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Infrared Experiments for Spaceborne Planetary Atmospheres Research

Executive Summary

Infrared Experiments Working Group

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Infrared Experiments for Spaceborne Planetary Atmospheres Research

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Infrared Experiments Working Group
Jet Propulsion Laboratory
Pasadena, California

National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

1981

EXECUTIVE SUMMARY

TABLE OF CONTENTS

PREFACE 2

CONCLUSIONS AND RECOMMENDED INSTRUMENT DEVELOPMENTS

A. Technical Conclusions 4

B. Recommended Techniques for Investigating the Physical Phenomena 5

C. Utilization of Near-Earth Orbital Platforms 7

D. Recommendations for Atmospheric Infrared Development Program . 8

TABLE OF CONTENTS OF FULL REPORT OF THE WORKING GROUP 10

PREFACE

Experiments conducted in the infrared spectral region provide a powerful tool for the study of the composition, structure and dynamics of planetary atmospheres. However, the field has become highly complex, especially that part associated with spacecraft sensing, and the range of technologies used so diverse that it is difficult to determine which of the available methods for making a particular measurement is to be preferred, even for those deeply involved in the field.

Unfortunately, some selectivity must be employed; not all approaches can be supported. Furthermore, the chosen methods are generally sufficiently untried that long pre-flight developments are necessary if viable proposals are to be written for future flight opportunities. These considerations clearly lead to a program of developments which must be coordinated on a national scale. Accordingly, Dr. Robert E. Murphy, the Discipline Scientist for Planetary Atmospheres in the Office of Space Science at NASA Headquarters, requested early in 1980 the formation of an advisory group of specialists in the field. Called the Infrared Experiments Working Group, its function was:

1) To evaluate the role of 0.5-300 micron remote sensing in planetary atmospheres exploration;

2) To identify key areas of infrared instrumentation requiring development for the investigations of atmospheres;

3) To provide the Planetary Programs Office with a framework within which such developments might be undertaken;

4) To document the state-of-the-art.

The approach used was to assess the value of a broad range of measurment techniques for the investigation of atmospheric phenomena, including quantitative intercomparisons of existing and planned instruments by a phenomenological method: given a particular measurement goal (e.g., composition and abundance, temperature structure, cloud and aerosol, etc.), what technique could, if properly developed, investigate the phenomenon? The charter of the group was limited to consideration of spaceborne and planetary probe instrumentation, principally for atmospheric investigations. The applicability of such instrumentation to the study of surfaces, comets and extended atmospheres was, however, included.

Agreeing to serve as members of the group were:

Reinhard Beer, Jet Propulsion Laboratory, Chairman
Daniel J. McCleese, Jet Propulsion Laboratory, Vice-Chairman
Jerome Apt, Jet Propulsion Laboratory, Secretary
Dale P. Cruikshank, University of Hawaii
C. B. Farmer, Jet Propulsion Laboratory
Uwe Fink, University of Arizona
J. Gille/M. Coffey/W. Mankin (alternates), National Center for Atmospheric Research

R. Hanel, NASA Goddard Space Flight Center
Andrew P. Ingersoll, California Institute of Technology
Barry Lutz, Lowell Observatory
Michael E. Mickelson, Denison University
Michael J. Mumma, NASA Goddard Space Flight Center
Alan T. Tokunaga, University of Hawaii
Martin G. Tomasko, University of Arizona
Laurence M. Trafton, University of Texas
Wesley A. Traub, Smithsonian Astrophysical Observatory
Fred C. Witteborn, NASA Ames Research Center

The group met on four occasions:

February 5-6, 1980 at JPL
May 6-7, 1980 at JPL
July 15-16, 1980 at JPL
September 16-17, 1980 at Goddard Space Flight Center

The group functioned by preparing internal working papers addressing each phase of the study which were then reviewed at length at the meetings. These papers were written by the working group members, who sought additional material on specific topics from the following individuals whose contributions we wish to acknowledge: R. Carlson, T. Gehrels, E. D. Hinkley, R. J. Huppi, H. P. Larson, R. Menzies, G. S. Orton, S. W. Petrick, and A. T. Stair.

The group has tried to avoid suggesting which scientific investigations ought to be pursued for the various atmospheres. Rather, we examined each of the phenomena which might be investigated by infrared techniques, determining whether a substantial contribution could be made in the infrared and if so providing criteria for the accuracy, time scale, and other parameters which would be required to advance current knowledge. The discussion of the phenomena and the criteria for their measurement comprise Chapter I. Chapter II is an overview of existing infrared techniques and their achieved performance. In order to compare proposed techniques for investigating the various phenomena we performed detailed analyses of the techniques for selected cases. These appear in Chapter III together with discussions of the critical items requiring development for each technique. Additional discussions of critical technologies appear in Appendix A. The detailed assessments defined both the optimum strategies for investigating the phenomena and the developments required for their implementation. Both the technical conclusions emerging from these studies and the recommended development program appear in Chapter IV. Some strategies require little development; their omission from the recommended development program indicates that proposals for flight hardware can be written within the current state-of-the-art.

