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RAIDS: An Orbiting Observatory for Ionospheric Remote Sensing from Space

R. P. McCOY, L. J. PAXTON, R. R. MEIER, D. D. CLEARY,
D. K. PRINTZ, and K. D. WOLFRAM
E. O. Hulburt Center for Space Research
Naval Research Laboratory
Washington, DC 20375-5000

and

A. B. CHRISTENSEN, J. B. PRANKE, and D. C. KAYSER
Space Sciences Laboratory
Laboratory Operations
The Aerospace Corporation
El Segundo, CA 90245-4691

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SPACE SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
Los Angeles Air Force Base
P.O. Box 92960
Los Angeles, CA 90009-2960

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Leslie Belsma

LESLIE BELSMA, CAPT, USAF
MOIE Project Officer
SSD/DAAX

James A Beres

JAMES A. BERES, LT COL, USAF
MOIE Program Manager
AFSTC/WCO OL-AB

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A NOAA TIROS satellite currently scheduled to be launched in mid 1990 will contain a payload of optical sensors for ionospheric remote sensing known as RAIDS (Remote Atmospheric and Ionospheric Detection System). The RAIDS experiment consists of eight separate optical instruments which have a combined spectral coverage of 500 - 8700 Å. Seven of the instruments will be mounted to a scan platform and will mechanically scan the earth's limb from 75 - 750 km, while the eighth obtains height images without being scanned. These instruments will measure naturally occurring airglow emissions from the upper atmosphere and ionosphere and will provide altitude profiles of ion and neutral atmospheric constituents along the satellite track on both the day and night side of the earth. The purpose of the RAIDS experiment is to demonstrate a technique for ionospheric remote sensing from space and to produce a global data base of ionospheric and neutral atmospheric composition.

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PREFACE

RAIDS is a Naval Research Laboratory experiment in collaboration with The Aerospace Corporation. Support for the development of RAIDS is provided by the Office of Naval Research through the Atmospheric and Ionospheric Remote Sensing (AIRS) Accelerated Research Initiative and the Defense Meteorological Satellite Program. Spaceflight sponsorship for RAIDS is provided by the Space Test Program. The extreme ultraviolet detector is being provided with the assistance of S. Chakrabarti of the University of California, Berkeley, and the far ultraviolet detector is being provided by G. Fritz of the Naval Research Laboratory.

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I. INTRODUCTION

Many of the important ion and neutral species in the upper atmosphere have optical emission or absorption signatures which allow them to be observed remotely from space. On the dayside, emissions are produced by sunlight either directly through scattering of sunlight, or indirectly, through photoelectron impact excitation. On the nightside, airglow emissions result from the release of stored chemical energy either through ion-electron recombination or molecular formation by atom-atom recombination. Measurements of the altitude distribution of these various airglow emissions by limb-scanning or limb-imaging instruments from satellites can be inverted to deduce the altitude profiles of the emitters. The Remote Atmospheric and Ionospheric Detection System (RAIDS) is a satellite experiment designed to perform a comprehensive mapping of these airglow emissions to develop and test techniques for global remote sensing of the neutral atmosphere and ionosphere.

The RAIDS experiment is currently scheduled to be launched aboard a polar orbiting NOAA TIROS satellite in mid 1990. The RAIDS instrument package consists of one limb-imaging and seven limb-scanning optical sensors which will scan the altitude range 75 - 750 km with a wavelength coverage from 500 to 8700 Å. Each RAIDS limb scan will record a series of airglow profiles which can be inverted to produce a simultaneous set of density profiles of a number of atmospheric constituents. This simultaneous set of neutral and ion densities can either be used as inputs to photochemical, dynamical, and ionospheric models, or to provide checks on the accuracy of the model outputs.

An important opportunity afforded by the RAIDS satellite observatory is the possibility to perform a detailed study of the global morphology of the ionosphere and upper atmosphere. RAIDS should be able to define the location of ionospheric disturbances and map their development, thus providing optical measurements of "ionospheric weather" conditions. Without having to resolve the smallest scales associated with regions of the ionosphere giving rise to scintillations, RAIDS observations may be able to identify disturbed regions of the ionosphere where irregularities are likely to occur. By observing the plasma flow in the vicinity of the equatorial anomaly, RAIDS will provide information on ionospheric and neutral winds. The altitude and wavelength coverage of RAIDS makes it an ideal observation platform for studying the interaction between the magnetosphere, ionosphere, and thermosphere.

