# RADIATIVE FORCING OF CLIMATE CHANGE

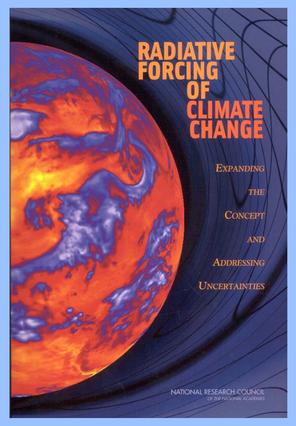
*Expanding the Concept and Addressing Uncertainties*

A ***climate forcing*** is an energy imbalance imposed on the climate system either externally or by human activities.

Knowledge of the natural and anthropogenic processes that affect the Earth's energy balance is critical for understanding <u>how Earth's climate has changed in the past and will change in the future</u>.

The concept of radiative forcing provides a way to <u>quantify and compare</u> the contributions of different agents that affect surface temperature.

This study examines the current state of knowledge regarding the direct and indirect radiative forcing effects of gases, aerosols, land use changes, and solar variability on the climate of the Earth's surface and atmosphere, and identifies research needed to improve our understanding of these effects.




There are <u>three main classes</u> of climate forcings:

1. **Direct radiative forcings** directly affect the radiative budget of the Earth.
   **EXAMPLES:** Added $CO_2$ absorbs and emits infrared radiation
   Land-use changes alter surface albedo properties
   Solar irradiance and insolation changes

2. **Indirect radiative forcings** create an energy imbalance by first altering climate system components, which then lead to changes in radiative fluxes.
   **EXAMPLE:** Added aerosols modify the precipitation efficiency of clouds, leading to changes in cloud radiative properties.

3. **Nonradiative forcings** create an energy imbalance that does not directly involve radiation.
   **EXAMPLE:** Increasing evapotranspiration flux from agricultural irrigation.

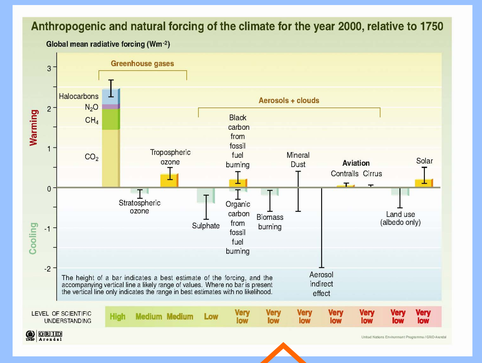
<u>**RECOMMENDATIONS**</u>:

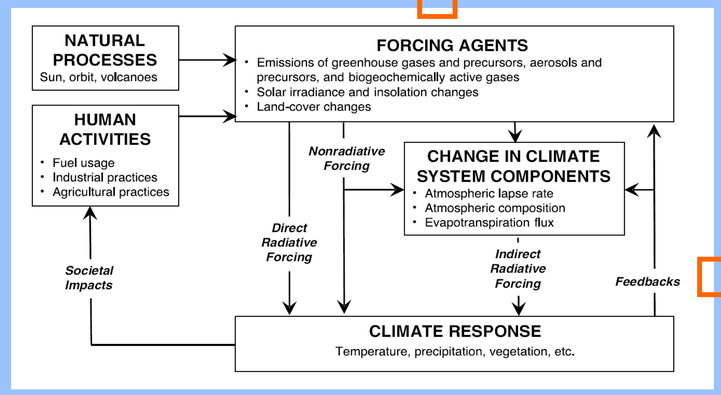
**Expand the radiative forcing concept** to account for
(1) the vertical structure of radiative forcing,
(2) regional variability in radiative forcing,
(3) nonradiative forcing.

**Provide improved guidance to the policy community** by encouraging policy analysts and integrated assessment modelers to incorporate new global and regional radiative and nonradiative forcing metrics as they become available.

