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Previous research results summarized in "Ice Particulates in the Mesosphere," by E. T. Chasworth and L. C. Hale, published in Geophysical Research Letters, 1-8 Dec 74, led to the conclusion that the mesosphere contains a high density of very small particulates which normally dominate ionization loss processes. This idea has now been extended to encompass the transport of particulates and their role in coupling processes between the upper and lower atmosphere. This report consists of a resume of the research performed, a manuscript of a paper summarizing important scientific findings, a list of publications and a list of scientific personnel.

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Final Report

ARO-D Grant No. DAA629-75-G-0031

U.S. Army Research Office

Research Triangle, North Carolina

Submitted by

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July 15, 1977

INTRODUCTION

This is the final report on research done on Grant No. DAA629-75-G-0031, covering the period of September 15, 1974 to July 15, 1977. The report consists of a resume of the research performed, a manuscript of a paper summarizing important scientific findings, a list of publications and presentations, and a list of scientific personnel.

RESUME' OF RESEARCH

This research began in September 1974 with the submittal for publication of a paper entitled "Ice Particulates in the Mesosphere" by E. T. Chesworth and the principal investigator, which was subsequently published in Geophysical Research Letters 1-8, December, 1974. This paper summarized previous research leading to the conclusion that the mesosphere contains a high density of very small particulates which normally dominate ionization loss processes. The principal subsequent progress on the subject grant has been to extend this idea to encompass the transport of particulates and their role in coupling processes between the upper and lower atmosphere.

During the first year a payload utilizing a Gerdien condenser with a flashing ultraviolet lamp was flown from Poker Flat on March 10, 1975. This flight provided the first instance in which highly detailed mobility spectra could be obtained from a Gerdien condenser, and the analysis of data from this flight provided the basis for Charles Croskey's Ph.D. thesis.

A new design of Gerdien condenser was launched in Poker Flat in February, 1976 and this led to the design of additional payloads which were launched during project "Aurorozone" at Poker Flat in September of 1976.

Gerdien condenser, blunt probe, and ultraviolet lamp assemblies were supplied for the Stratcom series of balloons. The data from these flights has been summarized in papers presented and published. (See list of publications and presentations).

During the third year of the Grant the principal investigator spend 9 months with the U.S. Army Research and Strandardization Group (Europe) in London, England. During this time he was able to analyze previously collected data and visit European groups working on related problems, including several laboratories in Germany. He was also able to engage in laboratory calibrations of the Gerdien condenser-UV lamp payload configuration at the Von Karman Institute in Brussels, which will lead to a better understanding of data acquired with this system. A special test payload was build to do this and the tests were planned on a trip to Brussels on April 5-8, 1977 and conducted on May 30 - June 3, 1977. Finally, a paper was written which summarizes the scientific progress on this grant, "Particulate Transport Through the Stratosphere and Mesosphere," which has been accepted for publication in Nature, and which follows.

PARTICULATE TRANSPORT THROUGH THE MESOSPHERE AND STRATOSPHERE

The "aerosol layers" frequently observed at about 50 km. altitude may be due to downward transport from above of particulates, possibly of extra-terrestrial origin. This transport would be more efficient at higher altitudes (the mesosphere) than lower altitudes (the stratosphere) thus causing the layering seen in the stratopause region. The flux of particulates through the stratosphere provides a potential scavenging mechanism for pollutants and a source of condensation nucleii to the troposphere. Electric field variations, probably induced from above, can modulate this flux, providing a possible coupling mechanism between geomagnetic activity and terrestrial weather. The particulate distribution is also affected by the general circulation and atmospheric dynamics. The density of particulates is much greater than generally recognized, indicating that their role in chemical and thermal processes should be reassessed.

Noctilucent clouds provide visible evidence of the occasional presence of particulate matter in the high latitude summer mesopause region, but there is also evidence for the continual presence at many latitudes of a high density of very small (< 10nm) aerosol particles in the mesosphere and stratosphere. This evidence includes unexpectedly low and variable ion mobility and conductivity observations (refs 1-6) and ionospheric data such as the normally low density of electrons in the mesopause region[4] and the very rapid loss of electrons during solar eclipse totality.[7] Features of the "winter anomaly" in ionospheric radio wave absorption, such as the large variability[4] and solar zenith angle dependence[7] of electron density, can be explained by the absence of these particulates on "anomalous" days.

