SEMI-ANNUAL REPORT

for

Grant NGR 06-002-102

Radiation Measurements from Polar and Geosynchronous Satellites

Period: 1 October 1970 - 31 March 1971

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May 1971

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SUMMARY

This is the first report under grant NGR 06-002-102. It shows that a balanced program of research and development using meteorological satellite data is beginning.

Diagnostic studies using radiation measurements from the near-earth satellites will be applied to problems of atmospheric energetics and circulation. Specifically, we are using measurements from Explorer VII (1959) thru Nimbus III (1970) to examine the planetary scale, atmosphere and oceanic cause/response to observed interannual variation of the equator-to-pole gradients of net radiation. In addition we are investigating the separate synoptic scale energetics of the atmosphere (apart from the ocean) by using independent measurements at the "top of the atmosphere" (from satellites) and at the air/ground interface.

Data from geostationary satellites (ATS I and III) are relatively recent. Their potential has not yet been completely realized. We are considering one of their most important uses, the capability to track clouds, as a research tool.

Opportunities for improved meteorological experiments on future spacecraft are also under study in areas related to grant research.

1.0 Introduction

During the first six months of the grant period the principal investigator has been joined by three (MS) students. Each of them is presently beginning a thesis project under grant sponsorship and in line with grant research objectives. These studies (and others guided solely by the P.I.) represent the relatively long term portion of the research effort.

Several short term efforts are also reported in this document (in the appropriate sections and appendix). Others, particularly regarding the data reduction of Nimbus III MRIR measurements for radiation budget purposes, will be summarized in NASA documents in preparation.

The following section outlines work presently underway in 3 general areas. It is followed by plans for subsequent periods as well as comments and recommendations.

2.0 Discussion

2.1 Studies of the Radiation Budget and Atmospheric Energetics

Most of the ongoing research involving reduction and analysis of Nimbus III data is reported in the papers noted in Appendix B. The work progresses well as does initial comparison with radiation budget measurements from the earlier satellites. New work, beginning recently, deals with two advanced areas of radiation budget studies: (a) the separate energetics of the atmosphere and the ocean and (b) study of the measured interannual variations of energy exchange between earth and space. Furthermore, section 2.3 discusses new opportunities for improved measurements; requirements stem in part from the research reported in this section.

Additional topic areas include:

2.11 Detailed study of an oft-quoted steady state model of Budyko (e.g. "a 1% change in insolation will cause a 1.1°K decrease in planetary surface temperature").

While the "trigger" for climate change is the insolation (i.e. drop), the "amplifier" in Budyko's model is an assumed departure (expansion) of the area having a high planetary albedo due to snow and ice at the surface. We plan further study using observed polar albedo (and temporal variations) together with a knowledge of cloudiness (invariant in Budyko's work).

2.12 Interannual variations of equator-to-pole radiation gradients have been measured. At present we are compiling indices of atmospheric circulation during the same periods. The correlative study will be followed by diagnostics using a hierarchy of models for experimentation (from one similar to Budyko's, above, ranging to the more complex P.E. versions). Initially, we hypothesize negative feedback via the cloud fields.

2.13 In collaboration with Kirby Hanson of NOAA, AOL, we plan special gross parameterization of the solar energy absorbed separately by the atmosphere and ocean. Parameters will include measurements of planetary albedo, cloud amount (and perhaps water vapor content) from satellites. Relationships will be derived using surface solar energy data compiled by the Main Geophysical Observatory, Leningrad.

2.14 All first and second generation satellite experiments for radiation budget show differences from earlier estimates that can be attributed to errors in climatological cloud data. To check this we have completed a one year study of global cloud amount using satellite observations. Many of these have already been done and we shall make comparisons. An advantage to our method is "calibration" over certain locations against ATS cloud observations to remove diurnal bias.

Other work including preparation of photographic cloud average and special radiation budget analyses over BOMEX will progress at the pace of Nimbus III analysis.