**Address key uncertainties** by pursuing the following research areas:

- Accurate long-term <u>monitoring</u> of radiative forcing variables
- <u>Attribution</u> of decadal to centennial climate change
- <u>Policy analysis</u> (e.g., integrate climate forcing criteria in the development of policies for air pollution control and land management)
- Improve understanding and parameterizations of <u>aerosol radiative forcing</u> (e.g., indirect radiative and nonradiative effects)
- Improve understanding of <u>ozone radiative forcing</u>



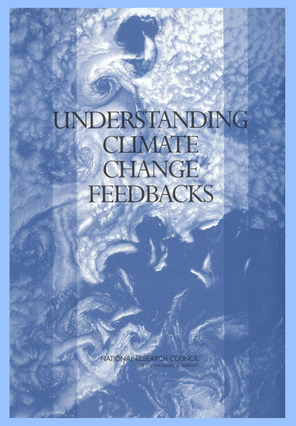

# UNDERSTANDING CLIMATE CHANGE FEEDBACKS

A ***climate feedback*** is an internal climate process that amplifies or dampens the climate response to a specific forcing.

A substantial part of the uncertainty in projections of future climates is attributed to <u>inadequate understanding of climate feedback processes</u>.

According to estimates generated by current climate models, <u>more than half of the warming</u> expected in response to human activities will arise from feedback mechanisms internal to the climate system.

This study looks at what is known and not known about climate change feedbacks, seeks to identify the climate feedback processes most in need of improved understanding, and guides the development of future research agendas targeted at improving understanding of these key climate feedback processes.




There are <u>three main types</u> of climate feedbacks:

1. Feedbacks that primarily affect the **magnitude** of climate change
   **EXAMPLES:** Cloud and water vapor feedbacks (see figure below)
   Biogeochemical feedbacks and the carbon cycle
   Atmospheric chemical feedbacks
   Ice albedo feedback

2. Feedbacks that primarily affect the **transient response** of climate.
   **EXAMPLE:** Ocean heat uptake and circulation feedbacks

3. Feedbacks that primarily influence the **pattern** of climate change.
   **EXAMPLES:** Land hydrology and vegetation feedbacks;
   Natural modes of climate system variability

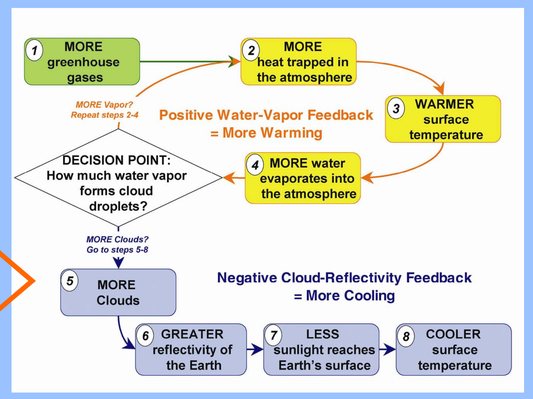
<u>**RECOMMNEDATIONS**</u>:

An **enhanced research effort** is needed to better observe, understand, and model key climate feedback processes.

An integrated global climate monitoring system must include **observation of key climate feedback processes.** Stable, accurate, long-term measurements should be made of the variables that characterize climate feedbacks.

Both global and regional **metrics that focus on feedback processes** responsible for climate sensitivity should be used to more rigorously test understanding of feedback processes and their simulation in climate models.

Climate modeling facilities in the United States must be given the capability and mandate to **test understanding and simulation of climate feedback processes and their interactions using the best observational constraints.** Periodic assessment of the progress being made by major climate models should be conducted to evaluate the ability of these models to simulate the processes underlying key climate system feedbacks.




**ACKNOWLEDGEMENTS**

Support for these projects was provided by the National Oceanic and Atmospheric Administration, U.S. Global Change and Research Program (through the National Aeronautic and Space Administration), and the National Science Foundation.

The nation turns to the National Academies—National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and National Research Council—for independent, objective advice on issues that affect people's lives worldwide.
www.national-academies.org

To read these or other National Academies reports, please visit the National Academies Press home page
www.nap.edu

A list of reports produced by the Board on Atmospheric Sciences and Climate can be found at
dels.nas.edu/basc/

# THE NATIONAL ACADEMIES

*Advisers to the Nation on Science, Engineering, and Medicine*

**AUTHORS**

Ian Kraucunas (ikraucunas@nas.edu),
Chris Elfring and Amanda Staudt
The National Academies
Board on Atmospheric Sciences and Climate

Dennis Hartmann
Department of Atmospheric Sciences
University of Washington

Daniel Jacob
Department of Atmospheric Sciences
Harvard University