CHAPTER 5

ATMOSPHERIC COMPOSITION

from the

Strategic Plan
for the
Climate Change Science Program

By the agencies and staff of the
US Climate Change Science Program

Review draft dated 11 November 2002

Contents

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11 November 2002

Dear Colleague,

The Climate Change Science Program will hold the U.S. Climate Change Science Program Planning Workshop for Scientists and Stakeholders at the Marriott Wardman Park Hotel in Washington, D.C., from 3-5 December 2002. The purpose of the Workshop is to provide a comprehensive review of the discussion draft of the Strategic Plan for U.S. climate change and global change research. This Workshop will offer extensive opportunities for the scientific and stakeholder communities to provide comment and input to the Climate Change Science Program Strategic Plan. When finalized by April 2003, the Strategic Plan will provide the principal guidance for U.S. climate change and global change research during the next several years, subject to revisions as appropriate to respond to newly developed information and decision support tools.

We are writing to request your comments on the discussion draft of the Climate Change Science Program Strategic Plan. Comments on all elements of the plan from all communities are essential in order to improve the plan and identify gaps. In your review, we ask you to provide a perspective on the content, implications, and challenges outlined in the plan as well as suggestions for any alternate approaches you wish to have considered, and the types of climate and global change information required by policy makers and resource managers. We also ask that you comment on any inconsistencies within or across chapters, and omissions of important topics. For any shortcomings that you note in the draft, please propose specific remedies. To participate in the review it is not necessary that you review the entire plan.

We ask that comments be submitted by E-mail to <comments@climatescience.gov>. All comments submitted by 13 January 2003 will be posted on the <http://www.climatescience.gov> website for public review. While we are unable to promised detailed responses to individual comments, we confirm that all submitted comments will be given consideration during the development of the final version of the Strategic Plan.

Attached to this letter are instructions and format guidelines for submitting review comments. Following the instructions will ensure that your comments are properly processed and given appropriate consideration. If you wish to distribute copies of the plan to colleagues to participate in the review, please provide them with a copy of this letter as well as the attached instructions and format guidelines. We have posted the plan on the workshop website at <http://www.climatescience.gov>. PDF files for individual chapters of the plan can be downloaded from this site. If you have any questions, please contact: Sandy MacCracken at 1-202-419-3483 (voice), 1-202-223-3065 (fax), or via the address in the footer below.

We appreciate your contribution of time and expertise to this review, and look forward to your response.

Sincerely,

James R. Mahoney, Ph.D.
Assistant Secretary of Commerce for Oceans and Atmosphere, and
Director, U.S. Climate Change Science Program

Instructions For Submission of Strategic Plan Review Comments

Thank you for participating in the review process. Please follow the instructions for preparing and submitting your review. Using the format guidance described below will facilitate our processing of reviewer comments and assure that your comments are given appropriate consideration. An example of the format is also provided. Comments are due by **13 January, 2003**.

- Select the chapter(s) or sections of chapters which you wish to review. It is not necessary that you review the entire plan. In your comments, please consider the following issues:
  - **Overview**: overview on the content, implications, and challenges outlined in the plan;
  - **Agreement/Disagreement**: areas of agreement and disagreement, as appropriate;
  - **Suggestions**: suggestions for alternative approaches, if appropriate;
  - **Inconsistencies**: inconsistencies within or across chapters;
  - **Omissions**: omissions of important topics;
  - **Remedies**: specific remedies for identified shortcomings of the draft plan;
  - **Stakeholder climate information**: type of climate and global change information required by representative groups;
  - **Other:** other comments not covered above.
- Please do not comment on grammar, spelling, or punctuation. Professional copy editing will correct deficiencies in these areas for the final draft.
- Use the format guidance that follows for organizing your comments.
- Submit your comments by email to <comments@climatescience.gov> by 13 January, 2003.

Format Guidance for Comments

Please provide background information about yourself on the first page of your comments: your name(s), organization(s), area of expertise(s), mailing address(es), telephone and fax numbers, and email address(es).

- Overview comments on the chapter should follow your background information and should be numbered.
- Comments that are specific to particular pages, paragraphs or lines of the chapter should follow your overview comments and should identify the page and line numbers to which they apply.
- Comments that refer to a table or figure should identify the table or figure number. In the case of tables, please also identify the row and column to which the comment refers.
- Order your comments sequentially by page and line number.
- At the end of each comment, please insert your name and affiliation.

