

**ROCKETSONDES AND SATELLITE SOUNDINGS:  
WILL THE BEST DATA SOURCE PLEASE STAND UP?**

By

Paul J. McCrone

For

Professor Morss

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Creighton University  
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TABLE OF FIGURES

Figures

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**ABSTRACT**

Since the late 1950's, meteorologists have engaged in many studies of the upper atmosphere, and specifically, the stratosphere. In order to obtain data in this region, three methods are used to retrieve stratospheric data: (1) Rocket-borne instruments (Rocketsondes), (2) conventional radiosondes, and (3) Satellite remote soundings. This paper will concentrate on the data obtained by the Rocketsonde and Satellite, compare the two, and provide an evaluation of the quality of the two data types. Satellite soundings are found to have a slight edge over rocketsonde data for routine applications.

## INTRODUCTION

Numerous studies of the upper atmosphere have been conducted. Specifically, work in the upper troposphere and the entire stratosphere has radically changed many viewpoints regarding the state of the atmosphere, to include a consideration of chemical constituents, thermodynamic variables, electromagnetic phenomenon, velocity flow patterns, etc. Recent work has indicated that the stratospheric winds play a decisive role, <sup>transition?</sup> determining climatological weather patterns. In order to most effectively study this layer in the atmosphere, three methods are used: (1) Meteorological Rockets, (2) Radiosondes (and Rawinsondes), and (3) Meteorological Satellites. This paper will focus on the Rocketsondes and Satellites, since both are capable of sounding the entire vertical extent of the stratosphere. Radiosondes, though highly valuable in any stratospheric analysis, will only reach altitudes of roughly 30 km. Both the Rocket and the Satellite will be introduced in turn, then, a review of overall data quality will be presented. First, though, it is necessary to establish a criteria whereby we can decide upon which of the two to choose. This is presented below.

### I. CRITERIA FOR A GOOD DATA SOURCE

In order to best choose a data source, we need to set up some guidelines for data quality. With reference to studying the

stratosphere, we would desire data that:

- (1) applies directly to the stratosphere  
(in other words, USEFUL data),
- (2) maintains an acceptable level of precision,
- (3) possesses low, simple, system bias errors,
- (4) exists in abundance (Quantity), and, finally,
- (5) is easily available.

*P*The issue of usefulness is not trivial. Certain studies may seek to explore the atmosphere over a mesoscale or synoptic area. Others may only be interested in a specific place. Some studies may only be interested in a certain level of the stratosphere (i.e. the radiosondes might be good enough), where some may wish to explore the entire layer. *P*Precision is obviously important. If the data received has a low degree of precision, then the numbers are to be 'taken with a grain of salt'. Similarly, the exterior influences that may introduce non-statistical errors can also be problematic. A rocket, for example, may have an electrical problem with its temperature probe, causing unknown errors. *P*Next, the data must be plentiful, especially if it is going to be used to make conclusions about the overall global flow patterns. A network of systematic observations is a must for this kind of data. *P*Finally, availability is an important issue. If the data is not shared, but kept within the confines of a research organization, then little benefit is gained from this data, at least as far as the scientific community at large is concerned. Also, it is ideal if the system in question does not cost a great amount of money.

*Suggested paragraphs vice the single long style done here*

With this overview of criteria in place, we can now look at the Rocketsonde and Satellite sensors, and make a good decision about the quality<sup>?</sup> of both data types. As a first step, though, it is necessary to review both systems individually. The following discussion will give the reader a background <sup>on</sup> ~~in~~ the available systems.

## II. ROCKETS: AN OVERVIEW

A rocket is a jet-propelled vehicle that characteristically carries with it not only its fuel supply but also the means for burning it. The rocket, unlike the jet aircraft, does not depend on oxygen from the atmosphere for the latter function<sup>?</sup>. Operation of the vehicle is based on a simple principle: the ejection of the high speed propellant requires that the rocket system gain momentum in the opposite direction to that propellant (assuming no other forces are involved) [Craig, 1965]. Newton's basic laws

*spacing problem*  
of motion come in to play here: "to every action there is an <sup>← out of place at the end of the para.</sup> equal and opposite reaction". <sup>⚡</sup> The current system in use in the United States today is the Super Loki rocket motor (which is a propulsive first stage), and non-propulsive dart atop the Loki motor. Figure (1) shows the overall system diagram. At launch, the system accelerates to 1500 m/sec (5000 ft/sec) during a 2-second burn time. The Loki motor propels the dart to the maximum altitude (apogee), which is usually over 100 km (special systems have made it to 400 km). Shortly after the initial two-second burn, drag forces<sup>really?</sup> cause the Loki motor to separate from the dart. At apogee, the dart, which contains a payload of measuring

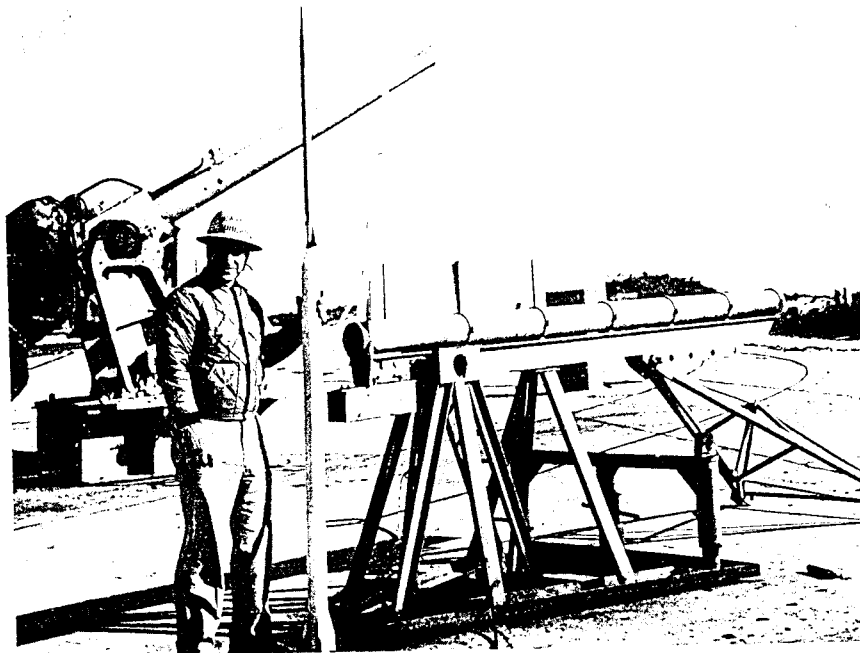
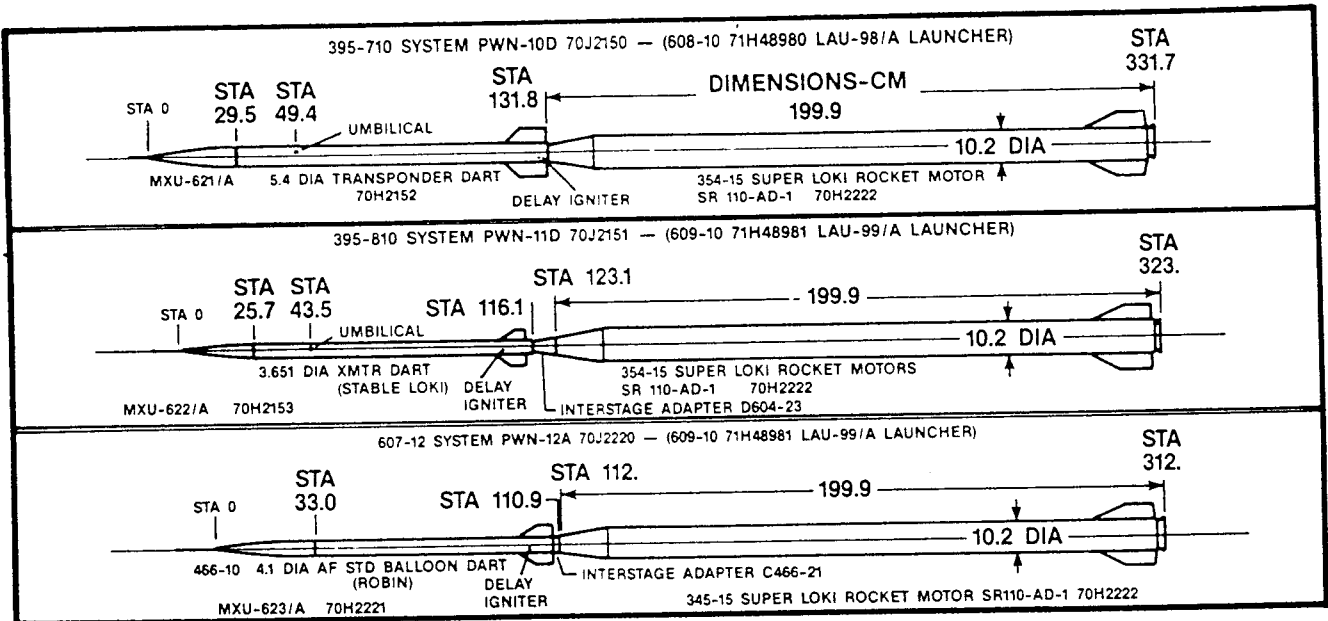