II. SCIENCE OBJECTIVES

While the RAIDS instruments will measure emissions from a wide variety of atmospheric constituents, the primary focus of the experiment is on F_2 region ionospheric airglow. Techniques for determining electron densities optically involve measurements of radiation from ionospheric ions and inference of electron density by overall plasma charge neutrality. This is especially effective in the F_2 region where the O^+ ion is the dominant ion, with strong dayside and nightside optical signatures.

On the dayside, RAIDS will be able to detect O^+ ions by measurement of radiation in the extreme ultraviolet (EUV) portion of the spectrum (primarily at 834 Å). The ionized oxygen dayglow is produced initially from ionization-excitation of atomic oxygen in the lower thermosophere by sunlight and energetic electrons. When the upward-directed half of this radiation enters the F_2 region, it undergoes multiple resonant scattering, with O^+ ions picking up the signature of the ambient ion distribution. Limb scans of these optically thick EUV emissions can be analyzed with a radiative transfer model to infer ion and electron densities [Kumar et al., 1983; McCoy and Anderson, 1984; McCoy et al., 1985].

RAIDS will detect O^+ ions at night by measurement of the neutral atomic oxygen emission produced by the recombination of either O^+ or O_2^+ ions with electrons. This recombination nightglow appears at a number of wavelengths ranging from the far ultraviolet (FUV) to the near infrared (NIR). Because most of the O^+ nightglow emissions that will be measured by RAIDS are optically thin, limb-scan profile measurements can easily be inverted to yield O^+ densities. Meier and Opal [1973] and Tinsley and Bittencourt [1975] have shown that the magnitude of the nightglow emission rate is proportional to the square of the peak electron density. Other investigations of the ion recombination nightglow have been performed by Hicks and Chubb [1970], Chandra et al. [1975], and Anderson et al. [1976].

Secondary objectives of the RAIDS experiment include measurements of the neutral atmospheric composition (N_2, O_2, and O), temperature, energetic photoelectron flux, and the densities of several minor constituents. Temperatures will be obtained from scale heights of the measured airglow emission profiles and from the distribution of rotational line intensities in molecular spectra. The measured value of radiation produced by photoelectron impact excitation is proportional to the product of the density of the emitting species and the photoelectron flux and can be inverted to yield both quantities. Two-body and three-body atom recombination reactions produce chemiluminescence which is observable at night and can be analyzed to yield the concentrations of the reacting species.

Table 1 gives a summary of the major airglow excitation processes that will be investigated and lists the corresponding derivable quantities that are included in the RAIDS mission scientific objectives.

Table 1. Airglow Excitation Processes and Observable Densities

Airglow Excitation Process	Observable Quantities
Dayside:	
Multiple resonant scattering by O^+	[O^+, e]
Solar resonant scattering	[O, N, He, Na, Mg^+]
Photoelectron (PE) impact excitation	[N_2, O, PE flux]
Solar fluorescent scattering	[N_2, NO]
Dissociation/ionization excitation	[N_2, N^+]
Absorption	[O_2]
Auroral electron excitation	[N_2, O, electron flux and energy]
Chemiluminescence	[$O(^1D)$, temp]
Nightside:	
Ion-electron recombination	[O^+, e, O_2^+]
Chemiluminescence	[N, O, O_3, H, Na, temp]
Auroral electron excitation	[N_2, O, electron flux and energy]

III. INSTRUMENTATION

Figure 1 shows an artist's conception of the RAIDS observation platform mounted to the nadir side of the NOAA TIROS-N satellite. The primary instrument package consists of three parts: a central T shaped structure housing the flight microprocessor, scan mechanism, and the FUV imaging spectrograph; and two rotating side compartments housing the remaining seven limb-scanning instruments. The RAIDS package has the dimensions X: 53.3 cm, Y: 63.5 cm, Z: 83.8 cm, where X is in the nadir, Y is in the anti-velocity direction, and Z is along the long axis of the satellite.

