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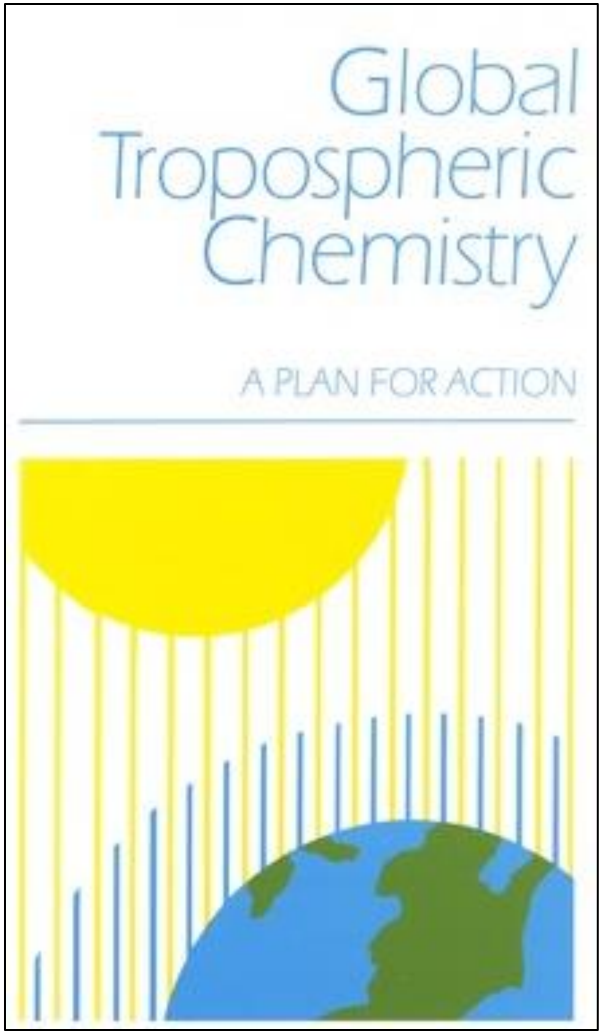
Progress in Last Three Decades

- Last comprehensive review of atmospheric chemistry in 1984
  - Focus of field expanded from local air quality issues to global atmospheric chemistry
- Continued growth of field in intervening decades
- **Atmospheric Chemistry has become a robust scientific discipline**



This Study

- Sponsored by NSF Atmospheric Chemistry Program
- To identify priorities and strategic steps for atmospheric chemistry research in the next decade

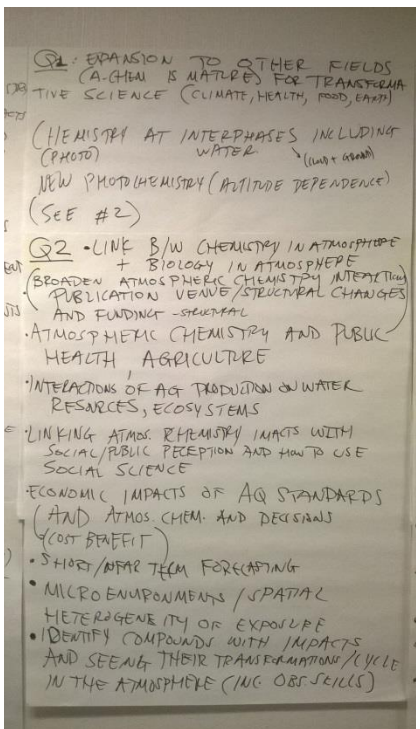
Committee's Task

- Rationale and need for supporting a comprehensive U.S. research program in atmospheric chemistry
- Commentary on the broad trends in laboratory, field, satellite, modeling studies, and applications
- Priority areas for advancing science
- Analysis of research infrastructure needed

Committee Roster

- **Robert A. Duce (co-chair),** Texas A&M University-College Station
- **Barbara J. Finlayson-Pitts (co-chair),** UC Irvine
- **Tami Bond,** UI Urbana-Champaign
- **William H. Brune,** Penn State
- **Annmarie Carlton,** Rutgers
- **Allen H. Goldstein,** UC Berkeley
- **Colette L. Heald,** MIT
- **Scott C. Herndon,** Aerodyne Research, Inc.
- **Dylan Jones,** University of Toronto
- **Athanasios Nenes,** Georgia Tech
- **Kimberly A. Prather,** UC San Diego
- **Michael J. Prather,** UC Irvine
- **Allison Steiner,** University of Michigan
- **Christine Wiedinmyer,** National Center for Atmospheric Research,
- **Lei Zhu,** New York State Department of Health

Committee Process



- Community input
  - 5 town hall meetings
  - Online questionnaire
  - Input from > 250 people
- Deliberations
  - 6 in-person meetings
- Rigorous review
  - 14 outside experts

Committee developed:
- **Priority Science Areas**
- **Programmatic Recommendations**

Priorities and Recommendations

- **Priority Science Areas**
  - **Fundamental Atmospheric Chemistry**
    - **Develop a predictive capability for distributions, reactions, lifetimes**
    - **Quantify emissions and removal**
  - **Societal Challenges**
    - Improve climate modeling and weather forecasting
    - Elucidate role of atmospheric chemistry in human health impacts
    - Understand feedbacks with natural and managed ecosystems

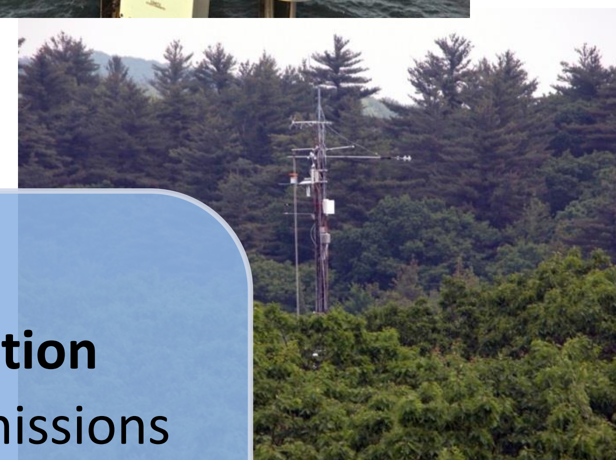
Priority Science Area 1:
Advance the fundamental atmospheric chemistry knowledge that enables predictive capability for the distribution, reactions, and lifetimes of gases and particles

Key Science Gaps

- Quantify reaction rates and understand **detailed chemical mechanisms**
- Quantify atmospheric **oxidants**
- Develop stronger understanding of **heterogeneous chemistry**
- Understand **tropospheric distributions** → coupling between chemistry and meteorology
- Understand **stratospheric distributions** → coupling between chemistry, dynamics, and radiation

Priority Science Area 2:

Quantify emissions and deposition of gases and particles in a changing Earth system



Key Science Gaps

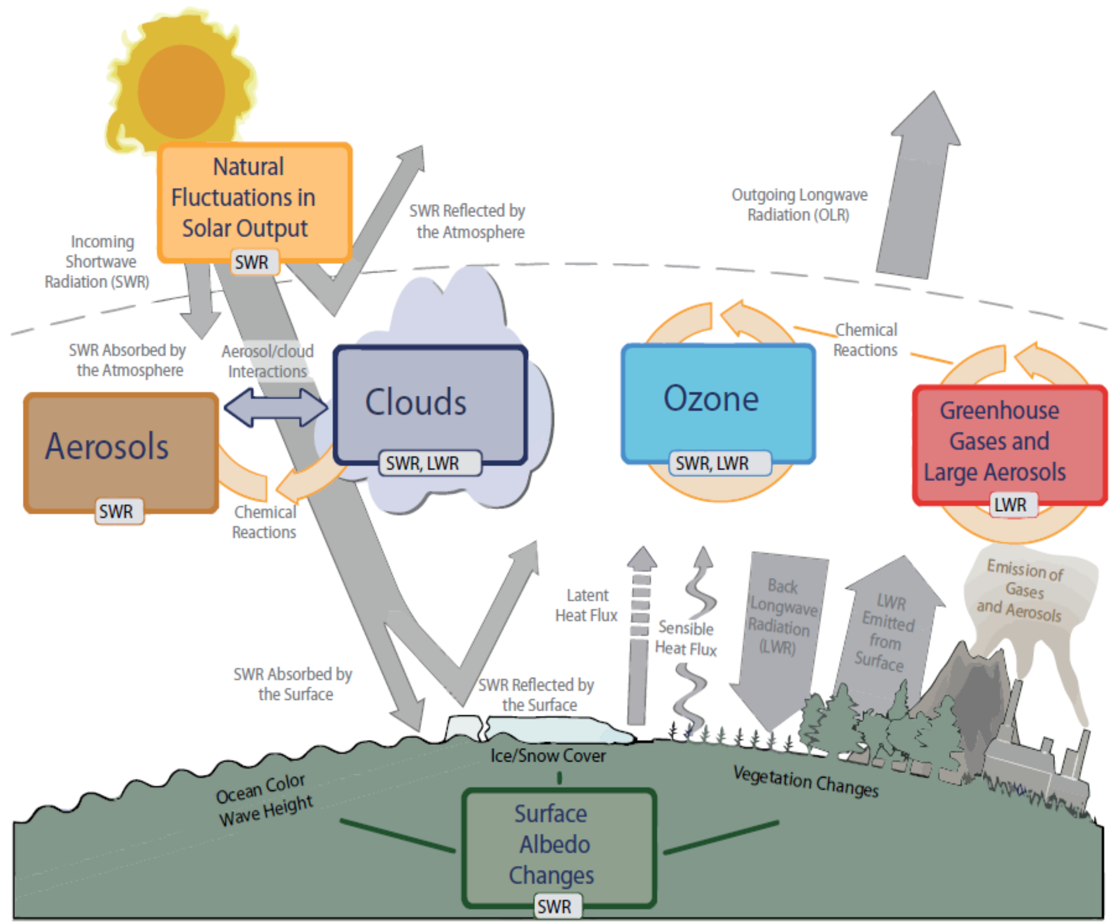
- Better define **emissions**
- Measure rates for **wet and dry deposition**
- Determine **role of meteorology** on emissions and deposition
- Determine **role of global change** and societal choices on emissions and deposition
  - Climate change, energy choices, land use

