IN 35 -R
OCIT
42590
P- 10

Final report.

31 Dec 1994

The TIMED Imaging Photometer Experiment (TIPE).

NAS 5 - 32573

Submitted to :

National Aeronautic and Space Administration,
Goddard Spaceflight Center,
Greenbelt Road,
Greenbelt, Md 20771.

By:

Lockheed Research and Development,
Space Science Laboratory, 91-20, 252
Lockheed Missile and Space Company Inc.
3251 Hanover Street,
Palo Alto, CA 94304

Abstract:

This document contains a summary of the TIPE instrument study at the time of the termination of project due to TIPE being de-selected from the TIMED mission.

(NASA-CR-197431) TIMED IMAGING PHOTOMETER EXPERIMENT (TIPE) Final Reoprt, 31 Dec. 1994 (Lockheed Missiles and Space Co.) 10 p

N95-23087

Unclas

G3/35 0042590

TIMED Imaging Photometer Experiment (TIPE)

DESCOPED VERSION SUMMARY

Principal Investigator

Mende, Stephen B.
Lockheed Palo Alto Research Laboratory
Palo Alto, CA 94304
Phone 415-424-3282
Fax 415-424-3333
Email Span=Lockhd::Mende

Co-Investigators

Fritts, D. C.
University of Colorado
Boulder, CO 80309

Hecht, James H.
Aerospace Corporation
Los Angeles, CA 90009

Killeen, T. L.
University of Michigan
Ann Arbor, MI 48109

Llewellyn, Edward J.
University of Saskatchewan
Saskatoon SK S7N 0W0
Canada

Lowe, Robert P.
University of Western Ontario
London, ON N6A 3K7
Canada

McDade, Ian C.
University of Saskatchewan
Saskatoon SK S7N 0W0

Ross, Martin N.
Aerospace Corporation
Los Angeles, CA 90009

Swenson, Gary R.
Lockheed Palo Alto Research Laboratory
Palo Alto, CA 94304

Turnbull, David N.
University of Western Ontario
London, ON N6A 3K7
Canada

Walterscheid, Richard L.
Aerospace Corporation
Los Angeles, CA 90009

1.0 TIPE INVESTIGATION AND TECHNICAL PLAN

TIMED / TIPE Scientific Objectives
1 Determines the temperature structure of the mean state and the superimposed waves in the 80 - 100 km altitude region through remote sensing passive observations
2 Determines the global distribution of the wave contribution to the energy budget of the mesophere, lower thermosphere, and ionosphere (MLTI)
3 Determines the horizontal wave-number spectrum of the airglow image for studies of temporal (seasonal, diurnal), spatial (mountains, oceans), and meteorological (ITCZ, highs & lows) variations
4 Determines the distribution and seasonal variability of tides and planetary waves, and determines the effects of these waves on the mean state
5 Investigates interactions between waves (gravity, tidal and planetary) and the role these interactions play in the variability of gravity wave activity and tidal and planetary wave amplitudes and phases

TOH-083

The TIMED Imaging Photometer Experiment (TIPE) provides a fundamental contribution to the characterization of the energetics and dynamics of the mesosphere and lower thermosphere. Atmospheric gravity waves, tides, and planetary waves are a major source of energy in the region. These waves passing through the 80-100 km region affect the airglow emissions in several ways. The airglow layers have FWHM thicknesses of ~8 km so that information extracted relates to a relatively narrow atmospheric region. Waves cause perturbation of the atmospheric temperature which can then be measured optically from the rotational distribution of molecular emission bands. In addition, because gravity waves affect the number density of reacting species and (through the change in temperature) the rate constants of chemical reactions, the intensity of the emission is also modulated and can be observed optically. Imaging observations from TIMED spacecraft provide a convenient way of optically monitoring the rotational temperatures and the intensity of the airglow. These observations provide the mean values as well as the superimposed wave-modulated components.

Achievement of the TIPE scientific goals are essential to accomplishment of the first five TIMED mission objectives (Figure 1-1).

