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MANUAL GRIDDING OF DRIR FACSIMILE PICTURES

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ABSTRACT

This report presents a method for manual geographical referencing of Direct Readout Infrared Radiometer (DRIR) data from the Nimbus C meteorological satellite, assuming no satellite attitude error. The procedure leads to geographically referenced DRIR data, with labeled five degree latitude and a longitude lines drawn at the correct locations.

The method requires the use of one of a set of three transparent latitude-longitude grids. The grids have fixed latitudes, at five degree intervals. Unassigned longitude lines are also at five degree intervals, except at latitudes greater than 60^{o}, where, due to convergence of the meridians, the interval is greater. Absolute values of longitude are determined by reference to the longitude of the subsatellite track of a particular orbit. By suitable rotation and/or inversion, the grids may be used for both the northern and southern hemispheres, and for either southbound or northbound passes.

FOREWORD

This report describes and illustrates a technique for manual gridding (geographical referencing) of Direct Readout Infrared Radiometer (DRIR) data from the Nimbus C meteorological satellite. The work was performed by ARACON Geophysics, division of Allied Research Associates, Inc., Concord, Massachusetts for the Goddard Space Flight Center, National Aeronautics and Space Administration, under Contract No. NAS 5-3253.

The author wishes to acknowledge substantial contributions made by Dr. W.K. Widger, Jr. Messrs. W.P. Smith, of ARACON Geophysics, and C. French, of Allied Research Associates, computed and drafted the DRIR grid illustrated in the report.

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1. INTRODUCTION

The striking success of the Nimbus I Satellite's High Resolution Infrared Radiometer (HRIR) in depicting nighttime cloud cover[1,2,3] has led to the development of a Direct Readout Infrared Radiometer (DRIR) system for Nimbus C. The Nimbus C DRIR system will permit the HRIR data not only to be recorded aboard the spacecraft for later readout at the Fairbanks and Rosman Data Acquisition Facilities (as in the case of Nimbus I), but also their immediate broadcast through the APT transmitter. Accordingly, properly equipped ground stations, when within line of sight of the satellite, will be able to receive the HRIR data in the DRIR mode at the same time they are being fed in parallel to the HRIR recorder aboard the spacecraft. Ground station requirements to receive DRIR data are met by most standard APT stations with suitable modifications, including a change in the rate of the facsimile recorder. The details as to the modifications are published in other NASA sponsored documents.

The purpose of this report is to present a method for geographically referencing DRIR data from the Nimbus C satellite, assuming no satellite attitude error. This manual procedure leads to geographically referenced DRIR data, with labeled five degree latitude-longitude lines drawn at the correct locations.

The DRIR data will be presented as shades of white, gray and black, (corresponding to cold, cool and warm radiating surfaces, respectively) on facsimile paper.† For the Fairchild facsimile recorder, the total width of the data is 21.5 cm (8.45 inches). Within this width, the data from earth and atmosphere (from horizon to horizon) will occupy approximately seven cm (2.75 inches), the remainder representing space and the bottom of the Nimbus spacecraft. The APT facsimile scan rate is modified to synchronize with the scan rate of the HRIR, approximately 44.7 RPM. The facsimile stylus moves across the paper at a constant rate, so distance across the paper is directly proportional to angular rotation of the HRIR scanning mirror.†† Since the line width (in the direction of paper feed) of the facsimile scan is nominally 0.0254 cm (0.01 inch), the rate of data (paper) advance is 1.14 cm min^{-1} (0.447 inch min^{-1}).

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† For some recording papers, the data are presented in analogous tones of sepia.

†† Accordingly, the presentation is increasingly foreshortened from center (satellite subpoint) to horizon (see Section 3 and Fig. 2), but in a manner somewhat different from that in the HRIR photofacsimile recordings,[1,3] where the recording system operates at a constant angular rate.

The DRIR data are of slight value until they are geographically referenced. While this might be done by reference to coastlines or other identifiable geographical features (see Section 4.6), or crudely by reference to cloud features which can be associated with those on a recent weather map, these are special cases and are usually of marginal utility. For example, they are seldom if ever applicable over oceans.

The construction of latitude and longitude lines directly on the facsimile presentation of the DRIR data permits the analyst to locate features without any loss of detail. It also provides the geographical referencing data required if it is desired to transfer the DRIR data to standard weather maps. While at times such transfers of the data are desirable to assist comparisons with other meteorological data, it is a laborious and time consuming process. Accordingly in operational use of DRIR data, such transfer should ordinarily be limited to features and areas of direct concern to the operational analyst or forecaster. Methods applicable to the transfer and depiction of the DRIR data are described in Section 3 of Reference 3. References 2 and 3 also discuss the present state of the art of the meteorological interpretation and application of DRIR data.

