ARTICLES

IMPACT OF AVIATION ON CLIMATE

Research Priorities

BY GUY P. BRASSEUR AND MOHAN GUPTA

Using gap analysis and priority-driven research reduces uncertainties in aviation climate impacts and will yield an improved scientific basis vital for decision making.

Today, approximately 23,000 aircraft operated by more than 2,000 airlines carry more than 2.2 billion passengers annually and serve about 3,750 airports throughout the world (based on the BACK Official Airline Guide aviation fleet/schedule/ancillary data; available online at www.oagaviation.com). Mostly confined within the flight corridor at cruise altitudes between 8 and 13 km (26,000–40,000 ft), aircraft engines emit carbon dioxide (CO_2), water vapor (H_2O), nitrogen oxides (NO_x), sulfur oxides (SO_x), hydrocarbons (HC), and soot particles, which progressively mix and interact with the surrounding air. The NO_x emissions enhance photochemical production and loss of tropospheric ozone and methane (CH_4), respectively. Water vapor releases trigger the formation of contrails in sufficiently cold air. Contrails may persist for hours and thus increase cirrus cloudiness in ice-supersaturated air. At present, aviation accounts for approximately 2% of the worldwide CO_2 emissions. For 2005, aircraft emissions impacts (excluding induced cirrus clouds) contribute 3.5% (in a range of 1.3%–10%, which is a 90% likelihood range) of total anthropogenic forcing. Inclusion of aviation-induced cirrus cloud impacts will increase this magnitude to 4.9% (2%–14%, which is a 90% likelihood range; see Lee et al. 2009). Aircraft emissions are expected to increase with projected growth in aviation and will likely result in enhanced environmental impacts unless scientifically informed mitigation measures are implemented.

Environmental protection is an important component of the U.S. Next Generation Air Transportation System (NextGen; information online at www.jpdo.gov/nextgen.asp). NextGen is being implemented to meet projected growth in aviation and to achieve a balance between its economic and transport benefits and the environmental impacts. To meet NextGen environmental goals, the Federal Aviation Administration has developed the Aviation Climate Change Research Initiative (ACCRI) with participation from the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the Environmental Protection Agency (EPA). The main objective of ACCRI is to identify and address key scientific gaps and uncertainties while providing timely scientific input to inform decision making.

Here, we provide a brief overview of current research gaps and priorities that were identified by the ACCRI-funded white papers, a workshop, and a report (online at www.faa.gov/about/office_org/headquarters_offices/aep/aviation_climate/). Details on these priorities are provided in companion papers published in the present issue.

ASSESSMENT OF CLIMATIC IMPACT OF AVIATION. The assessment of the effects of aviation on climate (Fig. 1) requires specialized models that accurately treat the chemical and microphysical processes controlling the perturbation caused by aircraft emissions, as well as related atmospheric processes that govern the evolution of climate (i.e., the impact of greenhouse gases and aerosols, atmospheric dynamics, clouds, and the water cycle). Because many effects occur on spatial scales that are unresolved by climate models (e.g., cirrus cloud changes, plume processing of emissions), such assessments require suitable parameterization schemes that are consistent with the model processes acting on the resolved scales. Numerical simulations are then performed for a range of aviation emission scenarios. Unfortunately, these model projections are still subject to significant errors, which reflect, in part, a lack of understanding of certain fundamental processes governing the interaction of aircraft exhaust and the atmosphere. Therefore, to understand and predict aviation impacts, process studies must be conducted with a hierarchy of models to improve our knowledge of the dynamics, chemistry, and microphysics of the upper troposphere (UT) and lower stratosphere (LS).

RESEARCH PRIORITIES. Among the major questions to be addressed to understand the impact of aviation on climate are the microphysical and optical properties of contrails; the mechanisms that either generate cirrus clouds by persistent contrails (contrail cirrus) or modify existing cirrus; the role of soot aerosols in upper-tropospheric ice formation and their direct role in climate change; the exact nature of the chemical cycles involving NO_x, HO_x, and halogens in the UTLS; and the scavenging of chemical compounds by ice particles from these atmospheric layers, including the role of heterogeneous chemistry (aerosol and ice phase).

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The abstract for this article can be found in this issue, following the table of contents.
DOI:10.1175/2009BAMS2850.1

In final form 7 August 2009

Contrails and induced cirrus clouds. Improved characterization of the climate effects of contrails requires the development of better atmospheric observational datasets and related analysis in correlation of aviation activity, emissions, and atmospheric variability. Observations of ice-supersaturated regions with high accuracy and with high vertical and horizontal resolution are urgently needed. The global distribution of ice supersaturation should be further evaluated using radiosonde, airborne, and satellite-based data on upper-tropospheric relative humidity. We need to expand the database of in situ cirrus microphysical observations with recently developed instruments and methods that either correct or filter for instrument errors. Laboratory studies of exhaust soot and field studies targeting soot effects on cirrus are also necessary.

The development of contrail cirrus should be investigated with cloud-resolving models with supersaturation capability, while the community explores the use of sensors on commercial aircraft to improve our understanding of water vapor–contrail relationships. Aerosol indirect effect on ice clouds should be studied using in situ and satellite data.

Physical climate impacts resulting from contrails and contrail cirrus can only be evaluated using global climate models. Sensitivity experiments estimating the complete life cycle of contrails and contrail cirrus clouds and their climate impact must be conducted. Large-scale models should incorporate more accurate representations of 1) ice supersaturation and cirrus development, 2) ice cloud microphysics, and 3) cirrus and contrail optical properties.