Priorities and Recommendations

- **Priority Science Areas**
  - Fundamental Atmospheric Chemistry
    - Develop a predictive capability for distributions, reactions, lifetimes
    - Quantify emissions and removal
  - **Societal Challenges**
    - **Improve climate modeling and weather forecasting**
    - **Elucidate role of atmospheric chemistry in human health impacts**
    - **Understand feedbacks with natural and managed ecosystems**

PSA 3: Atmospheric Gases and Particles Affect Climate and Weather

- Greenhouse gases and aerosol particles
  - Aerosols and clouds key uncertainty in climate and weather models
- Droughts, heat, cyclones, floods cost $billions



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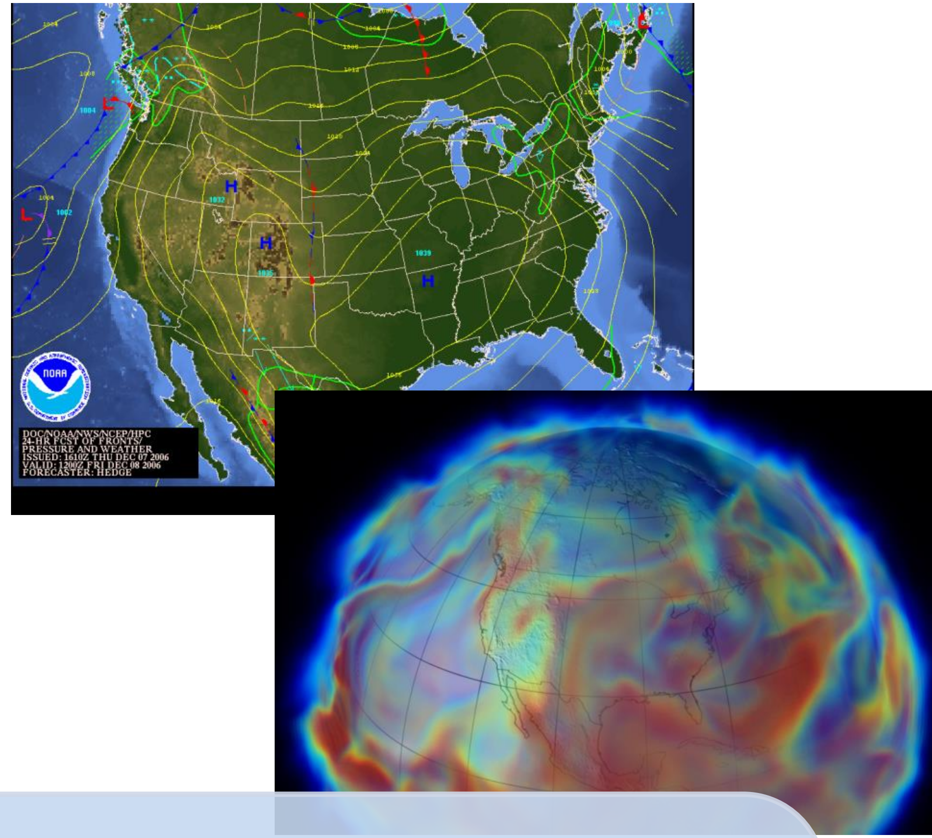
Priority Science Area 3:

Advance the integration of atmospheric chemistry within weather and climate models to improve forecasting in a changing Earth system



Key Science Gaps

- Determine global **distributions** of climate-relevant gases and aerosols
- Understand aerosol particles influence on **cloud microphysics** and precipitation efficiency
- Represent chemical and physical evolution of atmospheric constituents in climate and weather **models**

PSA 4: Atmospheric Chemistry Affects Human Health

More than 13,000 excess deaths in London smog of 1952

- 1 out of 8 deaths globally caused by air pollution
  - 3.3 million premature deaths/yr
- Gaseous pollutants
  - Carbon monoxide, nitrogen oxides, sulfur dioxide, ozone
- Particulate matter

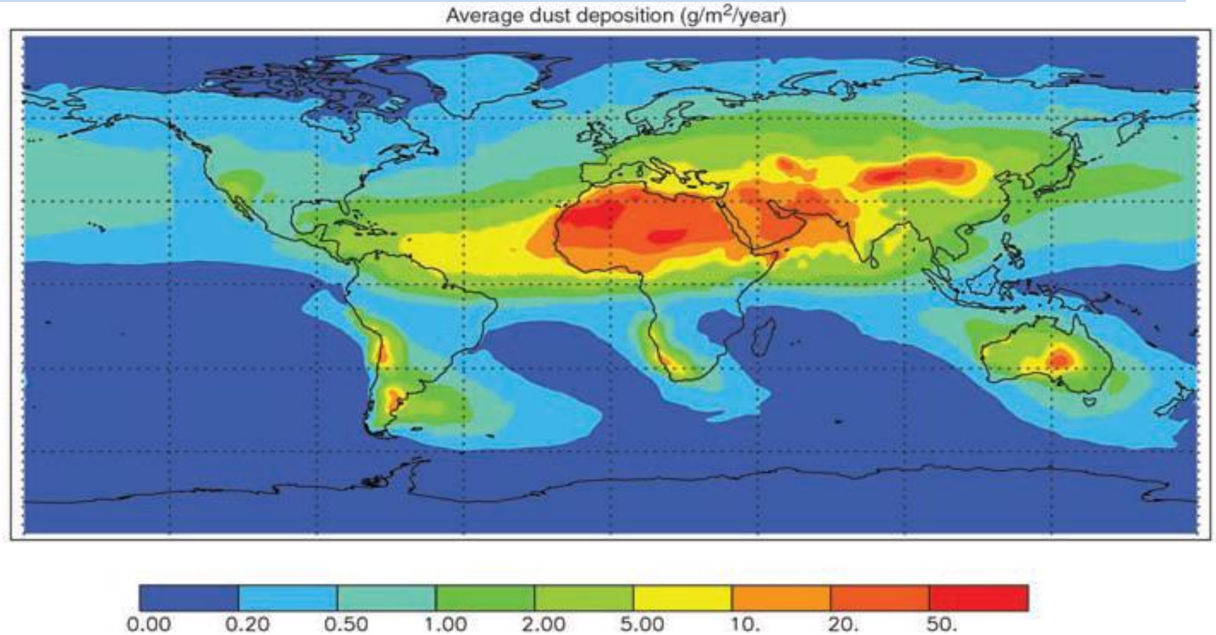
Priority Science Area 4:

Understand the sources and atmospheric processes controlling the species most deleterious to human health

Key Science Gaps

- Understand **composition and transformations** of species that impact human health
- Quantify **distribution** of atmospheric constituents that impact human health
- Determine unique sources and chemical reactions in **indoor environments**

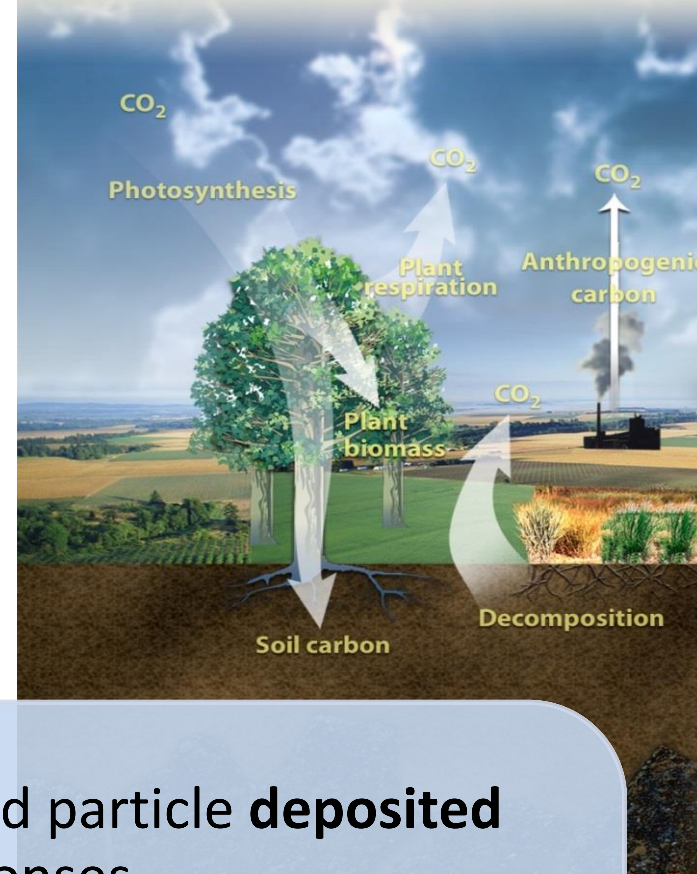
PSA 5: Atmospheric Chemistry Interacts with Natural and Managed Ecosystems