CONCLUSIONS AND RECOMMENDED INSTRUMENT DEVELOPMENTS

A. Technical Conclusions

The working group evaluated various strategies for measuring the atmospheric phenomena outlined in Chapter I on various planets and satellites (Chapter III). These studies were designed to allow quantitative comparison of the strategies; they also led to several general technical conclusions:

1. Sounding of the middle and lower stratospheres of the outer planets must be made while viewing through their relatively hot upper stratospheres (the outer planets exhibit strong stratospheric temperature inversions). If these upper levels contribute appreciable opacity in the observed spectral interval, the radiant energy observed may be dominated by flux from the upper stratosphere. In order to sound temperature or composition in the lower stratosphere, an instrument must have spectral resolving power $\lambda/\Delta\lambda > 10^6$ in order to select the near wings of the spectral lines.

2. Detailed calculations of the expected signal-to-noise ratio from Uranus and Neptune show that nadir sounding for composition, abundance, and minor constituent temperature sounding on these objects beyond the region where solar reflection is significant is not viable at spectral resolutions necessary to perform detailed atmospheric studies.

Solar occultation experiments offer significant advantages for the investigation of atmospheres above the main cloud deck. Even at the distance of Neptune the Sun subtends 1 arc min, well above the diffraction limit of even modest sized collectors at $\lambda = 20$ μm. Furthermore, the viewing mode is that of a limb sounder, offering excellent height resolution and increased sensitivity to minor constituents because of the very long path lengths. Since it may be expected that the Sun will fill, or nearly fill, the field-of-view of the spectrometer, signal-to-noise ratio is not a problem. We recognize, however, that such an experiment places severe demands on all aspects of the mission and orbiting spacecraft systems.

Infrared surveys of minor constituents in the atmospheres of the far outer planets should employ solar occultation spectroscopy for the region above the clouds. The flux levels of thermal and IR reflected solar radiation for these bodies do not permit acceptable results for minor constituent detection to be obtained from nadir or limb viewing emission experiments in reasonable integration times. Initial exploration of these atmospheres can be carried out from suitable Earth orbiting instruments.

3. The addition of an infrared spectrometer to the instrument complement of an entry probe can significantly increase understanding of atmospheric and cloud composition and abundance of species. Suitable instrumentation can profile constituents such as water vapor, and detect complex molecules with greater certainty than that provided by a gas chromatograph/mass spectrometer alone.

4. Knowledge of local and global radiative budgets is presently limited by the state of on-board radiometric calibration of both the reflected solar flux and emitted thermal flux.

B. Recommended Infrared Techniques for Investigating the Physical Phenomena

Infrared techniques can substantially increase our understanding of the phenomena discussed Chapter I. The working group's quantitative assessments of various strategies for investigating these phenomena are discussed in Chapter III. We summarize here the techniques felt to be best suited to measure each of these phenomena.

Global and Local Radiative Budget

- Bolometric Radiometry
  - Required Development:
    - More precise absolute calibration

Radiative Flux Profiles

- Solar and Thermal Net Flux Radiometers
  - Required Developments:
    - Improved chopping techniques
    - Methods of clearing windows and optical paths
    - Addition of narrow spectral channels
    - Modeling of probe entry dynamics

Winds

- Gas Correlation Spectroradiometry (terrestrial planets)
  - Required Developments:
    - Long hold-time gas cells
    - Improved gas monitoring and radiometric calibration
- Imaging in Combination with Cloud Height and Temperature Field Determination (outer planets)
  - Required Developments:
    - One or two dimensional IR arrays
    - Effective coordination of measurement strategies, including cloud height sensor (CCD imaging, photopolarimetry, or radiometry)

Temperature and Pressure

- Gas Correlation Spectroradiometer (low pressure regions $\lesssim$ 40 mb)
  - Required Developments:
    - Long hold-time coolable gas cells
    - Improved gas monitoring and radiometric calibration
- Intermediate Resolution Spectroradiometer (for Troposphere)
  - Required Developments:
    - Coolable, lightweight instrument
    - Imaging capability

Transient and Marginal Atmospheres

- Low and High Resolution Spectrometers
- Filter Radiometer

Planetary Rotation and Global Atmospheric Activity

- Imaging to $\lambda \lesssim 5$ microns for deep methane band feature tracking in visibly featureless methane-rich atmospheres (Titan, Uranus, and Neptune)
  - Required Developments:
    - One or two dimensional near IR detector arrays

Abundance of Stable Constituents

I. Surveys of Unexplored Atmospheres

- Earth Orbital Spectroscopy (for the region above the clouds)
  - Required Developments:
    - Coolable, lightweight spectrometer
- In-Situ Infrared Spectroscopy (below the clouds)
  - Required Developments:
    - Probe-certified hardware
    - Radiation sources
    - Sampling procedure