2.2 Special Application of Geosynchronous (ATS) Satellite Measurements

Proposed work using combined infrared and reflected solar radiance for nephanalysis can begin since the IR data is now available. In relation to deriving winds from cloud motions two items warrant reporting:

2.21 Joint THIR/ATS study of the height of measured cloud displacement is underway in cooperation with the P.I.'s former research group at the University of Wisconsin. After several years of experimental development, a quantitative, (moderately) fast computer-oriented technique for "wind-finding" is now available. This project will provide specially processed THIR data and share in techniques development and scientific analysis. As stated in the grant proposal, cooperative research is more efficient and economical than separate software development at each university.

2.22 At the request of the UCAR GARP Task Group on Scale-Size Interactions in the Tropics (first meeting, April 20-21, 1971) a very basic synopsis report was prepared on the opportunity to infer winds from measured cloud motions. The report is included as Appendix A; some further discussion of its Figure 1 follows.

Considering only the problem of accuracy of determining cloud displacements allows the study of an effective lower limit of accuracy of resulting winds. This assumes that problems dealing with

(a) the assignment of the cloud displacement in 4-dimensional space, and (b) the relation between cloud displacement and "true" horizontal wind, simply add to this lower limit of absolute error. With the aid of Figure 1 we may:

(1) evaluate existing "wind-finding" systems;

(2) plan future satellite experiments designed to meet requirements of research and/or operations (i.e. GARP).

Entry parameters to the nomogram are:

(a) highest frequency of (ATS) picture acquisition for a specific data set (generally an experimental or operational constraint),

(b) minimum bias error of the technique or apparatus being used,

(c) required absolute accuracy of cloud displacement measurement,

and (d) the half-life of the longest lifetime clouds capable of serving as good tracers.

Regarding (1), the problem of evaluation is not yet completely bounded. Critical information regarding the relation between cloud (tracer) size and half-life is lacking. Cloud sizes from 0.5 km to "that size at which the cloud becomes a system of its own" must be studied. The upper limit undoubtably depends on cloud type. For cumulus clouds (generally regarded as good low-level tracers in plentiful supply) some information may be available at the upper range of the size spectrum from radar data. We plan to examine this source.

The same problem of cloud lifetime influences complete application of the nomogram for planning purposes. However, much can be learned at this time. For example, change of GARP data requirements from 3 to 2 m/sec can readily be studied assuming proper clouds have half-lifes as great as two hours. In this case, maximum tolerable alignment bias error (ΔS_B) must be correspondingly reduced from ±12 to ±7 nautical miles. New and better alignment techniques may be required.

Furthermore, tradeoffs between picture-taking frequency and alignment accuracy can be examined. Under all plausible cloud half-life assumptions the latter rather than the former has the greater effect on attainable cloud displacement accuracy. This indicates that improved technology to acquire more frequent pictures may be misdirected if wind-finding is a major goal. Rather, the improved technology should be directed toward more precise measurement of spacecraft attitude.

2.3 Possibilities for Advanced Meterological Spacecraft Experiments

A spinoff of the radiation budget research lead to a separate joint proposal with NCAR for an engineering design study of a global radiation budget experiment from a lunar site. The opportunity from this platform looks very attractive for longterm global measurements. Other satellite experiments also need study, especially one from geostationary orbit to acquire very important information about diurnal variation of budget parameters. The author and colleagues are well aware of this problem area from study of sun-synchronous satellite data.

For geosynchronous satellites also, previous work on the opportunity for sounding the atmosphere from these vehicles has left the author as a "most interested" scientist and potential user of such soundings. One of our grant students has acquired a special background in radiation transfer and inversion techniques. Several applications of her interests to geostationary sounder problems are under study.

3.0 Program for the Next Reporting Period

All research areas mentioned will receive further attention. Nimbus-III data reduction procedures for heat budget will be documented and analysis of the final results will begin this summer. Early emphasis will include study of the first four-season data set from the Nimbus MRIR. The THIR/ATS wind study will be expanded and the bi-spectral (perhaps tri-spectral) nephanalysis will be tested. Opportunities for advanced experiments in areas related to grant research will be studied.