To obtain a set of airglow measurements that will satisfy the above objectives, the RAIDS instrument package includes eight separate instruments. The instrument package includes two spectrographs with microchannel plate (MCP) array detectors, three spectrometers with scanning gratings and photomultiplier detectors, and three single-wavelength photometers. The spectrographs record several wavelengths simultaneously, while the spectrometers can either scan across their entire wavelength interval or stop to obtain limb scans at a fixed wavelength. Table 2 gives a summary of the RAIDS instrument types and capabilities.

The EUV spectrograph has an f/5 near-Wadsworth optical configuration and uses an MCP detector with a wedge-and-strip readout anode which provides a linear array of 128 pixels. The rectangular field of view of this instrument is aligned parallel to the horizon, and this instrument is mechanically pivoted to scan the limb. The FUV spectrograph has a Wadsworth optical design and is used to image the limb without mechanical motion. This spectrograph has a wedge-and-strip type detector which uses 256 pixels in the wavelength dispersion direction and 64 pixels along the vertical or altitude direction. This instrument uses an off-axis telescope to image the limb and obtains simultaneous altitude and wavelength information without any moving parts.

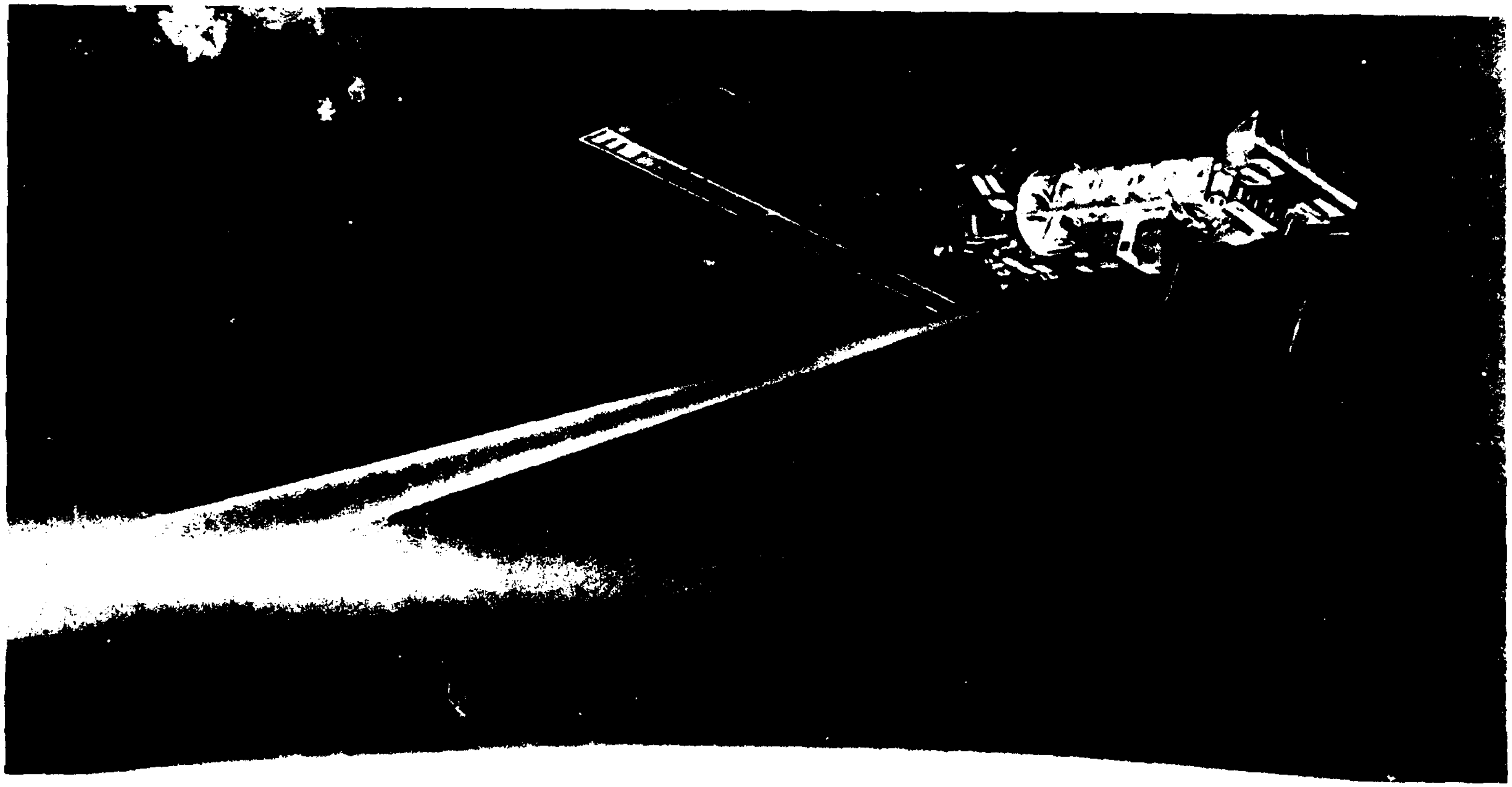


Fig. 1. RAIDS Shown in an Artist's Conception Aboard a TIROS Spacecraft

Table 2. RAIDS Instrument Parameters

Instrument Name	Instrument Type	Detector Type	Detector No. of Pixels	Detector Photo-cathode	Wavelength Range (Å)	Bandpass (Å)	Field of View* (deg^2)	Peak Sens. (C/s/R)
EUV Spectrograph	Near-Wadsworth	W/S#	128	MgF_2	500-1100	12	0.1 x 2.6	0.5
FUV Spectrograph	Imaging-Wadsworth	W/S	256 x 64	CsI	1300-1700	8	4.0 x 0.1	2.5
MUV Spectrometer	Ebert-Fastie	PMT	1	CsTe	1900-3200	11	0.1 x 2.1	7.5
NUV Spectrometer	Ebert-Fastie	PMT	1	Bi-Alkali	2950-4000	9	0.1 x 2.1	1.8
NIR Spectrometer	Ebert-Fastie	PMT	1	GaAs	7250-8700	7	0.1 x 2.1	2.8