Figure 1 Loki sounding rocket and launcher.

apparatus, detonates a charge that forces this payload out of the forward end of the dart. As the payload descends, it serves as a target that can be tracked by ground based radar and/or telemetry equipment (the system can optionally be equipped with a system that transmits position data back to the ground). The dart can actually provide either of two different payloads at present: a falling sphere, and a rocketsonde.

The sphere is actually an inflatable sphere known as a ROBIN (ROcket Balloon INstrument), which is a radar reflective package containing sensors to detect temperature and other thermodynamic parameters. Displayed in Figure (2), the ROBIN is 1 meter in diameter after inflation. Using a ground-based tracking radar, the ROBIN provides atmospheric density data and wind velocity by determining the fall velocity of the sphere. The Loki-ROBIN system is nominally capable of reaching an apogee of 115 km, and is normally used to sound the atmosphere from 100 to 30 km.

The rocketsonde is a modified dart. The device is tracked by ground-based radar, providing altitude, position, and wind data. The temperature is measured with a loop mounted bead thermistor and transmitted to a ground receiving station. Another modification of this system exists, where the rocket itself transmits all the data to a ground station using onboard equipment. This is referred to as a "transpondersonde". These systems normally reach an altitude of approximately 70 km.

In order to support a rocket observation (ROCOB), a significant infrastructure must exist. "Aside from launch and test equipment, basic metrocket ground equipment falls into three

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Figure 2 Inflatable Sphere with Metalized Coating (the Robin)

categories: (1) position tracking and recording (RADAR); (2) telemetry receiving and recording; (3) telemetry receiving and recording with radio direction-finding and ranging capability" [Carnaham, 1988]. Examples of the kind of equipment involved are given in <sup>↑</sup>figures (3) and (4).

In the late 1950's through mid 60's, the metrocket was a popular (and only) choice for the study of the upper atmosphere. At that time, a small network of rocket observations was maintained, usually at special missile test sites, such as White Sands, New Mexico. Figure (5) shows the stations that comprised the Meteorological Rocket Network (MRN). Due to budgetary constraints, this original network has been reduced. Table 1 gives a summary of current metrocket sites.

*Point out that there are the US part of larger global net.*

The original MRN engaged in a wider variety of measurement techniques. Figure (6) shows these methods. In addition to the ROBIN sphere and conventional rocketsonde, two other techniques were used. One method used a release of chaff at several altitudes. Wind velocity could be measured through a radar tracking system. Though chaff is not a discrete target, such as a ROBIN, technology existed to accurately track this cloud of particles, and derive accurate winds. This method was limited to a maximum altitude of about 60 km. A second method used early in the development of the metrocket was the wind-sensing parachute, a 4.5 meter metallic parachute that was ejected from the early Loki and older Arcas rocket systems [NASA, 1966] This system was tracked, again, with ground-based RADAR, in order to compute wind velocity. This system was limited to 70 km for

