UCAR Quarterly Summer 2008

Finding pay dirt aloft

Widespread fires and pollution deliver for ARCTAS

by Bob Henson and Nicole Gordon

Their views were often shrouded in haze and smoke. But for more than 100 atmospheric scientists and technicians who embarked this spring on the discipline's biggest airborne field study in more than two years, the rewards were clear.

Rodney Weber (Georgia Institute of Technology) readies a set of sample vials that stored fine water-soluble particulates. These were collected during DC-8 flights for later analysis of a variety of aerosol properties. (Photo by Bob Henson.)

"We had no problem finding smoke," says Jack Dibb (University of New Hampshire). Dibb was among the lead scientists for the NASA-led ARCTAS campaign (Arctic Research of the Composition of the Troposphere from Aircraft and Satellites). The project involved NASA's DC-8, P-3, and B-200 aircraft, which together carried more than 30 instruments on flights based out of Fairbanks, Alaska (March–April), and western Canada (June–July).

Assessing the impact of high-latitude fires on air quality and climate was one of the project's main goals. As if on cue, a swarm of fires swept across a swath of Canada's boreal forests just as scientists and technicians were hunkering down in Cold Lake, Alberta, and Yellowknife, Northwest Territories, for the ARCTAS summer field phase. "Much of Saskatchewan was burning the whole time we were there," recalls Dibb. The proximity of the fires reduced the amount of flight time in transit for each mission, allowing the aircraft to carry out hours of intensive sampling.

Smoke, soot, and sun

ARCTAS is the largest airborne experiment ever undertaken to study the impact of air pollution on northern polar climate. "The Arctic is a beacon of global change," notes Guy Brasseur, head of NCAR's Earth and Sun Systems Laboratory. "There's an urgent need for research to better understand changes in the atmospheric composition and climate of this vulnerable place."

The springtime flights out of Fairbanks focused on Arctic haze—a product of industrial emissions from Eurasia and North America that drift into the Arctic's winter vortex, then react photochemically once spring sunshine arrives. The result is an urban-style stew of ozone and aerosols (airborne particles) incongruously suspended above pristine polar landscapes. A key concern is that soot and other particles can change the radiative qualities of arctic clouds and hasten the melting of snow and ice, with implications for longer-term climate change. Complicating the matter, many of the pollution layers are quite thin, making it hard to discern their complex structures.

The many shades of fire plumes: NASA's P-3 flew near smoldering ground fires and "black smoker" crown fires during ARCTAS. These images were taken on 10 July at the Lake Athabasca fire complex in northern Saskatchewan. (Photos courtesy Cameron McNaughton, U. of Hawaii).

Along with shedding light on high-latitude air chemistry, the data collected from ARCTAS will help validate satellite observations. The five satellites now in NASA's A-Train (two more are scheduled for launch later this year) allow scientists to monitor pollution's worldwide reach on a regular basis. The satellites orbit in a tight formation, measuring gases, aerosols, clouds, and radiative fluxes. Because the A-Train is in polar orbit, it provides an especially rich set of data at high latitudes, where the orbital tracks meet.

Flight tracks and mission schedules for ARCTAS were designed to mesh with the paths and instrumental qualities of the A-Train satellites. For example, tight spirals around a large smoke plume provided columns of data well suited for comparison with the vertical cross-sections gathered by the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation, or CALIPSO. (The pairing came none too soon for CALIPSO, which is less than a year away from the end of its three-year projected lifespan.)

The P-3's payload was specially designed to capture how atmosphere and ground reflectance are shaping the region's radiative balance, according to NASA P-3 platform scientist Philip Russell. "Radiant energy exchange is essential not only to validating our satellite measurements but also to determining climate, which has been changing most rapidly in the Arctic," notes Russell.

Anne Thompson (Pennsylvania State University) worked with NOAA's Samuel Oltmans in planning the ARCTAS fleet of ground-based ozone sensors as well as ozonesondes. The latter consist of balloon-borne weather observing packages (radiosondes), plus ozone-measuring equipment and a balloon large enough to loft the sonde up to 35 kilometers (22 miles), well into the stratosphere.