5890 Photometer	Filter	PMT	1	GaAs	5890	20	0.4 x 2.1	4.6
6300 Photometer	Filter	PMT	1	GaAs	6300	20	0.2 x 2.1	8.0
7774 Photometer	Filter	PMT	1	GaAs	7774	20	0.2 x 2.1	6.2

*The first and second values correspond to the field of view in the altitude direction and perpendicular to that, respectively.

#W/S denotes a wedge-and-strip anode detector; PMT denotes photomultiplier tube.

The three scanning spectrometers, which are 125-mm focal length Ebert-Fastie design, cover the middle and near ultraviolet (MUV, NUV), and near infrared (NIR). The photometers use interference transmission filters to isolate the atomic oxygen 6300 and 7774 Å lines and the sodium D line at 5890 Å. Both the spectrometers and photometers use off-axis telescopes and rectangular slits to define the fields of view.

IV. OBSERVING SCHEME

RAIDS will be mounted to the nadir side of the TIROS satellite, which will occupy an early-afternoon sun-synchronous 870-km circular orbit. The instruments will view along the anti-velocity direction and scan (or image) in the orbital plane. The RAIDS scan platform uses a stepper motor to scan the instrument lines of sight through angles ranging from -10 to -26.5 deg below the local horizontal. This corresponds to tangent ray altitudes (minimum altitude along the line of sight) ranging from 750 to 75 km. Most of the observed airglow signal originates in the vicinity of the tangent ray point. Each repetition of a limb scan will take a total of 92 sec: 77 sec for the down scan and 15 sec for flyback. The principal scan direction is downward, since the tangent point moves away from the satellite as the satellite moves away from the observation point. This motion acts to limit the horizontal spread of the region being observed at the tangent point.

The RAIDS experiment is microprocessor controlled and, in addition to limb scanning, the platform can be positioned to view at any chosen altitude while the spectrometers scan through their wavelength intervals. A series of these measurements can be added together to form an image similar to that obtained with the FUV spectrograph.

