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# LONG-TERM, FREQUENT DUST COLLECTIONS IN THE TROPOPAUSE REGION

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## ABSTRACT

A long-term, frequent monitoring program of aerosols in the tropopause region, preferably in the lower stratosphere, will have scientific merit. It will have a strong educational impact in aspects of collection and characterization of mostly solid dust particles in a part of the atmosphere that is generally poorly covered by existing dust collection programs, apart from specific 'target dusts' (*e.g.* aircraft soot). The opportunity using the existing SOFIA upper deck infrastructure discussed here will collect and identify all dusts. It will eventually produce a compressive survey of dust types, their physical properties and the temporal variations of source-specific particles.

## INTRODUCTION

Up front, long-term, frequent dust collections in the tropopause region do not seem to make much sense. After all, in terms of aerosols the Earth's upper troposphere and lower stratosphere are probably the dirtiest places excepting the air mass in the lowermost few hundreds of meters from the surface. The upper stratosphere >30 km is the ideal location to collect dust that reached the Earth from sources in space, *viz*. interplanetary dust particles (*IDPs*) and reentering space debris although a major volcanic eruption could inject dust to the middle and upper stratosphere (Rietmeijer 1993a). During the late 1960s balloons were used to carry dust collectors aloft to altitudes as high as ~37 km (Bigg et al., 1970). The scientific results were limited but they showed proof-of-concept. Brownlee et al. (1973) completed the first successful collection of IDPs at 35 km altitude but also found mostly 2-3 μm $Al_2O_3$ spheres that were solid-rocket fuel effluents. Another balloon-borne dust collection experiment between 34-36 km during May 1985 that was intended to collect meteoric debris from the condensation of meteor ablation vapors (Testa et al., 1990) unexpectedly found significant volcanic dust mostly <2 μm in size (Rietmeijer, 1993a). Balloon-borne dust collectors must be active collectors, *i.e.* vacuum cleaners'. Deploying small inertial-impact collectors mounted underneath the wings of high-flying aircraft (*e.g.* U2) in the lower stratosphere between 15-20 km would be a more expedient way to collect aerosols, including elusive meteoric debris (Rietmeijer, 2001). Such collections began in March 1974 (Brownlee et al., 1976).

## DUST COLLECTION IN THE LOWER STRATOSPHERE

Using the same experimental set-up, the NASA Johnson Space Center (JSC) Cosmic Dust Program made its first sampling flight in the stratosphere between 17-19 km altitude on May 22, 1981 (Zolensky et al., 1994). It has since developed into a routine sampling program of lower stratospheric dust albeit too haphazard to qualify as a monitoring program but which was never its intended purpose. The program was designed to provide IDPs for research purposes. The collected particles range from ~2 μm to ~50 μm with an average collected particle size of ~15 μm. Particles, including condensed aerosols (*e.g.* $H_2SO_4$), are collected on Lexan plates covered by a layer of high viscosity silicone oil to entrap collected particles that impact the collectors. Four collectors are housed in each of two pylons mounted underneath the wings of the aircraft. A pressure sensor opens and closes the pylons when to airplane has reached the collection altitude (Zolensky et al., 1994). The particles from this NASA program are cataloged and each particle is classified as belonging to one of four categories based on bulk composition, morphology and selected optical properties:

1. “cosmic” [C] dust (or IDPs),
2. “terrestrial contamination, natural” (TCN) (mostly volcanic ash; biomass burning carbon),
3. “terrestrial contamination, artificial (TCA) [spacecraft paints and metal alloys], and
4. “AOS spheres” [Al-oxides spheres solid rocket fuel exhaust].

The label ‘contaminant’ expresses the intended bias of the program but doesn’t mean that these particles have no valuable information. Mateshvili and Rietmeijer (2002) used this NASA collection to extract volcanic dust settling rates. Zolensky et al. (1989) predicted that when most of the AOS debris is related to the US Space Shuttle program, these particular spheres should disappear from the lower stratosphere following the Challenger accident, which was found to be the case (Rietmeijer and Flynn, 1996). It goes to show that long-term aerosol monitoring, with emphasis on solid debris, is a powerful, yet simple, tool to obtain useful information on the processes and residence times that affect these aerosols in the lower stratosphere and of their mineralogical and chemical properties. Another programs that used the same NASA aircraft flew a time-of-flight mass spectrometer to determine the chemical composition of aerosols mostly between 200 nm and 2 μm at the Northern Hemisphere during a period of low volcanic activity (Murphy et al., 1998). A group of aerosol with high Fe-ion (+ minor Mg, Na, Al, K, Ca, Cr, Ni) was considered to be meteoric dust (Murphy et al., 1998).