*Need to add info on current obs - how often, etc to really make a comparison*

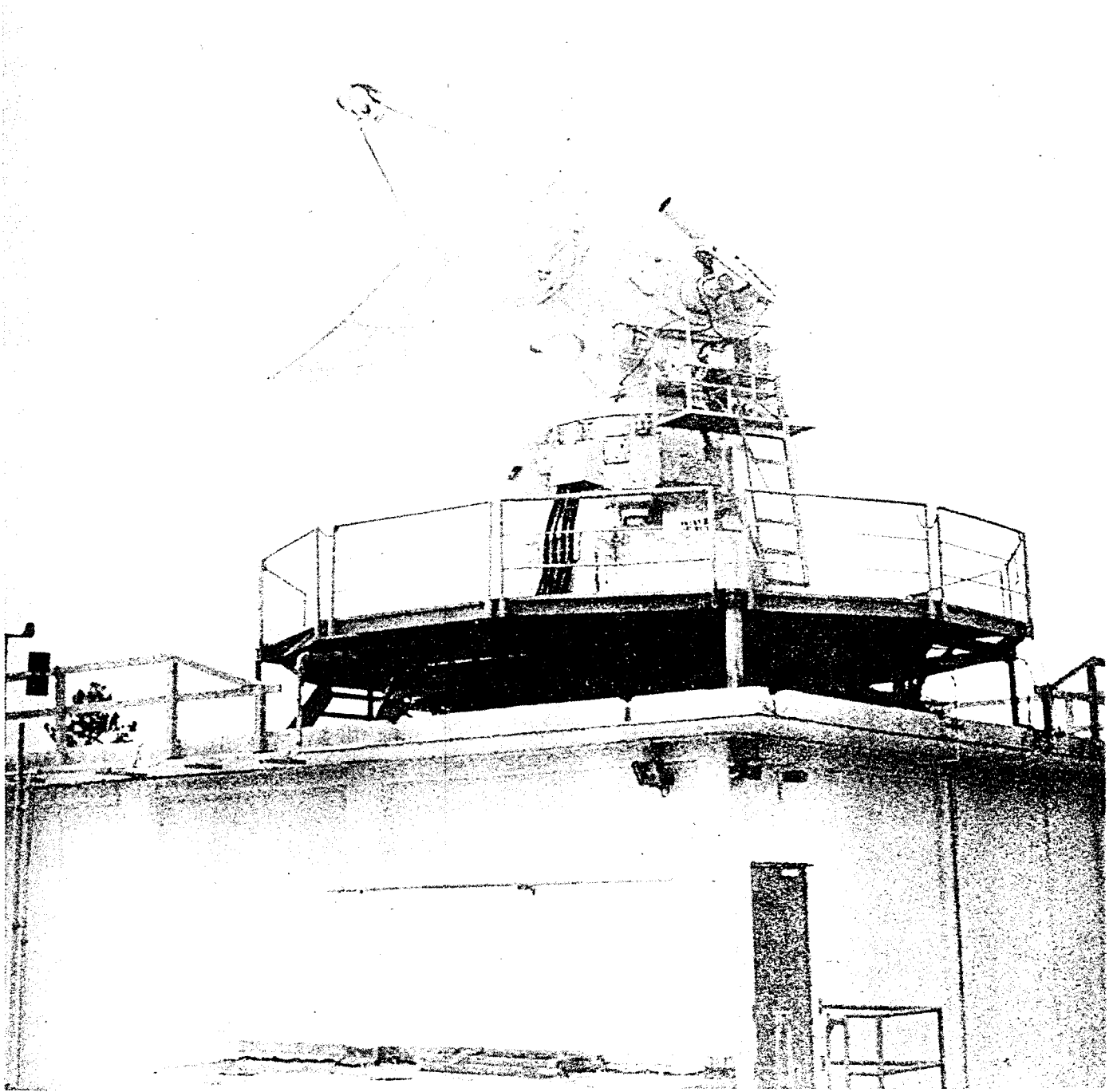


Figure 3 Radar Tracking System (AN/FPS-16)

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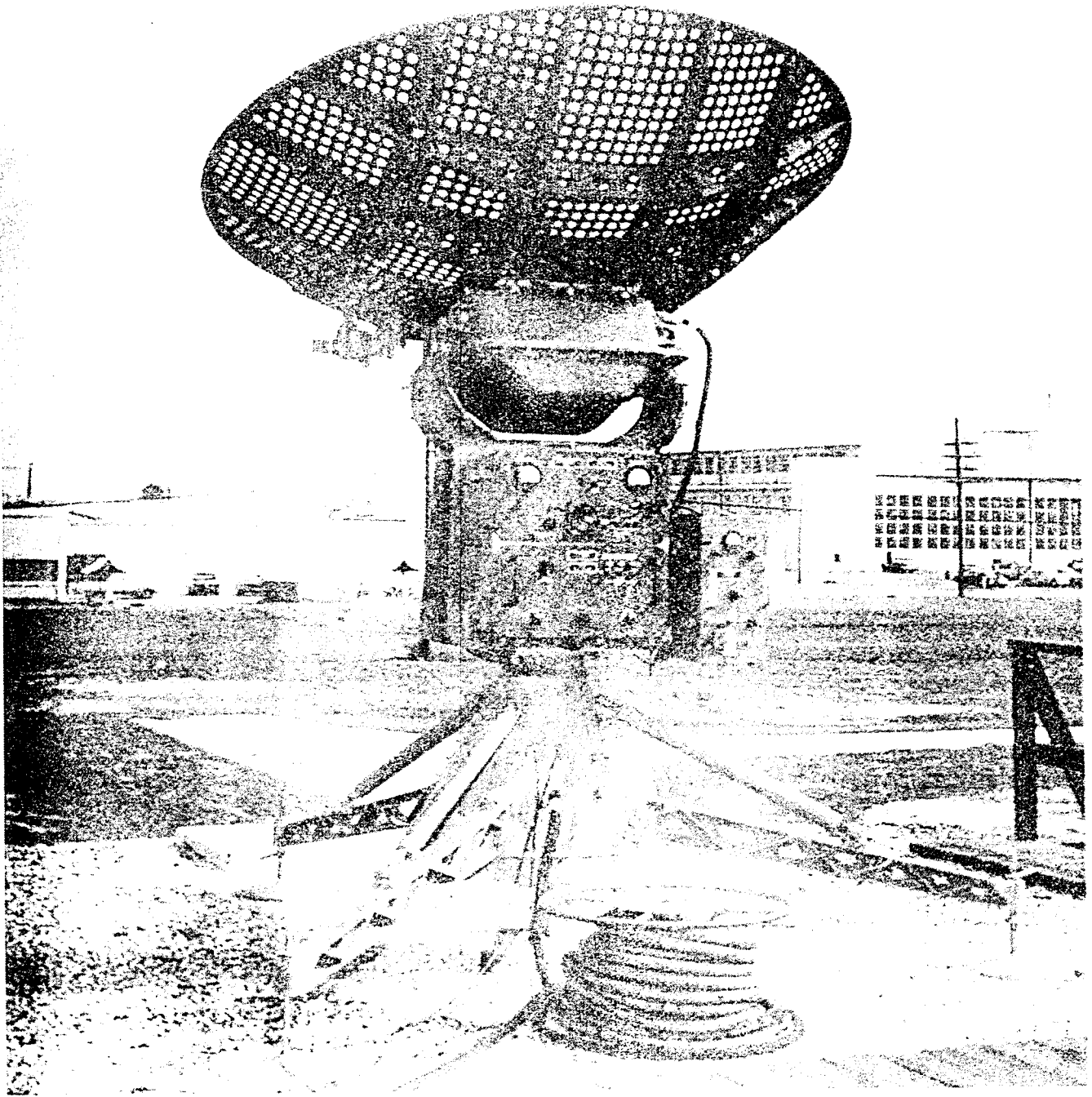


Figure 4 Ground Meteorological Direction-Finder (AN/GMD-5)

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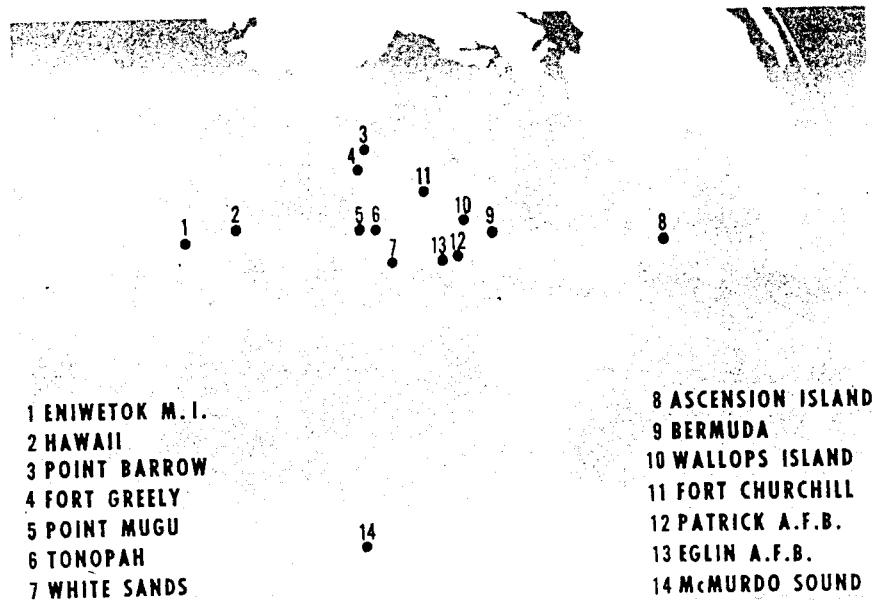


Figure 5—Location of sites from which small meteorological sounding rockets have been launched since 1959.