The table relates investigation data products (right column) to the respective TIMED science objective. The short wavelength waves carry much of the momentum in the upper atmosphere. The TIPE instrumentation is specifically designed for the observation of short (<10 km) wavelength waves. Two nadir viewing optical modules view the airglow layer directly downward for optimization of the spatial resolution. Medium wavelength (50-250 km) waves are imaged just below the limb with TIPE's high resolution limb viewing modules. Long waves, tides, and planetary waves are best examined from true limb view where altitude distribution of the wave-modulated airglow layers can be obtained directly by the two high-resolution limb-viewing modules. In the orbit plane limb view images, obtained in rapid sequence, permit the tomographic inversion of the volume emission distribution as a function of altitude and distance along the orbit. Also, the altitude of peak emission, as modulated by gravity and planetary waves, is measured .

SCIENCE OBJECTIVE	CONNECTION TO MEASUREMENT	MEASUREMENT	DATA PRODUCT LEVEL 1	DATA PRODUCT LEVEL 2
1.	Remote sensing of rotational temperatures	Nadir T_r and limb T_r	2,4 * 7	6,7 *
2.	Energy transport by waves primarily by small scales waves	Nadir intensity, T_r, and vertical gradients	1,2 5	1,2 4,6,8
3.	Remote sensing of wave distributions	Nadir intensity, T_r, and limb intensity, T_r	1-7	1-8
4.	Measurement of altitude distributions and profiles	Limb intensity, T_r	3,4 6,7	3,5
5.	Remote sensing of wave wave interactions	Short wavelength Nadir Intensity, T_r Long wavelength intensity, T_r	1-7	1-8

TOH-073

Figure 1-1. The TIPE instrument measurements and data products are essential ingredients for the accomplishment of several primary TIMED mission science objectives

** See section 3.0 TIPE Data Product Summary*

A unique feature of the TIPE investigation is that the same volume of atmosphere is studied from both nadir and limb view on the same satellite.

The rapid motion of the satellite assures that the same volume of the mesopause region is imaged in the nadir and limb views during a time period which is short compared to temporal changes in the distributions. The limb data provides altitude information for geophysical inference of gravity wave activity measured by the nadir instrument.

The instrument, flown on both TIMED spacecraft, has four modules observing simultaneously. At 400 km altitude, the nadir modules provide a continuous image with a 400 km crosspath dimension for a full orbital night at 3.2 km resolution for structures of wavelength <10 km. The two limb modules are looking ahead (or behind) in the orbit plane at the airglow layer to create near limb views to measure waves in the 50 to 250 km wavelength range and to generate altitude intensity and temperature profiles. The observation scenario is schematically illustrated in Figure 1-2.

One nadir-looking channel and one limb-looking module observe the $O_2(0,0)$ band, which is radiating predominantly in the 90-100 km altitude region. The O_2 band is a wavelength region of choice due to the relatively large emission intensity and the limited transmittance of the lower atmosphere minimizing light contamination from the earth's surface. The other nadir- and limb-looking modules observe the mesopause OH emissions which are emitted in the 80-90 km region. We have chosen the $O_2(0,0)$ band and the OH Meinel bands in the near infrared to observe the short wavelength features with adequate signal-to-noise ratio and to perform the studies related to our objectives.

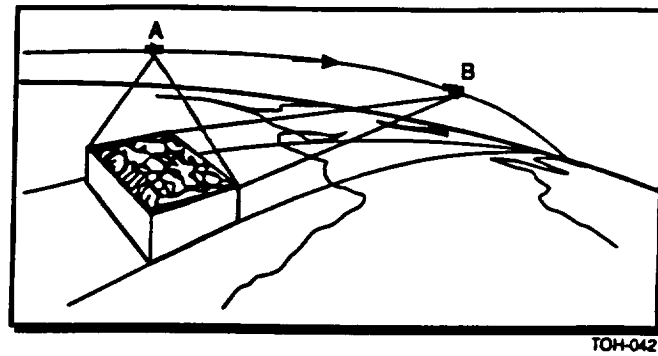


Figure 1-2. Position A, nadir-viewing channels observe the region below the satellite. Position B limb channels make limb observations over the same 400 km wide region

The TIPE instrument-observing modules are summarized in Figure 1-3.