- Ecosystems rely on the atmosphere for uptake of carbon, oxygen, nitrogen; emit gases and particles
- Changes in atmospheric chemistry affect health of forests, agricultural lands, and oceans

Priority Science Area 5:

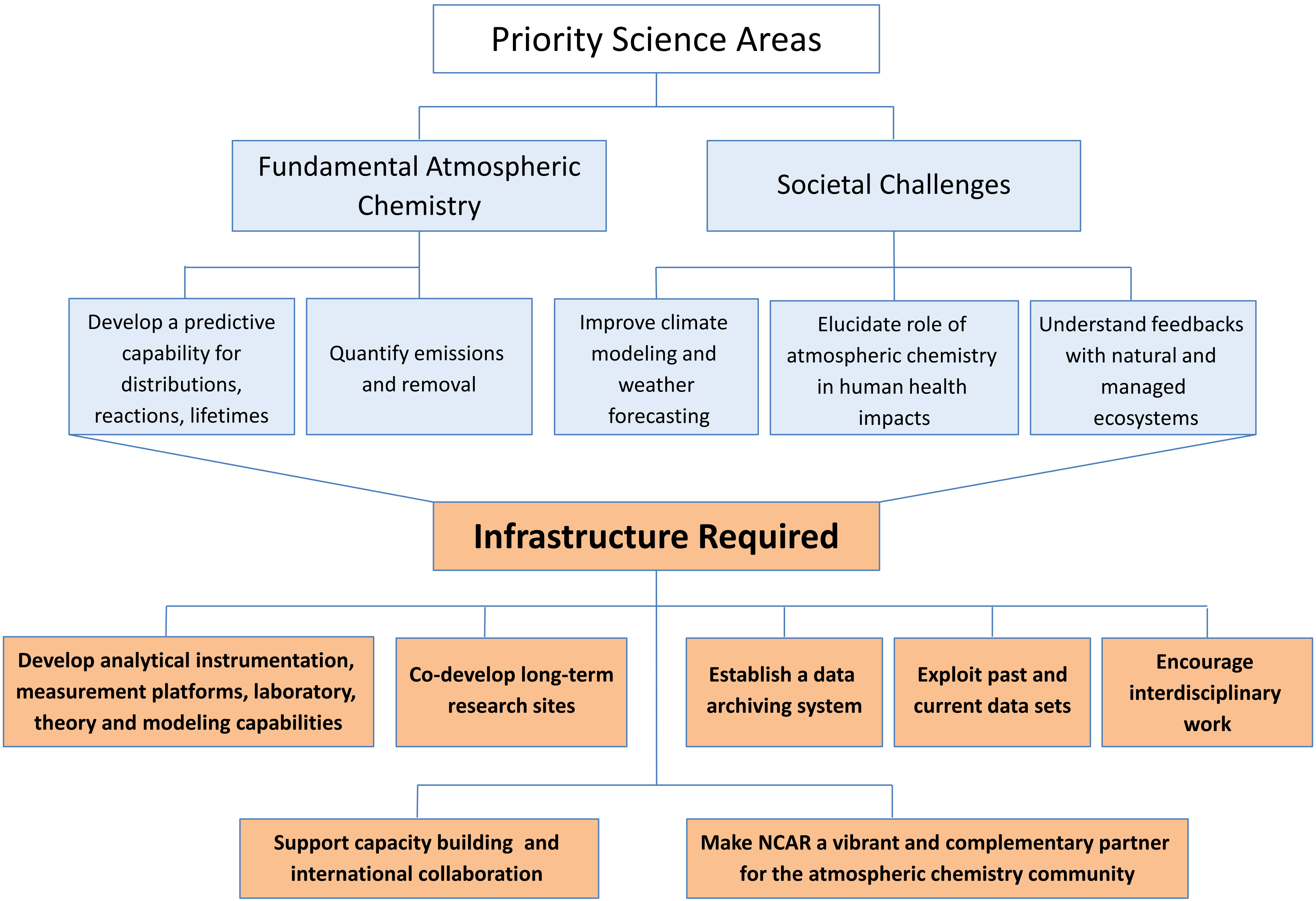
Understand feedbacks between atmospheric chemistry and biogeochemistry of natural and managed ecosystems



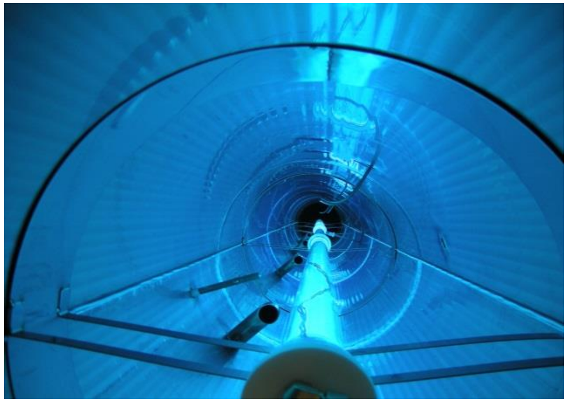
Key Science Gaps

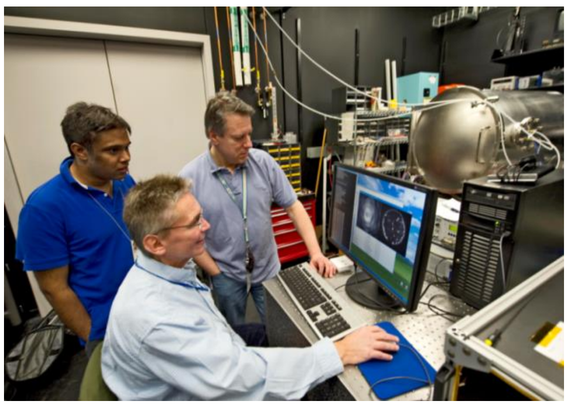
- Quantify suite of trace gases and particle **deposited** and connect to ecosystem responses
- Quantify composition, transformations, bioavailability, and transport of **nutrients and contaminants**
- Identify **feedbacks** between atmospheric chemistry and biosphere

