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AN INVESTIGATION INTO THE PROPER SPATIAL AND TEMPORAL FREQUENCY OF THE METEOROLOGICAL ROCKETSONDE NETWORK

By

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13. ABSTRACT

This study presents a brief history of the rocketsonde network and lists the present and anticipated requirements for rocketsonde data. The authors present their views for an optimum network which would satisfy the spatial and temporal requirements necessitated by the expanding need for timely and accurate rocketsonde observations. While the authors are Air Weather Service (MAC) personnel, this technical note does not constitute a position paper of the Air Weather Service, the Air Force, or the Department of Defense.

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EDITOR'S PREFACE

This study was undertaken at the direction of the Commander, 6 WWg, and presents a brief but excellent summary of the early history of the rocketsonde program and existing and anticipated requirements for rocketsonde data. The authors also set forth their suggestions on what, in their opinion, must be implemented if the requirements for rocketsonde data are to be adequately served in the future. While the actions suggested in this study and the conclusions reached by the authors may be similar to those held by other personnel, both military and civilian, involved in the overall rocketsonde program, the publication of this report should in no way be construed as establishing the authors' findings as being the official Air Weather Service position on the future requirements and recommended changes of the Rocketsonde program. This report contains solely the views and findings of the authors and its publication offers the reader only an insight into the complex rocketsonde efforts of the meteorological community.

LAWRENCE BERRY
Editor

PURPOSE

From its very beginning the meteorological rocket network has been primarily a network of opportunity, both spatially and temporally. This was due to the initial requirements being for direct support to larger missile systems. As the accumulated data base enlarged and the requirements expanded, it became apparent that a more synoptically-oriented network was the most practical approach to satisfying existing demands. In 1968 the first efforts were made to orientate the network temporally. This study resulted in the establishment of launch schedules which varied for each station depending on its latitude and the time of the year. Spatial distribution was not considered because of the limited data base available and the lack of other facilities to support meteorological rocket stations.

In spring 1971, the Commander of the 6th Weather Wing directed his staff to conduct a study of the proper spatial and temporal distribution of the meteorological rocket network. This study, completed in November 1971 by 6th Weather Wing staff personnel, has two advantages over the 1968 study: a better data base from which to work, and the availability of more locations for installation of meteorological rocket stations if deemed necessary.

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AN INVESTIGATION INTO THE PROPER SPATIAL AND TEMPORAL FREQUENCY OF THE METEOROLOGICAL ROCKETSONDE NETWORK

History

During World War II, sounding balloon technology was improved to provide routine measurement of the atmosphere to 100,000 feet. Subsequent to this era, the artificial satellite provided similar capabilities for the region above 500,000 feet. The meteorological rocket was developed to eliminate the obvious data void between these two systems. Initial meteorological rocket soundings were conducted with rather large off-the-shelf missile systems immediately after World War II. In the early 1950s, the first exploratory meteorological missile system was developed. This system used an existing Army rocket motor (LOKI) with a chaff-filled dart, deploying a chaff cloud at approximately 200,000 feet. Although the reliability of the wind and density data derived from radar tracking of this chaff cloud was limited, this system did act as a filler until high altitude sensor development could catch up with existing requirements. In the late 1950s, the ARCAS (the first truly meteorological missile system) was developed by the US Navy. With this new system we could measure temperature, winds, and, indirectly, obtain density with acceptable reliability. The ARCAS became the prime vehicle for the high altitude meteorological observing program until the late 1960s. Once the capability to conduct these measurements was available, the entire scientific community insisted on not only more data, but also a better distribution of measurements geographically. From this need evolved the USAF Rocketsonde Network Program, later named the Air Force Environmental Rocket Sounding System (AFERSS). Because support to the large missile systems had the overriding priorities for these data, the initial stations of this network were located on the Atlantic Missile Range (later named Eastern Test Range), Pacific Missile Range, Eglin AFB, Wallops Island Missile Range, and Fort Churchill Missile Range. As systems and logistical support became available, the network was expanded to satisfy specific requirements. There has been extensive cooperation between all Federal agencies from the beginning of this program; in the mid-1960s, most of the Federal agencies involved in conducting meteorological rocket programs joined the AFERSS, thereby making this, in fact, an actual Federal Cooperative Meteorological Rocket Network (CMRN).

Although the network had a reliable missile system to accomplish its mission, it was hampered by the relatively high cost of this system (ARCAS). In 1967 a significant engineering breakthrough was realized with the development of an instrument for the previously-mentioned LOKI system. The first large purchase of these systems was made in 1968 at a cost of $858 each, thus realizing a savings of approximately $1400 per system over the ARCAS. During the same period, it was determined that we could decrease the launch frequency at each station. This was possible because the variability of the atmosphere at a particular station depended, largely, upon its geographic location and time of year. These two actions resulted in a program budget reduction of approximately 50% with no degradation in the program quality. The instrumented LOKI (PWN-8B) system has now become the primary vehicle of the AFERSS. For many years we were unable to acquire all the required data to 100 km, due to the excessive cost of rocket vehicles. In 1970, with the availability of the relatively inexpensive Viper Dart system, we commenced high altitude sensing at five stations weekly.

Air Force Cambridge Research Laboratories is now conducting a qualification and standardization program on a Super LOKI system. This system will perform all meteorological rocket requirements at approximately one-half the present budget. With this system we will have one motor which will launch the non-transponder 60-km payload, the transponder 60-km payload, and the 100-km passive sphere.

Meteorological Rocket Data Requirements

The scientific community has profited greatly from meteorological rocket observations. The literature contains numerous articles on such phenomena as "stratospheric warming" or "26-month cycle of high altitude equatorial winds" in which meteorological rocket observations contributed significantly. As a result, the meteorologist has been able to gain some basic knowledge on the interactions between the very high atmosphere and the lower atmosphere. In this way, the forecaster has been given an additional tool to improve his forecasts both for the lower and upper atmosphere. The most important and direct uses made of meteorological rocket data, however, are related to the missile and satellite operations. In support of missile/satellite operations the meteorological rocket data are used for planning, go-no go decisions, vehicle design, and vehicle performance assessment. The most important atmospheric parameters needed for this support are density and winds.