The OH nadir looking module maps the fine structure of OH emission in a broad wavelength band. The altitude difference between the emitting regions of the O_2 and OH bands directly provides information about the vertical structure. The OH limb view takes advantage of the limb enhancement of the rotational lines and provides intensities to complement the higher altitude O_2 band limb data. The combined data, therefore, provide a self consistent set for deriving the wave-induced intensity and temperature distributions in latitude, longitude and altitude for the 80-100 km region.

The TIPE experiment team consists of scientists who have a proven track record shown by their extensive publications in the field of MLTI airglow, wave and related fields. The five key science objectives of TIPE are closely associated with the five highest priority science objectives of the TIMED program. The TIPE investigators are

Module No.	Modular Band	Direction	No. of channels	Function	Wavelength A & (bandwidth)	F.O.V. (Degree)
1	O_2 Atmospheric (0,0)	Nadir	2	Rotational temperature	P lines (15)	66 X 24
2	O_2 Atmospheric (0,0)	Limb	2	Rotational temperature	P lines (15)	20 X 5
3	OH meinel (9, 4), (5, 1), & (6, 2) and	Nadir	2	Intensity and	7680-8600	66 X 24
	Background			background	8200	
4	OH Meinel (9, 4), (5, 1) & (6, 2) and	Limb	2	Intensity and	7680-8600	20 X 5
	Background			background	8200	

TOH-067A

Figure 1-3. Module summary table identifies the airglow function, viewing considerations, and wavelengths measured by TIPE

divided into science study groups according to their responsibilities. We have formed seven science study groups. The team structure is expected to mature as the TIMED instrument complement is established in Phase B.

TIPE Science Study Groups

The five study groups are identified with the major tasks of the participants and relevant TIPE science objective numbers in Figure 1-4.

The investigation has the following unique features:

- Measures horizontal intensity and temperature distribution of the short wavelength waves in the 90-100 km altitude region
- Measures high signal-to-noise $O_2(0,0)$ intensity with low background (i.e., opaque through lower atmosphere)
- Effectively discriminates against scattered albedo contamination originating from the emissions themselves or from spectrally uniform sources
- Observes each volume element from two (nadir and limb) key vantage points
- Determines limb altitude intensity and temperature distribution for the mean and wave-induced fluctuations for long wavelength waves
- Produces appropriate time series data for tomographic inversion suitable for true emission intensity distributions for the mean atmospheric glows and the superimposed longer wavelength waves
- Measures intensity distribution of the small scale features at a second region, 80-90 km, in order to study the vertical propagation of the waves
- Measures limb intensity /altitude distribution of the longer wavelength waves at the lower altitude region

Each multi-wavelength channel imaging photometer module (Figure 1-3) has multichannel telecentric imaging capabilities allowing simultaneous observation of two wavelength bands. For every wavelength channel, the image is relayed to a CCD. The nadir viewing modules altogether have four wavelength channels and all four CCDs are operated in the Time Delayed Integration (TDI) mode where the image is shifted to compensate for the satellite motion and each pixel can be integrated for 20 seconds without smearing the image. The limb module CCDs are operated in the frame transfer mode. The digitized signals from the CCDs are processed in the experiment DPU and transmitted to the spacecraft in a compressed mode. The CCD binning, wavelength channel selection, and the on board data handling parameters can be changed through ground command.

The system has the following unique advantages:

- All measurements of intensity ratios and background corrections are truly simultaneous from identical emission volumes resulting in a high quality data product
- Maximum use of the available light is made in each channel
- No moving parts such as filter wheels or shutters are employed
- No high voltage devices are used
- Flight proven passive cooler uses no spacecraft power