4.0 Conclusions and Recommendations

From section 2.22 and Appendix A it is apparent that a simple method for evaluating proposed wind-finding techniques is available. It can be of use to the scientists (e.g., those involved with this grant) who wish to consider research objectives and to the scientific planners interested in building systems to meet requirements. It evaluates cloud displacement accuracy, the lower limit of wind accuracy. We recommend its use.

Data processing complexities and priorities are standard procedure in our research. This report provides an opportunity to acknowledge all of the many at Goddard Space Flight Center who have supported our research data needs in a professional and enthusiastic manner.

As always, we encourage more direct scientific discussion between members of our university research group and scientists in the laboratory.

Some "conclusions" are contained in the papers of Appendix B and a more extensive summary will be included in the Annual Report.

Appendix A: 3 May 1971

Opportunities for Use of Satellite Data in Support of Research in Tropical Meteorology

Part I: Winds from Cloud Motions

(An informal synopsis prepared for the UCAR GARP Working Group on Scale Interaction Problems in Tropical Meteorology, by Tom Vonder Haar, Colorado State University, with comments and contributions by other interested scientists.)

1. Purpose

Throughout its first meeting at NCAR on 20-21 April 1971, the Working Group often discussed a need for use of satellite observations in support of their several research efforts. There was a recurring statement of the need for some basic notes regarding use of certain types of satellite observations that have special application to tropical research. At the present time, the required information is adequately contained in the literature and in special summaries and reports prepared by government agencies; however, it is not conveniently summarized in any single document. These notes will not provide such a summary, but will serve as a synopsis to allow common discussion of possible data use and also common use of the same data. Such cooperation is one goal of the Working Group. Updates to these notes (especially regarding access to specific types and periods of data) will be distributed in the future.

2. General Working Group Satellite Data Needs

Most of the Working Group discussion centered on use of existing data (e.g., from the previous exploratory tropical field programs) for present-day research. Thus, a first discussion of satellite data will be confined to that already in hand for the time period 1967-68-69. The general summary of "most-inquired-about" data is listed in Table 1.

Table 1 : General Working Group Satellite Data Needs.

DATA TYPE	SATELLITE	FORM	COMMENTS	BASIC SOURCE
Cloud motions	ATS	movie loops "special" photos digital tapes	6-8 possible techniques	NOAA NASA U. of Wisconsin U. of Chicago
High resolution, quantitative cloud images	ATS NIMBUS (IR)	"special" photos digital tapes		NASA NOAA U. of Wisconsin
Cloud climatology and disturbance census	ESSA-I, -III NIMBUS ATS	maps tapes		NOAA U. of Hawaii
Vertical temperature and water vapor profiles (begun 4/69)	NIMBUS (N_V)	listings tapes	3-4 techniques	NOAA NASA
Surface wind from sun glint	ATS	(under development)		U. of Wisconsin NOAA
Sea surface temperatures	NIMBUS (IR)	tapes maps	experimental or operational	NOAA NASA

Examples of the first three data types in Table 1 were displayed by several groups during the Working Group session. The latter three were mentioned during the discussions.

Of the satellites mentioned, ATS (Applications Technology Satellites) are in equatorial geostationary orbit (22, 500 miles from earth center with an orbital period of 24 hours); NIMBUS and NOAA satellites are near-polar orbiters (1,000 km height), "sun-synchronized" so that they observe nearly all points of the earth's surface close to only two local times (one during day, one at night twelve hours later).[1] For tropical research use the ATS satellites offer the tremendous advantage of nearly continuous time coverage to offset the limited space coverage [approximately 50 degrees of great circle arc about a (controllable) equatorial subpoint].

Data form lists the more research-oriented means of data availability. A more and more common receptacle these days is the computer-compatible digital tape. It is useful for immediate computation and/or display at most university and research computer centers.

Comments are elaborated below as each primary data type is discussed in more detail; basic source is included more to acknowledge contributions in a given area rather than to indicate an address to which orders may be sent. The proper addresses and best sets of data for tropical research will be summarized and distributed by staff of the UCAR Task Group following personal inquiries with the scientists involved at the data centers.