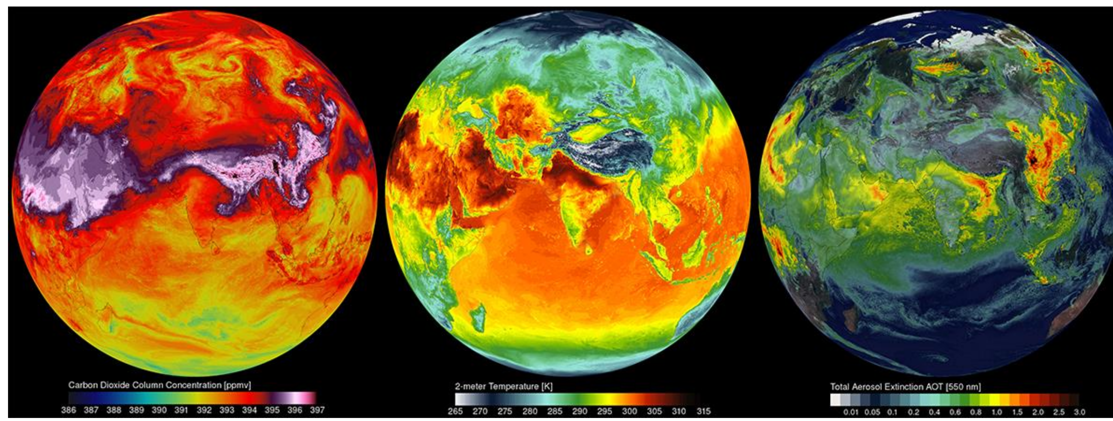
Priorities and Recommendations



Develop Tools





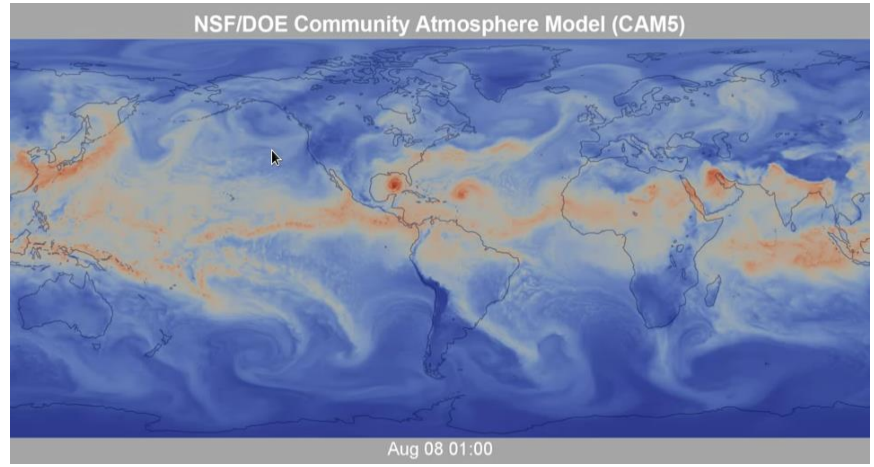


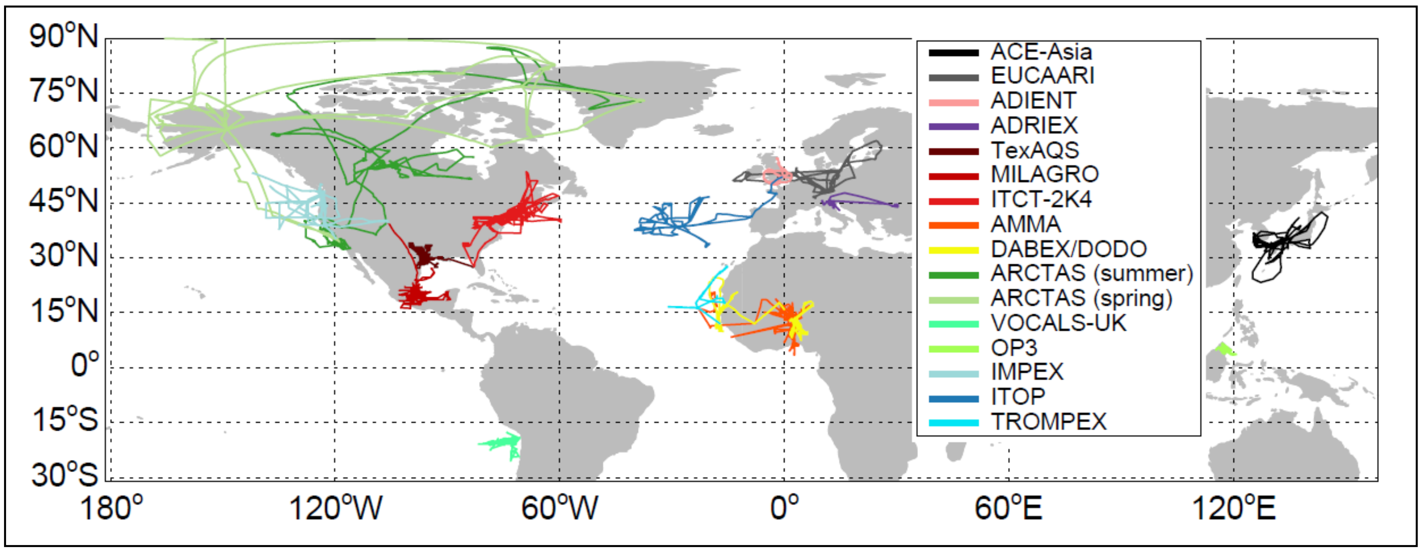
***Recommendation 1:* NSF should ensure adequate support for the development of the tools necessary to accomplish the scientific goals for the atmospheric chemistry community, including the development of new laboratory and analytical instrumentation, measurement platforms, and modeling capabilities**

Co-develop Long-term Research Sites

***Recommendation 2:* NSF should take the lead in coordinating with other agencies to identify the scientific need for long-term measurements and to establish synergies with existing sites that could provide core support for long-term atmospheric chemistry measurements, including biosphere-atmosphere exchange of trace gases and aerosol particles**

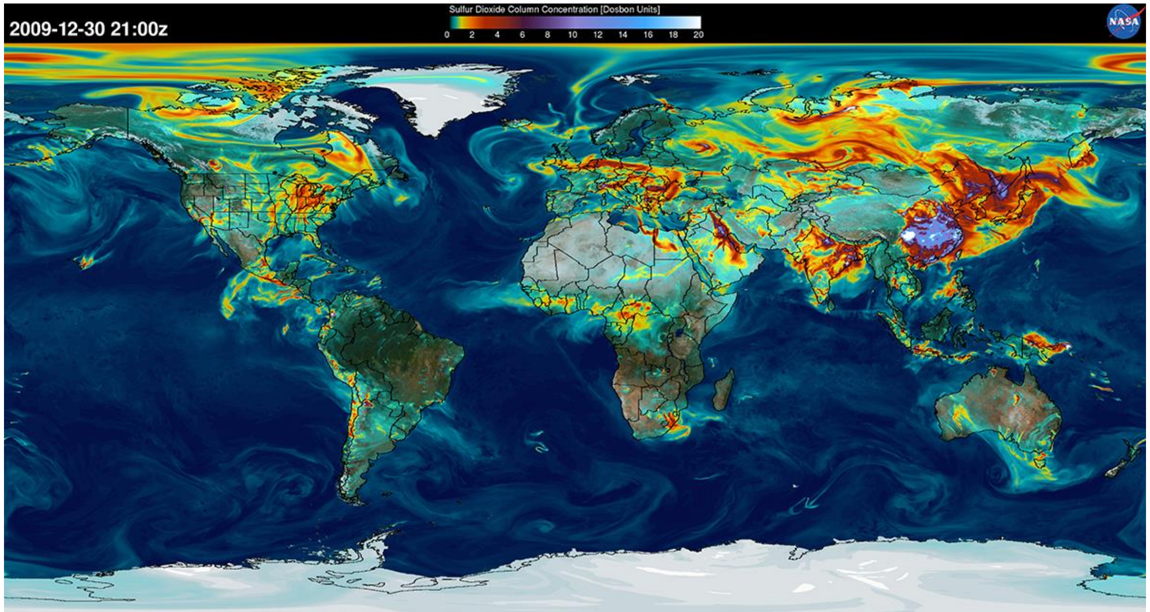
Exploit Past and Current Data Sets





***Recommendation 3:* NSF should encourage mining and integration of measurements and model results that can merge and exploit past datasets to provide insight into atmospheric processes, as well as guide planning for future studies**

Establish a Data Archiving System



Recommendation 4: NSF should establish a data archiving system for NSF-supported atmospheric chemistry research and take the lead in coordinating with other federal and possibly state agencies to create a comprehensive, compatible, and accessible data archive system

Encourage Interdisciplinary Work

***Recommendation 5:* NSF should improve opportunities that encourage interdisciplinary work in atmospheric chemistry and facilitate integration of expertise across disciplines and across academia, institutes, government, and industry. This improvement may include support of focused teams and virtual or physical centers of sizes appropriate to the problem at hand**

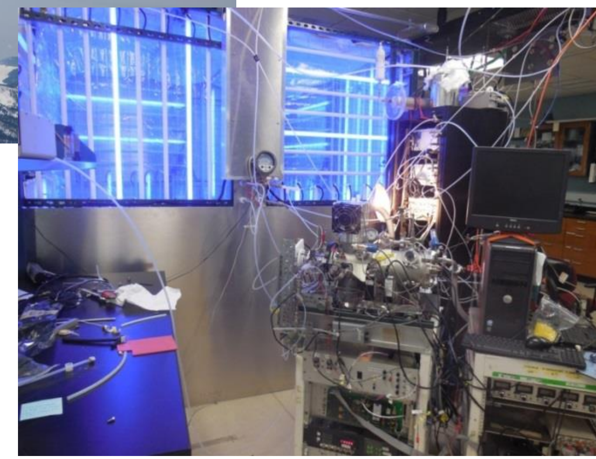
Capacity Building & International Collaboration

INTERNATIONAL GLOBAL IGAC ATMOSPHERIC CHEMISTRY

Recommendation 6: NSF, in coordination with other agencies, should continue to encourage and support U.S. scientists involved in atmospheric chemistry research to engage with underserved groups, in capacity building activities, and in international collaborations

Make NCAR Vibrant and Complementary Partner for Atmospheric Chemistry Community

National Center for Atmospheric Research



Recommendation 7: NCAR, in conjunction with NSF, should develop and implement a strategy to make NCAR a vibrant and complementary partner with the atmospheric chemistry community. This strategy should ensure that scientific leadership at NCAR has the latitude to set an energizing vision with appropriate personnel, infrastructure, and allocation of resources; and that the research capabilities and facilities at NCAR serve a unique and essential role to the NSF atmospheric chemistry community

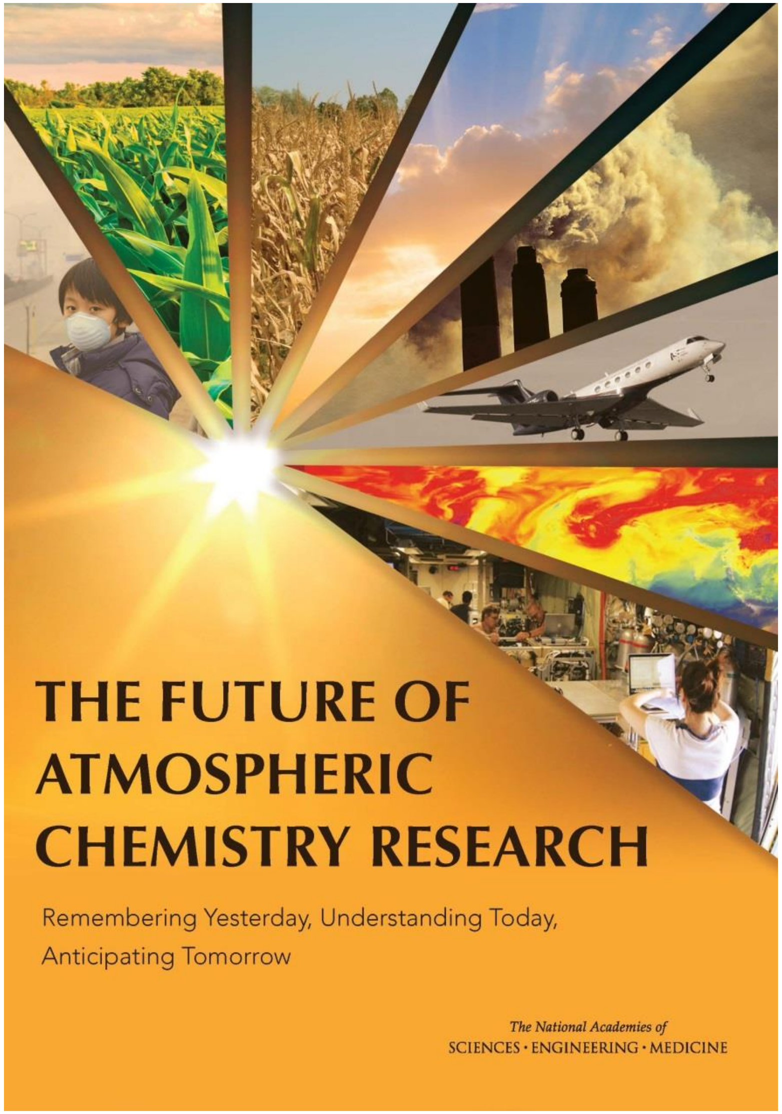
Conclusion

- Atmospheric chemistry has become a robust scientific discipline
  - Building on history of success
- Shift to full embrace of dual role
  - Fundamental understanding of Earth system
  - Advance research key to address challenges affecting society – climate change, health of humans and ecosystems
- Predictive capability is key step