Figure 2 compares the fields of view of the instruments and shows the region of the atmosphere observed during a limb scan as seen from the perspective of the satellite. The seven limb-scanning instruments have the long side of their rectangular fields of view oriented parallel to the horizon. In Fig. 2 the fields of view are represented (not to scale) by the dark rectangle at the top of the scan. The spatial resolution of each instrument at the limb is roughly 5 km vertically by 110 km horizontally. The FUV spectrograph field is oriented perpendicular to the horizon as shown in Fig. 2 by the cross-hatched area. This instrument views from 75 to 300 km with 3.5-km resolution. As the scan platform moves downward, the fields of all eight instruments overlap below 300 km. The FUV spectrograph image integration time will be synchronized to the scan platform period.

Determination of the spatial resolution of the instruments along the line of sight (into the page of Fig. 2) depends on the characteristics of the airglow emission, i.e., optical depth and emission scale height, and the motion of the spacecraft. For a nominal optically thin emission at 200 km with a scale height of 30 km, the spatial resolution along the line of sight would be about 1200 km. This means that, at a tangent altitude of 200 km, the line of sight is measuring airglow along a 1200-km path. Between limb scans the satellite will travel approximately 750 km, and so the next observation at 200 km will overlap the previous one by at least 450 km. Successive limb scans can be differenced to increase the spatial resolution from 1200 km to 750 km. The spatial resolution is limited only by the spacecraft velocity and scan period. For optically thick emissions, the spatial resolution along the line of sight is dependent on the opacity of the atmosphere but is typically much smaller than for thin emissions since absorption limits the observation distance.