Chemical composition of the upper troposphere and lower stratosphere. Specific analysis of space observations in correlation with aviation activities will increase our knowledge of ozone production and loss that can be ascribed directly to aircraft emissions. We need to resolve the discrepancies that remain between modeled and observed HO_x species at high NO_2 values in the region where subsonic aircraft emissions are the most significant perturbation to chemistry. Improved parameterizations of deep convection and lightning production of NO_x should be developed and verified in multiscale models in order to better constrain the relative contributions of different emissions to the NO_y budget in the UTLS. Improved multiscale models are necessary to investigate the dispersion and transport of aircraft emissions from aviation corridors to the regional scale. Evidence is mounting that there is significantly more inorganic bromine in the UT than previously be-

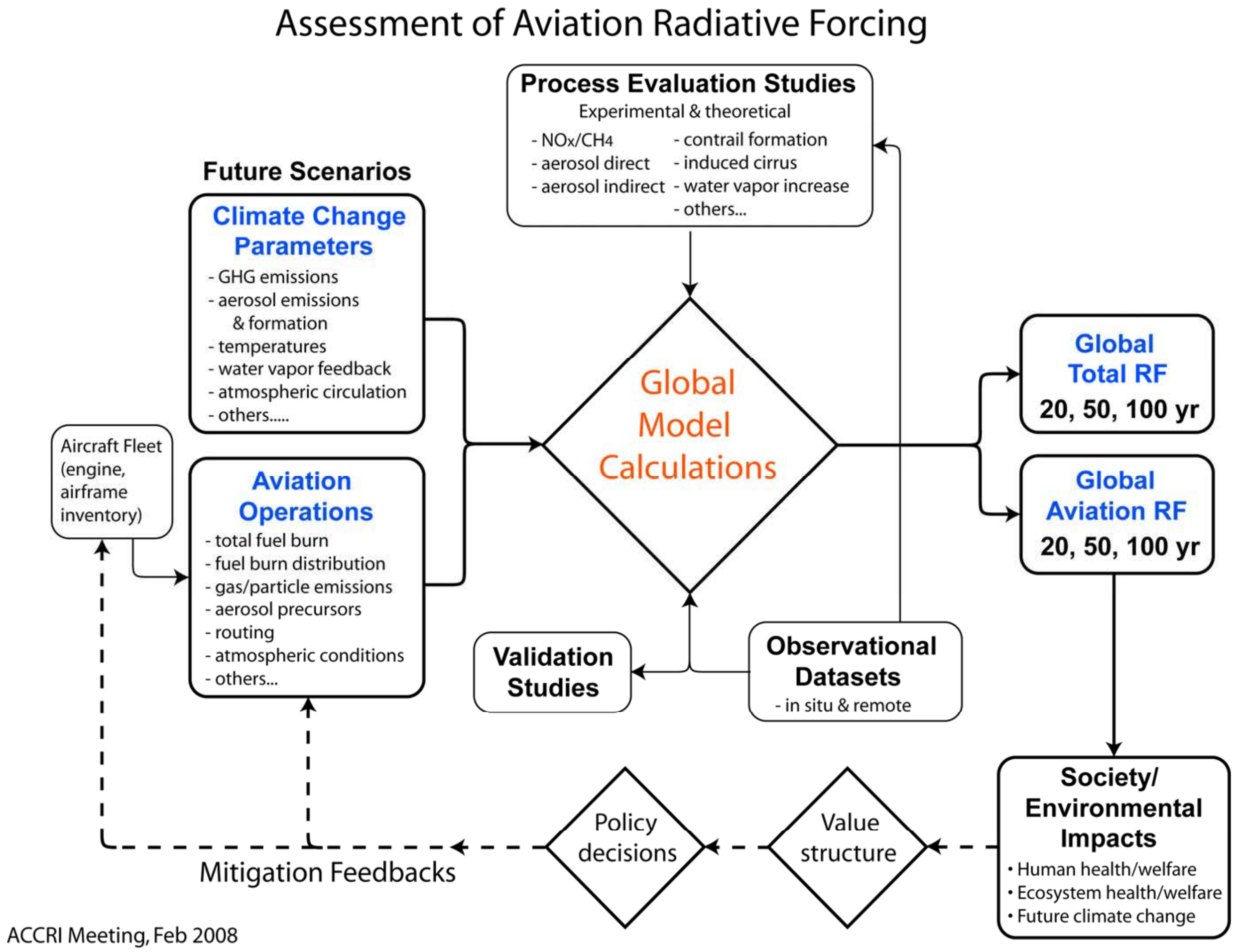

Fig. 1. Schematic description of the different elements that will lead to an integrated assessment of the effects of aviation on climate. (Figure courtesy of D. Fahey.)

lieved, presumably resulting from efficient transport of short-lived bromine sources. The balance between ozone production by high NO_x and ozone destruction by halogen species needs to be studied with high-resolution measurements and models. Finally, we need to assess how future climate changes and cruise altitude thermal structure will affect climate impacts of aviation.

Climate impact metrics for aviation. Climate change policies require suitable metrics for quantifying the global and regional impacts of aviation emissions and mitigation scenarios. Despite its known limitations, we suggest using radiative forcing, along with global temperature potential (as a measure of "end-point" climate impact; i.e., the temperature change at a particular time in the future) and global warming potential, as metrics to evaluate climate impacts of aviation and compare them to the impacts of other emissions. Finally, we need to adapt common metrics across sectors and to develop new, well-evaluated socioeconomic metrics.

Development of timely and workable mitigation solution requires focused aviation specific climate research with a clear programmatic vision. While benefiting from national and international atmospheric and climate research programs and working with broad scientific community, we can make a way forward in improving our understanding of the climate impacts of aviation.

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