GROUP NO.	MAJOR GROUP TASK (CHAIRMEN)	PARTICIPANTS	RELEVANT TIPE SCIENCE OBJECTIVE
1.	Horizontal, airglow intensity and temperature wave analysis by transform decompositions (Hecht)	Hecht, Lowe, Mende, Swenson, Turnbull	1,2,3
2.	Investigation of the relationship of waves to temporal (seasonal, diurnal) spatial and meteorological features (Swenson)	Hecht, Mende, Swenson	3
3.	Measurement and computation of vertical temperature and intensity profiles	Llewellyn, McDade, Mende, Ross	1,2,5
4.	Tomographic inversion of intensity profiles (McDade)	McDade, Ross, Mende	1,2,5
5.	Modeling of vertical flux transfer by waves from direct limb measurements and from inference from horizontal wave observations (Fritts)	Fritts, Killeen, Lowe, Turnbull, Walterscheid	2,4,5
6.	Gravity wave and tidal interactions (Walterscheid)	Walterscheid, Fritts, Hecht, Swenson	5
7.	Parameterization of wave quantities and wave forcing for inclusion to global models (Killeen)	Fritts, Killeen, Walterscheid	1,2,3,4,5

TOH-074

Figure 1-4. Task participants are organized to accomplish five scientific objectives

2.0 INSTRUMENTATION

The TIMED Imaging Photometer Experiment is a remote sensing instrument characterizing the energetics and dynamics of the mesopause region through the remote observation of wave activity. The instrument consists of four multi-wavelength channel imaging photometer modules. Each module has a multichannel telecentric imaging capability allowing simultaneous observation in two wavelength bands. An optical system is telecentric when all chief rays at the image are parallel with the optic axis. The net effect is that the angular distribution of the rays (hence the spectral band pass profile) is the same for every point in the image. For each module there is a CCD to pick up the dual image. The nadir viewing modules have four wavelength channels and these CCDs are operated in the Time Delayed Integration mode where image shifting compensates for the satellite motion and each pixel is integrated for 25 seconds without smearing the image. The CCDs in the limb modules are operated in the frame transfer mode. The digitized signals from the CCDs are processed in the spacecraft borne experiment DPU and are transmitted to the spacecraft in a compressed mode. The CCD binning, the wavelength channel selection, and the on board data handling parameters are programmable while in orbit.

INSTRUMENT DESIGN REQUIREMENTS	TIPE ATTRIBUTES	
	NADIR	LIMB
High signal-to-noise ratio	>100	>100
High spatial resolution	4 x 4 km	3 km alt.
Large area coverage	400 km wide	533 km wide
Simultaneous measurement of channels to be compared	4 channels	4 channels
Narrow band (Wavelength resolution)	15 Å	15 Å
Long term reproducibility	Built-in self calibration	
No moving parts	None	
No high voltage devices	<50 V	
CCD format	1024x512	1024x512
Avoidance of complexity and the use of well established designs	No new development	
Long life time in space environment	Best possible approach	
Minimum cost	See Cost	
Minimum power	<7 W	
Minimum data bandwidth	Variable data modes	
Minimum weight	10.97 kg	

TOH-031

Figure 2-1. Instrument requirements and TIPE attributes which optimize scientific objectives and the spacecraft environment

Nadir Modules: Distance to airglow layer is assumed to be 310 km.
Image is 400 x 200 km
Field of view 65.6 x 35.7 degrees
Number of binned CCD pixels 128 x 64 bins (8 x 8 binning)
Pixel on ground 3.2 km x 3.2 km
Mode of scan: TDI. (At 400 km altitude scan time 25 sec)
Effective focal length: 12 mm
Data read out rate: 12 bits x 64 x 128 / 25 sec = 3932 bits/sec
Limb Modules: Distance to limb airglow layer is assumed to be 2025 km.
Used pixels on CCD 1024 x 256
Image is 667 x 177 km (708 wide and 177 km altitude)
Field of view 20 x 5 degrees
Number of binned CCD pixels 16 x 42 bins (64 x 16 binning)
Pixel on limb 42 km x 4 km
Mode of scan: frame transfer every 6 seconds
Effective focal length: 47 mm
Data read out rate: 12 bits x 16 x 42 / 6 sec = 1344 bits/sec

TOH-028

Figure 2-2. Summary table of the optical and detector considerations for the nadir and limb modules

