This project consists of the design and fabrication of a satellite-borne ultraviolet atmospheric experiment. The components of the instrument will both image and make quantitative polarization measurements of the scattered light from polar mesospheric clouds (PMC) occurring in the high-latitude summertime mesosphere at heights of 85 km. Its scientific objectives are: (1) to determine the morphology, scattering and attenuation properties, occurrence frequency statistics, and statistical distribution of spatial scales of PMC and other aerosol layers in the upper mesosphere; (2) to derive information on the atmospheric wave activity in the summertime mesosphere over all horizontal spatial scales greater than about 2 kilometers; and (3) to determine the mean particle size of PMC particles, to characterize its dependence on latitude, longitude, wave activity and PMC brightness.
ANNUAL REPORT
PMC EXPERIMENT

This project was approved in mid-1986, and funded in September, 1986 through September 30, 1988. The total value of the contract is $751,000, of which $326,000 has been received (as of June, 1987). During the first phase of the contract, we conducted a study of the scientific requirements, rationale and observational strategy for the various experiment modules. This has resulted in a firm set of requirements for the three imaging experiments: (1) wide-angle (morphology) imaging experiment, (2) narrow-angle (waves) imaging experiment, and (3) nadir-viewing (high-resolution) imaging experiment. A summary of the functional requirements for each of the above is given in Enclosure 1.

The functional requirements for the fourth and fifth modules are currently being defined. These experiments are (4) microphysics (UV polarization) experiment, and (5) mesopause temperature experiment.

Detailed engineering design efforts are now underway for experiments (1) - (3). To briefly summarize these designs to date: the UV imagers which view the limb (1) and (2) have anamorphic lenses to obtain images stretched by a factor of 10:1 in the direction parallel to the horizon. This more closely matches the inherent resolution of limb sounding in the horizontal plane, and also maximizes the light input. They also contain image intensifiers and reticon image sensors (64 x 64 pixels). UV bandpass filters will limit the spectral resolution to the vicinity of 265 nm. The nadir imager has 2 UV transmitting lens, and a one-dimensional reticon detector (1 x 100 pixels).

The three UV imagers will provide sequences of images from which a three-dimensional cloud scene can be generated. The entire polar cap area around each summer pole can be mapped once per day, provided the experiment is flown on a low circular, polar orbiter. At the center of each low-resolution strip, a moderate-resolution image will magnify the scene. At the center of each moderate-resolution image will be a high-resolution image. This nesting will give successive magnifications, or 'zoom' factors which provide a continuously-varying resolution down to the smallest scales (about 2 km). The various coverages and resolutions of each imager is described in Enclosure 1.

ACTIVITIES DURING THE YEAR (1986 - mid 1987)

(1) The University of Colorado played host to an S.D.I. Workshop on the Middle Atmosphere on November 17-18, 1986. A copy of the agenda and a list of participants is enclosed.

(2) The Principal Investigator, G. E. Thomas, attended a meeting held at Riverside Research Institute in Arlington, Va. The purpose of the meeting was to brief various S.D.I. representatives on the research program on the natural environment within the Innovative Science Program of S.D.I.

(3) In response to a possible opportunity for our experiment to be carried on board a French satellite in 1989, we performed an exercise in which we proposed to S.D.I. to fly a scaled-down experiment consisting of two UV imagers. We provided cost, weight, power, envelope and telemetry requirements to the Program Director, Paul Twitchell, and to Col. Arthur Boright, both of S.D.I.
ENCLOSURES

ENCLOSURE 1. Functional requirements for Morphology, Waves and Nadir Imagers
ENCLOSURE 3. List of attendees at Boulder Workshop.
ENCLOSURE 4. Copy of overhead transparencies presented at Boulder Workshop
ENCLOSURE 1.

FUNCTIONAL REQUIREMENTS FOR MORPHOLOGY, WAVES AND NADIR IMAGERS
NOTE: These are preliminary functional requirements and are subject to change.

September 21, 1987

TABLE IV-1
MORPHOLOGY

This section of the experiment creates low resolution images which will cover the entire pole giving an overall picture. The purpose of the morphology experiment is to map the location and brightness of the clouds over the entire pole. It will find the variation of clouds in time, location and altitude.

(1) ALTITUDE
   (A) RESOLUTION 3.3 km sample
   (B) COVERAGE 70 - 100 km (64 samples total, 8 selected and transmitted)
   (C) CONTRAST 10:1 min

(2) WAVELENGTH
   (A) RESOLUTION 20 nm
   (B) COVERAGE 1 wavelength, 265 nm

(3) HORIZONTAL
   (A) RESOLUTION 33 km sample
   (B) COVERAGE 2000 km (45° FOV) in 64 samples (too big for lense)
   (C) CONTRAST 10:1 min

(4) POLARIZATION not needed

(5) LIMBS Forward limb only.