When ballistic missiles and orbital space vehicles re-enter the high atmosphere, an ionized plasma sheath builds and surrounds the re-entry vehicle. These sheaths are persistent through a large percentage of the re-entry phase and, because of their electrical properties, are extremely detrimental to the propagation of electromagnetic energy to and from the vehicles. Radio performance is often impaired to the point where actual communication "black-outs" occur. The ionized wake of the re-entry vehicles, as well as the electromagnetic energy emitted by the vehicle, changes the cross-sectional signature to such an extent that tracking radars are often unable to accurately fix the vehicle's position in space. Since the range of frequencies of this induced electromagnetic radiation covers a broad band of the spectrum, including the visible portion, the consequences of the atmospheric-vehicle interactions on defense systems that use electromagnetic techniques in tracking and targeting are obvious.

Guidance systems used in missiles are of various types, all of which are susceptible to wind effects. All guidance systems are of a dynamic character and are sensitive to resonance. Thus, while it is necessary to predict the wind profile as a function of altitude for guidance computations, it is also vital to have gust data so as to account for the various wind loads imposed upon a missile system. These data are needed in the form that will present oscillatory wind variations that the missile will encounter rather than the probability of a single existence of a wind or gust magnitude at various altitudes. Closed loop stability characteristics in the guidance system may be such that when the controlled system is coupled with the bending modes, the resultant deflections can be driven to considerably larger amplitudes than those due to discrete gusts in the vicinity of maximum dynamic pressure. Guidance systems establish requirements for wind data at much higher altitudes than those from structural consideration. At altitudes above main-engine burnout, there may exist marginal damping at frequencies very close to the low resonant frequency of the rigid body. Pitching motions may be built up in this situation by repeated application of random winds. This motion determines the controlled requirements at second-stage separation and ignition which often occur at altitudes greater than 100,000 feet. Wind requirements needed for trajectory-error analysis vary considerably. One of the important factors for trajectory calculations is how does the wind deviate as a function of time and space. For trajectory calculations there appears to be sufficient dynamic pressure up to altitudes of 200,000 feet to establish wind requirements to this altitude.

The effects of atmospheric density on space vehicles, both aerodynamic and ballistic, are many and varied. Aerodynamic pressures that occur during the flights of ballistic and aerodynamic vehicles are functions of the ambient atmospheric density and its variability in time and space. If the ambient density actually encountered by a ballistic missile during the boost phase is higher than the assumed value, the dynamic pressure and resultant stress on the vehicle will be proportionately higher. These dynamic stresses can place an intolerable burden on structural design capabilities. Atmospheric density also affects the re-entry performance of missiles in a variety of ways. The most detrimental of these effects are on the range and fuzing of the warheads, which can result in excessive errors in the Circular Error Probability (CEP). Therefore, accurate ambient density data are required over the entire range of the missile to help reduce these CEP errors to permissible limits. As weapons systems become more refined, the probability of their attaining high Mach numbers in the sensible atmosphere will be increased. Thus, an accurate prelaunch similation of aerodynamic heating may be required to preclude heat damage to the vehicle and nose cone during the boost phase.

Boost-glide vehicles are aerodynamic. Therefore, atmospheric density will have a variety of effects upon them, including the following influences:

a. Heating of the glider and booster during launch and boost.

b. Structural integrity due to aerodynamic pressures.

c. Range of the orbital vehicle.

d. Altitude damping rate.

e. Flight level maneuver margin.

f. Performance characteristics.

If the density at given altitude is higher than programmed for a given boost trajectory, the heat transfer rate into the vehicle will be higher by an amount determined by the ratio of the actual density to the assumed density raised to the 0.8 power (assuming turbulent flow). For example, if the actual density were 50% greater than assumed, the heat transfer would be 38% higher. Therefore, ambient density values with an accuracy of 2 to 3% are required to calculate the actual aerodynamic heat transfer rates into these boost-glide vehicles.

The maneuver margins for glider re-entry are functions of atmospheric density. If, at the time of injection, the actual density profiles are less than assumed by 10 and 50%, the maneuver margin will be reduced by 7 and 35%, respectively. Similar deleterious effects on glider lift will be encountered if the deviation from assumed density is on the plus side. These density variations can be tolerated if they are known beforehand and a suitable trajectory is programmed. However, results can be disastrous if the flight trajectory is programmed to intentionally approach the temperature limit, assuming a 10% deviation, and the glider encounters a 50% deviation. Horizontal variations in atmospheric density can have similar restrictive effects on the maneuver margin if they are not known. The net effect of not having accurate ambient density measurements below 400,000 feet is to seriously degrade the design capabilities of the boost-glide vehicles by forcing the test engineers to program an overestimation of ambient atmospheric conditions.

In addition to safety of flight considerations, ambient density data are also needed in conjunction with on-board glider measurements to determine boost-glider performance characteristics such as the lift and drag coefficients, stability derivatives, and aerodynamic heating parameters during the test phase of development. In this connection, accurate ambient density data are necessary to confine the uncertainty in flight test data to the vehicle performance rather than to the environment. For boost-glide vehicles, then, it can be concluded that prediction of ambient atmospheric-density data or realistic density design criteria will be required to above 400,000 feet at the launch site, at the orbital injection point, and along the re-entry path.

Another example may be cited as to why better knowledge of the ambient density is required to levels above 300,000 feet. Consider the weight-drag ratio or ballistic coefficient of a re-entry vehicle. This coefficient appears in each missile design and performance consideration, and is defined as W/CA where W is vehicle weight, A is the vehicle cross-sectional area, and C is the drag coefficient, which is directly proportional to density. Test engineers have determined that the error in the ballistic coefficient can not exceed 10% if test objectives are to be achieved. If an error in density must be conservatively estimated as 30% in the absence of exact data, this 10% accuracy for the ballistic coefficient can never be achieved. To decrease this value to permissible limits will require specific measurements of ambient density to 400,000 feet to an accuracy within 3%.

