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LONG-TERM, FREQUENT DUST COLLECTIONS IN THE TROPOPAUSE REGION

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ABSTRACT

The long-term, frequent observation of aerosols in the tropopause region will have considerable scientific merit and make a significant educational impact in aspects of dust characterization and collection in the upper-troposphere/lower-stratosphere (UT/LS) zone that is poorly covered by existing dust collection programs but is of significant interest to global climate change effects. The SOFIA upper deck's infra-structure offers a significant opportunity to observe and identify solid aerosols to build a comprehensive survey of dust types, their chemical and physical properties and temporal variations of source-specific terrestrial and extraterrestrial dust particles.

INTRODUCTION

Upfront long-term, frequent dust collections in the tropopause region do not seem to make sense as in terms of aerosols the UT/LS region is quite dusty with dust that reached the Earth from sources in space and from sources at the Earth's surface whereby both sources include natural and anthropogenic dusts. The upper stratosphere (>30km) is an ideal location to collect extraterrestrial dust (interplanetary dust particles; *IDPs*) and reentered space-age debris as well as very fine-grained dust from rare major volcanic eruptions (Rietmeijer 1993a). In the late 1960s balloons carried aerosol collectors to ~37 km that showed proof-of-concept (Bigg et al., 1970). Brownlee et al. (1973) completed the first successful collection of IDPs and 2-3 μm Al_2O_3 spheres (solid-rocket effluents) at 35 km altitude. A balloon-borne collector to sample meteoric dust from the condensation of meteor ablation vapors (Testa et al., 1990) found mostly volcanic dust <2 μm in size between 34-36 km during May 1985 (Rietmeijer, 1993a). These collectors have to be active 'vacuum cleaners'. Small inertial-impact collectors mounted underneath the wings of high-flying aircraft (*e.g.* U2) between 15-20 km in the lower stratosphere proved to an expedient way of collecting IDPs and other dust, *e.g.* meteoric dust (Rietmeijer, 2001). Such collections began in March 1974 (Brownlee et al., 1976). The NASA Johnson Space Center (JSC) Cosmic Dust Program made its first flight between 17-19 km altitude on May 22, 1981 (Zolensky et al., 1994).

DUST COLLECTION IN THE LOWER STRATOSPHERE

This NASA program conducts routine dust samplings in the lower stratosphere albeit too haphazard to qualify as a monitoring program but which was not its intended purpose. Dust and (rare) condensed aerosols (*e.g.* H_2SO_4), are collected on Lexan plates covered by a layer of high-viscosity silicone oil to entrap mostly ~2 μm to ~50 μm dust. The collectors are housed in pylons mounted underneath the aircraft wings (Zolensky et al., 1994). A particle is assigned to one of four categories based on bulk composition, morphology and optical properties:

- ✓ "cosmic" [C] dust (or IDPs),
- ✓ "terrestrial contamination, natural" (TCN) (mostly volcanic ash; biomass burning carbon),

- ✓ "terrestrial contamination, artificial (TCA) [spacecraft paints and metal alloys], and
- ✓ "Al-oxides spheres" [AOS]

The contaminant label doesn't mean the particles have no intrinsic valuable information. For example Mateshvili and Rietmeijer (2002) used the NASA collection to extract volcanic dust settling rates. Zolensky et al. (1989) predicted that AOS particles overwhelmingly from the US Space Shuttle should disappear from the lower stratosphere after the Challenger accident. This was indeed the case (Rietmeijer and Flynn, 1996), showing that long-term observations are a powerful tool to obtain information on the mineralogical and chemical aerosol properties, their lower-stratospheric residence times and sources. A time-of-flight mass spectrometer is flown on same NASA aircraft to determine the chemical composition of aerosols between 200 nm and 2 μm at the Northern Hemisphere during a period of low volcanic activity (Murphy et al., 1998). However, chemistry alone cannot identify the true nature of the aerosols.

NASA/JSC Cosmic Dust Program deploys small area (SACs; 30cm^2), require 30-40h collection time to gather 10 to 15 IDPs (the program's target), and large area collectors (LACs; 300cm^2) that need only ~10h former the same result. The LACs can be used for "targeted collection" (Mackinnon, 1985), *e.g.* dust monitoring in an aging volcanic eruption plume (Mackinnon et al., 1984) or dust from a particular meteor stream (Messenger, 2002). A Leonid storm (comet Tempel-Tuttle debris) become an opportunity to test another collector design (Rietmeijer et al., 2003) deployed onboard the USAF/NKC-135 FISTA aircraft of the 2002 Leonid MAC Airborne Mission (Jenniskens, 2002). This effort demonstrated the feasibility of dust collection in the UT/LS region using a 'slow-moving' aircraft. A similar collector to be part of the NASA Stratospheric Observatory for Infrared Astronomy (SOFIA) Upper Deck Facility would offer a great research and teaching opportunity.

SOFIA is scheduled to fly ~1,000h per year for 20 years from three different bases that will become the centers of an accumulated grid of trajectories roughly centered on (1) ~40N [US west coast; NASA ARC], (2) ~50N [northern Germany] and (3) ~45S [New Zealand]. SOFIA will accumulate long-term observations and dust collections across three different geographical regions, viz. (1) across a continental land mass/ocean interface (ARC), (2) small scale sea/land interaction across a highly industrialized region sandwiched between the Eurasian landmass and the Atlantic ocean (Germany) and (3) across the southern Pacific ocean remote from anthropogenic dust production sources. These different areas are excellent opportunities for long-term observations of dust-supplying sources, regional and hemispherical dust distributions and comparison between dusts on the Northern and Southern hemispheres. The measured physical and chemical properties of collected dusts will complement remote sensing observations.