Pyrocumulonimbus: a different kind of firestorm

Mike Fromm has a meteorological mission—to better understand a rare and powerful type of thunderstorm called pyrocumulonimbus, or "pyroCbs." Generated by large wildland fires, pyroCbs have many of the earmarks of typical thunderstorms, including lightning and anvil-shaped cirrus clouds, but many weather experts don't even know they exist.

Michael Fromm. (Photo courtesy NASA)

Fromm, who is based at the Naval Research Laboratory in Washington, D.C., saw ARCTAS as a natural avenue for investigating pyroCbs. The meteorologist's quest to understand these mysterious storms began about a decade ago. His NRL job at the time involved analyzing polar stratospheric clouds, which form only in winter.

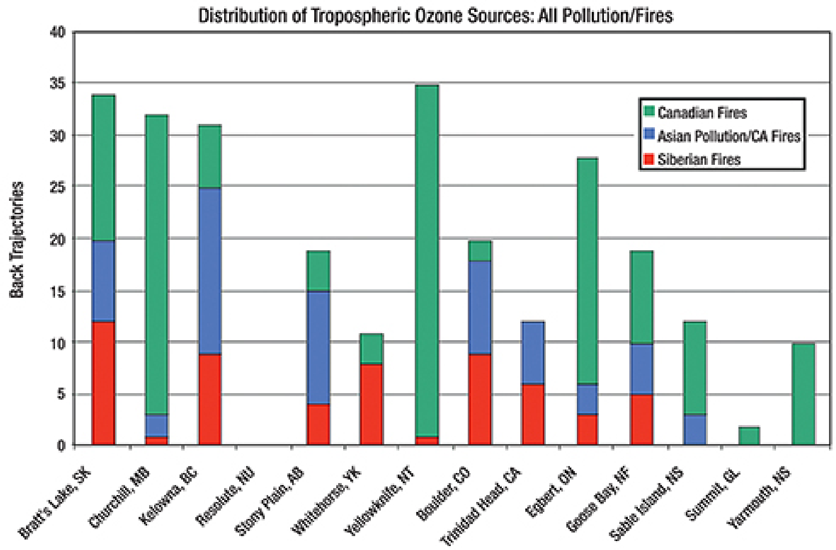
"It turns out our satellite instrument was picking up strange signals in the summertime. These looked like cloud layers, and we couldn't figure out what they were," says Fromm. By carrying out back-trajectory analysis and poring over satellite imagery, he and his peers made the connection to wildfires. Fromm also learned that firefighters had long recognized the existence of pyroCbs. Yet, he says, “when I showed the satellite imagery to other people, they shrugged it off as some kind of weird optical illusion.”

Even the strongest thunderstorms on Earth top out little higher than the tropopause (the base of the stratosphere). Some of Fromm’s data indicate smoke from pyro-Cbs extending as high as 9 km into the stratosphere. Only volcanoes were thought to inject debris that high. In fact, says Fromm, the pyrocumulonimbus is like a mini–volcanic eruption, sending updrafts and debris well into the stratosphere. He suspects the smoke within a pyroCb allows for large volumes of ice production (the topic of one of his recent papers).

This intense, tornado-spawning pyrocumulonimbus formed atop a severe wildfire near Canberra, Australia on 18 January 2003. (Photo courtesy New South Wales Rural Fire Service

PyroCbs produce little or no rain, but they can apparently spawn twisters. The catastrophic fires that swept into Canberra, Australia, in January 2003 produced a pyroCb with a bona fide tornado, rated at F2 on the Fujita scale. This tornado moved out ahead of the fire itself, says Fromm, unlike the far more common spin-ups called fire whirls that are often sighted along walls of flame in a big fire.

Two pyroCbs were detected during ARCTAS, one in the Northwest Territories on 28 June and the other in Alaska on 8 July. The DC-8 successfully sampled the plume of the 28 June storm a day after it formed. “It wasn’t obvious whether we knew enough to send the plane to the right place, but we got lucky,” says Fromm. The scientists later carried out back-trajectory analysis that linked the aircraft observations to satellite imagery of the pyroCb itself—a scientific first, Fromm says. He’s eager to learn more about the dynamics of this case and about pyrocumulonimbus in general. “We’ve gone from a lot of skepticism and not a lot of understanding of pyroCbs to a lot of people thinking, ‘This is pretty amazing stuff.’”