Format Example for Comments

I. Background Information

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II. Overview Comments on Chapter 5: Atmospheric Composition

First Overview Comment: (Comment)
Reviewer's name, affiliation: John Doe, University College

Second Overview Comment: (Comment)
Reviewer's name , affiliation: John Doe, University College

III. Specific Comments on Chapter 5: Atmospheric Composition

Page 57, Line 5: (Comment)
John Doe, University College

Page 58, Line 32 - Page 59, Line 5: (Comment)
John Doe, University College

Table 1-4, Row 3, Column 6: (Comment)
John Doe, University College

Please send comments by email to <comments@climatescience.gov>

Foreword

In February 2002 President George W. Bush announced the formation of a new management structure, the Climate Change Science Program (CCSP), to coordinate and direct the US research efforts in the areas of climate and global change. These research efforts include the US Global Change Research Program (USGCRP) authorized by the Global Change Research Act of 1990, and the Climate Change Research Initiative (CCRI) launched by the President in June 2001 to reduce significant uncertainties in climate science, improve global climate observing systems, and develop resources to support policymaking and resource management.

The President's Climate Change Research Initiative was launched to provide a distinct focus to the 13-year old Global Change Research Program. The CCRI focus is defined by a group of uncertainties about the global climate system that have been identified by policymakers and analyzed by the National Research Council in a 2001 report requested by the Administration.

The Climate Change Science Program aims to balance the near-term (2- to 4-year) focus of the CCRI with the breadth of the USGCRP, pursuing accelerated development of answers to the scientific aspects of key climate policy issues while continuing to seek advances in the knowledge of the physical, biological and chemical processes that influence the Earth system.

This *discussion draft* strategic plan has been prepared by the thirteen federal agencies participating in the CCSP, with input from a large number of scientific steering groups and coordination by the CCSP staff under the leadership of Dr. Richard H. Moss, to provide a vehicle to facilitate comments and suggestions by the scientific and stakeholder communities interested in climate and global change issues.

We welcome comments on this draft plan by all interested persons. Comments may be provided during the US Climate Change Science Program Planning Workshop for Scientists and Stakeholders being held in Washington, DC on December 3 – 5, 2002, and during a subsequent public comment period extending to January 13, 2003. Information about the Workshop and the written comment opportunities is available on the web site www.climatescience.gov. A specially formed committee of the National Research Council is also reviewing this draft plan, and will provide its analysis of the plan, the workshop and the written comments received after the workshop. A final version of the strategic plan, setting a path for the next few years of research under the CCSP, will be published by April 2003. We appreciate your assistance with this important process.

James R. Mahoney, Ph.D.
Assistant Secretary of Commerce for Oceans and Atmosphere, and
Director, Climate Change Science Program

Table of Contents
of the
Strategic Plan for the Climate Change Science Program

CHAPTER 5

ATMOSPHERIC COMPOSITION

This chapter's contents…

The global and regional composition of the atmosphere—its gases and particles—is at the intersection of global and regional changes and their relation to humankind:

- **The atmosphere is shared by all.** It links the other components of the Earth system, including the oceans, land, terrestrial and marine plants and animals, and the frozen regions. Because of these linkages, the atmosphere is a *conduit of change*. For example, natural events and human activities that change atmospheric composition will change the Earth's radiative (energy) balance. Subsequent responses by the stratospheric ozone layer, the climate system, and regional chemical composition (air quality) create multiple environmental effects that influence the well being of human and natural systems.
- **Atmospheric composition changes are indicators of many potential environmental issues.** Observations of trends in atmospheric composition are among the very earliest harbingers of global changes, such as the growth rates of carbon

dioxide (CO_2) concentrations in the atmosphere. Similarly, the decline of the concentrations of ozone-depleting substances, such as the chlorofluorocarbons (CFCs), has been the first measure of the effectiveness of international agreements to end production and use of these compounds.

- **The atmosphere can be a forcing-agent "reservoir" for long-term changes.** The long removal times of some compounds, such as CO_2 (>100 years) and perfluorocarbons (>1000 years), may imply virtually irreversible global changes over decades, centuries, and millennia—for all countries and populations, not just the pollutant emitters.