For support of satellite operations, density forecasts and observations are needed at all altitudes at which the aerodynamic drag has a significant effect on satellite orbits and re-entry trajectories. The accuracy of density data derived from observations of changes in satellites ephemerides is degraded because of the assumption necessary in the derivations. Direct density measurements on a real-time basis are therefore needed to develop necessary forecasting techniques.

In summary, it has been shown that ambient density data to 400,000 feet and an accuracy of plus or minus 3% are needed. These accurate density data are required in the analysis of test flight performance in order to confine the uncertainties of the test evaluation to the vehicle hardware rather than to the environment. The penalty for not satisfying this requirement for accurate density data can be delineated as follows:

a. Excessive aerodynamic heating of boost-glide vehicles that can limit the vehicle's performance or, in extreme cases, lead to vehicle destruction.

b. Continued inability to properly assess the effects on high performance missiles during the boost phase.

c. Continued uncertainty in man's knowledge of constants and coefficients that are density dependent.

d. Continued inability to properly assess the atmospheric effects on electromagnetic blackouts so that these effects can be overcome.

e. Continued inability to properly track and assess a re-entry vehicle during the test phase because of electromagnetic wake effects that inhibit tracking.

f. Continued inability to properly assess the range and fusing of re-entry warheads.

Spatial and Temporal Frequencies to Satisfy Current and Anticipated Requirements

When the Cooperative Meteorological Rocket Network (CMRN) was established in 1959, data requirements, as stated in the previous section, had not dictated specific sampling frequency or station location. In most instances, location had been a case of siting where possible and sampling when time and personnel permitted. Meteorological rocket-launch locations had been established at existing test ranges, previously chosen with safety and security as the primary considerations. Hence, launch locations are on coasts, in deserts, and in other sparsely populated areas. Temporally, launches were scheduled for local noon (plus or minus 3 hours) and 1-5 times a week. This frequency was increased whenever special data were needed in support of missile launches, systems testing, scientific investigations, etc. Scheduling launches at local noon was the best compromise possible to achieve a near synoptic network. Although it was desirable to have some launches conducted at night, this was not possible at most network stations due to economic constraints.

In an attempt to answer the sampling frequency question, the Scientific Advisory Group (SAG) of the Interdepartment Committee for Applied Meteorological Research conducted a survey of rocketsonde data customers (1970). The consensus was that there is a need for increased horizontal coverage. Specifically, increased coverage was needed in the polar and southern latitudes. The latter could perhaps be covered by further expansion of the Experimental Inter-American Meteorological Rocket Network (EXAMETNET), which provides a Southern Hemisphere extension of the CMRN and provides for exchange of data between member countries and with the CMRN. Two other selected general areas in need of better coverage were east of Greenwich to the mid-Pacific and within 5 degrees either side of the equator. Additionally, it was proposed that 6-10 stations be established along an arc of longitude from the Arctic to the Antarctic.

The results of the SAG survey regarding temporal variations specified a change from the present near-local-noon launch to a rotation throughout the day. This rotation would result in three benefits to the scientific and military communities. One would be the enhancement of the study of atmospheric tides and diurnal variations. Also, we would be able to unbias our climatologies which are currently based on measurements taken at near maximum heating times. With unbiased climatologies and more information on tides and diurnal variations, better support could be provided to test programs. Lastly, our ability to identify and track stratospheric warmings would be greatly improved; perhaps leading to a better understanding of this stratospheric event and its impact on tropospheric weather.

From the SAG survey we have compiled a list of suggestions for improvement of our rocketsonde network; the question now is "is this enough or too much"? To answer this question we must examine the data to determine wave lengths, wave speeds, wave amplitudes, and wave frequencies of the meteorological parameters. Once this information is available, we can determine a minimum array of observing stations which can optimally define density waves above 30 km. USAFETAC Report 5913[1] presents density data for 30-, 40-, 50-, and 60-km levels in a format easily adapted to visual and statistical interpretation. Since density is the most important parameter between 30-60 km, we shall attempt to answer the posed question for density alone and allow temperature and winds to fall into place through inference. A statistical pilot study of one month's data (May 1968) for a single station (Cape Kennedy) was initially performed. Cape Kennedy data for the month of May were chosen because of the completeness of observations. Reports from other months and stations of the AFERSS and the CMRN contained too many data gaps. For the subject month, 20% of the data were "manufactured" by extrapolation and linearization techniques. If all stations and months had been used, this figure would easily have increased to 50%, and at 60 km, as high as 60%.

Tables 1-4 show the results of a harmonic analysis of the May 1968 data. The rankings are by percentage of the variance explained (PVE). Enough harmonics were totaled to explain not less than 90% of the variance.

May 1968

TABLE 1 (30 km)

HAR	P(days)	PVE(%)
5	6.2	38.55
9	3.4	14.16
4	7.8	12.34
6	5.2	7.40
3	3.9	7.33
13	2.4	3.88
10	3.1	3.53
11	2.8	2.87

TABLE 2 (40 km)

HAR	P(days)	PVE(%)
4	7.8	40.20
1	31.0	18.47
2	15.5	1[illegible].15
3	10.3	6.02
12	2.6	5.03
15	2.1	4.76
5	6.2	3.00
7	4.4	2.52

TABLE 3 (50 km)

HAR	P(days)	PVE(%)
1	31.0	32.55
3	10.3	24.59
5	6.2	19.88
2	15.5	6.61
7	4.4	3.51
12	2.6	3.17

TABLE 4 (60 km)

HAR	P(days)	PVE(%)
2	15.5	40.72
1	31.0	16.06
5	6.2	8.93
3	10.3	7.38
4	7.8	6.34
7	4.4	5.05
9	3.4	2.70
10	3.1	2.36
8	3.9	2.31

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[1] USAFETAC Report 5913, June 1970 (unpublished).

If Table 1 is compared to 2, 3, and 4, the obvious question is "what happened to the 1st and 2d harmonics"? A partial answer could be that since the 1st and 2d harmonics were waves with very low amplitudes at 30 km, they could easily have been lost in the noise, or stratonull[2] which often exists near that level. To investigate their behavior even further, two additional months' (February and July 1970) data were analyzed. The results are shown in Tables 5-12. In the July 1970 data, the climb of the 1st harmonic from fifth place at 30 km to first place at 40, 50, and 60 km was not as dramatic as in the pilot data. However, it is interesting to note that the February 1970 data have the 1st harmonic in first place at all levels. There is an obvious inference which could be made concerning the seasonal occurrence of the stratonull at 30 km, but the data sample is too small to actually state it.