(6) SAMPLE CYCLE TIME 12 sec (100 km) (integration time < 12 sec)

(7) SENSITIVITY NEEDED
dim cloud 10 kR/A
bright cloud 1000 kR/A

(8) PRECISION NEEDED 10% (repeatability and noise for scattered light greater than 10kR/A

(9) ACCURACY NEEDED 20% to map cloud brightnesses (absolute calibration)

(10) POINTING Knowledge: 2 km (0.06 degrees)
     Real time: 100 Km (3 degrees)

(11) BIT RATE 0.34 kilobits/sec (8×64 8 bit words/12 sec)
TABLE IV-2
WAVES ON THE LIMB

The waves or dynamics section of the experiment makes higher resolution images (a zoom factor of 8 from the Morphology experiment) of the PMC's to examine and understand the atmospheric waves that are often seen in ground observations.

1. **ALITUDE**
   - **RESOLUTION**: 0.4 km sample
   - **COVERAGE**: 80-88 km (64 samples total, select and transmit 20)
   - **CONTRAST**: 10:1 min

2. **WAVELENGTH**
   - **RESOLUTION**: 20 nm
   - **COVERAGE**: 1 wavelength, 265 nm

3. **HORIZONTAL**
   - **RESOLUTION**: 4 km sample
   - **COVERAGE**: 250 km (5.6 degrees) in 64 samples
   - **CONTRAST**: 10:1 min

4. **POLARIZATION**
   - **NOT NEEDED**

5. **LIMBS**
   - **FORWARD LIMB ONLY**: Forward limb only; centered on Morphology exp.

6. **SAMPLE CYCLE TIME**
   - **1 sec (7 km)**

7. **SENSITIVITY NEEDED**
   - **DIM CLOUD**: 10 kR/A
   - **BRIGHT CLOUD**: 1000 kR/A

8. **PRECISION NEEDED**
   - **10%** (repeatability and noise for scattered light greater than 10kr/A)

9. **ACCURACY NEEDED**
   - **20%** to map cloud brightnesses (absolute calibration)

10. **POINTING**
    - **KNOWLEDGE**: 2 km (0.06 degrees)
    - **REAL TIME**: 10 km (0.30 degrees, this may require our own pointing)

11. **BIT RATE**
    - **10.3 kilobits/sec (20x64 8 bit words/sec)**
TABLE IV-3
WAVES IN THE NADIR

The nadir experiment will collect high resolution images along a 64 km swath at the sub-satellite point. This experiment is particularly valuable during twilight conditions when the shadow height exceeds 70 km above the earth's surface.

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<th>Specification</th>
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<td>(1) WAVELENGTH</td>
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<td>(A) RESOLUTION</td>
<td>20 nm</td>
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<td>(B) COVERAGE</td>
<td>1 wavelength, 265 nm</td>
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<td>(2) HORIZONTAL</td>
<td></td>
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<tr>
<td>(A) RESOLUTION</td>
<td>2 km (1×1 km samples)</td>
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<tr>
<td>(B) COVERAGE</td>
<td>64 km in 64 samples</td>
</tr>
<tr>
<td>(C) CONTRAST</td>
<td>100:1 min *</td>
</tr>
<tr>
<td>(3) POLARIZATION</td>
<td>not needed</td>
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<td>(4) SAMPLE CYCLE TIME</td>
<td>0.14 sec (1 km along the orbit track)</td>
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<td>(5) SENSITIVITY NEEDED</td>
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<tr>
<td>dim cloud</td>
<td>0.1 kR/A</td>
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<td>bright cloud</td>
<td>10 kR/A</td>
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<td>Rayleigh background</td>
<td>2-7 kR/A</td>
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<tr>
<td>(6) PRECISION NEEDED</td>
<td>1% (repeatability and noise for scattered light greater than 1 kR/A)</td>
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<tr>
<td>(7) ACCURACY NEEDED</td>
<td>none</td>
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<tr>
<td>(8) POINTING</td>
<td>2 km (0.2 degrees)</td>
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<tr>
<td>(9) BIT RATE</td>
<td>7.68 kilobits/sec (64 12 bit words/0.1 sec)</td>
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* we want to know that a 1% change in the observed radiance is real
ENCLOSURE 2.