NASA/JSC Cosmic Dust Program uses (1) small area collectors (SACs) of 30 $cm^2$ and (2) large area collectors (LACs) of 300 $cm^2$. To collect 10 to 15 IDPs (the program’s collection target) the SACs will require 30-40 hours collection time, whereas this time for the same result using LACs is ~10h. Thus, LACs would allow “targeted collections” (Mackinnon, 1985), *e.g.* dust evolution in a volcanic eruption plume (Mackinnon et al., 1984) and the dust stream from comet Grigg-Skjellerup (Messenger, 2002).

The Leonid storm, dust from comet Tempel-Tuttle, was an “opportunistic” effort (Rietmeijer et al., 2003) that flew onboard the USAF/NKC-135 FISTA aircraft of the 2002 Leonid MAC Airborne Mission (Jenniskens, 2002). With ‘lessons learned and experienced gained’ this effort demonstrated the feasibility of dust collection in the dirty region of the tropopause using a ‘slow-moving’ aircraft. A similar collection technique as part of the SOFIA Upper Deck Facility would offer a great research and teaching opportunity. The NASA “Stratospheric Observatory for Infrared Astronomy" (SOFIA) is scheduled to perform 960 hours of flight per year for 20 years.

## DUST COLLECTOR

The inertial-impact, flat-plate collector was a transparent 26 $cm^2$ plastic plate mounted on top of a supporting foam layer that was mounted inside a transparent, one-cm high plastic box with a removable lid held in place by side-mounted screws on a rectangular Plexiglas plate that was the median plane of a Plexiglas tube that was capped at both ends. This tube was place in an existing periscope assembly, *i.e.* a metal tube (15 cm in diameter) that fitted snuggly in a gimbal assembly mounted on the aircraft through a window port. The metal tube capped at one end and had a cut-away opening near to the capped end. A matching cut-away hole was made in the Plexiglas cylinder. In this assembly the collector was at ~20 cm distance from the aircraft hull. The lid of the plastic box was removed prior to take-off and replaced immediately upon landing. The collector was opened once the aircraft had reached collection altitude.

Clean collection plates were prepared inside a laminar flow bench at UNM for shipment to the Curatorial Brach at NASA/JSC were each place was coated with same highly-viscous silicone oil used by the Cosmic Dust Collection Program (see, Zolensky et al., 1994). The transparent silicone oil does not interfere with light-optical inspection of collected dust albeit that very small silica dust will be invisible because of the similar refractive indices of this oil and quartz.

Light-optical particle identification was performed the closed collector box using a binocular microscope adopting the same criteria for color, luster (vitreous, dull and metallic), dust transparency, translucence or opaqueness, and shape (sphere, equant or irregular), employed by the Cosmic Dust

Program (Zolensky and Mackinnon, 1985). In this manner each of 986 collected particles >10 µm could be assigned to one of three groups, viz. (1) natural terrestrial, *i.e*. volcanic, dust, (2) anthropogenic dust, and (3) probable extraterrestrial spheres. Dust was collected during the night of the Leonid Storm (Nov. 19) and on flights, prior to and after this event (Nov 16/17; Nov. 20) to determine the dust background in the region of the tropopause. On another flight the 'closed' collector mode was successfully tested (Rietmeijer et al., 2003). Optical scanning of both background collectors found the same amounts of particles and identical dust type distributions. It gave ample proof-of-concept of this collector design.

Fig. 1. View of the Leonid dust collection device viewed from inside the FISTA aircraft. It shows the metal tube (overexposed) wherein the Plexiglas tube with the collector mounted on the median plane was fitted prior to take-off. The capped end of the metal tube had holes to allow some air to escape. The collector box is visible to the right of the holes in the end cap. The operator manually controlled opening and closing of the collector. The "open" mode was when the cut-away holes overlapped; closure for take-off and landing was achieved by 180$^o$ rotation.

The Leonid MAC campaign conducted four flights: (1) Edwards Air Force Base (CA) to Omaha (NE) (Nov 15), (2) Omaha to Torrejon (Spain) (Nov 16/17), (3) Torrejon to Omaha (Nov. 19), and (4) Omaha to Edwards AFB (Nov. 20).

