

1.0. Executive Summary

Science Questions. Reductions of atmospheric concentrations of methane (CH_4), tropospheric ozone (O_3) and black carbon (BC) aerosols are effective measures to slow global warming and to improve air quality. Near-term mitigation of these short-lived climate forcers is a major component of current international policy discussions. ATom helps to build the scientific foundation for near-term mitigation strategies by systematically measuring reactive gases and aerosols over unprecedented scales spanning the Pacific and Atlantic Oceans. ATom's global-scale *in situ* measurements by continuous airborne vertical profiling ("tomographic sampling") enables quantitative analysis of key chemical processes and loss rates for CH_4 , O_3 , and BC, assessment of the global-scale effects of anthropogenic emissions, and critical testing of chemistry-climate models used to define policy options.

The central scientific questions for the primary ATom Mission (denoted "Tier 1") address the nexus of scientific and societal issues:

What are chemical processes that control the short-lived climate forcing agents CH_4 and O_3 in the atmosphere? How is the chemical reactivity of the atmosphere affected by anthropogenic emissions on the global scale? How can we improve chemistry-climate simulations of these processes?

ATom focuses on O_3 because it is a principal driver for tropospheric photochemical processes, is a short-lived climate forcer, and is a major ground-level pollutant. ATom focuses on CH_4 because it is a major source of O_3 and a medium-lifetime climate forcer. Both are greenhouse gases (GHGs) whose concentrations have risen significantly since the industrial revolution. Both CH_4 and O_3 control concentrations of the hydroxyl radical (OH), which in turn destroys other key pollutants including volatile organic compounds (VOCs) and hydrofluorocarbons (HFCs). ATom uses *in situ* airborne measurements in low-risk airspace over the oceans to provide information on CH_4 and O_3 processing relevant to more than 60% of the total reactivity of the global atmosphere.

ATom is tightly linked to satellites measuring atmospheric chemical composition and to global chemistry-climate models (CCMs):

- (i) ATom provides unique validation and calibration data for Orbiting Carbon Observatory (OCO)-2, Global Ozone Monitoring Experiment 2 (GOME-2), Tropospheric Ozone Monitoring Instrument (TROPOMI), Greenhouse gases Observing SATellite (GOSAT), and satellites in the Geostationary Monitoring Constellation.
- (ii) ATom uses satellite data to extend its airborne *in situ* observations to global scale.
- (iii) ATom directly engages CCM groups and delivers a single, large-scale, contiguous *in situ* data set for model evaluation and model improvement.

The ATom Mission further addresses important secondary questions (denoted "Tier 2") linked to climate forcing by aerosols and longer-lived GHGs and Ozone Depleting Substances (ODSs).

What are the distributions in remote areas of BC and other aerosols important as short-lived climate forcers? What are the sources of new particles in the remote troposphere, how rapidly do they grow to cloud condensation nuclei (CCN)-active sizes, and how well are these processes represented in CCMs?

ATom quantifies BC and aerosol composition to provide key constraints on removal processes in models. ATom further maps out new particle formation and the evolution of particle size distributions in under-sampled atmospheric regions that are highly sensitive to indirect cloud radiative forcing.

What are the vertical and horizontal gradients of GHGs and ODSs over remote ocean regions? How can we use the observed gradients to help identify influences on photochemical reactivity in air parcels, validate satellite data for these gases, and help refine knowledge of sources and sinks? ATom's "fingerprint tracers" help identify the origins of anomalies in photochemical reactivity and concentrations of aerosols, GHGs and ODSs, for which budgets and source identification have significant scientific and decision-support value.

Addressing National Aeronautics and Space Administration (NASA) Earth Science goals. ATom delivers

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Imaging the Chemistry of the Global Atmosphere

unique data and analysis to address the Science Mission Directorate (SMD) objectives of acquiring “*data sets that identify and characterize important phenomena in the changing Earth system*” and “*measurements that address weaknesses in current Earth system models leading to improvement in modeling capabilities*”.

Investigation overview. ATom deploys an extensive gas and aerosol payload on the NASA DC-8 aircraft for systematic, global-scale sampling of the atmosphere, profiling continuously from 0.2 to 12 km altitude from 85 °N to 65 °S in both the Pacific and the Atlantic (our definition of “tomographic”) in four separate seasons. ATom applies the data to model testing/development and satellite validation.

Instrument platform and payload. The NASA DC-8 provides range (5,400 nautical miles), payload (30,000 pounds (lb)), inlet configurations, and demonstrated ability to operate from multiple deployment sites, sequentially, with no specialized ground equipment. This platform enables systematic, tomographic, global-scale sampling for reactive gases, aerosols, and GHGs. The payload has 15 proven instruments for *in situ* measurements of reactive and long-lived gases, diagnostic chemical tracers, and aerosol size, number, and composition, plus spectrally resolved solar radiation and meteorological parameters. Overall ATom measures more than 100 distinct chemical, aerosol, radiative, and physical parameters. Fast instrument sampling rates provide spatially resolved, simultaneous, and contiguous observational data.

Modeling and analysis. ATom employs a variety of customized modeling tools to transform airborne observations into critical evaluations of CCMs. A key element is analysis of reactive and intermediate chemical species to produce tomographic cross sections of 24-hour average chemical rates for the reactions determining the chemistry of CH₄ and O₃. Further, tomographic data on aerosol properties coincident with oxidant and tracer data addresses conflicting hypotheses concerning new particle sources, processing and loss mechanisms, and their resultant climate effects. Finally, tomographic data on long-lived GHGs, ODSs, and other distinct tracers are used to attribute emissions of the short-lived climate forcers CH₄, O₃, and BC aerosol to particular sources and processes.

Schedule summary. ATom has a global scale deployment in each of 4 seasons over a 4-yr period in order to identify seasonal patterns in chemical reactivity and the integrated impact of anthropogenic emissions from the major continents. Each deployment is comprised of 10 flights in a circuit transecting the Pacific and Atlantic basins from nearly pole-to-pole.

Management structure and costs. ATom is led by Dr. S. Wofsy (Harvard, Principal Investigator (PI)) and Dr. M. Prather (University of California, Deputy PI). The Science Team, comprised of 15 instrument teams and several theory teams, is led by Dr. T. Ryerson (National Oceanic and Atmospheric Administration (NOAA)) aided by Drs. P. Newman (NASA Goddard Space Flight Center (GSFC)), T. Hanisco (NASA GSFC), and D. Fahey (NOAA). The Project Manager (PM) is M. Vasques (NASA Ames Research Center (ARC) Earth Science Project Office (ESPO)), the Mission Systems Engineer is J. Zavaleta (NASA ARC ESPO), the Aircraft Mission Manager is F. Cutler (NASA Dryden Flight Research Center (DFRC)), and the Instrument Integration Engineer is A. Webster (National Sub-orbital Education and Research Center (NSERC)). The total cost to NASA is \$29.85 million (M), of which \$3M is reserve. In addition, the NOAA Earth System Research Laboratory contributes \$1.1M in resources via Civil Servant salaries and other in-kind costs.