Table 1 Rocketsonde Stations Operated by the United States

Station	Location (Latitude, Longitude)	International Index Number
Thule, Greenland*	76.5N, 068.7W	70420
Primrose Lake, AB	54.7N, 110.0W	71124
Wallops Island, VA	37.9N, 075.4W	72402
Point Mugu, CA	34.1N, 119.1W	72391
White Sands, NM	32.3N, 106.4W	72269
Cape Canaveral, FL	28.4N, 080.5W	74794
Barking Sands, HI	22.0N, 159.7W	91162
Coolidge Field, Antigua	17.1N, 061.7W	78861
Kwajalein, Marshall Is.	08.7N, 167.7W	91366
Ascension Island	07.9S, 014.4W	61902

\* standby status

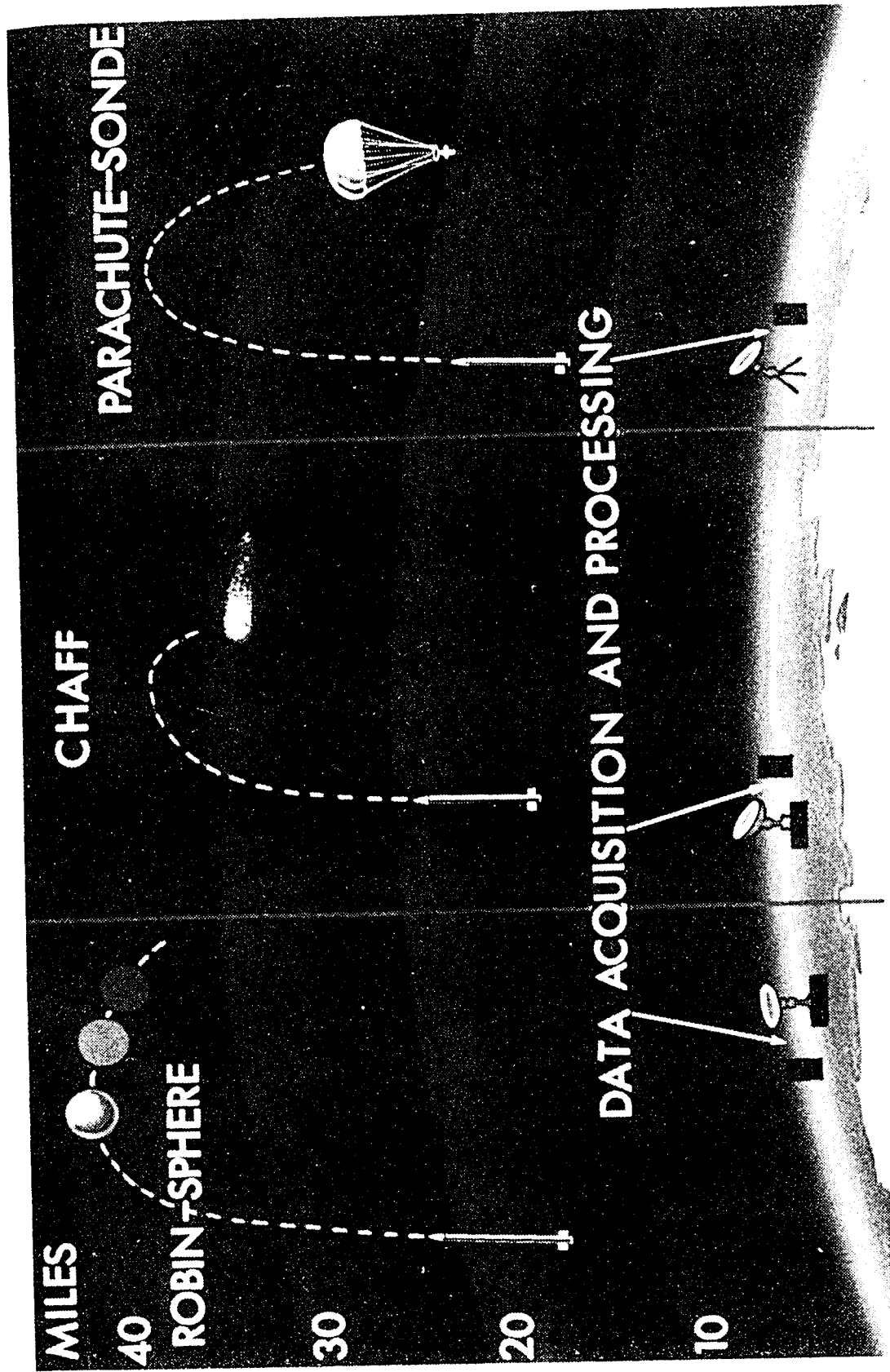


Figure 6 — Various techniques for making meteorological experiments with small sounding rockets.

maximum altitude.

### III. SATELLITE OVERVIEW

Rocket and RADAR observation are necessarily restricted in geographical and temporal coverage. Satellites, on the other hand, are much less restricted in these domains. Systems such as the NOAA TIROS Polar orbiting satellites, GOES Geostationary satellites, and the Defense Meteorological Satellite Program (DMSP) polar orbiters provide a tremendous amount of information to facilities like the National Meteorological Center (NMC), and many others. In particular, the polar-orbiting satellites provide the lion's share of the data currently fed to the numerical weather prediction (NWP) models, since they cover the entire globe in 12 hours. We will concentrate on the U.S. National Oceanic and Atmospheric Administrations' TIROS polar orbiters. An example of this system is found in <sup>↑</sup>figure (7).

In order to use these spacecraft, we must determine a methodology for obtaining useful information from them. In general, satellites need to have some kind of sensor onboard in order to detect a temperature. Currently, this 'sensor' is in the form of a spectrometer - a device that can determine the intensity and frequency of electromagnetic radiation that is emitted from the earth. This spectrometer is designed to detect certain wavelengths of radiation in the atmosphere. These wavelengths correspond to various properties of the atmosphere. In <sup>↑</sup>figure (8), we can see a clear depiction of the kinds of