2.1 Cloud Motions

The possibility to infer winds from cloud motions received the greatest amount of attention from the Working Group. L. Hubert and colleagues have clearly and candidly written informal notes on this

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[1] NIMBUS have 1130/2330 local time orbits; ESSA operational satellites have nominally either 0830/2030 or 0230/1430.

subject in several of the GARP literature and they provided an updated summary to members of the Working Group. In addition, several authors have contributed more formal papers to JAM, BAMS, etc. during 1970-71. The papers describe specific apparatus and techniques and present sample results.

Some very basic amplification of the comments referenced includes the following:

a. Wind from cloud motion measurements may be subdivided into steps or problem areas:

(1) Aligning or registering a pair (or sequence) of ATS images (images may be in photographic or numerical form). Only relative alignment is required.

(2) Identifying cloud tracers and measuring their movement or selecting cloud fields (patterns) and computing their common displacement.

(3) Assigning the resulting displacements, speeds/directions or vectors to a proper location in 4-dimensional space (x, y, z, t). Without infrared capability on the geostationary satellite (none will be available until 1972 because of low IR signals encountered at great distance) the assignment of height (z) is most difficult.

(4) Deciding on the relation between the space and time located cloud displacement vector and the "true" atmospheric wind at that point. Which clouds give the best (or poorest) depiction of the wind field?

b. The magnitude of problem areas (1) and (2), above, will differ depending on the apparatus or technique used; items (3) and (4) are common to all schemes. Basic techniques include:

(1) Manual methods, often using special jigs or photogrammetric techniques for alignment of images. Movie loops or sequential sketches or maps of the cloud fields allow identification of tracers followed by manual measurement. If the basic image, the alignment

procedures, and the measurement techniques contain high precision, the resulting cloud vectors may be very useful for research purposes. They can be obtained (slowly) with great care and with checks (i. e., of alignment against landmarks) and rechecks. Movie loops especially provide the operator with discernible differential motion fields that aid his subjective choice of a height for each measured displacement.

(2) Semi-automatic methods (sometimes called "man-machine") are used to handle greater amounts of data, faster and with greater flexibility than the manual techniques. They do allow the operator to perform two or more of the most crucial steps (i. e., alignment, selection of the tracer (or field) and/or measurement). Examples may range from special optical/mechanical image correlators to interactive display devices with video storage and recall capability. Often the output of these apparati is automatically coded for computer processing. These man-machine combinations hold great promise for operational use and for research as well, provided they can be operated with precision in the main problem areas of alignment, selection and measurement.

(3) Automatic (computer) techniques nominally perform all crucial operations objectively, given a set of high resolution image arrays. This includes alignment, selection (of sub-arrays), measurement, assignment of location (with the aid of infrared), objective analysis, initialization, and resulting prediction (!). Thus far, however, acceptable results require pre-selection to avoid heterogeneous cloud areas on the (non-infrared) images. In essence this is equivalent to manual selection of tracers, but the alignment and measurement functions remain automatic.

c. After discussing basic steps and several techniques we may consider the <u>absolute accuracy</u> of cloud displacements (vectors, speeds, or directions). After this is determined the remaining problems [(3) and (4) in a., above] of assignment and "representativeness" affect wind accuracy. Displacement accuracy is then the effective lower limit of wind accuracy.

For cloud displacement the problem is simply one of $V = S/T$, where T (the interval between pictures) is known precisely. Thus $\Delta V = \frac{1}{T}(\Delta S)$ and ΔS may contain ΔS_R, random errors of selection and measurement arising from imprecise techniques or changing cloud patterns; or ΔS_B, bias (systematic) error due to bad relative alignment of the image pair (or sequence). In most cases the researcher is interested in inferring winds at a finite grid mesh. If his cloud displacement techniques and the availability of clouds within a grid mesh combine to allow many determiniations of displacement S within the mesh, the influence of ΔS_R will diminish by the square root of number of observations, N. For a large mesh, precise technique and adequate number of clouds ΔS_R may become insignificant and $\Delta V = \frac{\Delta S_B}{T}$. Figure 1 shows this simple relationship.