An effective program of scientific inquiry relating to managed or unmanaged changes in atmospheric composition must address two major foci:

- **A focus on Earth system interactions:** How do changes in atmospheric composition alter and respond to the energy balance of the climate system? What are the interactions between the climate system and ozone layer? What are the effects of regional pollution on the global atmosphere and the effects of global climate and chemical change on regional air quality?
- **A focus on Earth system and human system linkages:** How is the composition of the global atmosphere, as it relates to climate, ozone depletion, ultraviolet radiation, and pollutant exposure, altered by human activities and natural phenomena? How do such composition changes influence human well being and ecosystem health?

The *overall research approach* is integrated application of long-term systematic observations, laboratory and field studies, and modeling, with periodic assessments of understanding and significance to decisionmaking. Specific emphasis will also be placed on *national and international partnerships*, recognizing that such partnerships are necessitated by the breadth and complexity of current issues and because the atmosphere links all nations.

In looking ahead at what the specific information needs associated with atmospheric composition will be, five broad challenges are apparent, with goals and examples of key research objectives outlined below.

Question 1: What are the climate-relevant chemical and radiative properties, and spatial and temporal distributions, of human-caused and naturally occurring aerosols?

STATE OF KNOWLEDGE

Research has demonstrated that certain atmospheric particles (aerosols) cause cooling of the climate system (e.g., sulfate), while others result in warming (e.g., black carbon or soot). When climate models incorporate this knowledge, they simulate the observed trends much better. However, one of the largest uncertainties about the impact of aerosols on climate is the diverse warming and cooling influences of the very complex mixture of aerosol types and their spatial distributions. Further, the poorly understood impact of aerosols on the formation of both water droplets and ice crystals in clouds also results in large uncertainties in the ability to predict climate changes.

ILLUSTRATIVE RESEARCH QUESTIONS

- What are the sources of atmospheric aerosols, and what are their magnitudes and variability?
- What are the global distributions and radiative characteristics of aerosols?
- What are the processes that control the spatial and temporal distributions and variability of aerosols and that modify their chemical and radiative properties during transport, and how well can these processes and resulting spatial distributions currently be simulated?
- How do aerosols affect a cloud's radiative properties and ability to generate precipitation?

RESEARCH NEEDS

A series of research activities are focusing on these questions. Remote-sensing instruments paired with correlative *in situ* observations will provide better data on global distributions of aerosols, their temporal variabilities, and resulting changes in radiative balance. Emission estimates and supportive direct measurements are critical for assessing the balance of human and natural influences on aerosol distributions. The exploration of critical aerosol and chemical processes will involve field experimentation, some laboratory studies, and model development and testing. Diagnostic model estimates, assessed against observations, will characterize aerosol-determined temperature change and its uncertainties. Measurements and models will form the basis for describing the interactions of various types of aerosols and their impact on the radiative effect of clouds.

PRODUCTS AND PAYOFFS

- Improved description of the global distributions of aerosols (2-4 years).
- Empirically tested assessment of the capabilities of current models to link emissions to (i) global distributions and (ii) chemical and warming/cooling properties (and their uncertainties) of atmospheric aerosols (2-4 years).
    - These capabilities will support the scenarios planned as decision support resources by providing better estimates of the uncertainties associated with those simulations.
    - Because of the relatively short atmospheric residence times of aerosols, this assessment will yield potential options for changing radiative forcing within a few decades, in contrast to the longer response times associated with CO_2.
- An improved estimate of the indirect climate effects (e.g., on clouds) of aerosols, compared to the benchmark of the Intergovernmental Panel on Climate Change (IPCC, 2001) (2-4 years).
- More accurate detection and attribution of temperature changes and more accurate analysis of climate model projections (4-6 years).

- Better understanding and description of uncertainties about the physical and chemical processes that form, transform, and remove aerosols during long-range atmospheric transport (4-6 years).
- Characterization of the impact of human activities and natural sources on global aerosol distributions (4-6 years).

Question 2: What is the current quantitative skill for simulating the atmospheric budgets of the growing suite of chemically active greenhouse gases and their implications for the Earth's energy balance?