This preliminary analysis by Stephan Gallagher (Pennsylvania State University) counts and classifies the number of air parcels over each sounding station during the ARCTAS study period (26 June–12 July 2008) that had incorporated smoke from fires in Canada (green) and Siberia (red) or Asian pollution and/or California fires (blue).

While at NASA, Thompson pioneered the concept of coordinated ozonesonde networks for validating satellite data, including an ongoing network in the tropics and three others for North American pollution campaigns since the A-Train's Aura satellite was launched in 2004. The ozonesonde network complemented the aircraft missions well, says Thompson: "It gave us the same information from the same spot every single day, so we could gather statistics to verify satellite algorithms and evaluate the models used for ARCTAS analysis."

Thompson and her PSU team assembled the ARCTAS Intensive Network Study (ARC-IONS), a 19-station ozonesonde network spanning high-latitude North America from Atlantic to Pacific coasts and extending as far south as Trinidad Head, California. Most of the launches were coordinated by NOAA and Environment Canada. PSU graduate student Alania Luzik and undergraduate Stephan Gallagher are now working to identify the multiple sources of ozone at each location.

In between the spring and summer phases of ARCTAS, NASA teamed with the California Air Resources Board for ARCTAS-CA. This set of June flights was aimed at quantifying smog and greenhouse gas production across the Golden State. It included a special P-3 mission to sample emission plumes from 19 ships off the California coast.

NCAR's David Knapp contrasts the air quality he found in the Los Angeles Basin during ARCTAS-CA with the highly visible smog he encountered in Mexico City during a 2006 field project on megacity pollution. "In terms of aerosol loading, the air in L.A. was considerably cleaner than in Mexico City, but in terms of gas-phase constituents, it was still very dirty," says Knapp.

Even a normally routine transit between research bases—in this case, from Palmdale and Moffett Field, California, to Cold Lake on 26 June—turned into a smoke-sampling mission, as the NASA planes cut through thick plumes sent out by California's intense lightning-sparked wildfires.

Off the charts

Like slot machines hitting jackpots, several instruments measured record-high amounts of airborne compounds during ARCTAS.

- A mass spectrometer from the University of Colorado in Boulder notched its highest-ever concentration of small aerosols while flying above the Saskatchewan fires.
- Carbon monoxide and carbon dioxide sensors from NASA's Langley and Ames Research centers hit records, with CO measurements at more than 12 parts per million on the Ames sensor aboard the P-3 as well as the Langley sensor on the DC-8.
- The University of Hawaii measured its highest-ever amount of aerosol light extinction (scattering plus absorption) during the P-3's fire-plume penetrations.

- Optical depth, a measure of attenuation of sunbeams, hit record values (exceeding 4) when a tracking sunphotometer from Ames on the P-3 viewed the Sun through smoke in Canada.
- Flying on the DC-8 near Los Angeles International Airport on 18 June, an NCAR nitrogen oxide sensor found concentrations as high as it's measured anywhere.

The aerosol mass spectrometer brought to ARCTAS by Jose-Luis Jimenez, left, (University of Colorado in Boulder) measured a record number of particulates. NCAR's Rebecca Anderson, right, carries out adjustments on an instrument from the DC-8 that measured hydrogen oxides. (Photos by Bob Henson.)

Cloudy with a chance of plumes

While aircraft buzzed through smoke and satellites spun above it, computers on the ground churned out chemical-weather forecasts that served as valuable guidance for ARCTAS. Three teams of modelers—led by Bryan Duncan (NASA Goddard), Gregory Carmichael (University of Iowa), and Louisa Emmons (NCAR)—produced an ensemble of chemical-weather products for each day's science planning meetings. These meetings were led by Daniel Jacob (Harvard University) and included weather forecasts from a Florida State University group headed by Henry Fuelberg.

Thomas Walker (University of Toronto), Alex Bryan (Valparaiso University), and Anne Thompson (Pennsylvania State University) prepare for an ozonesonde launch at

"One of the nice things about participating in ARCTAS, as well as other field experiments, is that it's a good test for our models," says Emmons. "We predict where a pollution plume is going to be and then the aircraft goes off and samples it, so right away we know whether our model was accurate."