AGENDA FOR NOVEMBER 17-18, 1986 WORKSHOP IN BOULDER, COLORADO
AGENDA

MIDDLE ATMOSPHERIC WORKSHOP
17-18 NOVEMBER 1986
UNIVERSITY OF COLORADO
LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS (LASP)
55th STREET FACILITY
BOULDER, COLORADO

PLENARY SESSION

0830
Welcome
Gary Thomas
Introduction
Paul Twitchell
SDIO Overview
Col. A. Boright, USAF, Special Assistant to the Deputy for Programs and Systems
Middle Atmosphere Dynamics
Cambridge University, P.H. Haynes

BREAK

Sensors and Electro-optical Phenomenology
SDIO Sensors Office, B. Katz
Density Variability in Middle Atmosphere
NASA/Arshall Space Flight Center, D. Johnson, S. Smith
Navy Middle Atmosphere Program
NRL, D. Anderson and R. Conway
Stellar Horizon Atmospheric Dispersions
ONR Boston, F. Quelle

1130 LUNCH

DYNAMICS

1300
Breaking Internal Gravity Waves
Gould Defense Systems, Newport, RI, J.B. Grant
Processes Responsible for Variability of Stratosphere and Mesosphere
Florida State University, R.L. Pfeffer and A.I. Barcilon
Gravity Wave Variability, Saturation, and Turbulence Generation in the Mesosphere and Lower Thermosphere
University of Alaska, D.C. Fritts

BREAK

Ultrafast Algorithms for Cloud Data Analysis
METSAT Inc., Fort Collins, CO, T.H. Vonder Haar and T.A. Brubaker
Cloud Cover over North America
University of Wisconsin, Madison, WI, V. Suomi, D.P. Wylie and E.W. Eloranta
Cubic Ice in Atmosphere
Desert Research Institute, Reno, NV, W.G. Finnegan and R.L. Pitter
Microphysical Studies of Noctilucent Clouds
State University of New York, B. Vonnegut and A.F. Roddy

1600
Working Groups and Charter defined, participants identified and spokesman selected

1630-1730
Tour of Solar Mesosphere Explorer (SME) Operations Facility
OBSERVATIONAL TOOLS

0830
Properties, Constituents and Clouds of Middle Atmosphere
   University of Wyoming, T.J. Pepin
Compact Lidar Systems
   University of Maryland, T.D. Wilkerson
Polar Mesosphere Clouds Structure
   Utah State University, J.C. Ulwick
Polar Mesosphere UV Imaging
   University of Colorado-Boulder, G. Thomas

BREAK
Working Groups Convene*
   Dynamics
   Cloud Physics
   Observational
Working Group Spokesman Report
Structured Workshop adjourns
Working space will be available for follow-on discussions by participants

1400
SDIO/IST Natural Environment "White Paper" Evaluation Committee Meeting

*While working groups convene, Government Managers will briefly meet
ENCLOSURE 3.

LIST OF ATTENDEES AT BOULDER WORKSHOP
<table>
<thead>
<tr>
<th>NAME</th>
<th>ORGANIZATION (MAILING ADDRESS)</th>
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<tr>
<td>Boright, Art</td>
<td>USAF - OSD/SDIO Innovative Science and Technology Washington, DC 20301-7100</td>
<td>(202) 653-0572</td>
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<tr>
<td>Brubaker, Thomas A.</td>
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</tr>
<tr>
<td>Burger, Ron</td>
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<tr>
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<tr>
<td>Eloranta, Edwin</td>
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<tr>
<td>Finnegan, William</td>
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</tr>
<tr>
<td>Fritts, Dave</td>
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</tr>
</tbody>
</table>
### PARTICIPANTS AT THE MIDDLE ATMOSPHERE WORKSHOP
**LASP - UNIVERSITY OF COLORADO, 17-18 NOVEMBER 1986**

<table>
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<tr>
<td>Grantham, Donald</td>
<td>AGL/LYA&lt;br&gt;Hanscom AFB, MA 01731</td>
<td>(617) 377-2982</td>
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<td>Haynes, Peter</td>
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<td>Hudson, Robert</td>
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<tr>
<td>Katz, Barry S.</td>
<td>OSD/SDIO&lt;br&gt;Pentagon Room 3C444&lt;br&gt;Washington, DC 20301-7100</td>
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<tr>
<td>Marcos, Frank A.</td>
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</tr>
</tbody>
</table>
## PARTICIPANTS AT THE MIDDLE ATMOSPHERE WORKSHOP
LA SP - UNIVERSITY OF COLORADO, 17-18 NOVEMBER 1986

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<td>Pepin, Thomas</td>
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<td>Quelle, Fred</td>
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<td>Reid, George</td>
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<td>Vonnegut, Bernard</td>
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<td>Wilkerson, Thomas</td>
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<tr>
<td>Wylie, Donald</td>
<td>Space Science &amp; Engineering Center University of Wisconsin Madison, WI 53706</td>
<td>(608) 263-7458</td>
</tr>
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</table>
ENCLOSURE 4.