STATE OF KNOWLEDGE

The increasing concentrations of atmospheric constituents that absorb infrared radiation, such as CO_2 (see Chapter 8), methane (CH_4), tropospheric ozone, nitrous oxide (N_2O), and the chlorofluorocarbons (CFCs) are the primary gases that are forcing agents of global climate change. The anthropogenic emission sources leading to the observed growth rates of CH_4 (the second-most influential anthropogenic greenhouse gas) and N_2O are qualitatively understood but poorly quantified (e.g., CH_4 emitted by rice agriculture). Trends in tropospheric ozone (the third-most influential anthropogenic greenhouse gas) are not well determined and are driven by a mix of emissions, including regional pollutants and CH_4. The atmospheric concentrations and sources of the CFCs are well studied because of their role in stratospheric ozone layer depletion. In addition to these gases, water vapor plays a strong role in amplifying greenhouse warming (see Chapter 6). Observations and trends of this highly variable constituent are problematic.

ILLUSTRATIVE RESEARCH QUESTIONS

Driven by the need to have a predictive understanding of the relationship between the emission sources of these gases and their global distributions and radiative forcing, several question face the research community. These include:

- What are global anthropogenic and natural (biospheric – see Chapter 10) sources of CH_4 and N_2O?
- What are the causes of the observed large variations in their growth rate?
- What are the global anthropogenic and natural sources (both biogenic and lightning-related) of nitrogen oxides?
- What are the trends in mid-tropospheric ozone, particularly in the Northern Hemisphere, and how well can the variations be attributed to causes?
- What water vapor observations will best test and improve the understanding of the water vapor feedback?

RESEARCH NEEDS

Field and laboratory studies, satellite observations, and diagnostic transport/chemical modeling are focusing on these questions. Examples of activities are:

- Global monitoring sites to continue recording the growth rate of CH_4 and its variations.
- Satellite observations to provide estimates of the global distributions of tropospheric ozone and some of its precursors (e.g., nitrogen dioxide).
- Planned satellite (Aura) measurements and focused field studies to better characterize water vapor in the climate-critical area of the tropical tropopause (the boundary between the troposphere and the stratosphere).
- Model studies to simulate past trends in tropospheric ozone to improve the understanding of its contribution to radiative forcing over the past ~50 years.
- Field studies to characterize the regional- and continental-scale changes occurring between emission areas and global tropospheric ozone distributions, thereby providing tests of and improvement in the ozone-related process representation of models.

PRODUCTS AND PAYOFFS

- Observationally-assessed and improved uncertainty ranges for future scenarios of the radiative forcing of the chemically-active greenhouse gases, which will be part of the 2006 Climate Change Research Initiative (CCRI) suite of climate change scenarios.
    - As a result, there will be a broader suite of options (i.e., in addition to CO_2) for potential choices to influence radiative forcing, particularly in coming decades (4 years).
- Better understanding of the processes that control water vapor in the upper troposphere and lower stratosphere, resulting in improved input to the planned evaluation of the knowledge of water vapor feedback in climate models (4-6 years).

Question 3: What are the effects of regional pollution on the global atmosphere and the effects of global climate and chemical change on regional air quality and atmospheric chemical inputs to ecosystems?

STATE OF KNOWLEDGE

Increased development in rapidly industrializing regions of the world has the potential to impact air quality and ecosystem health in regions far from the sources. Paleo-chemical data from ice cores and snow document past perturbations and demonstrate that even pristine areas, such as Greenland, are influenced by worldwide emissions.

ILLUSTRATIVE RESEARCH QUESTIONS

This emerging picture is shaping several policy-relevant questions, which include the following examples:

- What are the chemical exposures experienced by food-producing areas that are in proximity to large urban areas?

- How do the primary and secondary pollutants from the world's megacities contribute to global atmospheric composition?
- What are, and what contributes to, North American "background" levels of air quality—that is, what levels of pollution are beyond national control?

RESEARCH NEEDS

These questions are being addressed by measurements of key tropospheric constituents, including both global mapping by satellites and intensive local observations from surface sites or airborne platforms, supported by analyses and model simulations. The near-term goals include the following:

- Characterize the outflow from polluted regions around the world, with an initial emphasis on North American impact;
- Understand the balance between long-range transport and transformation of pollutants;
- Establish baseline observations of atmospheric composition over North America and globally;
- Quantify the inflow-outflow atmospheric composition budget of North America and project future changes; and
- Carry out the first global survey of vertically-resolved distributions of tropospheric ozone and its key precursor species.