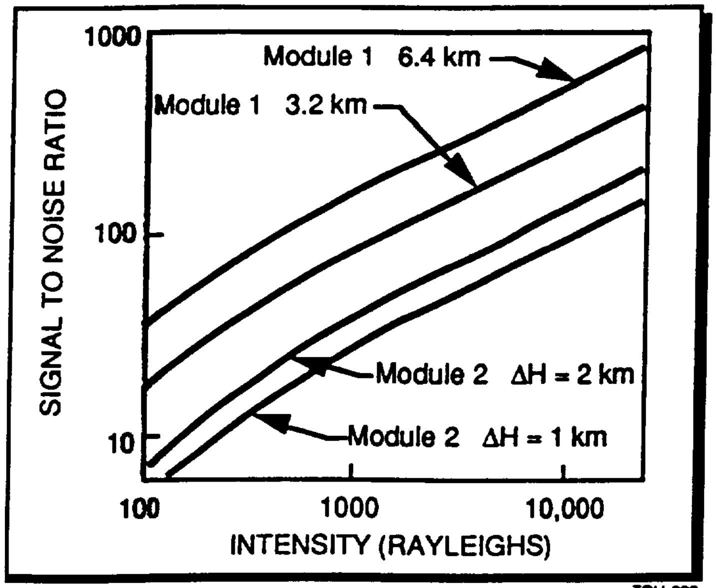
Figure 2-1 summarizes our system attributes which are optimized for the five scientific objectives. Figure 2-2 is a summary of the TIPE nadir and limb observing module specifications.

In Figure 2-3, the signal-to-noise ratios of typical modules of the TIPE instrument are illustrated. Our signal-to-noise ratio calculations are based on the parameters of the TIPE instrument, and the quantum noise of the signal, readout noise, and dark current-induced noise are included. The curves show the signal to noise ratio as a function of the intensity of the input signal.

The top two curves refer to the nadir view channels with pixel sizes of 6.4 and 3.2 km. The nadir intensity of the O_2 band is estimated to be several kR in total band intensity. The bottom two curves refer to the limb view channels with height resolution binning of 1 and 2 km. The limb intensity of the O_2 band is several hundred kR, and 30 to 40 kR can be expected to be in the filter bands. The curves show that a signal-to-noise ratio of 100 or more can be achieved with our design goals.

The CCDs can be "binned" further to increase the pixel sizes. This allows greater improvement in the signal to noise ratio at the expense of spatial resolution.

The measurement accuracy based on the signal-to-noise ratio of various TIPE data products is included on Figure 2-4. The instrument is illustrated on Figure 2-5.



TOH-039

Figure 2-3. The signal to noise ratio of typical modules of the TIPE instrument, including quantum, read out, and dark current noise contributions. The top two curves refer to a nadir view module with pixel sizes of 6.4 and 3.2 km. The bottom two curves refer to a limb view module with height resolution binning of 1 and 2 km.

Measured		Resolution (km)	S/N	Statistical Error
O_2 (0,0); Nadir	I	3.2 x 3.2	200	≤0.5%
O_2 (0,0); Nadir	Tr	3.2 x 3.2 6.4 x 6.4	80 160	≤3.5°C ≤1.76°C
O_2 (0,0); Limb*	I Tr	3.0 alt 3.0 alt	200 200	≤0.5% ≤0.7°C
OH; Nadir	I	3.2 x 3.2	190	≤0.6%
OH (6-2); Limb*	I	3.0 alt	120	≤0.83%

* Note: Altitude uncertainties are assumed 3 km from SC information whereas the instrument resolution used here is 1 km

TOH-077a

Figure 2-4. The relationship between the TIPE measurements, spatial resolution, signal to noise ratio and statistical r.m.s. error. Nominal average airglow intensities, and TIPE instrument parameters were used to calculate the signal to noise