Atmospheric chemistry research alone will not solve these challenges, but they will not be solved without atmospheric chemistry research

Acknowledgments

- NSF
- Committee
- Reviewers
- Academies Staff
- Numerous colleagues consulted during study
  - NOAA, NASA, EPA, DOE
  - Town hall participants
  - Questionnaire respondents



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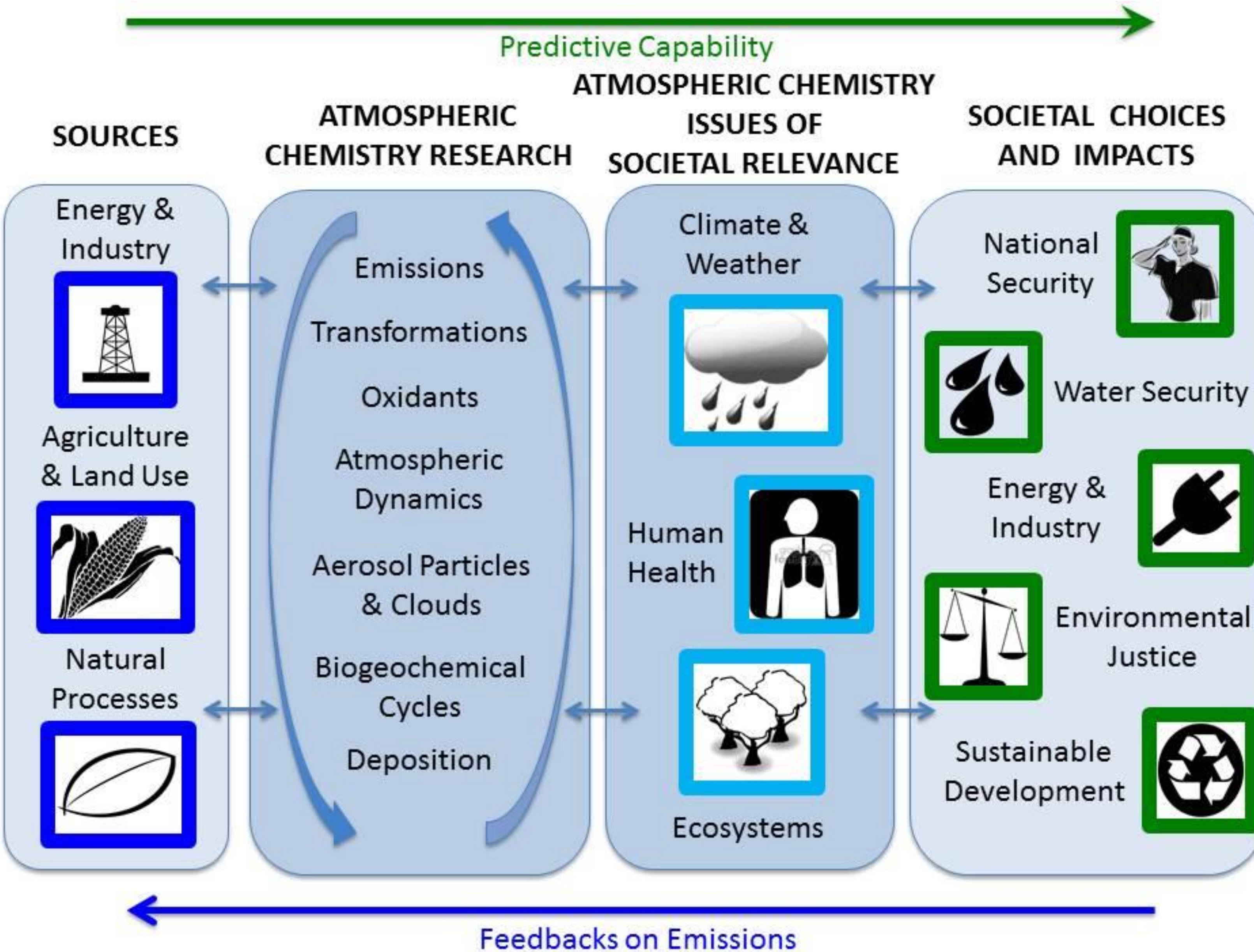
Extra Slides

Developing Predictive Capability



Statement of Task

An ad hoc committee will identify priorities and strategic steps forward for atmospheric chemistry research for the next decade, in the context of the current state of knowledge, ongoing research activities, and resource availability. The Committee will report a compelling research strategy and identify where additional investments in research infrastructure could best advance scientific understanding. The report will include the following elements:

- A brief summary of the rationale and need for supporting a comprehensive U.S. research program in atmospheric chemistry, including how research in this area contributes to advancing our understanding of climate change, air quality, the carbon and nitrogen cycles, the energy and water cycles, and the overall role of the atmosphere in Earth system science.
- A commentary on the broad trends in laboratory, field, satellite, and modeling studies of atmospheric chemistry, as well as application of atmospheric chemistry knowledge that may influence the overall field of Earth Sciences in the coming decade. [Continued…]

Statement of Task (cont.)

- A determination of the priority areas of research for advancing the basic science of atmospheric chemistry over the coming decade. In prioritization, the Committee should consider the need for a balance among laboratory studies, field campaigns, modeling efforts, and instrument development. The Committee is requested to provide research areas/topics sorted by their prioritization, and to explain how the priorities were developed.
- An analysis of the research infrastructure needed to address the priority research topics identified in the preceding point and identification of the highest priority needs for improvements in this infrastructure. This analysis will include an assessment of the need for new measurement technologies, observational platforms, and major infrastructure investments in atmospheric chemistry over the next decade.

The Committee's report should incorporate input from the broader atmospheric chemistry research community, including scientists working in academia, government, and private sector. The Committee should consider how the proposed research agenda relates to the broader federal agency and international context for atmospheric chemistry, but focus on those activities that might best be supported by the National Science Foundation. The Committee should not make specific budget recommendations, but should comment generally on budget implications as part of determining priority areas for research.

Core Areas of Atmospheric Chemistry

- Influence of humans on atmosphere
  - **Emissions**
- Fundamental elements of predictive capability – determine distribution, transport, and fate of chemicals
  - **Transformations**
  - **Oxidants**
  - **Atmospheric dynamics**
- Connecting atmospheric chemistry to other physical systems
  - **Clouds and aerosols**
  - **Biogeochemical cycles**