# Advanced TIROS — N (ATN)

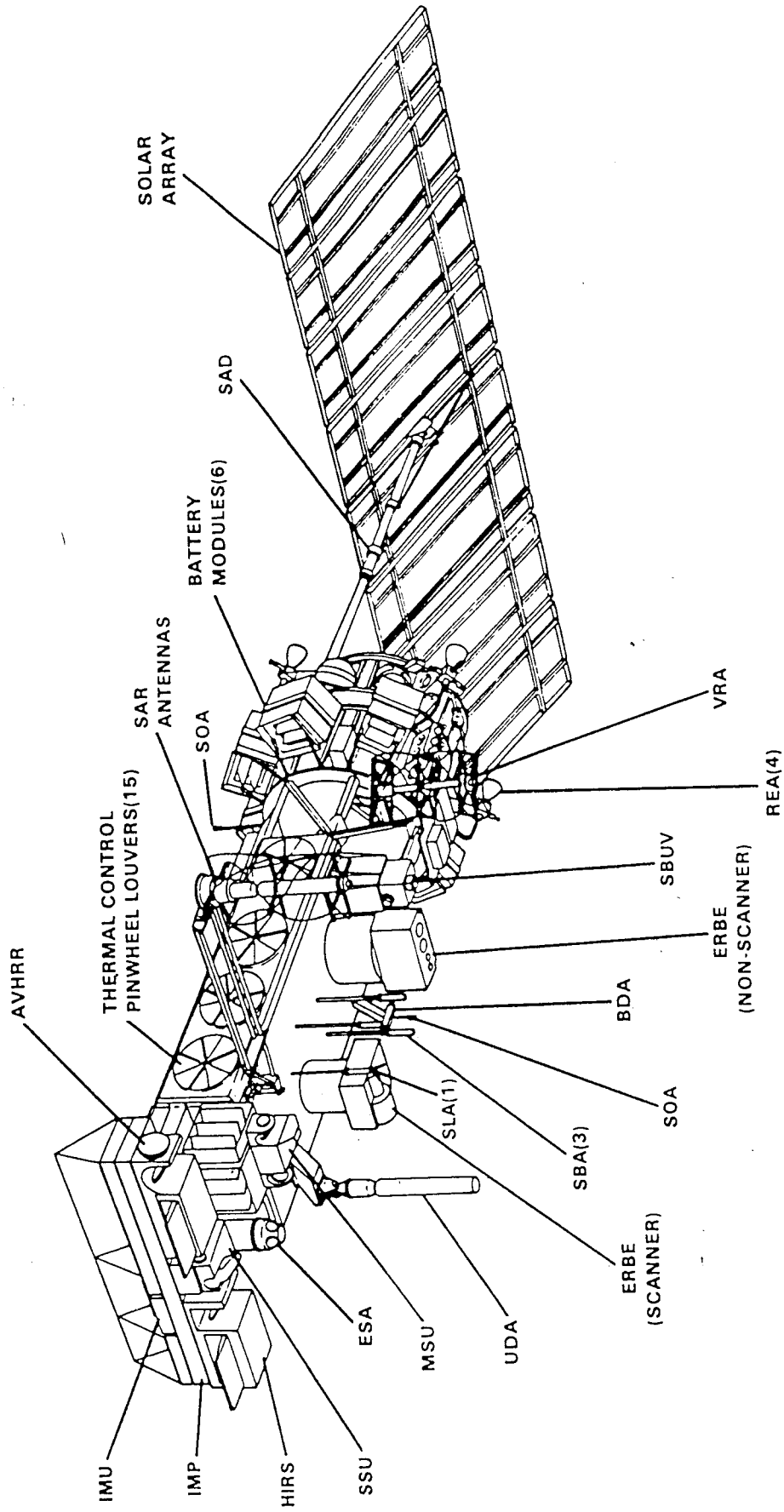
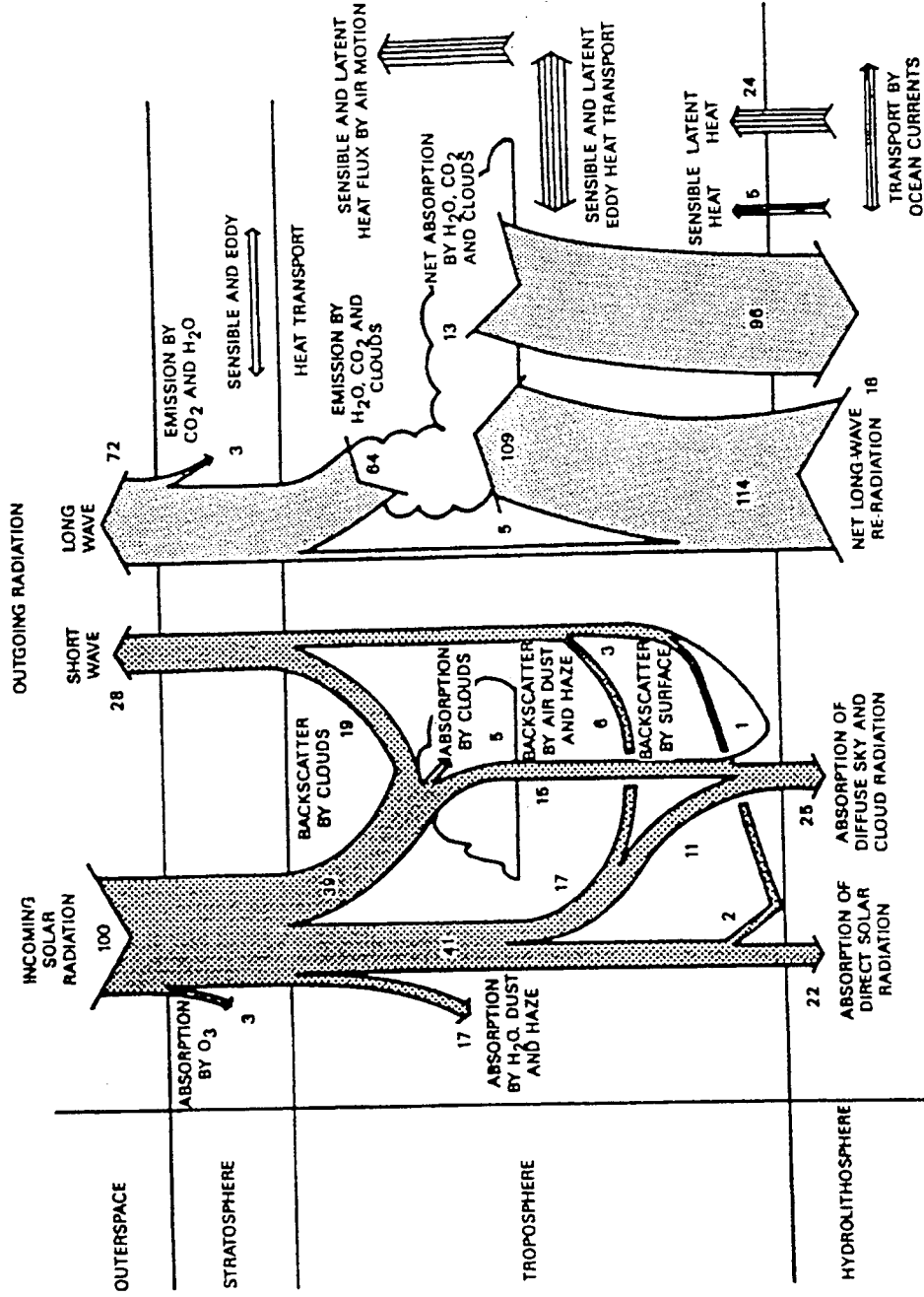


Figure 7

# ATMOSPHERIC ENERGY BALANCE

EARTH REMOTE SENSING



Schematic diagram of the disposition of absorbed solar energy in the Earth system.