February 1970

TABLE 5 (30 km)

HAR	P(days)	PVE(%)
1	28.0	53.21
2	14.0	10.76
4	7.0	9.14
6	4.7	4.91
14	2.0	4.59
3	9.3	3.72
12	2.3	3.19
5	5.6	2.54

TABLE 6 (40 km)

HAR	P(days)	PVE(%)
1	28.0	82.16
7	4.0	3.28
9	3.1	2.33
11	2.5	1.84
4	7.0	1.75

TABLE 7 (50 km)

HAR	P(days)	PVE(%)
1	28.0	50.44
2	14.0	25.77
3	9.3	8.11
4	7.0	6.57

TABLE 8 (60 km)

HAR	P(days)	PVE(%)
1	28.0	94.29

July 1970

TABLE 9 (30 km)

HAR	P(days)	PVE(%)
4	7.8	30.29
3	10.3	24.93
2	15.5	14.37
5	6.2	11.66
1	31.0	6.83
9	3.4	3.32

TABLE 10 (40 km)

HAR	P(days)	PVE(%)
1	31.0	59.50
3	10.3	14.85
4	7.8	11.75
5	6.2	4.16

TABLE 11 (50 km)

HAR	P(days)	PVE(%)
1	31.0	64.16
2	15.5	13.86
3	10.3	11.51
4	7.8	2.21

TABLE 12 (60 km)

HAR	P(days)	PVE(%)
1	31.0	67.88
2	15.5	20.37
4	7.8	6.80

To obtain an overall ranking, the PVEs for each harmonic per level were totaled. The results are listed in Table 13 (May 1968 data only). The results of the 1970 data were not included in Table 13 even though the first five harmonics were, as in the pilot study, the most important. Roughly 50% of the 1970 data was "manufactured" through linearization; consequently, the PVEs for the first few harmonics are undoubtedly inflated, e.g., see Table 8 where the 1st harmonic is credited with a PVE of 94.29%.

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[2] Willis Webb, private communication, 1972.

TABLE 13

MAY 1968 HARMONICS

HARMONICS	PERIOD (days)	WAVELENGTHS (km)
5	6.2	1000
1	31.0	4000
2	15.5	2400
4	7.8	1300
3	10.3	1600

Referring to Table 13, the second place harmonic (1st) with a period of 31 days can probably be attributed to the 27-day sun cycle and, hence, is very real. The 2d, 3rd, and 4th harmonics, with wavelengths ranging from 1-2400 km and periods from 7.8 to 15.5 days, can probably be attributed to the short and medium waves related to tropospheric systems. An inspection of the accompanying tropospheric analyses identified systems passing Cape Kennedy at intervals of 14 and 15 days. The 5th harmonic has wavelengths in the very unstable range of 800-1000 km. It is probably associated with weak frontal waves or fast moving gravity waves. Of this list, only those wavelengths which could be directly attributed to sun cycle and synoptic-scale tropospheric systems were chosen for consideration. These are harmonics 1-4 with periods ranging from 31-7.8 days and wavelengths varying from 4000-1300 km. With estimates of the wavelengths in hand, the problem now is to arrange a network of stations to properly detect, define, and, perhaps, for future considerations, provide forecast lead time with respect to the wavelengths of interest. The numerical relationships used below were taken from a report prepared by the Panel on Small Scale Observational Requirements (POSSOR). The POSSOR determined that to detect a wave of length L, the distance, d, between equilateral triangularly-arranged observing sites would have to be d = L. To insure that the detected wave would be defined, the relationship d = 1/2L would have to be satisfied. Lastly, in order to meet the forecast lead-time criterion, d = 1/3L would have to be met. Table 14 shows these relationships for the chosen harmonics; they are illustrated graphically in Figure 1.

TABLE 14

STATION DISTANCES

HARMONIC	PERIOD (days)	d=L (km)	d=1/2L (km)	d=1/3L (km)
1	31.0	4000	2000	1300
2	15.5	2400	1200	800
4	7.8	1300	650	400
3	10.3	1600	800	500

Considering the three network conditions mentioned above, it becomes apparent that the existing rocketsonde station network of North America has sufficient

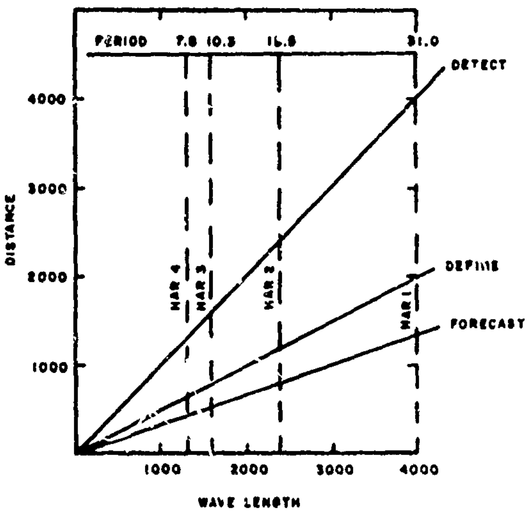

Figure 1. Station Distances Versus Wavelengths.

density to detect and define the longest waves (4000 km range); the furthest distance between launch sites being nearly 2400 km (reference Figure 2). The station complex of Canada, Alaska, and Greenland almost has the necessary density to satisfy the third condition of forecast lead time. On the shorter end of the spectrum (L ~ 1600) only a few stations pairs even come close to fulfilling the distance requirements for definition while most of the network, once again, can detect a wave. These pairs are (1) Pt. Mugu-White Sands Missile Range, (2) Primrose Lake-Fort Churchill, and (3) Cape Kennedy-Wallops Island. Each of these pairs have d ~ 1000 km; obviously, this network does not satisfy criterion 3 for forecast lead time. Just to properly define these short waves over North America, eight stations would have to be added to the existing CMRN. Four of these would have to be in the Canada-Greenland area, and the other four within the continental United States. These additions would increase the CMRN by more than 60%.