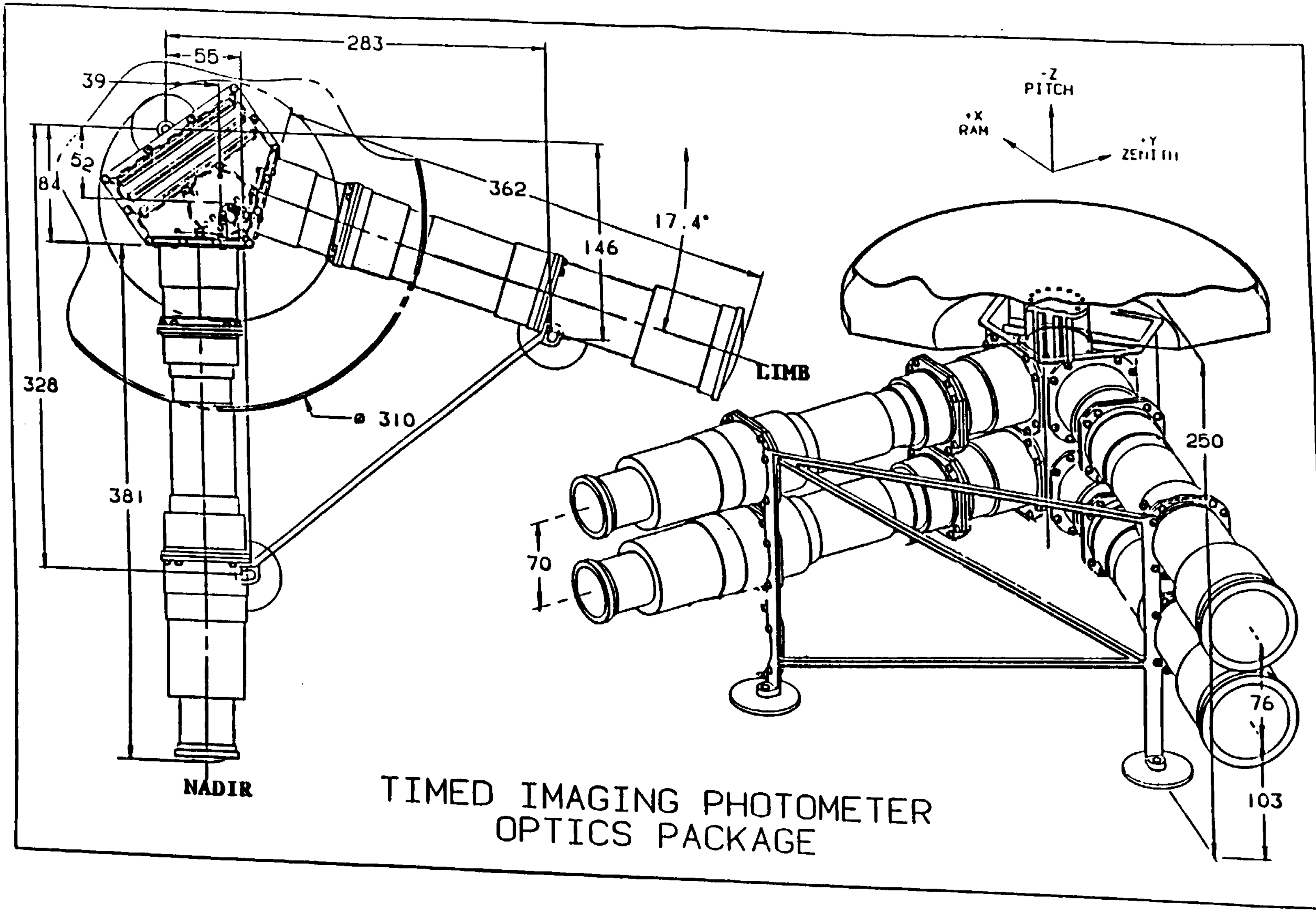


Figure 2-5. Isometric view of the TIPE Instrument.

3.0 TIPE DATA PRODUCTS SUMMARY

The data output of each channel is summarized in Figure 3.1. The data from the imaging channels is routed to the DPU. In the DPU the background correction and rotational temperature computations are performed. This reduces the data volume somewhat, as shown in Figure 3.2. The planned processed data products are geographic projections of physical parameters calculated from the raw data stream images. The basic product set includes surface projections for each nightside pass of nadir OH and O_2 intensity, nadir O_2 temperature, and limb projections and O_2 temperature. Intensity would be presented in rayleighs and temperature in K. Each nadir projection is effectively a continuous swath along the orbit groundtrack, while the limb projections are planned at approximately 2-degree intervals. The data processing steps include the application of calibrated instrument sensitivities and spacecraft orbital and attitude information. These Level 1 data products are summarized in Figure 3-3.

