Quantifying the Intercontinental and Global Reach and Effects of Pollution

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The Atmospheric Chemistry Modeling Group is participating in an international effort to explore the projected interactions of the atmosphere with biota, human activity, and the natural environment over the next three decades. The group uses computer simulations and statistical analyses to compare theory and observations of the composition of the lower atmosphere. This study of global habitability change is part of a more ambitious activity to understand global habitability. This broad planetary understanding is central to planetary habitability, biomarker detection, and similar aspects of Astrobiology.

The group has made highly detailed studies of immense intercontinental plumes that affect the chemistry of the global atmosphere, especially the region below the ozone (O_3) layer whose chemical composition defines the conditions for healthy humans and the biosphere. For some decades there has been concern about the pollution from cities and industrial burning and its possible effect in increasing smog ozone, not only in continental regions, but also in plumes that spread downwind. Recently, there has been new concern about another kind of pollution plume. Projections for a greatly expanded aircraft fleet imply that there will be plumes of nitrogen oxides (NO_x) from jet exhaust in the Northern Hemisphere downwind of major air traffic routes. Both of these are tied to large-scale O_3 in the troposphere, where it is toxic to humans and plant tissues.

Modeling at Ames, confirmed at the Royal Dutch Meteorological Institute, suggests that the NO_x pollution emitted from aircraft engines plays a surprisingly large role in producing pollutant ozone between 5 and 12 kilometers (km) in the atmosphere, that is, below the main O_3 layer shield. This could be determined only by close analysis of observed data and computer simulations. A large airborne observational project, the SASS Ozone and Nitrogen Oxides Experiment (SONEX), was mounted over the North Atlantic in October and November, 1997. The modeling group provided detailed pollution weather forecasts to the aircraft scientists in the field for planning and immediate analysis of the measurements. The group simulated chemical species with separately defined sources and simple transformation rules. Separate tracers were used to follow NO_x from industry and cities, from the newly suspect aircraft, and from lightning. Because there is no directly measurable indicator of aircraft-origin NO_x, simulations like those done at Ames are the only clear indicator of origins. Figure 1 shows the first-principles calculation of the effect of aircraft on the atmosphere at aircraft flight level, and also the amount that best matches observations. Careful statistical techniques were used to match the "fingerprints" (similar patterns of ups and downs) of observed NO_x peaks with the simulated tracers. They were "robust" against intermittent failures of simulation, such as missed weather forecasts. The second scale in figure 1 shows the amount required by such matching. In summary, the group has shown that the effects of aircraft emissions are widespread, they contribute much to the upper tropospheric chemistry, and they may be underestimated by perhaps a factor of two or more.

More theoretical studies have also aided Ames research. Work with Dalhousie University, Nova Scotia, has helped unravel the processes of ozone "superproduction." Not only NO_x, but also a supply of active photochemical species—radicals such as hydroxyl radical (OH) and hydroperoxy radical (HO_2)—are required to describe the O_3 and oxidation chemistry of the upper troposphere. One proffered counter-explanation of O_3 superproduction is that there might be an unmeasured, unnamed source of these radicals that could explain the O_3 production results, such as acetone. Analyses have shown that such sources should decrease the available NO_x to much lower quantities. Although this work has not pinpointed a solution to the "superproduction" dilemma, it has helped make connections between the situational modeling and global analysis simulations.

The Atmospheric Modeling Group has continued its highly detailed studies of global lower-atmospheric chemistry to describe the spread of smog-like pollution around the world. Studies have documented the exact African sources of pollutant compounds such as carbon monoxide (CO) and O_3, which the NASA DC-8 aircraft discovered in the middle and upper troposphere over Tahiti and even more remote regions of the Pacific Ocean. Previous ideas held that this region was a permanently pristine