COPY OF OVERHEAD TRANSPARENCIES PRESENTED AT BOULDER WORKSHOP
1. Introduction

- Noctilucent clouds
- Solar Mesosphere Explorer

2. Scientific Objectives

3. Instrument Descriptions

- Morphology Experiment
- Waves Experiment
- High-resolution (Nadir) Experiment
- Microphysics Experiment

4. Spacecraft and Mission Requirements

- Orbit
- Imaging Product
SUMMARY OF CLOUD PROPERTIES

1. Spatial and temporal properties

- latitudes above 60 deg.
- occur in both N and S hemispheres
- season begins one month before solstice
- season ends two months after solstice
- maximum activity 15-20 days after solstice
- height - 85.0 1.5 km (north)
- - 83.5 1.5 km (south)
- vertical thickness - 1 to 5 km
- horizontal scales -1 to 1000 km
• SUMMARY OF CLOUD PROPERTIES

2. Optical and physical properties

• generally accepted to be mostly ice

• particle radius \( r < 70\text{nm} \)

• average concentration \( n \approx 100 \text{ cm}^{-3} \)

• water vapor content of ice - \( \approx 100 \mu\text{gm-cm}^{-3} \)

• size distribution - narrow dispersion
3. Controlling or forcing factors

- temperature < 140K
- water vapor concentration
- vertical air motion
- turbulence
- weather fronts - perhaps
- sudden mesospheric coolings - perhaps
- no influence from geomagnetic storms, auroras, or solar activity
QUESTIONS REGARDING PMC AND NLC

1. What are the underlying causes?

2. What is the origin of wave structure?

3. What is the particle composition?

4. How do the optical properties relate to the physical properties?

5. What is the cause of the spatial and temporal variability?

6. What is the nucleation mechanism?

7. Is PMC activity directly related to IGW?

8. How do PMC particles affect the ionization properties of the D-region?
SCIENTIFIC OBJECTIVES

1. Morphology Experiment

To determine the morphology, occurrence frequency, and the distribution of large spatial scales of PMC, and other aerosol layers in the upper mesosphere.

2. Waves Experiment

To determine the statistical wave properties down to spatial scales of 10 km (horizontal) and 1 km (vertical).

3. Microphysics Experiment

To determine the mean particle size, and to characterize its dependence on latitude, longitude, wave activity and PMC brightness.

4. High Resolution (Nadir) Experiment

To determine the statistical wave properties to horizontal scales (1x1 km) for brightest PMC.
1. MORPHOLOGY EXPERIMENT

- a low-resolution, wide FOV imager

- FOV - 130 km (cross-track), 50 km (vertical)

- Resolution - 40 km x 3 km in image plane

- In-track resolution - 40 km (due to LOS smearing)

- Number of array elements - 32x16

- Wavelength - 265 nm

- Geographic coverage - 100% above 60°N
2. WAVES EXPERIMENT

- a medium-resolution imager

- FOV - 320km(cross-track), 16km(vertical)

- Resolution - 10km x 1km in image plane

- In-track resolution - 40km(due to limb smearing)

- Number of array elements - 32 x 16

- Wavelength - 265nm

- geographic coverage - 25% at 60°N
  - 100% above 82.8°N
3. HIGH-RESOLUTION NADIR EXPERIMENT

- Narrow FOV imager

- FOV - 80km(cross-track)

- Resolution - 2.5km(cross-track), 2.5 km(in-track)

- Number of array elements - 32 x 1

- Wavelength - 265nm
4. PMC MICROPHYSICS EXPERIMENT

- A limb-scanning two-color UV polarimeter

- measurements: $I_{||}, I_{\perp}$ at two wavelengths, $= 210nm$ and $= 265nm$

- effective FOV - 175km x 24km

- resolution - 175km in horizontal, 3 km in vertical

- angular coverage at limb - 360°

- number of array elements - 1 x 8

- Method of analysis to retrieve cloud particle parameters-

  Compare polarization and radiance as a function of scattering angle and compare with Mie scattering theory
to derive $\bar{r}$ = mean particle radius & particle concentration
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| Burger, Ron  | DOD/DIA                                                      | (202) 373-4549 |
|              | Washington, DC 20340-6053                                     |              |
| Dummire, Tom | SD/WE                                                        | (213) 643-0304 |
|              | Los Angeles AFS                                              |              |
|              | Los Angeles, CA 90009-2960                                   |              |
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|              | University of Wisconsin                                       | (608) 262-7327 |
|              | Madison, WI 53706                                            |              |
| Finneghan, William | Desert Research Institute  
|              | Reno, NV 89506                                              | (702) 972-1676 |
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|              | University of Alaska                                         |              |
|              | Fairbanks, AK 99775-0800                                     |              |
| Grant, John  | Gould Defense Systems, Inc.  
<p>|              | Ocean Sys. Div.                                              | (401) 849-5300 |
|              | One Corporate Place                                          |              |
|              | Newport Corporate Park                                       |              |
|              | Middleton, RI 02840                                          |              |</p>
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