PRODUCTS AND PAYOFFS

- Description of the changes in the impacts of global tropospheric ozone on radiative forcing over the past decade brought about by clean air regulations (2-4 years).
- A 21^{st} century chemical baseline for the Pacific region, against which future changes can be assessed (2-4 years).
- An assessment of the vulnerability of ecosystems to urban growth, with an emphasis on food production (4-6 years).

Question 4: What are the time scale and other characteristics of the recovery of the stratospheric ozone layer in response to declining abundances of ozone-depleting gases and increasing abundances of greenhouse gases?

STATE OF KNOWLEDGE

The primary cause of the stratospheric ozone depletion observed over the last two decades is an increase in the concentrations of industrially-produced ozone-depleting chemicals. The depletion has been significant, ranging from a few percent per decade at mid-latitudes to greater than fifty percent seasonal losses at high latitudes. Notable is the annually recurring Antarctic ozone hole, as well as smaller, but still large, winter/spring ozone losses recently observed in the Arctic. Reductions in atmospheric ozone levels lead to increased fluxes of ultraviolet radiation at the surface, with harmful effects on plant and animal life, including human health. In response to these findings, the nations of the world ratified the *Montreal Protocol on Substances That Deplete the*

Ozone Layer and agreed to phase out the production of most ozone-depleting chemicals. Ground-based *in situ* and satellite measurements show that concentrations of many of these compounds are now beginning to decrease in the lower atmosphere. In the absence of other atmospheric change, as the atmospheric burden of ozone-depleting chemicals falls in response to international efforts, stratospheric ozone concentrations should begin to recover.

ILLUSTRATIVE RESEARCH QUESTIONS

- How will changes in the atmospheric composition of greenhouse gases, such as CO_2 and N_2O, and the resulting changes in the radiation and temperature balance (e.g., stratospheric cooling), alter ozone-related processes?
- How will changes in the physical climate affect the distributions of ozone (e.g., unusually cold Arctic winters and particle-enhanced ozone-loss processes)?
- What are the ozone-depleting and radiative forcing properties of new chemicals, such as the substitutes for the now-banned ozone-depleting substances?

RESEARCH NEEDS

Improving our understanding of this complex and interactive ozone layer-climate system calls for detailed investigation of the relationships between the distributions of ozone, water vapor, aerosols, temperature, and relevant trace constituents, notably chlorine and bromine compounds and nitrogen oxides. Research needs include the following:

- Continue global monitoring of the changes in ozone-depleting substances and their substitutes and assessing compliance with the Montreal Protocol.
- Test the "ozone and climate friendliness" of proposed substitutes with laboratory chemistry and atmospheric models to provide early information to industry prior to large plant investments.
- Carry out focused aircraft, balloon, and ground-based campaigns, and chemical transport modeling activities with emphases on:
    - Cross-tropopause processes to better understand the ozone-depleting role of the newly proposed, very short-lived (days to months) substances;
    - The role of particles in accelerating ozone-loss chemistry; and
    - Stratospheric transport to better understand ozone-layer responses to climate change.
- Extend interagency and international satellite observations of ozone trends, with an emphasis on detecting and attributing recovery.
- Continue monitoring of the trends in ultraviolet radiation, particularly in regions of high radiation exposure and high biological sensitivity.

PRODUCTS AND PAYOFFS

- In 2006, the international ozone research community will provide decisionmakers an updated assessment of the state of the ozone layer, including new ozone and ultraviolet radiation trends, analysis of compliance, and forecasts of recovery. This sixth in the series of "operational" products of the ozone science community is a key to accountability in this issue; namely, is the outcome expected from international actions being observed?

Question 5: What are the couplings among climate change, air pollution, and ozone layer depletion, which were once considered as separate issues?