Many optical measurements, using a variety of techniques (Lidar, rocket and satellite scattering measurements at various wavelengths), have indicated "aerosol layers", frequently in the vicinity of 50 km. (ref 8 contains references to earlier observations). This layering in the stratopause region may be explained by the more effective downward transport in the mesosphere than the stratosphere of particulate matter, which may be of cosmic origin, possibly coated with ice or water.[4] Gravitational settling of 10 nm. particles is less than 10^{-1} m-sec^{-1} at 80 km, decreasing rapidly at lower altitudes.[9] The dominant diffusion process in the stratosphere and mesosphere is "eddy diffusion" and the applicable diffusion coefficient is much higher in the mesosphere than the stratosphere, which could produce layering due to "piling up" in the transition region, the stratopause. The expected eddy diffusion coefficient for the mesosphere[10] yields characteristic downward velocities of order 10^{-2} m-sec^{-1}, implying a trans-mesospheric transit time of order 30 days. A more rapid process might involve the vertical electric field, which is generally expected to be downward in the upper atmosphere.[11] In order to provide a net downward transport there must be an excess of positively over negatively charged aerosol particles (or a differential mobility). An excess of positively charged particles would be expected since free electrons form in this region due to detachment (or emission) from negative ions. It is not necessary to rely on speculation on this point, however, since Widdel, et al[2], using a parachute-borne Gerdien condenser, observed positive ions in the mesosphere with mobilities an order of magnitude less than that of the small positive ions, but did not observe the corresponding low mobility negative ions, indicating that negative particulates did not form, or, more likely, were of very short lifetime due to electron detachment. A consensus of the properties of the particulates in the mesosphere[4] would indicate a density of 10^9-10^{10} m^{-3} of less than 10 nm diameter and a mass of several thousand AMU. Recent USSR measurements of the vertical electric field indicate a field of order 1 $v\text{-}m^{-1}$ in the stratosphere, with some intensification in the mesosphere.[12] Assuming a 1 $v\text{-}m^{-1}$ field and mobilities for the particulate ions as for the lower mobility group seen by Widdel, et al[2], of 1 $m^2\text{-}v^{-1}\text{-}sec^{-1}$ at 70 km (10^{-1} at 60) yields velocities of order 1 $m\text{-}sec^{-1}$ at 70 km (10^{-1} at 60). Since at least 10% of the available aerosol particles can be expected to be charged (deducible from refs 2, 4, and 13), this will provide a transport mechanism at least comparable to eddy diffusion if the electric field measurements are correct.

Recent measurements by Hirono, et al[14], using both Lidar and direct electrical measurements on balloon-sondes, indicate a population of "Aitken" particles in the stratosphere having similar densities ($\sim 5 \times 10^9$ m^{-3}) to those deduced above for the mesosphere, with a relatively constant density (to a factor of 2) from the tropopause up to 30 km. The eddy diffusion coefficient is much smaller in the stratosphere[15] and the trans-stratospheric transport by this mechanism would be expected to take years. The density of particulates would imply a downward flux of order 10^6 $m^{-2}\text{-}sec^{-1}$. The corresponding electric field transport mechanism is hindered in this region by much lower mobilities (inversely proportional to air density), and is dependent for net transport on a differential density or mobility effect between positively and negatively charged particulates, as before. It would be expected that there might be some differential density effect due to detachment of electrons, as in the mesosphere. Assuming a reduced (STP) mobility of 3×10^{-5} m^2-v^{-1}-sec^{-1} (ref 2), the downward velocity would be 3×10^{-2} m-sec^{-1} at 18 km for a 1 v-m^{-1} electric field, and would be constant above this for the usual assumption that the electric field decreases exponentially with altitude in the stratosphere, consistent with the observation of a relatively uniform particulate density.[14] For a 1% net differential density of positive over negative particulates the downward flux would be of order 1.5×10^7 m^{-2}-sec^{-1} and trans-stratospheric transit would take about 10^3 days. Disturbances of the field, such as have been observed in connection with geomagnetic activity[16, 17] could modulate or interrupt the flow of condensation nucleii into the troposphere. This is the sort of mechanism which has been suggested to explain possible connections between solar and geomagnetic activity and weather.[18, 19]

The distribution of particulates would of course also be modified by atmospheric dynamics and the general circulation. One scenario for the "winter anomaly" in radio wave absorption in the mesosphere would involve the depletion of particulates in sub-auroral regions by an enhanced or reversed vertical electric field, with these regions then being transported by high velocity equatorward winds. The early winter downdraft at mid-latitudes[20] would be expected to move particulates into the troposphere. A wave-like structure in conductivity observed at a low latitude site[5] can be explained by a wave-induced bunching of particulates.

The presence of such a high density of particulates in generally downward flow throughout the mesosphere and stratosphere indicates that their role in chemical and thermal processes should be evaluated, but this will remain uncertain without knowledge of their structure and composition. For example, their effectiveness in scavenging could be greatly enhanced if they are water coated.

It is noted in passing that the "fair weather" electric field expected at the tropopause could be perturbed using high d.c. voltages on high electrodes or antennae, possibly utilizing tethered balloons. Less than 10^6 volts on an electrode 1 km above its image would produce an electric field sufficient to double or cancel the expected tropopause electric field (1-10 v/m) at any latitude. This suggests a means of testing for an interaction between the vertical electric field and atmospheric processes with Lidar or sonde measurements.

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A Model of Ionization in the Mesosphere, by L. C. Hale and E. T. Chesworth, presented at 1974 USNC/URSI-IEEE Meeting, Boulder, Colorado, October 14-17, 1974.

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Electrical Conductivity Measurements in the Stratosphere Using Balloon-Borne Blunt Probes, by J. D. Mitchell and L. C. Hale, presented at Ninth AFGL Scientific Balloon Symposium, Wentworth-by-the-Sea, New Hampshire, October 20-22, 1976, published in Proceedings, Ninth AFGL Scientific Balloon Symposium, AFGL, Hanscom AFB, Mass., December 15, 1976, 425-439.

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Electrical Conductivity Measurements in the Stratosphere Using Balloon-Borne Blunt Probes, by J. D. Mitchell and L. C. Hale, presented at XX th COSPAR Symposium, Tel-Aviv, Israel, June 17, 1977, to be published in Space Research 18.

Particulate Transport Through the Mesosphere and Stratosphere, by L. C. Hale, to be published in Nature.

SCIENTIFIC PERSONNEL

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