Community Input Gathering

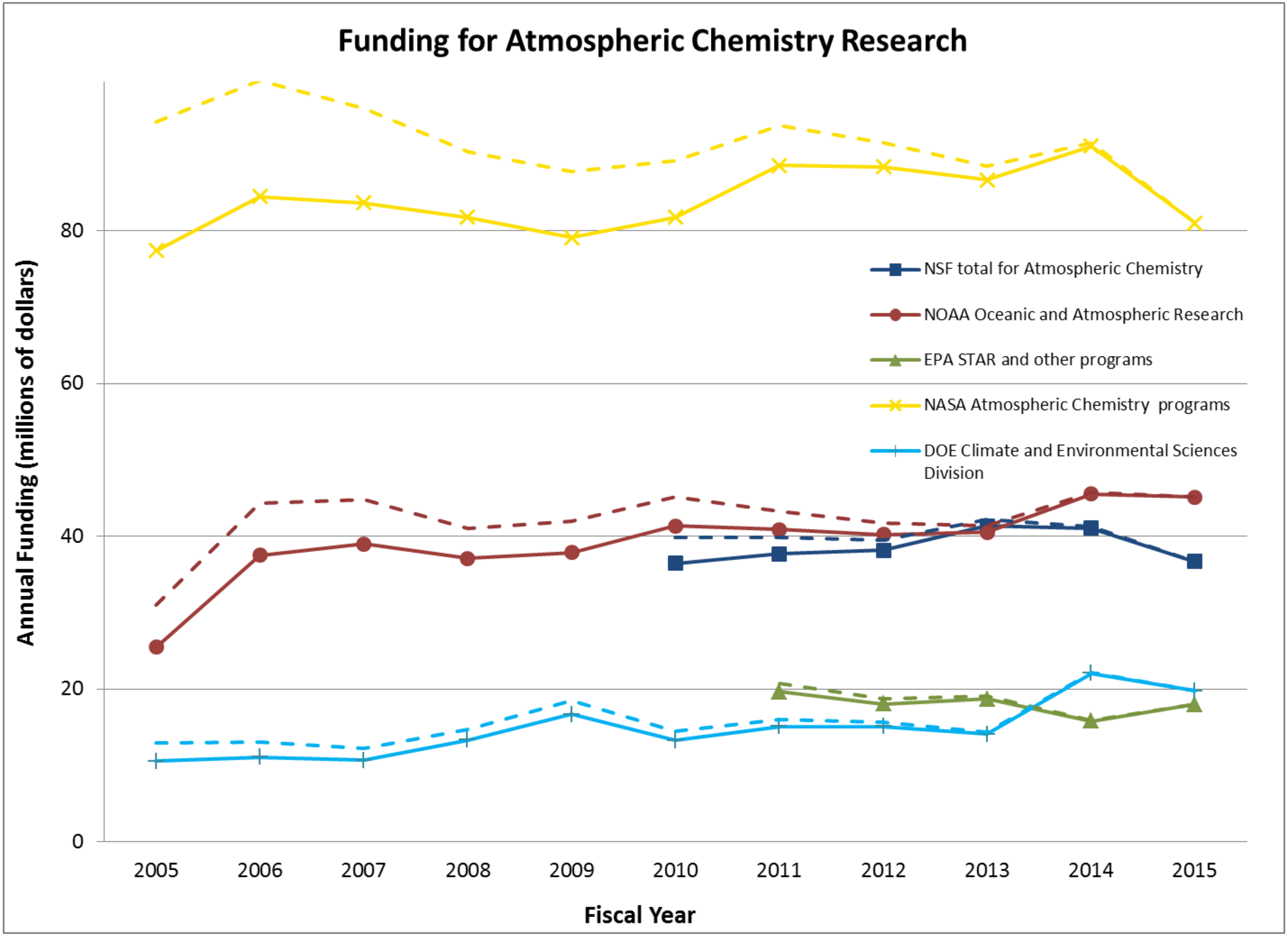
- What are the important areas of scientific research that could transform the understanding of atmospheric chemistry over the coming decade?
- What research linkages of atmospheric chemistry with other disciplines as well as with national or international research portfolios could produce transformational science over the next decade?
- How can advances in atmospheric chemistry, either alone or in tandem with other disciplines, play a critical role in addressing major societal challenges over the next decade?
- What infrastructure, new approaches, or other community capabilities, need to be maintained or developed to support advances in these topics? (You might consider shared models, facilities, platforms, instrumentation, or computing, but are not limited to these.)
- Do you have other comments pertinent to the Committee's Statement of Task?

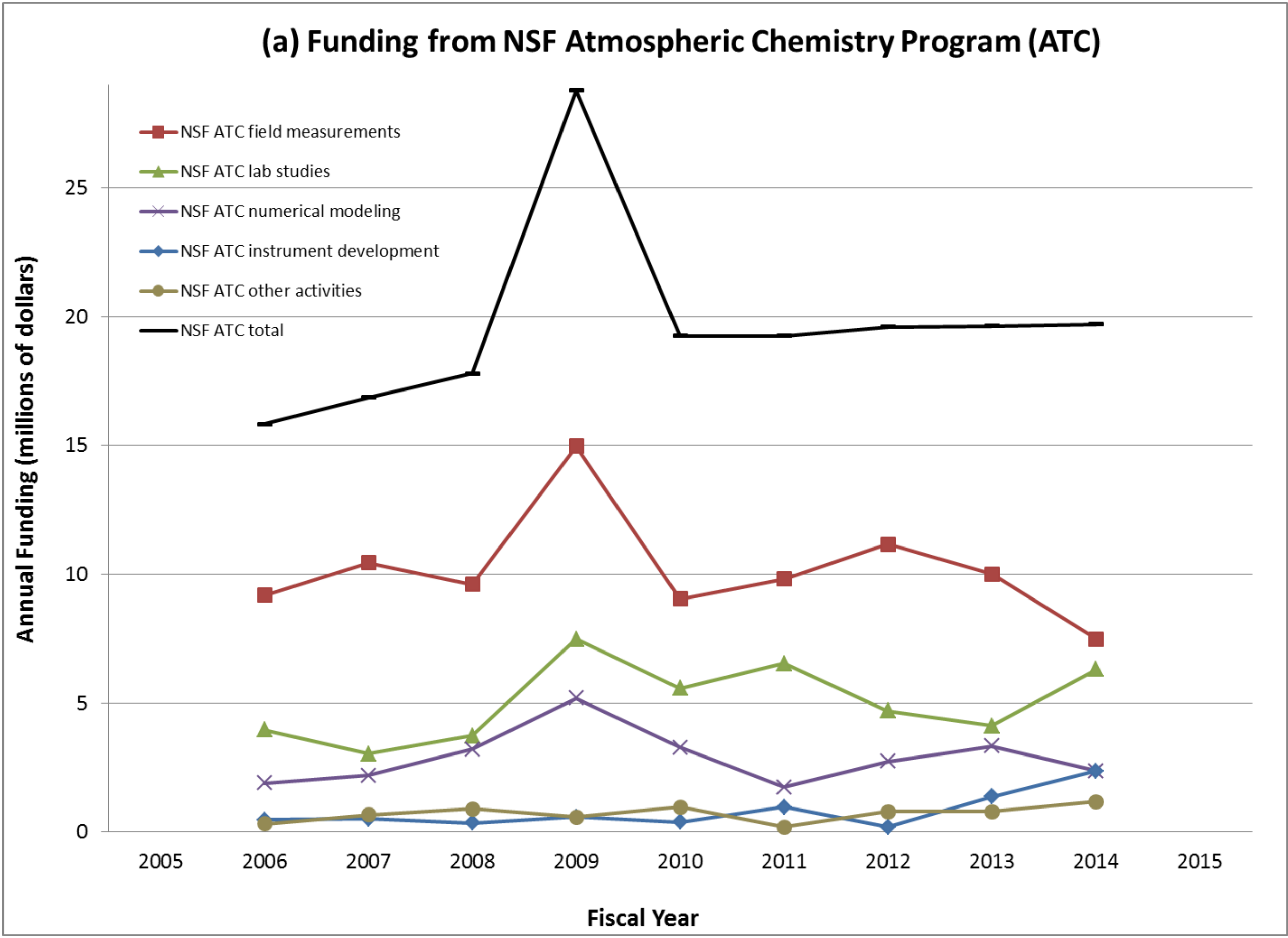
Societal Choices and Impacts

- National Security
  - Climate change → food and water shortages, pandemic disease, refugees, clashes over resources, and devastation by natural disasters,
- Water Security
  - Fresh water is central to human health and welfare, including food and energy production
- Energy and Industry
  - Increased demand increases requirements for control of gas and particle emissions, altering extraction practices and locations

Societal Choices and Impacts

- Environmental Justice
  - Systematic integration of perspectives would enable Earth system management in a way that is beneficial for all
- Sustainable Development
  - Many UN Sustainable Development Goals were developed from geoscience, particularly atmospheric chemistry, knowledge


Funding for Atmospheric Chemistry Research
Annual Funding (millions of dollars)
0
20
40
60
80
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Fiscal Year
NSF total for Atmospheric Chemistry
NOAA Oceanic and Atmospheric Research
EPA STAR and other programs
NASA Atmospheric Chemistry programs
DOE Climate and Environmental Sciences Division