References 1, 3, 4, or 5, give appropriate details on the HRIR sensor system.

2. DRIR GRID CHARACTERISTICS

This gridding procedure for DRIR data utilizes a library of three transparent latitude-longitude grids, constructed for a range of satellite heights bracketing the nominal Nimbus C altitude of 1110 km (600 n. mi.), which can be placed under the facsimile picture on a light table and thus used to geographically reference the data. The grids start at a latitude of 30°, cross the equator to one of the grographical poles, and continue to the 65° latitude circle. Thus the grid spans 135° of latitude. By turning the transparent grid end for end, and/or turning it over, it may be used in either the northern or the southern hemisphere for either southbound or northbound passes. Thus, the same set of grids can be used in all geographical areas.

Figure 1 shows a reduced-scale latitude-longitude grid for 1110 km (600 n. mi.). The straight line down the center of the grid represents the subsatellite track.[†] Since a perfectly sun-synchronous orbit at 600 n. mi. circular orbit altitude has an inclination of about 100° [††] (80° retrograde), the maximum latitude reached by the satellite is about 80°. Dashed horizon lines parallel the subsatellite track, about 3.5 cm (1.4 inches) from it on each side, when the grid is scaled to the Fairchild facsimile recorder. A time scale at one minute intervals, referenced to the equator crossing, is presented on each side, beyond the horizons. Arrows are placed beside the grid to indicate both the direction of movement of the satellite, and, by the particular arrows for which numbers and letters are upright, the latitudes within which the grid as oriented should be used for southbound passes.

Latitudes, at five degree intervals, are represented by curved lines which intersect the subsatellite track at angles of approximately 90° in low and mid-latitudes, and which are labeled. Small tick marks, corresponding to one degree intervals of latitude, have been entered on the longitude lines (except in areas, near both the poles and the horizons, where the compression of the latitude intervals makes it infeasible) to facilitate interpolation of the locations of features in the data.[†††]

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† As discussed later, perfect satellite orientation (no roll, pitch, or yaw) is assumed.

†† The precise value is 99.88°.

††† The use of one degree tick marks was based on considerations discussed in Reference 6.

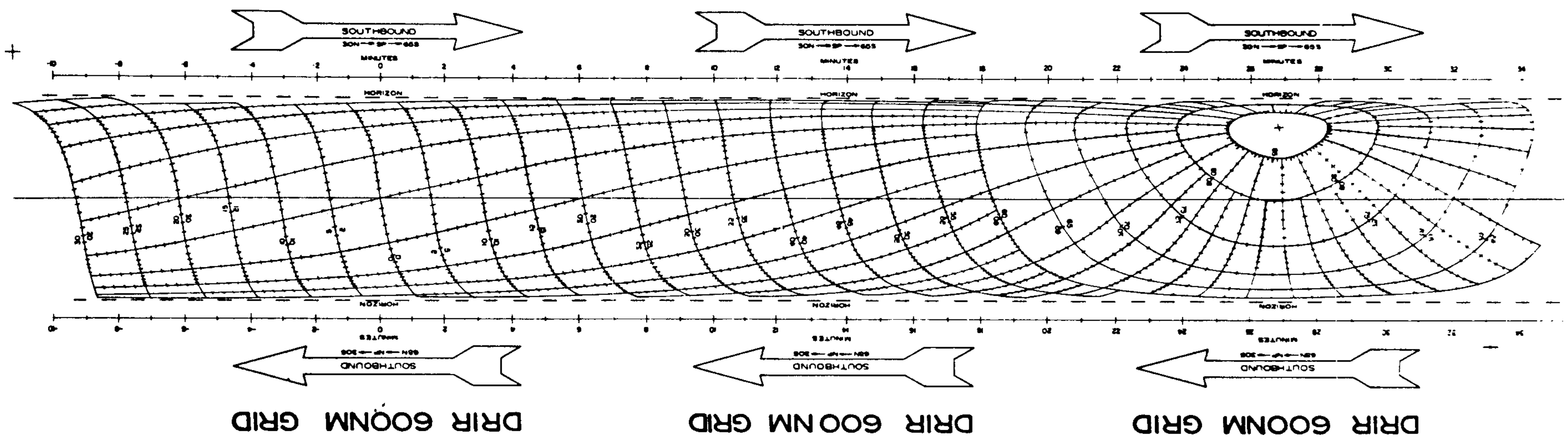

Figure 1. Reduced-Scale DRIR Latitude-Longitude Grid
(Change No. 1, February 1966)