STATE OF KNOWLEDGE

The atmosphere does not segregate atmospheric composition phenomena by scientific discipline or societal issue. For example, research has demonstrated that stratospheric ozone depletion not only causes increased exposure to ultraviolet radiation at the surface, but also exerts a cooling influence on the global climate. Conversely, climate-related changes may cool the lower stratosphere and increase the depletion of the ozone layer at high latitudes. Formation of tropospheric ozone, previously of concern primarily as a component of smog, is not only a local health risk, but also exerts a warming influence on the global climate. Emissions of sulfur dioxide from fossil-fuel combustion not only lead to the formation of regional acid rain, but also contribute to the hemispheric sulfate aerosol haze, which exerts a cooling influence on the global climate system. It is now clear that multiple issues that have been treated separately by scientists and policymakers alike are indeed coupled phenomena.

ILLUSTRATIVE RESEARCH QUESTIONS

- How do actions taken or considered with regard to one issue influence other issues, positively or negatively?
- What are the multiple stresses that climate change, ozone layer depletion, and regional air quality exert on humans and ecosystems?

RESEARCH NEEDS

- Build and evaluate diagnostic/prognostic models of the coupled climate, chemistry, transport, and ecological systems (in collaboration with other elements of the program).
- Synthesize the understanding of the impacts of multiple stresses on humans (e.g., heat and air quality) and ecosystems (e.g., soil moisture and chemical exposure).
- Build and evaluate models that couple the biogeochemical systems with the decisionmaking frameworks.
- Carry out multiple issue state-of-understanding assessments, in partnership with the spectrum of stakeholders, with the aim of characterizing integrated "If…, then…" options.

PRODUCTS AND PAYOFFS

- A policy-relevant assessment of the issues related to intercontinental transport and the climatic effects of air pollutants, in order to provide scientifically sound information to policymakers for consideration in developing integrated control strategies to benefit both

regional air quality and global climate change, and to assess local attainment of air quality standards (2-4 years).
- A *State of the Atmosphere: 2006* report that describes and interprets to the Nation the annual status of atmospheric phenomena such as atmospheric composition, ozone layer depletion, temperature, rainfall, and ecosystem exposure (see Chapter 3).
- Diagnostic/prognostic models of the coupled climate, chemistry/transport, and ecological systems (in collaboration with other elements of the program).
- A process that bridges various issues and stakeholders in order to conduct multiple-issue integrated assessments.

Key Linkages

The Atmospheric Composition research focus is linked via co-planning and joint execution to several national and international planning and coordinating activities. A few examples are:

- **USGCRP/CCRI:**
  - Interaction with the US Global Change Research Program (USGCRP) Climate Variability and Change (Chapter 6) and Water Cycle (Chapter 7) components, including radiative forcing input to climate model simulations, as well as characterization of other composition–climate processes (e.g., impact of aerosols on cloud formation and precipitation).
  - Interaction with the CCRI Scenarios near-term focus (Chapter 4), providing explicit simulations of emissions, atmospheric composition, and radiative forcing changes.
  - Interactions with the USGCRP Carbon Cycle component (Chapter 9) for CH_4 changes, Ecosystems (Chapter 10) for assessing chemical impacts, and Human Contributions (Chapter 11) for health impacts.
- **Interagency Programs:** Joint planning, such as the National Aerosol–Climate Interactions Program (NACIP) is a major vehicle for carrying out USGCRP/CCRI objectives.
- **Committee on Environment and Natural Resources: Air Quality Research Subcommittee (AQRS):** Joint research on the global/continental scales of the USGCRP and on the regional/local scales of the AQRS (global influences on the "natural background" of air pollutants and linkages with the stakeholders via the AQRS).
- **International Global Atmospheric Chemistry (IGAC):** IGAC, a Core Project of the International Geosphere-Biosphere Programme, coordinates several international projects focused on the chemistry of the global troposphere and its impact on the radiative balance, such as the new Intercontinental Transport and Chemical Transformation project, which involves Asian, North American, and European researchers.

References:

IPCC, 2001. Intergovernmental Panel on Climate Change, *Climate Change 2001*. Third Assessment Report of the IPCC. (Cambridge, United Kingdom, and New York: Cambridge University Press). Includes:

- IPCC, 2001a. *The Scientific Basis*, a contribution of Working Group I.
- IPCC, 2001b. *Impacts, Adaptation, and Vulnerability*, a contribution of Working Group II.
- IPCC, 2001c. *Mitigation*, a contribution of Working Group III.
- IPCC, 2001d. *Synthesis Report*. A Contribution of Working Groups I, II, and III

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