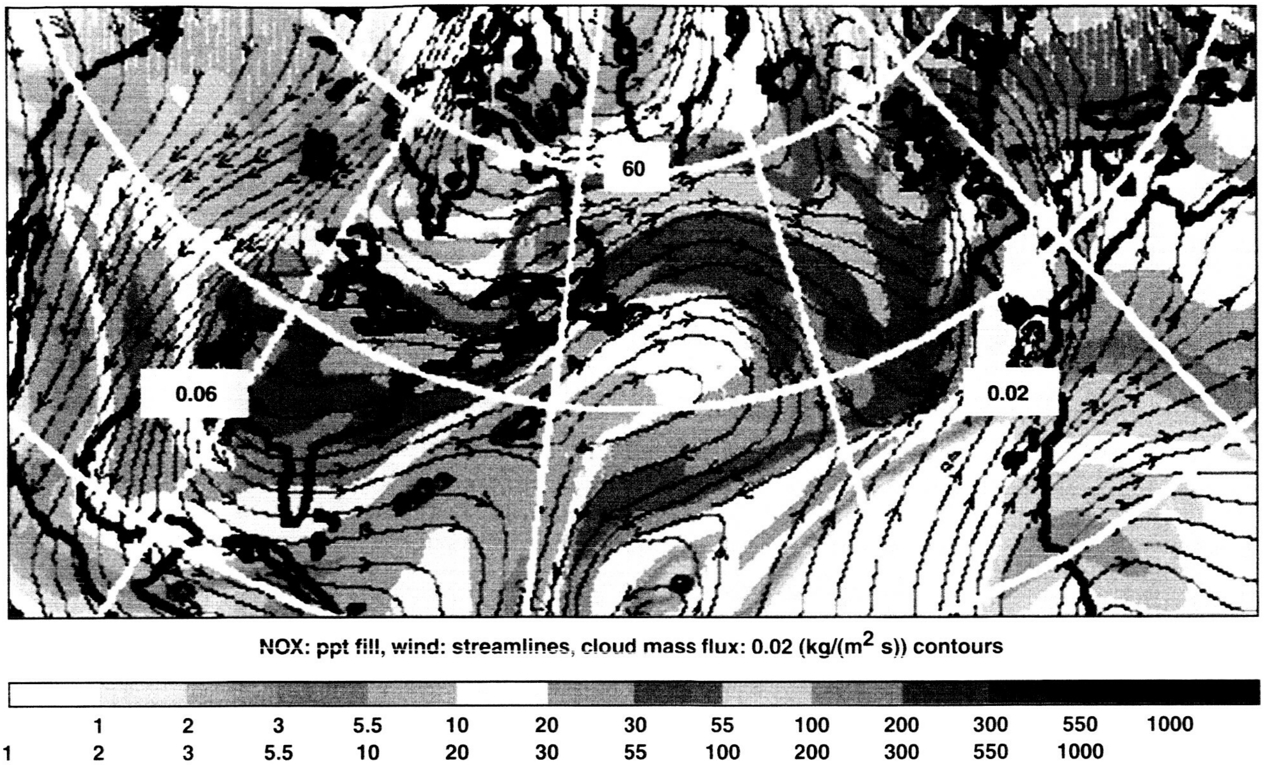

Fig 1. Spread of chemically active NOx from main aircraft corridors throughout the North Atlantic Ocean. The first scale, molecules per 10^{12} molecules (ppt), comes from direct calculation. The lower scale, however, which is almost two times higher, compares more directly to the data.

region. However, work recently published by the group has illustrated the role of thunderstorm clouds over the continents of Africa and South America in producing large plumes of pollution. Additionally, that work made important quantitative checks on the simulation of cloud venting.

The group has also shown how long, coherent strands of pollution were found to pulse along the subtropical jet region. Regions of the South Pacific once thought to be months removed from pollution effects were sporadically affected within 5 to 15 days. Individual storms over Africa were pinpointed as major pollution sources in several cases, but the large-scale buildup over the burning continents also contributed. This work continued the group's study of important CO features observed from the NASA Measurement of Air Pollution from Space (MAPS) satellite sensor, and on board the NASA DC-8, during the Pacific Exploratory Mission, Phase A (PEM-T A). These studies prepare for the instrument named MOPITT, which measures CO from the Earth Observing System (EOS) Terra satellite. Collaborators in this research include Ian Folkins (Dalhousie University, Halifax, Nova Scotia), and Glenn Sachse (NASA Langley Research Center).

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