Applying the POSSOR arguments to the SAG-solicited suggestion of 6-10 stations along an arc of longitude would produce a station array capable of detecting and defining waves of the L = 4000 km range. Definition of the shorter wavelengths would require a station density of at least 15 per longitudinal arc. To summarize, a network of rocketsonde stations in an equilateral triangular configuration, each station d ~ 800-1100 km apart, would detect and define waves of length L = 1600 km, or greater, and provide forecast lead time for waves longer than 2400 km.

The hypothetical existence of the network brings us to the next important question which is how often should we sample this 30-km slice of atmosphere. Presently, the USAF Environmental Rocket Sounding System (USAFERSS) averages [illegible] launches per week. This figure can vary from 1 launch per week during the summer to as many as 5 per week during spring, fall, and winter. There is also some dependency on latitude with the northernmost stations firing more frequently, but still within the stated rates.

Investigation of the map series accompanying ETAC Report 5913 produced the rough estimate of 3 mps as the average speed of density waves. It must be added that the paucity of data and resultant analysis smoothing probably makes this average speed too slow; however, we can use this figure in another POSSOR equation to produce a minimum observational frequency figure. POSSOR reasoned that the time interval between observations, t, should be not less than the time it takes for the subject wave to travel past a single station. If we consider waves of 1600 km and the 3-mps figure, the relationship,

$$t = \frac{1600 \text{ km}}{3 \text{ mps} \times 24 \text{ hr da}^{-1}}$$

produce a minimum time interval of 6 days. As previously mentioned, the current network firing frequencies equal or exceed this interval. According to the data compiled by Willis Webb[8], even the rapid spread of "Explosive Warmings" can be adequately tracked by time intervals of 2 days. The CMRN (and other locations around the world) generally go on a 5 per week firing schedule during occurrences of this stratospheric phenomenon. Although this paper does not address the sampling frequency required to study diurnal variations, it can be inferred that one additional launch per day (night) would satisfy this requirement. All of this suggests that our present sampling frequencies are adequate and that the major problem lies with the number of stations. Once the spatial frequency increase requirement is met, the scientific and military communities will have an increased data base to meet present requirements and the flexibility to respond to future requirements.

Conclusions Concerning the Optimum Rocketsonde Network Configuration

Before we construct the "ideal" rocketsonde network, we shall touch on two major limitations to expansion of the existing configuration, namely, area and economics. There is an areal limitation because of the requirement for a very large tract of land for each launch location. Meteorological rockets require a range of at least 80 km in length with at least 500 km of clear area encompassing the launch point. Additionally, 90 degrees of arc from the point of launch are needed. The size of the resulting area would be approximately 10,000 sq km. This consideration alone, aside from safety factors, requires establishment of launch locations in sparsely populated areas.

The economic limitation is the more important of the two; it restricts scientific and engineering advances required to increase the number of rocket sounding locations. To have full siting freedom, we would need either a total destruct mechanism on the rocket motor or development of a stable booster with a circular error probability of a few hundred feet. These are not new ideas; they are very feasible. Space Data Corporation (manufacturer of the Super LOKI) has done work in both areas and has test flown boosters of both types.

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[8] Webb, Willis L. Structure of the Stratosphere and Mesosphere. N.Y. Academic Press, 1966, 382 p.

AFCRL has a formal program for development of a stable booster for the Super LOKI. Personnel limitations are also only a matter of economics. Expansion of the training program at Vandenberg could accommodate the necessary manpower requirements for network enlargement. In essence, science and technology can meet the demands; only lack of funding bars the way to accomplishment.

With the major limitations behind us, we can now construct the expanded rocketsounding network. Figure 2 (distance in kilometers) shows the continental North American portion of the existing CMRN. The distance between locations illuminates the lack of a sufficient observing network along POSSOR-suggested lines. Figure 3 shows the CMRN in addition to existing launch locations; some of which are irregularly used and others which are not used at all. From this array we can put together a better network without incurring the expenses of construction. Green River, Copper Harbor, Resolute Bay, Point Barrow, and High Water could be incorporated into the network to produce the configuration shown in Figure 4. Green River is an Army location and is available for immediate occupancy; the USAF would have to supply only the hardware. High Water and Resolute Bay belong to Canada and would require more work and some sort of international agreement. Copper Harbor is owned by the University of Michigan; an agreement would have to be reached between school officials and the USAF. Point Barrow belongs to the United States. With little regard for areal or economic limitations, a quasi-optimum observing network would look something like Figure 5. Theoretical launch sites (eight) are indicated by Xs; their approximate locations are as follows:

a. 72°N, 120°W, near Victoria Island in the Beaufort Sea.

b. 63°N, 107°W, south-central Northwest Territories.

c. 61°N, 70°W, Cap Hopes Advance, Quebec.

d. 54°N, 128°W, coastal British Columbia.

e. 42°N, 124°W, near Cape Mendocino, California.

f. 46°N, 108°W, near Billings, Montana.

g. 40°N, 91°W, north of St. Louis, Missouri.

h. 30°N, 93°W, Louisiana coast west of New Orleans.

In an effort to make the recommended configuration compatible with existing locations, it was necessary to sacrifice the "d ≈ 800-1100 km" figure in several instances.

What has been suggested is an improvement of the best "network" in the world. To improve the worldwide network would require many more locations and many millions of dollars. In a preceding section, "Meteorological Rocket Data ...," we state the source of requirements for these data. It is highly unlikely that the demand to better define this portion of the atmosphere will diminish in the future; in all probability, it will increase. It is not suggested here that the world be criss-crossed by this type of network. Perhaps, because of the suspected conservative nature of density above 30 km, only a well sampled portion of the globe would be sufficient to infer density relationships for the rest of the atmosphere. The EXAMETNET and either one of the Poles could be likewise expanded to form the other half of a detailed network over roughly 1/3 of the globe.

It is assumed that in the future the United States will have the capability for indirect sensing of most of the atmosphere. But during the current development stage, corroborative "ground truth" data will be required. The meteorological rocket is the only efficient system currently available to provide these data up to 650 km.