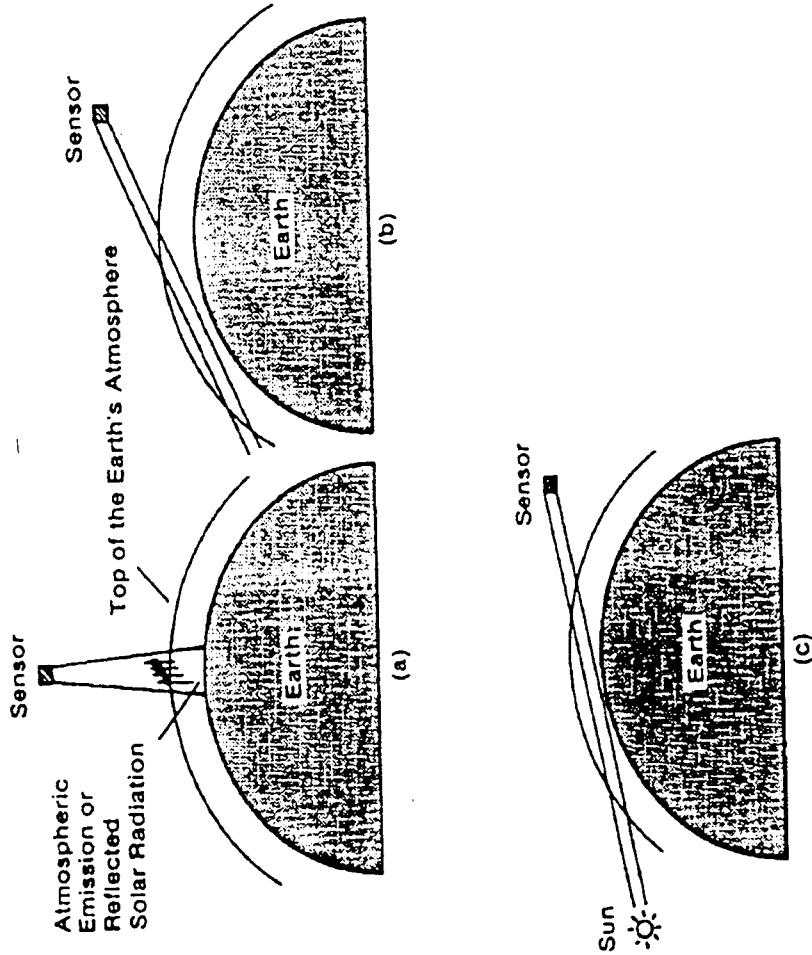
Figure 8

processes that are occurring in the atmosphere. Scattering, absorption, and emission are occurring in a complicated network. Note the constituents that are having the largest impact: O<sub>3</sub> (Ozone), H<sub>2</sub>O, and CO<sub>2</sub>. This is significant, since we can take advantage of the radiative properties of these constituents to obtain information about the atmosphere. Almost all satellite based sounders have frequencies that utilize the radiative spectra of water, ~~C~~arbon ~~D~~ioxide, and ~~O~~zone. We will focus on the TIROS-N Operational Vertical Sounder (TOVS) for our considerations.

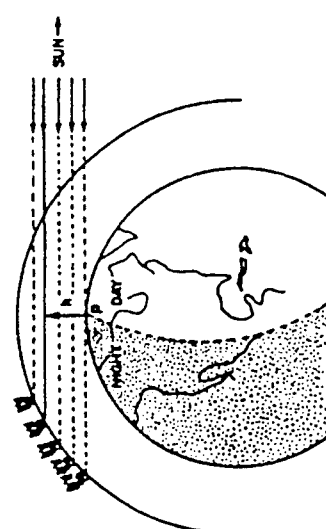
Before we consider the TOVS sensor, it is useful to consider the methods in which a satellite may scan the atmosphere for data. There are three basic ways in which a satellite can sound the atmosphere: Solar Occultation, Limb Sounding, and Nadir Sounding. Each is depicted in Figure (9). Briefly, Solar occultation views the atmosphere against the sun. It measures the absorption of direct sun at selected wavelengths in the ultra-violet (UV), ~~V~~isual (VIS), and infra-red (IR), enabling the detection of numerous chemical constituents in the atmosphere. Limb sounding is similar geometrically, except the instrument measures emissions <sup>from</sup> ~~for~~ the atmosphere. The instrument observes a black background, rather than using the sun. Temperature profiles can be determined from such a system, in addition to other profiles. IR emission bands are normally used for this system. Finally, Nadir sounding uses the spectral bands of "well-mixed gases (e.g. CO<sub>2</sub>)", and does so by looking straight down (or at least nearly so) into the atmosphere. Actually, the sensor

# SOUNDING GEOMETRY

EARTH REMOTE SENSING



(a) nadir sounding  
(b) limb sounding  
(c) solar occultation



Solar Occultation (Ref.33)

sweeps left to right, perpendicular to the spacecraft direction of motion. The Nadir sounder is the most common type of sounder, with TOVS a member of the group. Thus further considerations will assume a Nadir sounding geometry. One of the reasons for using a Nadir sounder is the issue of earth geolocation. A limb-sounding type of geometry lends itself well to determining the vertical structure accurately, but not towards locating that vertical structure over the surface of the planet. Potentially large errors are possible with this type of geometry.

TOVS is a complex sensor, consisting of a 20 channel High Resolution Infrared Sounder (HIRS), a 3 channel Stratospheric Sounding Unit (SSU), and a 4 channel Microwave Sounding Unit (MSU). The HIRS system has channels at  $0.7 \mu\text{m}$  (visible),  $3.7 \mu\text{m}$ ,  $4.3 \mu\text{m}$  ( $\text{CO}_2$ ),  $6.7 \mu\text{m}$  ( $\text{H}_2\text{O}$ ),  $9.7 \mu\text{m}$  ( $\text{O}_3$ ),  $11 \mu\text{m}$ , and  $15 \mu\text{m}$  ( $\text{CO}_2$ ). Possessing 17 km horizontal resolution, these channels are used to obtain vertical temperature profiles, Water Vapor Content, and Total Ozone Content.

The MSU has 109 km resolution, with four channels in the microwave regime from 50-57 GHz. These frequencies utilize the emissive properties of molecular oxygen.

The SSU has three channels that use the  $15 \mu\text{m}$   $\text{CO}_2$  band, possesses 147 km horizontal resolution, and measures temperature in the stratosphere.

Having determined that the HIRS and SSU can, in fact, detect phenomena in the atmosphere is valuable. However, we need to find a way to correlate the detected radiances with an altitude

in the atmosphere. Otherwise, the data is almost useless.

To consider the variations with height, let us look at the radiative transfer equation (equation [1]), below:

$$I(\nu) = B[\nu, T(x_0)] t(\nu, x_0) - \int_0^{x_0} B[\nu, T(x)] \times \frac{d}{dx} t(\nu, x) dx \quad [1]$$

where  $I(\nu)$  is the radiance or  $\swarrow$ intensity of radiation emitted by the earth-atmosphere system at a wavenumber  $\nu$ , which is observable by the satellite sensor,  $B$  is the Planck function,  $T$  is the  $\swarrow$ temperature,  $x$  is an independent variable which represents the vertical dimension (altitude, pressure, etc.), and  $t(\nu, x)$  is the transmittance of the atmosphere at certain wavenumber from the surface of the earth ( $x_0$ ) to the top of the atmosphere (0). "The transmittance depends on the magnitude of the gas absorption coefficient and the amount of absorbing gas above level  $x$ " [Rao, 1990]. The first term correlates to the contribution of the surface to the observed radiance, and the second term the contribution of the atmosphere. Equation [1] shows that the atmospheric component of the observed radiance is given by the contribution of the Planck function (at a given atmospheric layer) times the rate of change of the transmittance with respect to the vertical  $x$  dimension (note: this is the term identified by the special braces in equation [1]). This term, hence referred to as  $W$ , can be considered a weighting function. Weighting functions for the HIRS, MSU, and SSU are given in

Figure (10). For any wavenumber (wavelength), the weighting function indicates the portion of the atmosphere that contributes to the intensity observed.