With the time interval T having a lower limit defined by the picture-taking frequency on the day in question, any and all cloud displacement techniques can be evaluated on this same nomogram if their inherent errors ΔS_R and ΔS_B are known.[1] They can be evaluated to learn what the lower limit of wind error will be. Conversely, if the researcher has a firm error requirement known a priori, he can use Figure 1 to choose a technique to meet his needs.

d. Miscellaneous notes on winds from cloud motions:

(1) Hubert and Whitney plan to publish many of their results in Monthly Weather Review in mid-1971. Their statistically significant set of comparisons between cloud displacements and rawinsonde data treats the problem of "level assignment," "representativeness," and "displacement error" without separation, but with detailed discussion.

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[1] It should be noted that the relative alignment problem springs originally from departures of the satellite's orbit and altitude from the nominal. This error source varies from day to day. Thus, ΔS_B is a measure of each technique's ability to "correct" for this basic error.

(2) Bias error resulting from uncorrected misalignment may be circumvented in some cases by computing horizontal shear, divergence, or relative vorticity parameters directly from the cloud displacements. Vonder Haar, Smith, and Hasler have experimented with Lagrangian schemes to make such direct computations. Hasler has refined and applied the techniques to many tropical case studies.

(3) Where possible, simultaneous measurements of temperature (geopotential) and winds from cloud motions can be used in a form of the balance equation to yield a more mutually consistent (and hopefully more accurate) depiction of atmospheric conditions. More research is needed before mass application.

(4) The most detailed analyses of winds from cloud motions have been presented by Fujita and colleagues at the University of Chicago. They use a high precision movie loop scheme (ΔS_B about 10 km at best near picture center). Suomi and others at the University of Wisconsin have experimented with (and eliminated some) various methods of optimum wind-determination. They presently favor a specially designed (nearly) automatic method that has evolved from several years of study. At NESS, NOAA almost as many schemes have been considered and they are giving strong emphasis to a semi-automatic Electronic Animation System. Under contract to NASA and NOAA, Stanford Research Institute has developed both semi-automatic and automatic schemes and has assisted Hubert with rawin comparisons. Other groups are presently working or planning for research on wind determination from cloud motion. Working Group members who use the present-day methods and results will have an opportunity to suggest improvements in the design of future techniques.