Again following the procedures for IDPs (Zolensky and Mackinnon, 1985) all particles were rinsed off a collector plate with ultrapure Freon and hexane and deposited on a substrate for scanning electron microscope (SEM) analysis to determine the size, shape, morphology and composition of each collected particle. The SEM, equipped with an energy dispersive spectrometer for chemical analyses of major rock-forming elements including carbon and oxygen. The SEM procedures are standard use of this technique.

The smallest particles were ~3 µm; the largest dust, ~100 µm, were compact aggregates. Among 50 spheres, potentially extraterrestrial dust, were 'silicate' and Fe-spheres similar to those that are routinely found among the particles of the NASA/JSC Cosmic Dust Collection. Since Leonid dust collection was conducted at much lower altitudes, the most abundant natural particles collected were volcanic ash. Interestingly, and underscoring the potential of this type of collection on a long-term basis, there were to distinct populations of volcanic ash from

1. a size-sorted, probably global background layer, and
2. a juvenile point source in western Europe, possibly Mt. Etna (Sicily), perhaps just a transient cloud.

## SCIENTIFIC AND EDUCATIONAL IMPACT OF DUST COLLECTION

Aerosols in the tropopause region include (1) vapor-condensed liquids and solids and (2) solid dust particles. There are extensive data on the aerosol size distributions ranging from a few nanometers up to microns-sized dust but without a distinct upper limit. Less is known of the solid dust morphologies and even less of the chemical and mineralogical properties, *e.g*. crystalline (ordered) or amorphous and density, among other properties. Yet, solid aerosols could also affect the physical properties of the atmosphere that should be considered for implications in a context of global climate change and would be of interest to reduce data from Earth-orbiting satellites, among others. Dust in the lower stratosphere is supplied from two major 'reservoirs', *viz*.

- ✓ Dust from sources in space entering the atmosphere:
  - meteor ablation and fragmentation,
  - surviving IDPs and micrometeorites
  - condensed meteoric dust,
  - reentered space debris

- ✓ Sources at the Earth's surface:
  - infrequent major eruptions, e.g. Mt. Pinatubo (1991), El Chichón (1982) and Mt. St. Helens (1980), lofting dust to high stratospheric altitudes,
  - frequent minor volcanic eruptions mostly in equatorial regions (Rietmeijer, 1993b),
  - aeolian dust (natural and anthropogenic),
  - aircraft exhaust (mostly soot)
  - anthropogenic dust, predominantly fly-ash from coal-burning power plants

The scientific impact of a long-term monitoring program using the SOFIA aircraft as a platform would be a quantitative database on the amounts and types of dust particles. Sub-micron dust provides a tremendous surface area for catalytically-supported reactions among condensed aerosols at the surface, as well as scavenging condensed aerosols that become 'sequestered' on dust particles which would enhance their removal from the atmosphere. Variations in particle number density of solid debris are a function of supply rate and transient dust cloud formation, among others, that operate on local, regional, and global scales. Such variations in solid particulate matter number density affecting the transparency of the atmosphere would be of interest to ground-based astronomy (Rietmeijer, 1990). Long-term (multi-year), frequent (monthly?) monitoring of aerosols will contribute to a better understanding of the temporal and spatial scales of such variations of dust particles from a wide range of sources. This particular aspect offers a wide range of educational opportunities at the undergraduate and graduate levels in Atmospheric and Earth Sciences, both academically and hands-on experience, *viz*.

- laboratory-based collector preparation, collector deployment, and post-flight-handling,
- participation in dust collection opportunities onboard SOFIA,
- light-optical characterization of collected aerosols and preliminary source identification,
- learning about individual dust-contributing natural and anthropogenic sources,
- SEM laboratory characterization of aerosol properties,
- learning the physical and chemical controls of natural and anthropogenic, dust-producing processes and their regional and/or global impact,
- learning about the chemical and physical interactions of dust with the troposphere and stratosphere and developing sense of complexity of these interactions that could be source-specific,
- learning how to reduce the results to prepare for scientific communication and how aerosols form a part of a global framework,
- the possibility of a long-term program would allow a large group of students to get direct hands-on experience and develop market-competitive laboratory skills applicable to Environmental Science and environment-monitoring programs at county, state and federal levels, including private industries.

The Leonid dust collection experience showed that each of laboratory-based aspect listed is easily and well performed by students, who will be able to work semi-independent on either a small aspect of the long-term project or a comprehensive part should it so be desired for example as a thesis research subject.

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