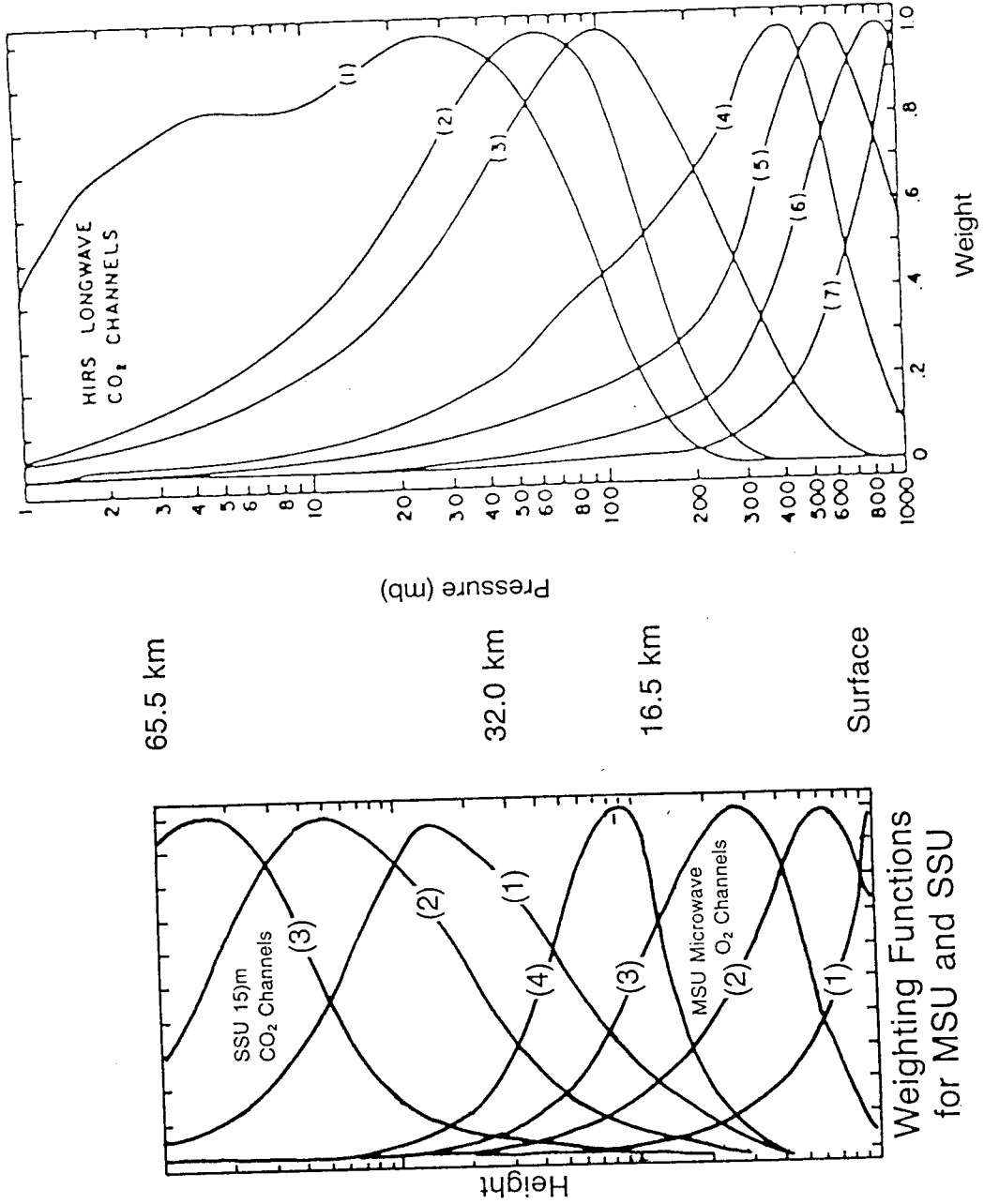
"The characteristic shape of the weighting functions results from the following process. In regions of moderate absorption, radiation originated at low levels is absorbed by the overlying atmosphere and so contributes little to the emerging radiation. On the other hand, because of low densities, the contribution from high levels is also small. Thus, characteristically, there is a peak in the weighting function at some level within the atmosphere."  
[Rao, 1990]

Wavenumbers with weak absorption are thus coming from lower levels, and wavenumbers with strong absorption are coming from higher levels. So, each wavenumber "sees" a different layer in the atmosphere. We can then carefully select which channels a given sensor will detect, thus resulting in a complete picture of the vertical atmosphere.

Regrettably, equation [1] is not easily solved. Thus, methods of retrieving temperature ( and other geophysical parameters ) are not trivial. Many current techniques employ the correlation ( and regression ) of satellite data to radiosonde (AND ROCKETSONDE!) data. Techniques to improve the retrieval of temperature data from sounding satellites are still being developed.

Having completed an overview of both the rocket and satellite systems, we can begin to discuss the issues regarding data quality. The rockets will be discussed first, then the satellites will be discussed. Afterwards, a comparison will be made.

# Fundamental Polar Satellite Products: TOVS



Weighting functions for various wavenumbers of the 15 µm carbon dioxide bands of the TIROS Operational Vertical Sounder (TOVS).

Figure 10

## ROCKETS: A CASE FOR THE ORIGINAL DATA SOURCE

The rocket has several advantages and disadvantages. In keeping with the stated criteria for data quality, let's examine the rocket closer. There may be some overlap of one area into another.

### I. USEFULNESS

The usefulness of the rocket stems from the work started in the early 1950's with the original Air Force V2 and US Navy Viking rocket programs. These gathered the first data regarding the upper atmosphere, making it to altitudes of 215 km+ [Craig, 1965]. Maintenance of a rocket observing network preserves an already sketchy history of stratospheric research. With the rocket, flexible chemistry experiments can be conducted. Air samples can be retrieved. Most importantly of all, *IN SITU* measurements can be made. With this information, statistical regressions for satellite retrievals of various geophysical parameters are possible. Even with today's technology, the ROCKET is still the only way to make direct measurements of the middle and upper atmosphere.

### II. PRECISION

The statistical precision of measurements can widely vary. The errors associated with the bead thermistor should be small, but other experiments, such as with the RADAR tracking of the ROBIN, can have potentially very high errors, depending on

human operators and the measurements they make. Overall, though, this is not considered a serious factor for rockets.

### III. QUANTITY

One of the largest drawbacks to rocket data <sup>15</sup> (in) the quantity. Compared to even the radiosonde network, the MRN is a very small network of ROCOBS. A more extensive number of rocket stations would be considered highly desirable from a purely scientific view.

*what about the global net?*

### IV. SYSTEMATIC BIAS

Systematic bias can consist of items such as the differences in the antenna patterns that are basic to the RADAR systems involved in making measurements. Most importantly, the bead thermistor, used to measure temperature, may have problems related to possible lag, radiative, and compressional heating errors. These are predictable errors, though, and this complex problem has been analyzed. The errors involved are held to be within 1 to 2<sup>0</sup>C up to 50-55 km. The reader is referred to FMH-10 (Federal Meteorological Handbook 10) on Meteorological Rocket Observations to inspect the care with which such errors are treated.

### V. AVAILABILITY

Several issues surround the availability of ROCOBS. First, since there are so few stations reporting, there is little data to obtain. Second, the establishment of a ROCOB station requires the following:

{A} Well trained personnel.

(B) Sufficient supporting infrastructure  
(i.e. RADAR systems, direction finders,  
etc.)

(C) Reasonable funding.

(D) Available Space

Part (A) should be self-evident. Without the people to make such an operation work, all is hopeless. Parts (B) and (C) go hand-in-hand. The RADARs are needed to accomplish the task of performing numerous measurements, and the funding must exist to get the equipment in the first place, then further funding is required to maintain, operate, and upgrade the systems. Part (D) is a reflection of the simple fact that metrockets can potentially do quite a bit of damage if fired on top of a local town. As a result, rocket sites are chosen so as to avoid potentially damaging impacts on the population. This further reduces the number of available sites to conduct ROCOBS (even if the funding is available). Also, existing sites often must delay (or cancel) the ROCOB if the potential exists for the system to drift into a populated area. This would have important consequences if the ROCOB was a part of a coordinated launching of other metrockets in the MRN (for scientific studies).

Finally, ROCOB data is transmitted (if it is sent at all) via the Automated Weather Network (AWN), so only those people with AWN access can get the data.