Longitudes are represented by lines more or less parallel to the subsatellite track, and so to the horizon lines, in low and mid-latitudes. The longitude interval is a function of latitude, a 5^{o} interval being used from the equator to 60^{o}, a 10^{o} interval from 60^{o} to 80^{o}, and a 20^{o} interval from 80^{o} to 90^{o}. Intermediate one degree tick marks are spaced along the lines of latitude at latitudes up to and including 60^{o}; poleward of 60^{o}, 5^{o} tick marks are used. Again, the tick marks are omitted in greatly foreshortened regions near the horizon. The longitudes have not been labeled on the grid, but must be determined by the analyst on the basis of the subsatellite track of each orbit interrogated, as described below.

To illustrate the procedures for labeling longitudes, if a descending node happened to occur precisely at 165^{o}E, the longitude line crossing the equator at the center of the grid would be labeled 165^{o}E, the longitude line 5^{o} to the east 170^{o}E, etc. Equator crossings at longitudes evenly divisible by five will be rare, however, and a more typical case is provided by a descending node at 166.1^{o}E; in such a case, 166.1^{o}E would be assigned to the longitude line through the center of the grid at the equator, with longitude values of $166.1^{o}E \pm n\ 5^{o}$ (where n is an integer) assigned to the other longitude lines. When working with the data, or transferring them to standard maps, it is obviously far more convenient to use longitudes which are integral multiples of five degrees. To facilitate the construction of longitude lines for integral multiples of five degrees, tick marks have been entered on latitude circles as described above. With their aid, a new set of longitude lines for integral multiples of five degrees can readily be constructed. More detailed descriptions of these procedures are provided in Section 4.4.

Upon only cursory consideration, it might at first seem satisfactory to simply slip the prepared grid sideways to make one of its longitude lines coincide with an integral five degree longitude near the subsatellite point. This would avoid the necessity of reconstructing longitude lines for integral values of five degrees. If the concern were only with data within a few degrees of the subsatellite point, no great error in geographical location would be made thereby; but, for areas more distant from the subsatellite point, the errors using this procedure increase rapidly toward the horizon. Hence, grid slipping is not acceptable as a general technique, and the method discussed above and in Section 4.4 must be used instead.†

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† Before adopting the five degree grid system described and recommended in this report, consideration was given to a two degree system, similar to that illustrated in Section 3.2 of Reference 3, with slippage of up to one-half degree of longitude (near the subsatellite track) to be required. Careful consideration indicated this would have two serious objections: (1) Serious errors in geographical location would still occur in regions near the horizons; and (2) a two degree grid interval is incompatible with almost all standard meteorological base maps,[6] so the drawing of five degree lines would still be desirable.

3. GEOMETRY OF HRIR SENSOR SCAN

This report is intended to provide instructions as to the use of the five degree latitude-longitude grids for geographic referencing of DRIR data. Accordingly, the method of construction of the grids is only summarized in Appendix A. Nevertheless, it will be helpful for grid users to have an idea of the geometry of the HRIR (and DRIR) scan across the earth. Figure 2 and the brief discussion below are presented for this purpose.

Figure 2, which shows the geometry of the HRIR scan over the earth, is drawn in a vertical plane perpendicular to the plane of the orbit, that is, in the plane of the HRIR scan; and is to scale for a satellite height of 600 n. mi. It is obvious that a change of satellite height changes both the distance between subsatellite point and horizon, and the nadir angles corresponding to given distances from the subsatellite point. Conversely, neglecting the oblateness of the earth, for a circular orbit the distances to the horizons, and the nadir angles corresponding to given distances from the subsatellite point, are functions only of satellite height. The orientation of the subsatellite track with respect to local direction (i.e., its azimuth) becomes a factor only when these relationships are used to determine the latitudes and longitudes of points scanned relative to those of the corresponding points along the subsatellite track. (These facts allow construction of one latitude-longitude grid for a given satellite height.)

The natural compression of the data near the horizon is also evident in Figure 2, especially when the relatively small nadir angle changes there corresponding to given distances on the surface of the earth are compared to the far greater nadir angle changes for the same distances when near the subsatellite point. This compression results in reduced geographical resolution; and this plus the relatively excessive local zenith angles of observation make it desirable to limit geographical gridding of DRIR data to distances from the subsatellite point where the elevation angles of the satellite are greater than about 18-20°.[3] Such a limit corresponds to a distance from the subsatellite point of about 16 or 18° of great circle arc for a satellite at 1110 km (600 n.mi.). Hence, the transparent latitude-longitude grids discussed in this report have been drawn only out to about 20° of great circle arc from the subsatellite point.