The emissions from fast-sprouting fires took at least a day to be incorporated into the chemical models, but once in the system, they could be tracked for days and even

Yellowknife, Northwest Territories. (Photo by Greg Merkes.)

weeks. NCAR modeler Gabriele Pfister used output from the center's Community Atmosphere Model with Chemistry (CAM-Chem) and Model for Ozone and Related chemical Tracers (MOZART) to help successfully guide the DC-8 into a week-old smoke plume that had drifted from Siberia toward the North Pole and Greenland. "We were able to time the flights and target this plume really well," says Pfister.

On occasion the modelers and flight planners faced an atmosphere that resembled a Dagwood sandwich, with multiple layers of smoke and pollution stacked atop each other. In early July, for example, three disparate sources of wildfire smoke converged on northern Canada: the high-altitude plume flowing east from Siberia, more localized plumes originating at ground level across Saskatchewan, and diluted smoke arriving at middle altitudes from the northern California fires.

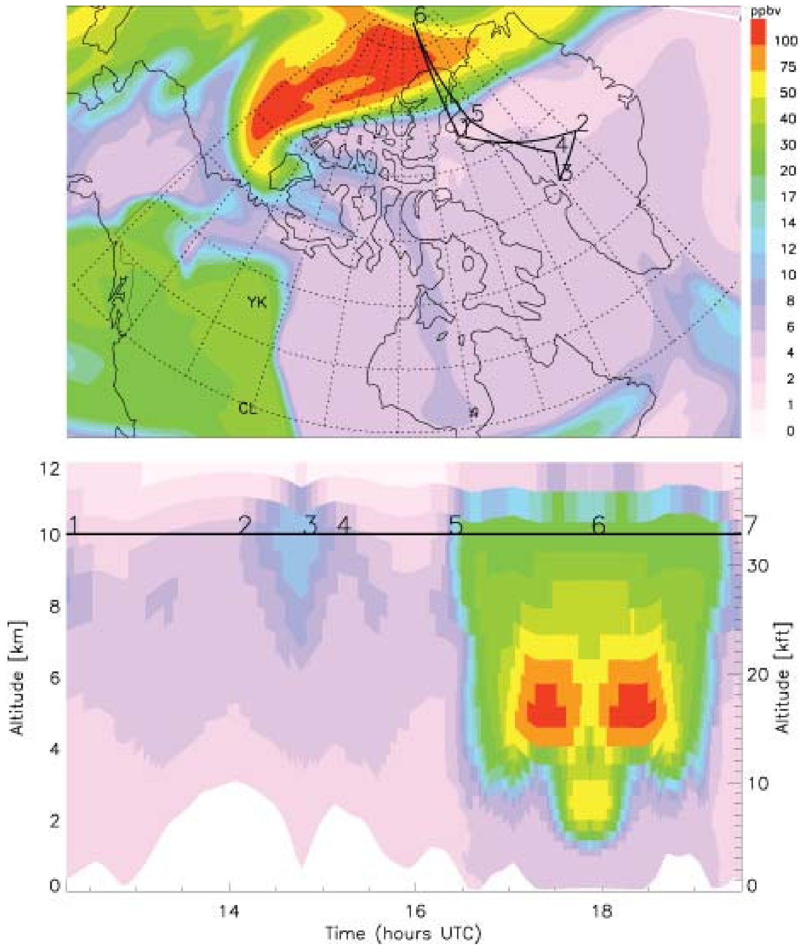
"Most striking to me was how many different kinds of emissions end up in the Arctic from both local and distant sources," says NASA's Russell. He was impressed by how vividly the trajectories of each pollutant were depicted in ARCTAS model outputs. "These not only guided our flight planning, but they were and will be tested by the flight and satellite data. It's a very powerful kind of synergism that has become a core characteristic of ARCTAS and other modern aircraft-satellite field experiments."

On the Web

ARCTAS

Arctic Intensive Ozonesonde Network Study

NCAR's David Knapp and Gabriele Pfister review model results from ARCTAS. (Photo by Bob Henson.)



NCAR's Model for Ozone and Related chemical Tracers (MOZART) produced these forecasts of carbon monoxide for a July 9 DC-8 flight from Thule, Greenland. At a height of 5 km (top), MOZART showed a broad plume of CO across the Arctic Ocean. A "curtain plot" (bottom) revealed a cross section of CO by height along the proposed flight track, helping flight planners to pick their desired altitude. (Illustrations courtesy Gabriele Pfister.)

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