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## I. USEFULNESS

The main usefulness of the data from satellites has been documented by Rao et al, 1990, where they cited numerous studies that compared NWP forecasts using satellite data to that NWP data which did not use the remote soundings. They reported that "the satellite temperature soundings contribute to increased forecast accuracy". Furthermore, Rao reported a study from the NASA Goddard Laboratory using their NWP model. They noted that use of satellite data in their model showed "...significant reduction of errors on the west coast of continents", a significant finding, since the conventional data coverage over oceans is small, usually leading to large errors in those regions.

Further studies by Lewis et al, 1980, indicated that, in using satellite soundings:

- "... The non-meteorological bulls-eye features could be eliminated...
- ... NMC has had good results using the TOVS satellite soundings in the stratospheric analyses...
- ... Coincident satellite soundings are internally consistent whereas coincident RAOBs are not always consistent..."

Clearly, the data obtained from satellites have earned their keep. However, significant points still remain.

## II. PRECISION

By a wide margin, precision is the biggest drawback to the satellite sounder. Even when ~~Nadir~~ sounding units are considered, the horizontal resolution of a scan spot from NOAA TOVS varies from 17 km (HIRS) to 147 km (SSU). Given that our emphasis is on the stratosphere, the 147 km resolution from the SSU sensor is most troubling. *What does this equate to from a grid viewpoint?*

If the horizontal resolution is mediocre, then the vertical resolution is little better. An inspection of the weighting functions for the HIRS and SSU clearly demonstrate this. The half-bandwidth associated with these sensors can be as much as 8 km thick! Given the possible variations, the results are still encouraging. Rao et al indicated reasonable results in comparing satellite temperatures to radiosondes. RMS errors in temperature differences were found to be low (approximately 2 to 3 degrees celsius). Also, Lewis et al, 1980, concluded that the "quality of the present DMSP and TOVS soundings in the stratosphere are comparable to RAOBS". So, while the potential for errors is still rather high, the sounders seem to be doing an acceptable job of sounding the atmosphere.

## III. QUANTITY

The work of Lewis et al, 1980, also stated that "... the amount of stratospheric data available to the analysis models more than doubles when satellite data are included". The NOAA systems process over 8000 soundings a day per satellite - a huge amount of data, even when compared to radiosondes.

I could find no text reference to this Table.

**Table 2** *Satellite-radiosonde temperature differences in °C. N is number of observations (Gruber and Watkins, 1982).*

CLEAR/PARTLY CLOUDY													
SUMMER 79			FALL 79			Winter 79			SPRING 80			Layer	
N	MEAN	RMS	N	MEAN	RMS	N	MEAN	RMS	N	MEAN	RMS	(cb)	
334	-0.1	2.0	1390	0.7	2.7	917	-0.5	2.9	760	-0.1	2.5	100-85	
991	0	1.3	3463	0.2	1.9	2417	-0.6	2.1	2041	-0.3	1.9	85-70	
989	-0.3	1.0	3418	0.1	1.5	2390	-0.2	1.7	2020	-0.4	1.6	70-50	
985	-0.5	1.4	3403	0.1	1.9	2367	0	1.9	2003	-0.6	2.0	50-40	
986	-0.8	1.7	3381	0.1	1.9	2352	0.2	2.0	1998	-0.4	2.0	40-30	
994	-0.9	1.8	3381	-0.1	2.1	2364	0.5	2.7	2002	-0.1	2.3	30-25	
983	-0.4	1.9	3400	0.1	2.2	2393	0.6	2.5	2016	0.2	2.5	25-20	
985	0.3	1.8	3422	0	2.2	2396	-0.3	2.2	2018	-0.6	2.4	20-15	
981	0.4	2.0	3427	-0.2	1.9	2390	-0.4	1.9	2015	-0.4	1.8	15-10	

CLOUDY													
SUMMER 79			FALL 79			WINTER 79			SPRING 80			Layer	
N	MEAN	RMS	N	MEAN	RMS	N	MEAN	RMS	N	MEAN	RMS	(cb)	
137	2.8	3.9	535	-0.5	3.6	507	-1.4	4.0	527	0.1	3.8	100-85	
293	-1.0	2.7	1488	-0.1	2.7	1333	-0.9	3.0	1388	-0.3	2.7	85-70	
289	-0.9	1.7	1475	0.1	2.0	1322	-0.4	2.2	1374	-0.4	1.9	70-50	
289	-1.3	2.3	1469	-0.2	2.5	1325	-0.2	2.4	1378	-0.8	2.6	50-40	
291	-1.6	2.6	1457	-0.3	2.6	1311	0.2	2.5	1355	-0.9	2.8	40-30	
293	-1.0	2.8	1457	-0.2	2.8	1305	0.8	3.1	1352	-0.6	3.2	30-25	
291	0.7	2.6	1472	0.2	2.5	1311	1.0	2.9	1364	-0.1	3.0	25-20	
287	0.5	2.2	1474	0.4	2.3	1314	0	2.3	1381	-0.3	2.5	20-15	
282	-0.5	1.9	1473	0.1	1.9	1314	-0.3	1.9	1374	-0.3	1.8	15-10	

Andrews et al, 1987, indicated that the SSUs onboard the NOAA spacecraft promise a great expansion of the observational basis of our knowledge of [various phenomena] in the middle atmosphere".

#### IV. SYSTEMATIC BIAS

The primary source of bias associated with a satellite sounder consists of numerous electronic issues which are well beyond the scope of this paper. The errors induced by this problem are well known, and taken into consideration when retrievals are conducted.

Other errors have been noticed when comparing soundings over cloudy regions and clear regions. The work of Reale et al, 1994, indicated that the soundings from the NOAA-11 satellite tended to be as much as 2 to 4 degrees (C) warmer than those from the NOAA-10 spacecraft during cloudy conditions. This is not fully understood, and work is ongoing to reduce these errors.

#### V. AVAILABILITY

Availability is now one of the strongest features of the satellite sounder. For NOAA TOVS, a system exists to actually retrieve real-time sounder data direct from the satellite. Conventional personal computers with HF receivers and antennas are able to receive and process TOVS data. Furthermore, archives of NOAA, GOES, and DMSP sounder data are available via the INTERNET through the National Geophysical Data Center (NGDC). While the cost of placing a satellite in space <sup>is</sup> ~~in~~ obviously high, it seems less a burden when forecasters and scientists around

the world can utilize satellites.

#### A COMPARATIVE LOOK

The Rocket systems seem to have two major drawbacks: Poor availability and low quantity. The availability issue is driven by cost, mainly. Quantity is problem that goes in step with the availability issue. The data provided by the rocket system is of a reasonable precision, low bias, and overall high usefulness.

The satellite system suffers from poorer data precision, and some unknown bias error(s). It is widely available, highly useful, and plentiful in quantity. It comes often enough to be used in practical weather prediction applications. On the other hand, the data retrieved from a satellite depends, in part, on the "ground truth" provided by radiosonde and metrocket data.

#### CONCLUSIONS

Given the utility of the satellite sounders to support NWP and other practical weather initiatives, making the atmospheric models more accurate, the author gives the edge to the satellite sounders. However, let it be noted that the rocket is a valuable tool for obtaining upper air data. In many ways, the two systems, provide totally different purposes. Rockets

can give the scientist the in situ truth that is so badly  
needed in a proper look at the atmosphere. As a final note,  
though, let it be said that 'progress marcheth on', and  
the satellites will<sup>may</sup>, one day, possess a similar capability of too strong  
the rocket with respect to measuring geophysical parameters.

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