DISTANCE, DEGREES OF GREAT CIRCLE ARC	NADIR ANGLE DEGREES
0	0
10	42.5
20	55.5
30	58.4
31.4 (Horizon)	58.6

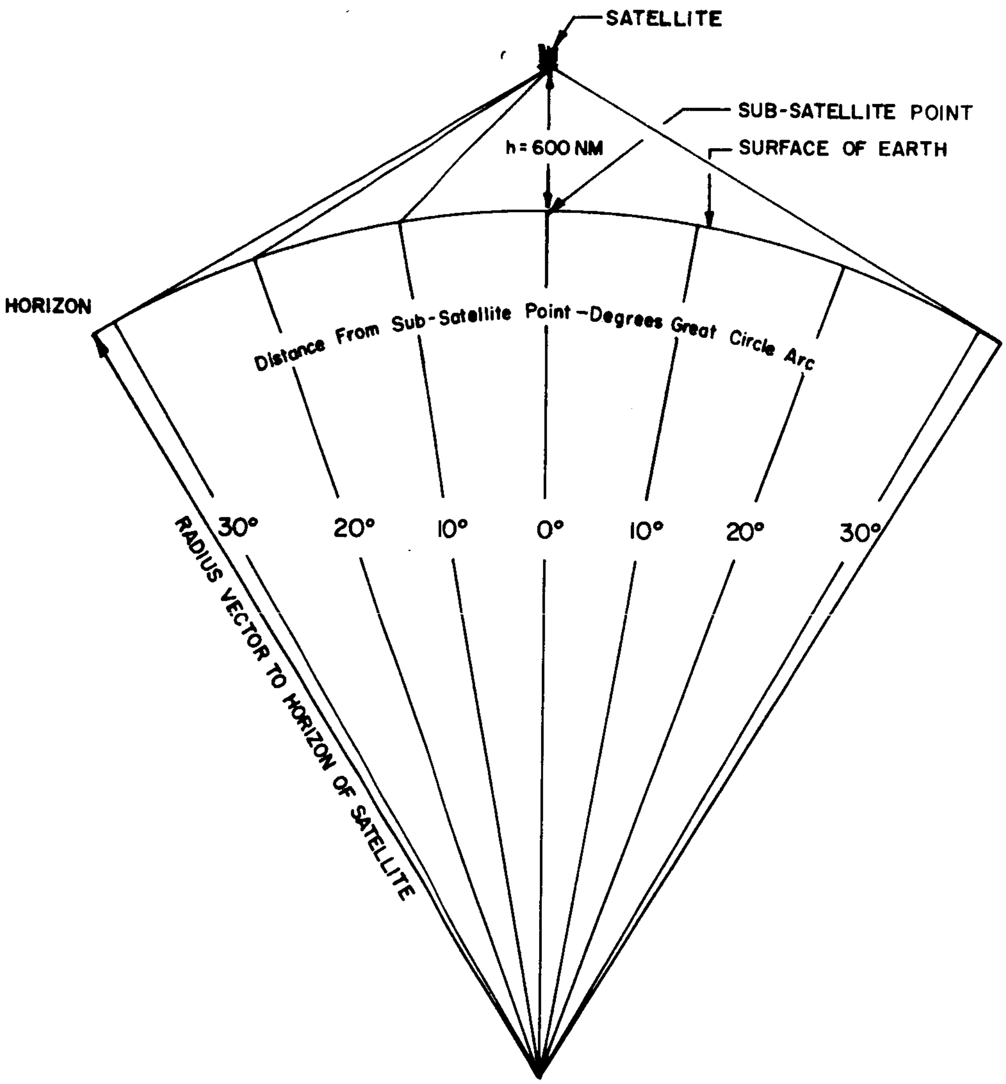

Figure 2. Geometry of HRIR Scan Mirror in Plane of Scan, for Satellite at 600 Nautical Miles.