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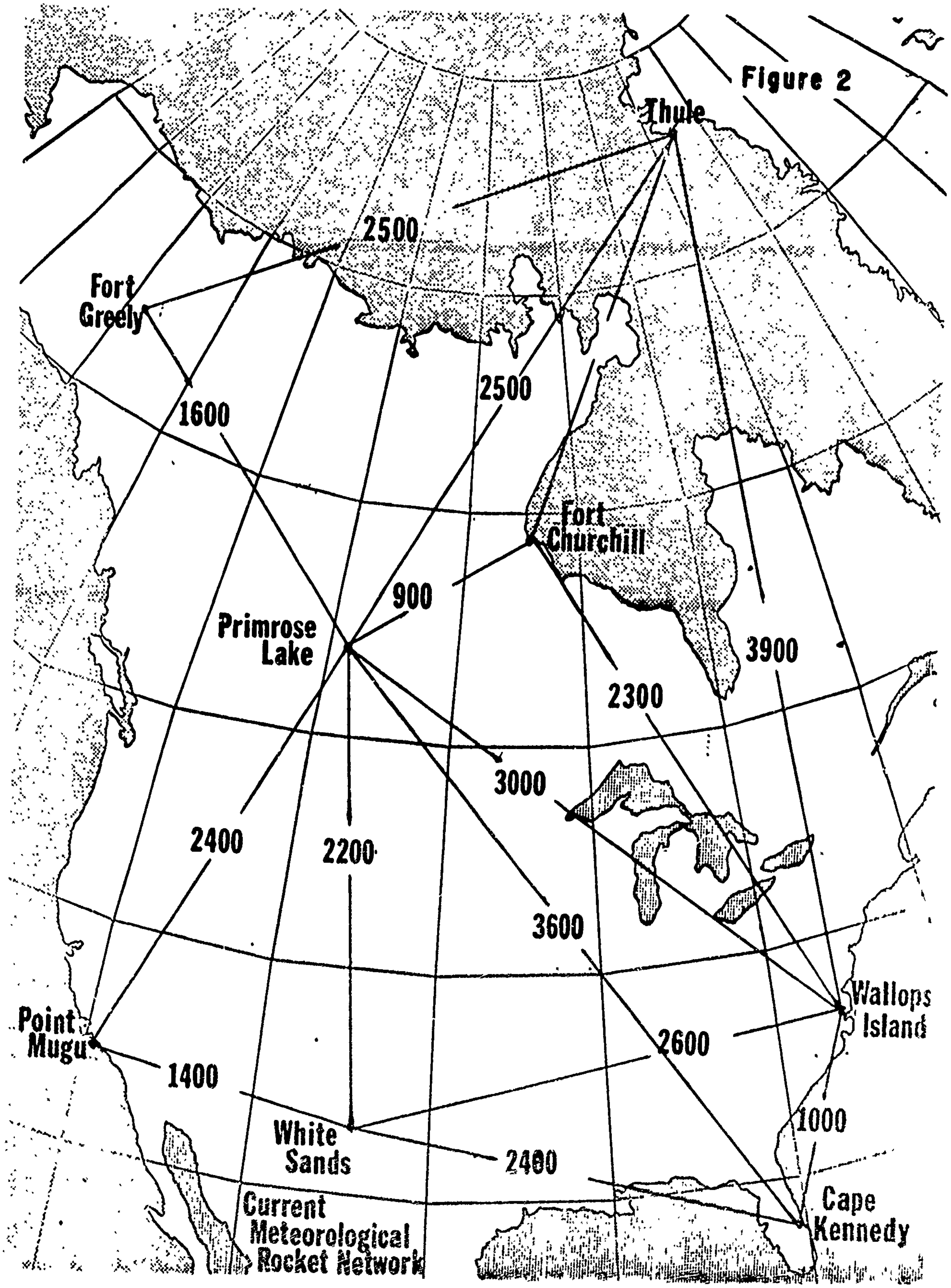

Figure 2. Current Meteorological Rocket Network.