(a) Funding from NSF Atmospheric Chemistry Program (ATC)
NSF ATC field measurements
NSF ATC lab studies
NSF ATC numerical modeling
NSF ATC instrument development
NSF ATC other activities
NSF ATC total
Annual Funding (millions of dollars)
0
5
10
15
20
25
2005
2006
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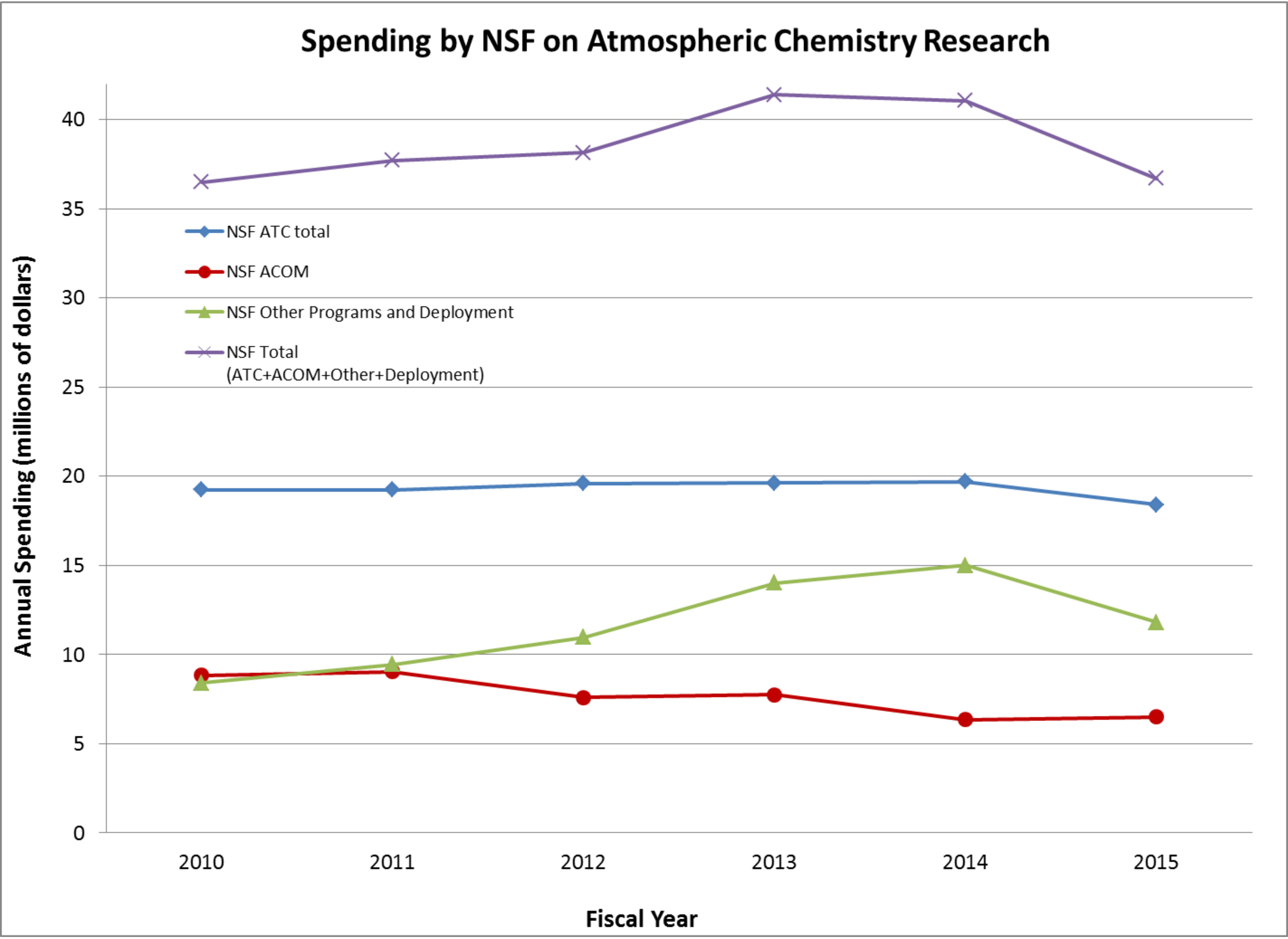
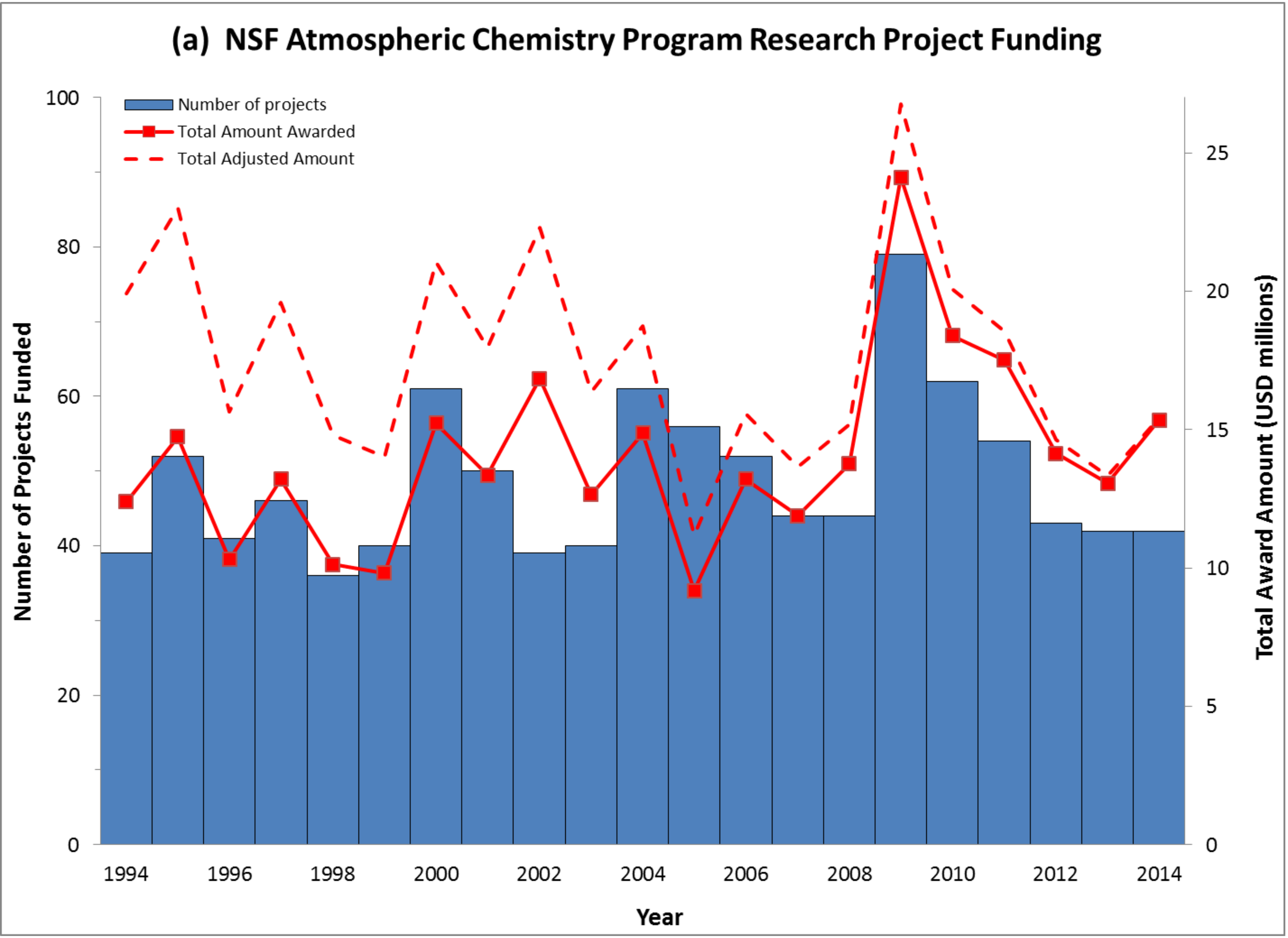
2015
Fiscal Year



Spending by NSF on Atmospheric Chemistry Research
Annual Spending (millions of dollars)
0
5
10
15
20
25
30
35
40
2010
2011
2012
2013
2014
2015
Fiscal Year
NSF ATC total
NSF ACOM
NSF Other Programs and Deployment
NSF Total
(ATC+ACOM+Other+Deployment)