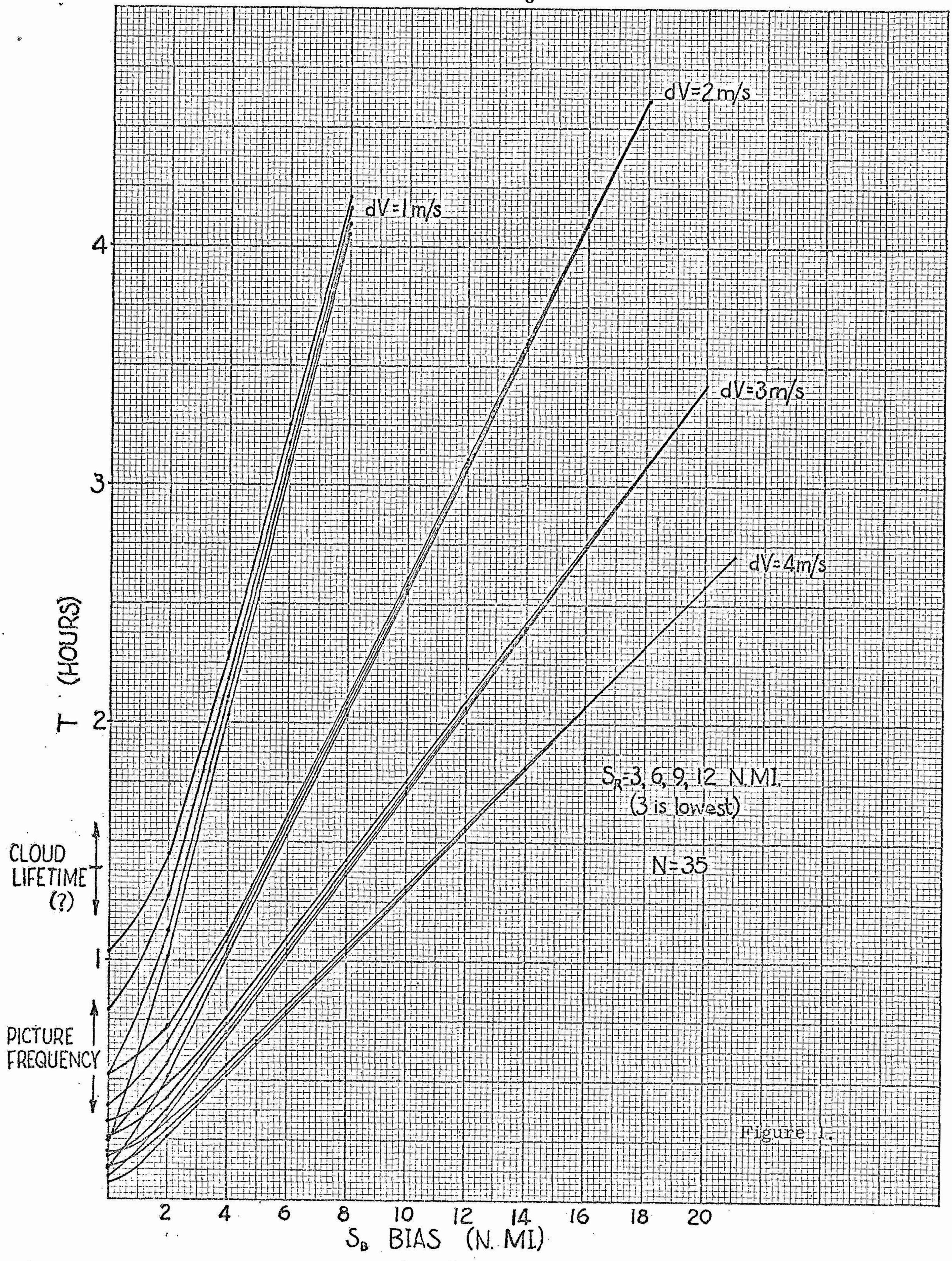
dV=1m/s
dV=2m/s
dV=3m/s
dV=4m/s
4
3
2
1
T (HOURS)
CLOUD LIFETIME (?)
PICTURE FREQUENCY
S_R=3, 6, 9, 12 N.MI.
(3 is lowest)
N=35
2
4
6
8
10
12
14
16
18
20
S_B BIAS (N. MI.)

Figure 1.

Appendix B: 3 May 1971

Papers and Publications During the Reporting Period

Preliminary work with heat budget measurements from Nimbus-III was partly supported by this grant. It was presented at the XIIIth Meeting of COSPAR, Leningrad, 1970, and will be published this year in Space Research XI (Springer-Verlag) as:

The radiation balance of the earth-atmosphere during June and July 1969 from NIMBUS-III radiation measurements--some preliminary results

by

E. Raschke, T. Vonder Haar, W. Bandeen, and M. Pasternak

The very early results of four seasons of Nimbus radiation data were compared to earlier results from other satellites, with METEOR data obtained during the same time period and with calculations in a paper presented at the January 1971 Annual Meeting of the American Meteorological Society:

Global measurements of the energy exchange between earth and space during the 1960's, including latest results from the NIMBUS-III satellite

by

T. Vonder Haar, E. Raschke, M. Pasternak, and W. Bandeen

Publication of these comparisons awaits analysis (in progress) of a more complete Nimbus data set.

In March 1971 the author presented an invited paper at the Miami Remote Sensing Workshop:

Global radiation budget and cloud cover by satellite measurements

by

T. Vonder Haar

In addition, he served as discussion leader of a section that considered present opportunities and future possibilities for parameterizing the atmospheric energy budget using satellite data. Proceedings of this workshop will be published.