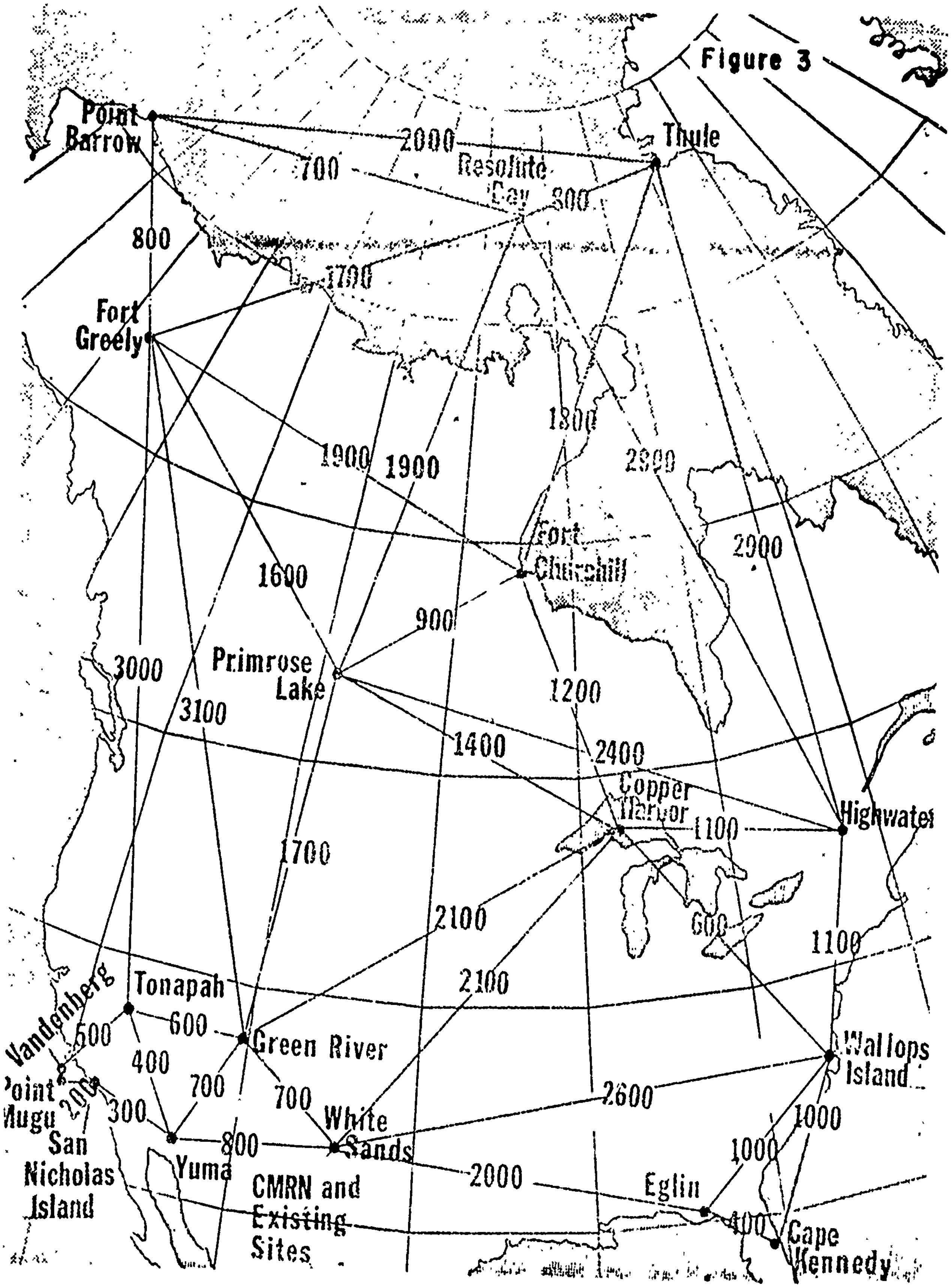
Figure 3
Point Barrow
Thule
Resolute Bay
2000
700
800
1700
Fort Greely
1800
1900
1900
2900
Fort Churchill
2000
1600
900
Primrose Lake
3000
3100
1200
1400
2400
Copper Harbor
1100
Highwater
1700
2100
600
1100
2100
Tonapah
Vandenberg
600
Green River
500
400
700
700
Wallops Island
Point Mugu
200
300
2600
1000
San Nicholas Island
Yuma
800
White Sands
1000
2000
Eglin
CMRN and Existing Sites
400
Cape Kennedy

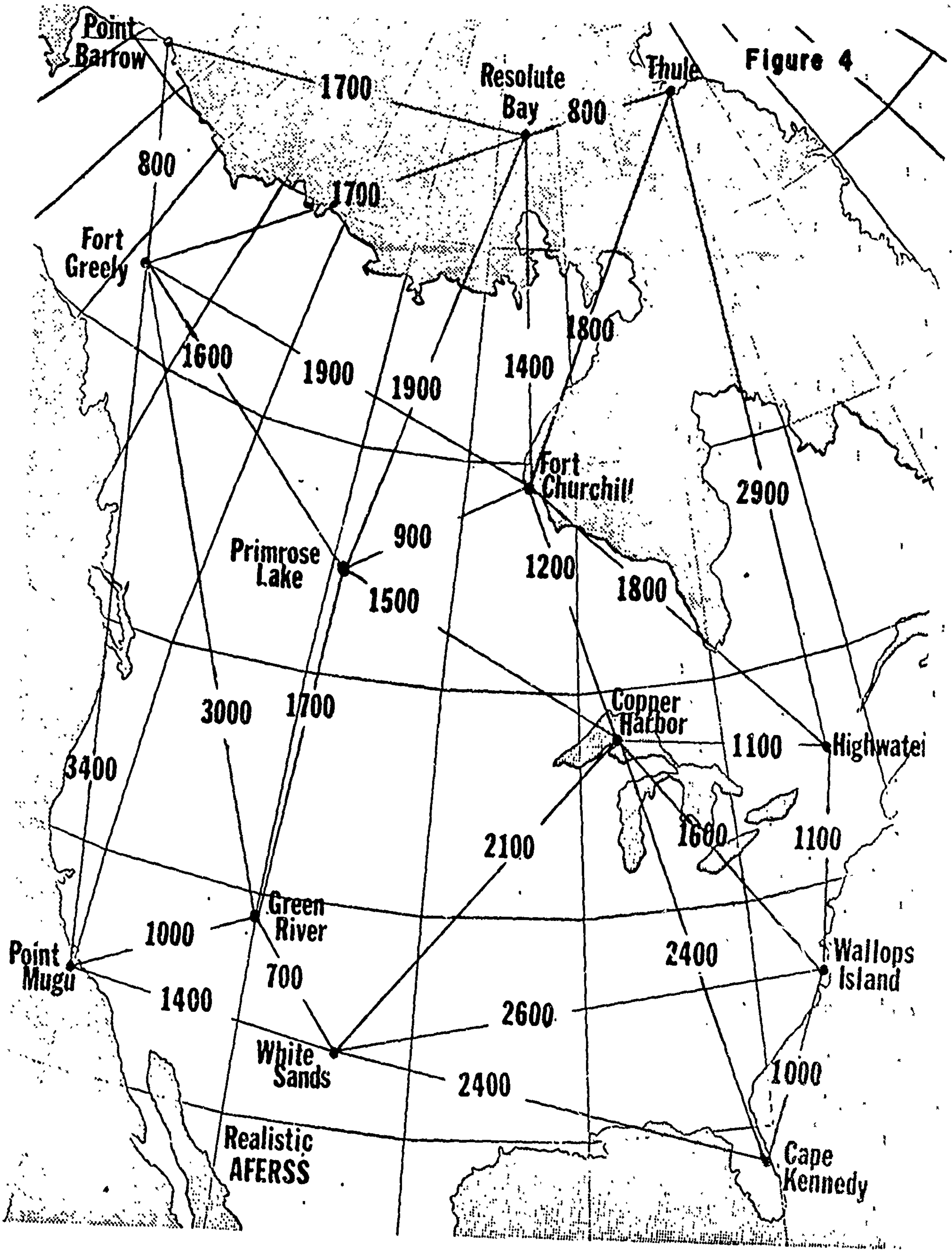

Figure 4. Realistic [illegible]