DUST COLLECTOR

The inertial-impact, flat-plate collector is a transparent 26-cm^2 plastic plate mounted on top a layer of supporting foam inside a transparent, one-cm high plastic box with a removable lid. The box was held in place by side-mounted screws on a rectangular Plexiglas plate that was the median plane of a Plexiglas tube capped at both ends. This tube was placed inside an existing periscope assembly, *i.e.* a metal tube (15 cm in diameter) that fitted snuggly in a gimbal mounted through a window port on the aircraft. The metal tube was capped at one end and had a cut-away opening near 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 after landing. The collector was opened once the aircraft had reached collection altitude. Each clean collection plate was coated with the same silicone oil used by the NASA Cosmic Dust 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 using a binocular microscope adopted 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 was 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 UT/LS region. The 'closed' collector mode was successfully tested (Rietmeijer et al., 2003). Optical scans of the background collectors found the same amounts of dust and identical dust type distributions, which is proof-of-concept of this collector design.

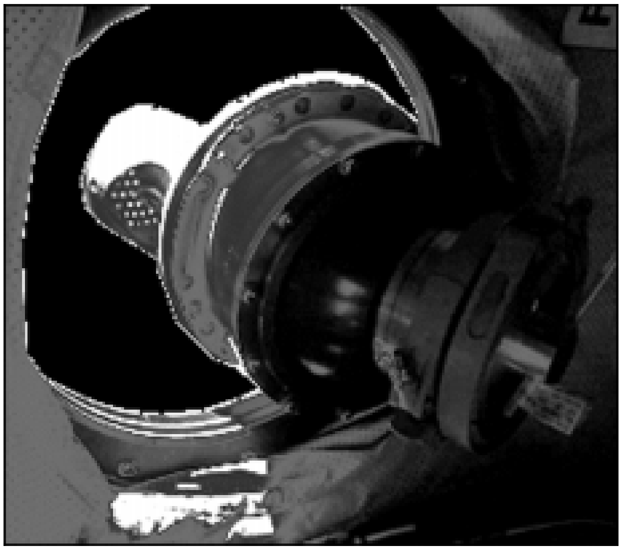

Fig. 1. View of the Leonid dust collection device viewed from inside the FISTA aircraft. It shows the metal tube (overexposed) wherein the Plexiglas tube with the collector mounted on the median plane was fitted prior to take-off. The capped end of the metal tube had holes to allow some air to escape. 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).

All particles were rinsed off of a collector plate using ultrapure Freon and hexane (Zolensky and Mackinnon, 1985) and prepared for scanning electron microscope (SEM) analysis to determine size, shape, morphology and composition of each dust particle. The SEM is equipped with an energy dispersive spectrometer for analyses of major rock-forming elements, including carbon and oxygen. The smallest particles were ~3 _m. The largest dust, ~100 _m, were compact aggregates. Among 50 spheres, potentially extraterrestrial dust, were 'silicate' and Fe-spheres similar to those routinely found in the NASA/JSC Cosmic Dust Collection. Since Leonid dust collection was conducted at much lower altitudes, volcanic ash was the most abundant fraction of collected natural particles. Underscoring the potential of this type of collection on a long-term basis, two distinct dust (solid aerosol) populations were identified:

- ✓ a size-sorted, probably global, background of volcanic ash, and
- ✓ a juvenile point source in western Europe of dust spheres; perhaps a transient cloud of ejecta from Mt. Etna volcano (Sicily), industrial coal fly ash, or surviving Leonid meteor debris.

This result is remarkable considering the simplicity of collector design and the ease of optical and SEM particle characterizations. Further studies will require more sophisticated techniques, e.g. transmission electron microscopes and stable isotope analyses, but on well characterized dust.

SCIENTIFIC AND EDUCATIONAL IMPACT OF DUST COLLECTION

Aerosols in the UT/LS 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:
    - o meteor ablation and fireball and bolide fragmentation,
    - o surviving IDPs and micrometeorites
    - o condensed meteoric dust,
    - o reentered space debris

- ✓ Sources at the Earth's surface:
    - o Rare major eruptions, e.g. Mt. Pinatubo (1991), El Chichón (1982) and Mt. St. Helens (1980), lofting dust to high stratospheric altitudes,
    - o Frequent minor volcanic eruptions, *incl.* those in the equatorial region (Rietmeijer, 1993b),
    - o aircraft exhaust (mostly soot)
    - o natural aeolian dust (*i.e.* Gobi desert dust; volcanic silica dust, asbestos),
    - o anthropogenic aeolian dust, mostly soot and fly-ash from coal-burning power plants

In the UT/LS region dust entering from space are less abundant than dust originating at the Earth's surface but incursions of stratospheric air masses and/or upwelling of troposphere air will perturb this simple picture. Dust collections and analyses will offer tracers of mixing caused by such disturbances. SURF dust observations will have a context of remote sensing observations, *e.g.* the twilight sounding method (Mateshvili and Rietmeijer (2002). The scientific impact of these long-term observations will 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 aerosol observations and laboratory analyses will contribute to a better understanding of the temporal and spatial scales of such variations of dust particles from a wide range of sources. It will offer a wide range of educational opportunities at undergraduate and graduate levels in Atmospheric Sciences, Earth and Environmental Sciences, Health Sciences, Chemistry and Physics, both academically and as real-life, 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 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 can be easily 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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