(a) NSF Atmospheric Chemistry Program Research Project Funding
Number of projects
Total Amount Awarded
Total Adjusted Amount
Number of Projects Funded
Total Award Amount (USD millions)
Year
0
20
40
60
80
100
0
5
10
15
20
25
1994
1996
1998
2000
2002
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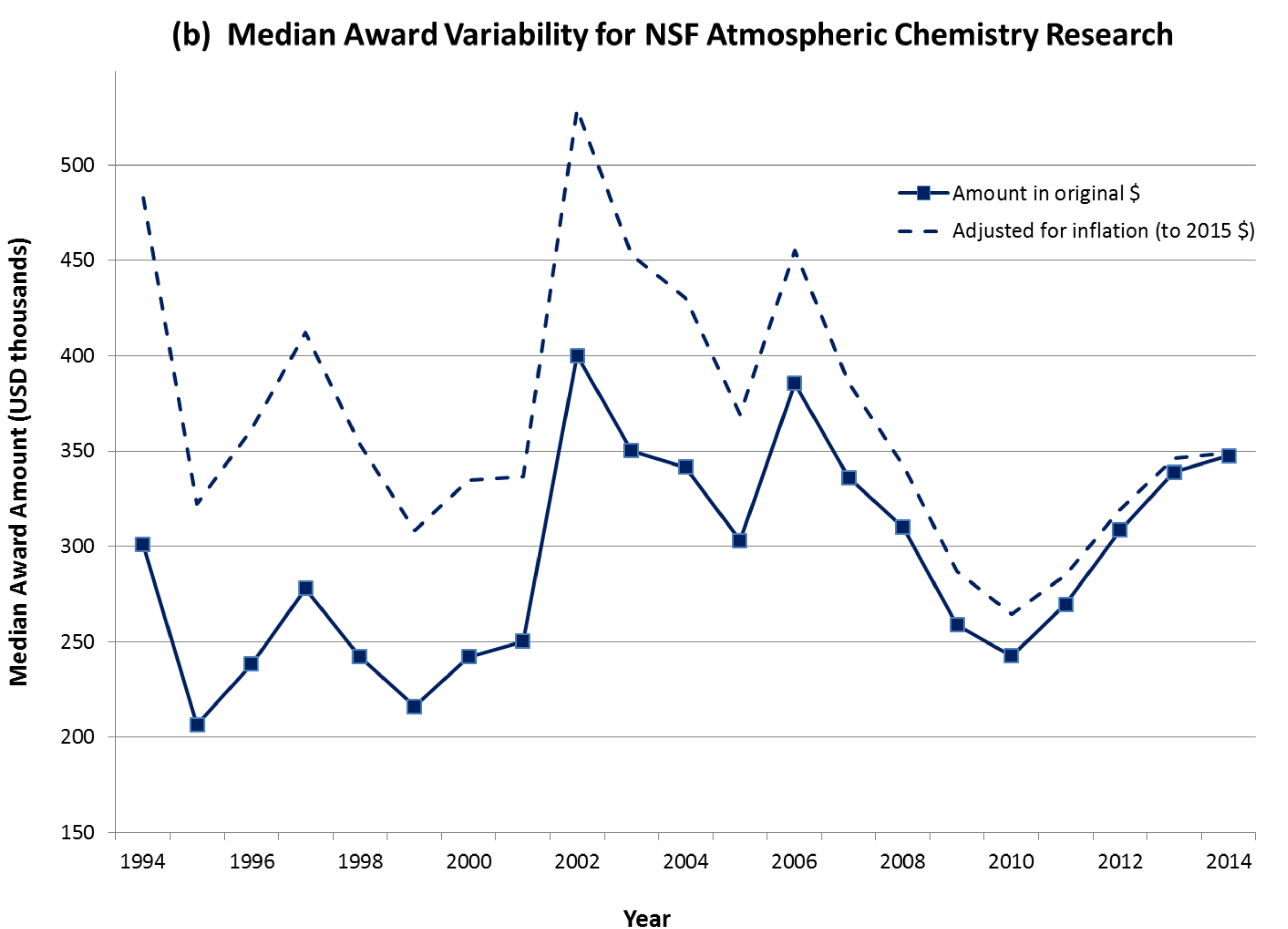
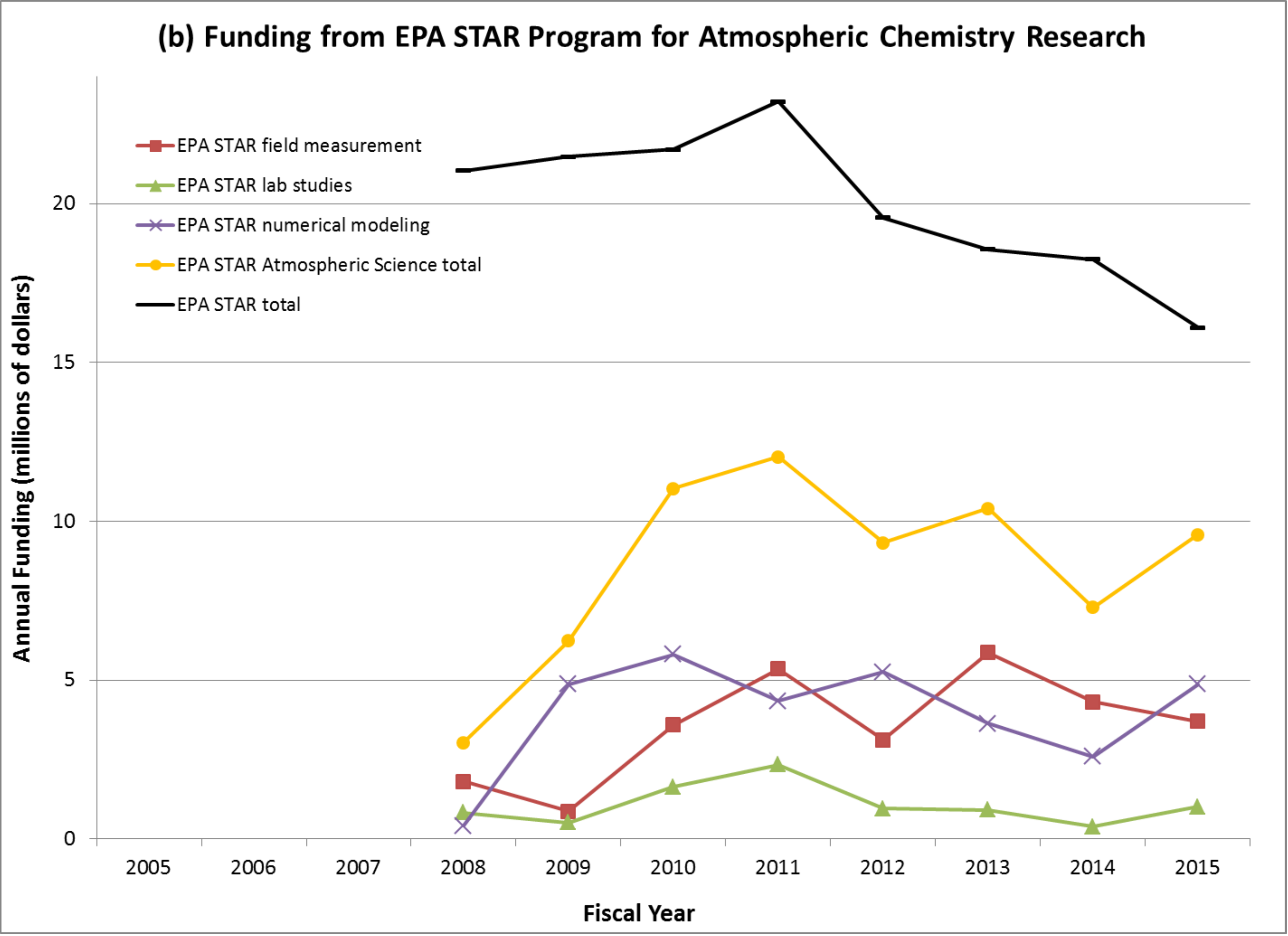

(b) Median Award Variability for NSF Atmospheric Chemistry Research
Median Award Amount (USD thousands)
500
450
400
350
300
250
200
150
Amount in original $
Adjusted for inflation (to 2015 $)
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
Year



(b) Funding from EPA STAR Program for Atmospheric Chemistry Research
EPA STAR field measurement
EPA STAR lab studies
EPA STAR numerical modeling
EPA STAR Atmospheric Science total
EPA STAR total
Annual Funding (millions of dollars)
0
5
10
15
20
2005
2006
2007
2008
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2011
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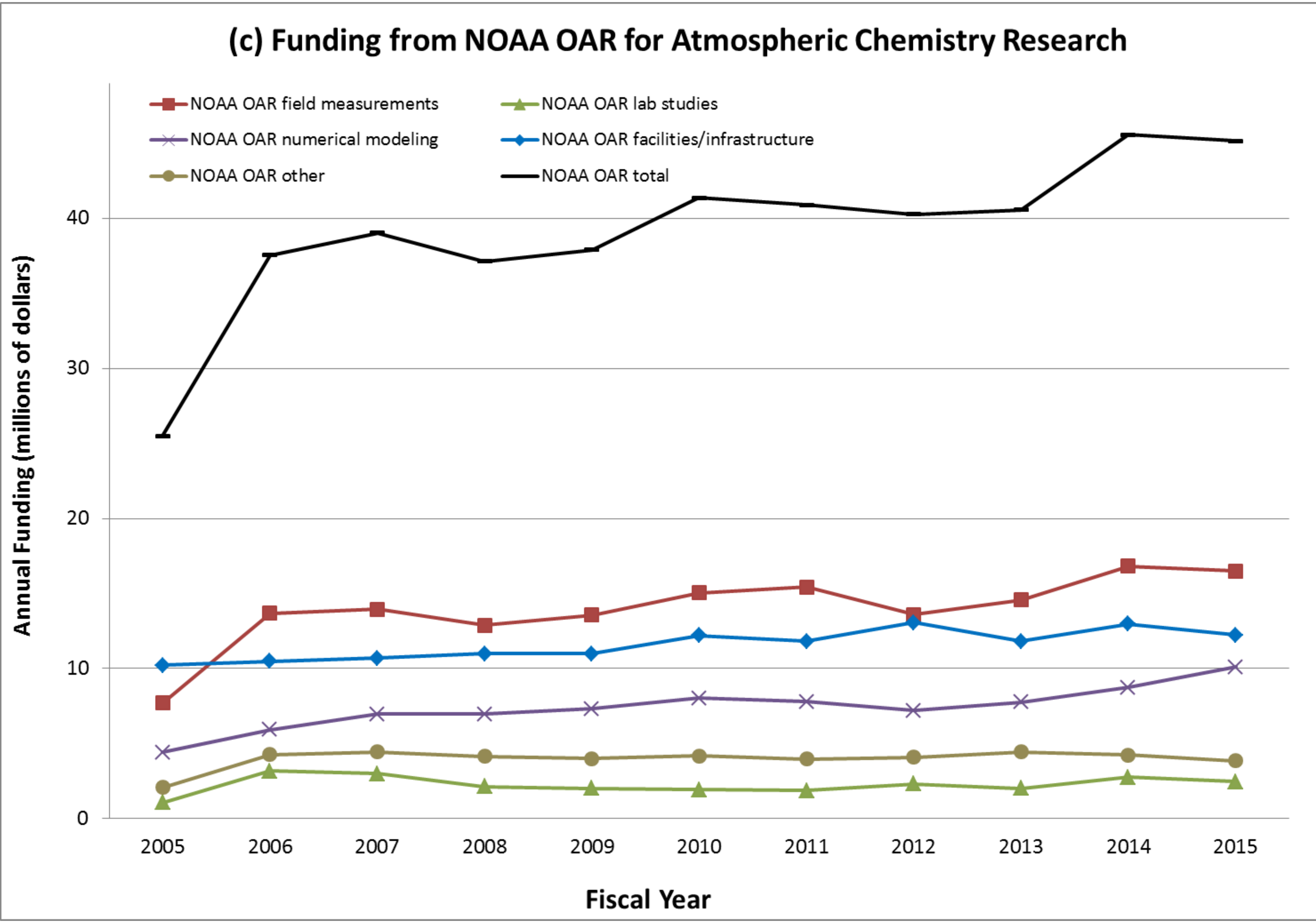
2014
2015
Fiscal Year


(c) Funding from NOAA OAR for Atmospheric Chemistry Research
NOAA OAR field measurements
NOAA OAR lab studies
NOAA OAR numerical modeling
NOAA OAR facilities/infrastructure
NOAA OAR other
NOAA OAR total
Annual Funding (millions of dollars)
0
10
20
30
40
2005
2006
2007
2008
2009
2010
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Fiscal Year