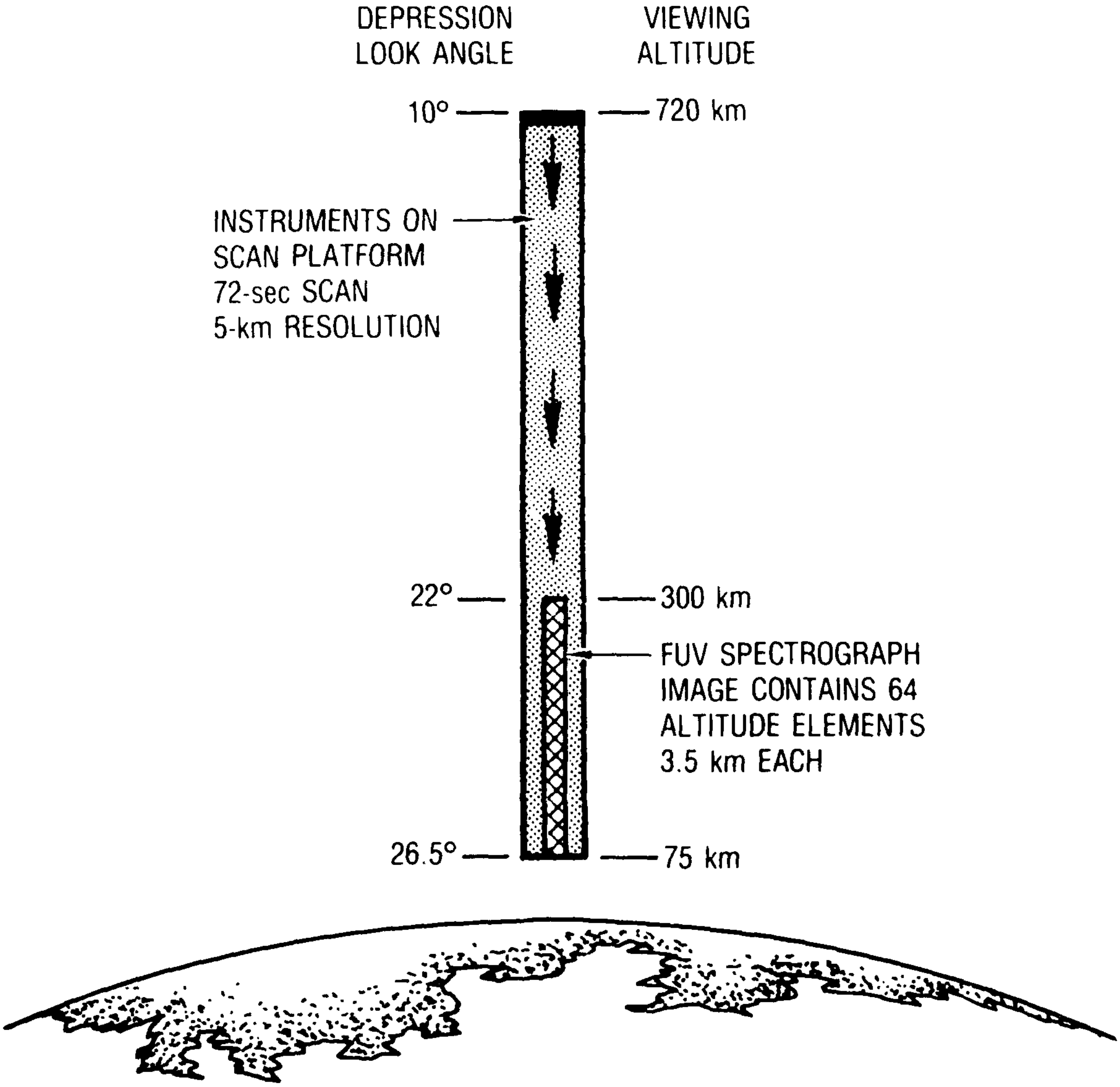


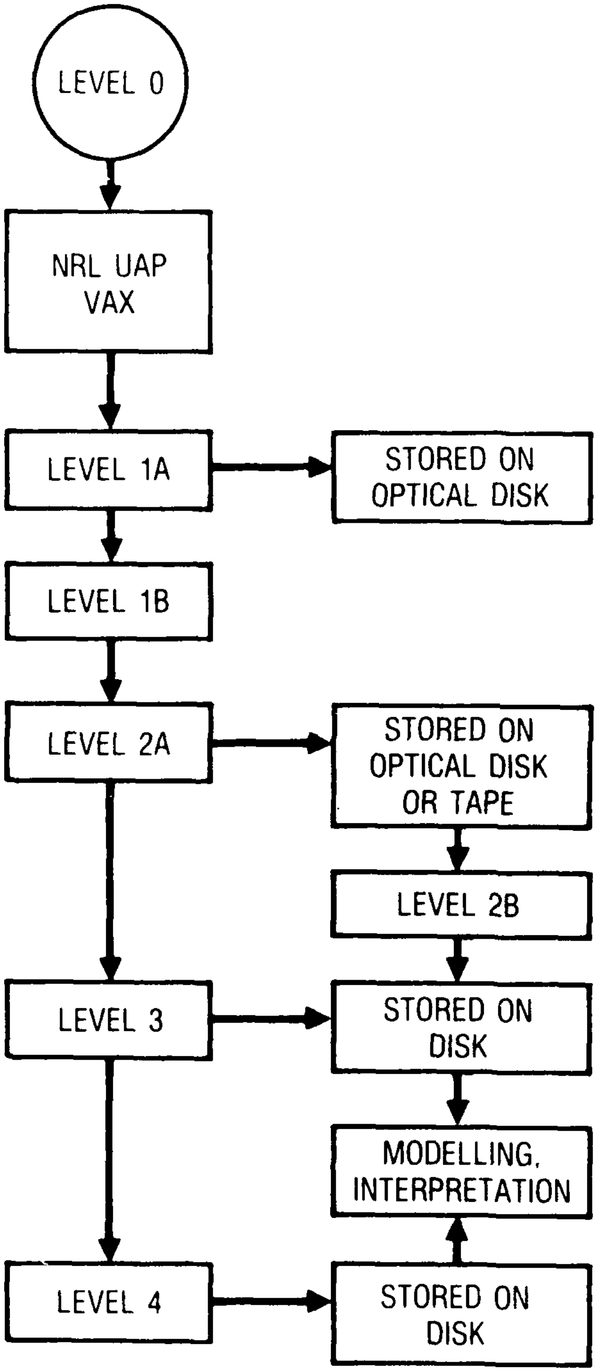
Fig. 2. The RAIDS Instruments' Fields of View