II. Explored Atmospheres

- Solar Occultation Spectroscopy (for the region above the clouds)
  - Required Developments:
    - On-board Processing
    - Large lightweight coolable, movable, optics
    - Pointing stability
- Gas Correlation/Filter Radiometer (Specific Constituents: 1 bar to LTE limit; above the clouds)
  - Required Developments:
    - Long hold-time coolable gas cells
    - Improved gas monitoring and radiometric calibration
- In-Situ Infrared Spectroscopy (below the clouds)
  - Required Developments:
    - Probe-certified hardware
    - Radiation sources
    - Sampling procedure

Vertical, Lateral, and Temporal Variability of Species

- Gas Correlation/Filter Radiometer
  Required Developments:
  See abundance of species section

- Imaging Spectrometer
  Required Developments:
  Coolable, lightweight instrument
  Imaging capability

Composition of Clouds and Aerosols

- Low-to-Medium Resolution Spectrometer

Radiative Properties of Clouds and Aerosols

- Multiple Wavelength Upward & Downward Diffuse Flux Radiometer on Probe
  Required Developments:
  Far Infrared Filters

- Imaging Long Wavelength Radiometer
  Required Developments:
  Calibration in 50 - 100 μm region
  Filters

Cloud Macrostructure and Microstructure

- Visible/Near IR Photopolarimeter

- Visible and near-IR imaging for macrostructure

- Entry Probes for vertical structure

Non-LTE Phenomena

- Medium-to-High Resolution Spectrometer

- Laser Heterodyne Spectrometer

C. Utilization of Near-Earth Orbital Platforms

Some experiments can be performed better from Earth orbit than from a planetary orbit or flyby. These include initial detection by high-resolution spectroscopy of low abundance atmospheric species and long-term monitoring of the variability of atmospheric composition and thermal structure on the brighter planets. Several Earth orbital platforms are planned which have relevance to infrared planetary investigations. Their full utilization should be part of the planetary exploration program. These platforms are the Infrared Astronomy Satellite (IRAS), the German Infrared Laboratory (GIRL), the Shuttle Infrared Telescope Facility (SIRTF), and the Space Telescope (ST). Appendix D describes each of these platforms and the opportunities and limitations they present for investigating the phenomena discussed above.

D. Recommendations for Atmospheric Infrared Instrument Development Program

For many solar system objects, we have advanced from initial surveys to detailed investigations of atmospheric physics and chemistry. Even for those bodies yet to be visited, prospects are excellent for the development of new strategies which will offer excellent scientific return even with constrained budgets. The working group found that there is no single measurement technique that permits the investigation of more than a few of the significant atmospheric phenomena.

The detailed technology assessments made by the working group (presented in Chapter III and Appendix A) have defined both the optimum strategies for investigating the phenomena and the developments required for their implementation. Some strategies require little development; their omission from the recommended development program indicates that currently available space-qualified hardware can be proposed for these strategies.

A stable long-term instrument development program is required to apply current laboratory techniques to the spaceborne measurements, take advantage of opportunities offered by Earth orbital platforms and atmospheric entry probes, and improve science return from conventional infrared instruments. With such a plan the United States planetary exploration program will be prepared to use fully the powerful infrared spectral regime to bring our knowledge of composition, structure, and dynamics of planetary atmospheres to levels which our experience with Earth has shown are necessary for an understanding of the origin, chemistry and physics of atmospheres.

Instruments for entry probes, flybys, planetary orbiters, and near-Earth facilities are each important parts of a balanced planetary exploration program; thus the order of recommendations does not denote priority. We recommend:

- That support be given for the development of high and ultra-high resolution planetary infrared spectrometers for Earth orbiting telescopes. Spectrometers which resolve pressure broadened lines and spectrometers which resolve Doppler-broadened line cores are required.

- That support be given to the development of gas correlation spectrometers for the study of physical and species-specific chemical properties of planetary atmospheres.

- That support be given for the utilization of infrared detector arrays in low to intermediate spectral resolution cryogenic imaging systems.

- That support be given to the design of a high resolution solar occultation interferometer for survey investigations of the minor and trace components of atmospheres. Such an instrument can provide high sensitivity for the detection of constituents above cloud layers.

- That studies be initiated to define the required characteristics of a probe/in situ planetary infrared spectrometer for detection and measurement of composition as a function of height below cloud level. An instrument of this type would add significantly to the science return from a probe instrument set.

- That studies be initiated to improve substantially the state-of-the-art of on-board radiometric calibration of reflected solar and thermal flux.

INFRARED EXPERIMENTS FOR
SPACEBORNE PLANETARY ATMOSPHERES RESEARCH

TABLE OF CONTENTS OF FULL REPORT

Preface

Summary of Principal Conclusions and Recommendations

Chapter I — The Role of Infrared Sensing in Atmospheric Science

Chapter II — Review of Existing Infrared Measurement Techniques

Chapter III — Critical Comparison of Proposed Measurement Techniques

Chapter IV — Conclusions and Recommended Instrument Developments

Appendices:

A — Critical Technologies

B — Applicability of Atmospheric Infrared Instrumentation to Surface Science

C — Supporting Studies in Data Analysis and Numerical Modeling

D — Description of Planned Earth Orbital Platforms

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16. Abstract

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