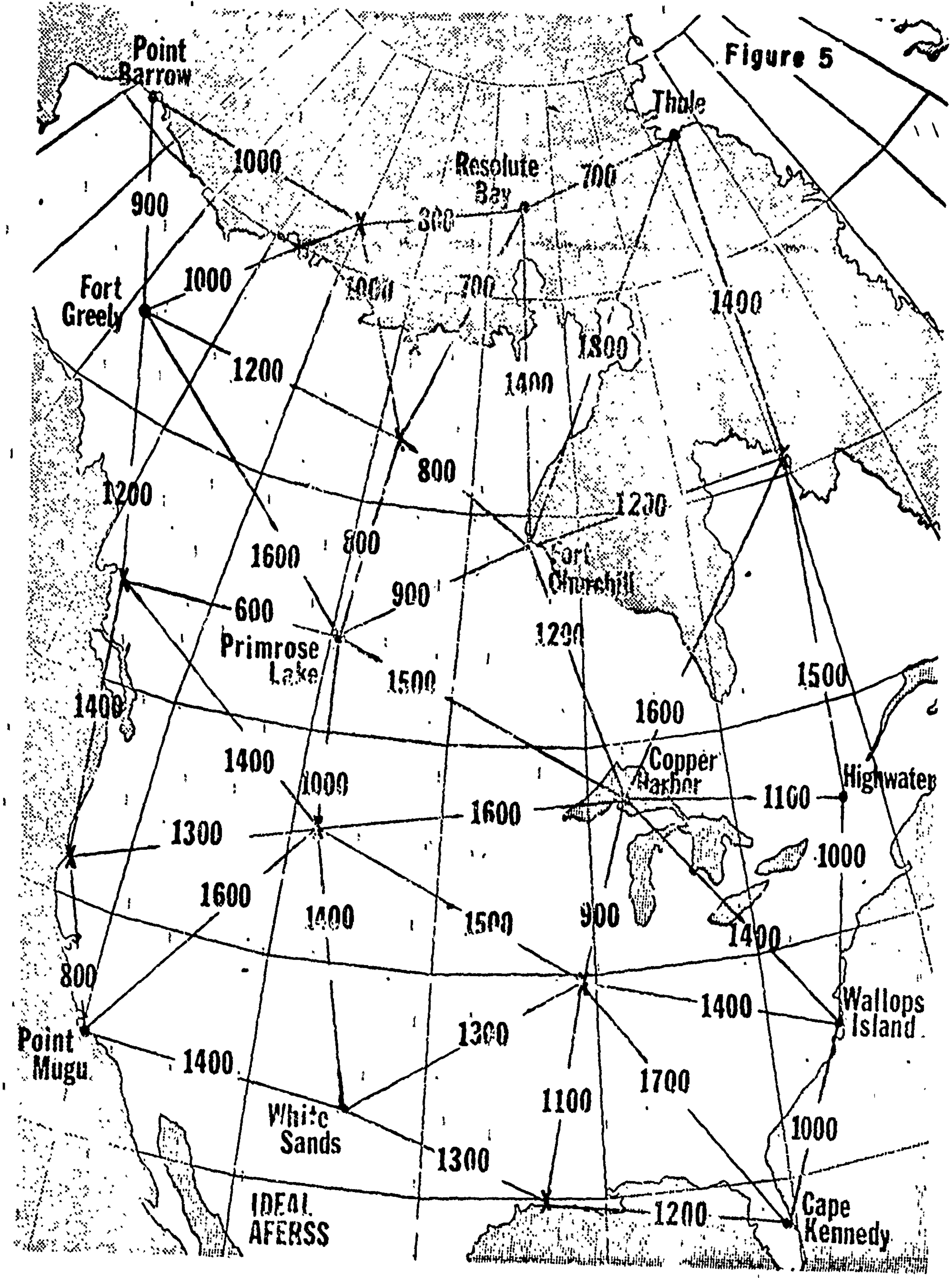

Figure 5. Ideal AFERSS.

LIST OF USAFETAC TECHNICAL NOTES

Number	Title	Date
71-1	Interim Instructions for the Use of the National Meteorological Center Air Pollution (APP) Products (AWS distribution only) (AD-718966)	Feb 71
71-2	A Reprint of Use of FOUS (Detailed PE Guidance) (AWS distribution only) (AD-719866)	Mar 71
71-3	Superseded by USAFETAC TN 72-3	
71-4	Diurnal Variation of Summertime Thunderstorm Activity over the United States (AD-724645)	Apr 71
71-5	Preliminary Verification of AFGWC Boundary-Layer and Macroscale Cloud-Forecasting Models (AD-725738)	Jun 71
71-6	Use of Extrapolation in Short-Range Forecasting (AD-729022)	Sep 71
71-7	Glossary of Spanish, French, German, English Selected Climatological and Meteorological Terms (AD-731554)	Aug 71
71-8	A Prediction Method for Blast Focusing (AD-732765)	Sep 71
71-9	Determination of Maximum Emission Rates to Meet Air Quality Standards (AD-733505)	Aug 71
71-10	A Resume of Short-Range Forecasting Techniques (AD-731162)	Sep 71
71-11	Numerical Preprocessing of Rawinsonde Position Vectors (AD-732205) (Limited distribution only)	Oct 71
71-12	Clock-Hour/Instantaneous Rainfall Rate Relationships Applicable to the Eastern United States (AD-733586)	Dec 71
72-1	A Guide for the Editorial Preparation of Technical Reports for Publication by Hq Air Weather Service (AWS distribution only)	Jan 72
72-2	A Survey of Availability of Hurricane/Typhoon Packages and Associated Data (AD-736451)	Jan 72
72-3	Listing of Seminars Available at AWS Wings (AWS distribution only) (AD-736452)	Feb 72
72-4	A Selected Annotated Bibliography on the Tropopause (AD-738594)	Feb 72
72-5	A Selected Annotated Bibliography of Environmental Studies of Italy (1952-1971) (AD-)	May 72
72-6	An Investigation into the Proper Spatial and Temporal Frequency of the Meteorological Rocketsonde Network	Jun 72