V. DATABASE MANAGEMENT SYSTEM

On the NOAA TIROS satellite, the RAIDS experiment will have a continuous telemetry rate in excess of 11,200 bits per second. This high telemetry rate will enable the production of a very high quality database of global atmospheric and ionospheric measurements. The RAIDS database will provide the temporal, spatial and spectral resolution to enable studies of the morphology of auroral and equatorial ionospheric perturbations, ionospheric patchiness and irregularities, and the transient behavior due to solar and magnetospheric storm effects. While the high data rate makes it possible to take full advantage of the diverse nature of the RAIDS observations, it does present a significant database management challenge. For example, more than a terabit of data will be generated by the end of the second year of operation. Further complications arise out of the need to coordinate the observations made with the eight separate RAIDS instruments, each with its own operating characteristics and capabilities. A final challenge is presented by the requirement to include ground truth measurements in the database, including ground-based ionospheric soundings from RAIDS overflights of ionosondes and radars and data from other coordinated campaigns.

An unconventional approach to database management is required to accomplish the above goals. One technique that will be used is to group large amounts of the RAIDS data into two-dimensional arrays to allow the data to be viewed and analyzed as false-color images or maps. For example, data can be sorted by wavelength, latitude, altitude, time, atmospheric species, etc., and then viewed as a function of any two independent variables. To ensure that efficient and timely use is made of the RAIDS data, the RAIDS database management effort is comparable to that invested in the RAIDS science and hardware development.

The steps planned for processing the RAIDS data are illustrated in Fig. 3. A single day of data will be delivered on a single 6250-bpi tape



- NOAA DATA TAPES STORED
- ARRIVAL AND TIMESPAN (rev no., date, etc.) OF NOAA TAPES CATALOGED ON A PC AT USING RBASE. NOAA TAPES CONVERTED FROM IBM FORMAT TO VAX FORMAT
- DATA BLOCKS: RECONSTRUCTED TIME-ORDERED DATA
- AVERAGED, CALIBRATED DATA (intensity units)
- MAPS OF OBSERVED INTENSITIES FOR SELECTED FEATURES: AURORAL AND AIRGLOW BACKGROUNDS
- 2A MAY BE FURTHER CONDENSED TO MINIMIZE STORAGE SPACE OR ACT AS A BROWSE FILE
- EMISSION RATES, DENSITY PROFILES, ATMOSPHERIC COMPOSITION
- SCIENTIFIC ANALYSIS
- "FINAL" PRODUCT AS MAPS TEC, f_oF_2, H_{max}, n_{max}, ELECTRON, ION AND NEUTRAL TEMPERATURES

Fig. 3. The RAIDS Database Design

(data Level 0). This data tape will be processed to yield time-ordered and contiguous data records as well as associated ancillary engineering data. The reconstructed data at Level 1A will represent the first point at which the instrument data can be accessed for analysis. Because of the high spatial and temporal resolution of the experiment, there will be applications where the data can be averaged spatially or temporally. In all cases the data reaches Level 1B in physical units rather than engineering units. It is at this point that the data will be compressed and sorted into maps. These images will be routinely produced for a subset of the emission features observed by RAIDS and will comprise Level 2A in the database. These maps could then make up a browse file which could be examined in support of particular activities (e.g., scene generation and verification).

Above Level 2 the application of inversion techniques is required to yield additional information. For instance, volume emission rates and density profiles can be obtained. The production of data at Level 4 requires some interaction with Level 3 and modelling and interpretation of the results. This represents the final step in the processing of the RAIDS data: the production of such physical ionospheric parameters as the electron density profile, TEC, f_oF_2, H_{max}, etc.

VI. CONCLUSIONS

The RAIDS observatory will provide a unique opportunity to study space weather and, in particular, ionospheric weather in the mid 1990s. This ambitious new program embodies new remote sensing techniques, advances in optical instrument and detector design, and benefits from the advent of efficient and practical means for dealing with large databases. The ultimate goal of the RAIDS observing program is to distill from the enormous number of atmospheric soundings simple relationships between ionospheric airglow and the atmospheric composition and structure on both the day and night side of the earth. A number of relationships have been identified and await further verification and validation. The simple relationships that will be developed under the RAIDS program should help optimize future optical remote-sensing sensors and lead to operational systems for real-time global ionospheric remote sensing.

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