The basic physical parameters generated for Level 1 are used to generate Level 2 data. These Level 2 products are summaries of statistical information over an orbit, extending the physical parameters to dynamically relevant information. This information is used in modeling and statistical studies of atmospheric processes. Level 2 data products are listed in Figure 3-4.

Clearly there are additions which can be made to the Level 2 data. Orbital data is suitable for selected global statistical studies. Other dynamic categories include diurnal, seasonal, orographic, latitudinal, and focused wave correlations which could be separated from the Level 1 data base and processed independently.

We have focused here on a set of Level 2 data products which are of value for the investigations proposed by this team. The Level 1 data set forms a basic reference from which other Level 2 sets can be derived. The specific relationship of the data products to each of the TIMED science objectives addressed by the TIPE instrument is presented in Figure 1-1 in section 1.0.

TIPE DATA FORMATS

	Band	Wavl (Å)	Number of pixels	Exp. T	bit/sec
Module 1 (Nadir) Channel a Channel b	 O_2 O_2	 7624 7608	128 x 64 = 8192	25	3932 3932
Module 2 (Limb) Channel a Channel b	 O_2 O_2	 7624 7608	42 x 16 = 672	6	1344 1344
Module 3 (Nadir) Channel a Channel b	 OH broad band background	 7650 + 8200	128 x 64 = 8192	25	3932 3932
Module 4 (Limb) Channel a Channel b	 OH broad band background	 7650 + 8200	42 x 16 = 672	6	1344 1344 Total 21,104

TOH-043b

Figure 3-1. Raw data or input to DPU

TIPE DATA FORMATS			
	Band	Wavelengths	bit/sec
Module 1 (Nadir)			
SO1	O_2 nadir intensity	1a + C1 x 1b - C3 x 2b	2949
SO2	O_2 nadir rot T(8 bit)	(C2 x 1a - C3 x 2b) / (C4 x 1b - C3 x 2b)	2949
Module 2 (Limb)			
SO3	Limb O_2 intensity	3a + C5 x 3b - C6 x 4b	1344
SO4	Limb rot temp (8 bit)	(C7 x 3a - C8 x 4b) / (C9 x 3b - C8 x 4b)	896
Module 3 (Nadir)			
SO9	nadir background	2b	3932
SO5	OH nadir int (8 bit)	2a - C4 x 2b	2949
Module 4 (Limb)			
SO7	Limb OH int (8 bit)	4a - C10 x 4b	896
			Total =15,915

Nighttime is at most 41% of the orbit, providing an orbit average data rate of 6525 b/s.

TOH 3-2

Figure 3-2. Output from DPU

PRODUCT	PARAMETER	FORMAT	FREQUENCY	MODE SOURCE
1	Nadir I (O_2)	Geog. projection (map)	1/orbit	SO1
2	Nadir Tr (O_2)	Geog. projection (map)	1/orbit	SO2
3	Limb I (O_2)	Ht. vs. Crosstrack I Image	Each 2°	SO3
4	Limb Tr (O_2)	Ht. vs. Crosstrack Tr Image	Each 2°	SO4
5	Nadir I (OH)	Geog. projection (map)	1/orbit	SO5
6	Limb I (OH)	Ht. vs. Crosstrack I Image	Each 2°	SO7

Tr = Rotational temperature   I = Intensity (emission rate)

TOH-020

Figure 3-3. Level 1 Products

PRODUCT	PARAMETER	FORMAT
1	Nadir h, O_2	Geog. projection (map)
2	Nadir Horizontal Wave Number Spectra, O_2	x,y plots
3	Limb Horizontal Wave Number Spectra, O_2	x,y plots
4	Limb Horizontal Wave Number Spectra, OH	x,y plots
5	Horizontal Temperature Gradient, O_2	Geog. projection (map)
6	Vertical Gradients	x,y plots

Note: $h = (\Delta I/I) / (\Delta T/T)$ for an airglow disturbance due to atmospheric gravity waves

TOH 3-4

Figure 3-4. Level 2 Products