4. PROCEDURE FOR USING LATITUDE-LONGITUDE GRIDS

The purpose of this section is to provide step by step instructions in the use of latitude-longitude grids for geographic referencing of DRIR facsimile data. The procedures for determining the subsatellite track, determining the APT antenna tracking data, tracking the satellite, and acquiring the data are essentially identical with those for obtaining APT pictures (see Refs. 7 or 8). Note, however, there is a different procedure for obtaining observation times (see Section 4.3.3). It is further to be noted that the DRIR data are acquired from continuous scans, not discrete frames as in the case of APT pictures. Accordingly, a manual phasing will be necessary if the part of the scan covering the earth should be split between the two edges of the recorder paper.

4.1 Grid Selection

The proper grid is selected from among the three available grids on the basis of satellite height. Grids have been prepared for heights of 1020 km (550 n.mi.), 1110 km (600 n.mi.) and 1200 km (650 n.mi.). For a circular orbit, the grid for the height closest to the observed satellite height is used for all acquisitions. For an elliptical orbit, it will usually be satisfactory to use only a single grid for any one acquisition, that corresponding to the satellite height nearest the midpoint of the acquisition (i.e., usually, at the point where the satellite passes closest to the APT station). The satellite heights in various portions of the orbit are given in the APT message (see Refs. 7 or 8, and Section 4.3.1). (In the unlikely event that satellite heights are not received, they may be estimated from the width of the earth image between horizons; see Appendix B).

4.2 Grid Orientation

With proper orientation, the grids may be used for either southbound or northbound passes, and in either the northern of southern hemisphere. Although the grids are marked to aid proper orientation for southbound passes, it may be helpful to remember that a sun-synchronous satellite always moves over the earth with at least a slightly westward component. Table 1 can also be used to guide the orientation of the grid.

Table 1

Relative Position of Pole on Grid, When Data Are Oriented with North at Top

	Pass Direction	
Hemisphere	Northbound	Southbound
Northern	Upper Right	Upper Left
Southern	Lower Left	Lower Right

4.3 Matching the Grid to the DRIR Data

On the basis of the procedures given in Section 4.2, the grid can be approximately oriented relative to the data. Proper placement of the grid on the data requires:

1. Information on the path of the subsatellite track across the earth, and on the times at which the satellite will be over various points along this path.

2. Determining the times at which the data for specific scan lines were being recorded on the facsimile paper.

3. The coordination of the above information to determine the proper position of the grid along the data, and so the latitude coordinate.

4. Use of the horizon visible on the data to determine the proper position of the grid in the direction across the data. (Although precise positioning of the grid across the data should be deferred until the proper position along the data has been determined, the approximate "across" position is obvious, since the center line of the grid (subsatellite track) should correspond to the centerline of the data, and horizons visible on the data should match as closely as possible the horizons marked along the edges of the grids.)

With very limited exceptions (principally those regarding the use of landmarks), the following procedures assume the satellite is properly oriented (no attitude error relative to any of the three axes). In general, the DRIR stations will have no information on, or ways to detect, such errors unless they are persistent and they are notified of them. The one situation in which a DRIR station will be able to detect non-persistent attitude errors is in the case of short period (approximately two minute) roll errors, which can easily be detected from excursions of the horizons if they amount to more than about one degree. Unless the attitude errors are rather large, the slight gain in accuracy from their correction may not merit the time required to achieve the corrections.

In the exceptional case where corrections for attitude errors are merited, the procedures given in Reference 9 can be applied. Although these correction procedures were developed for use with the HRIR backup grids, the general method is also applicable to the DRIR grids discussed here.

4.3.1 The Subsatellite Track

DRIR data will normally be obtained on the dark side (southbound segment of the Nimbus II orbit) of the earth. Ephemeris data are required to determine antenna tracking information in a manner similar to the APT procedures (Refs. 7, 8). However, the APT daily teletype message will contain ephemeris data for the daylight portion of the earth only.

DRIR users will be required to exploit the data contents and procedures of an experimental communication subsystem called Data Code, which is an integral part of the Nimbus II APT signal. Data Code format, contents, suggested utilization and procedures are fully described in "The Nimbus II Data Code Experiment" (Reference 10). Ephemeris data for an entire reference subsatellite track are provided in a Nimbus II Ephemerides Message. The first message will be disseminated shortly after launch during unscheduled time on the WMO teletype circuits and mailed to known DRIR participants not on the WMO networks. Subsequent messages will be mailed to all known DRIR users by the National Aeronautics and Space Administration. Data Code contents (appearing along the edge of the APT image) provide picture timing data and information required to update from the reference subsatellite track to the desired data acquisition orbit. The updated subsatellite track is then used to determine tracking data for acquiring the nighttime DRIR signal.

In the event information on the subsatellite track and height are not received, alternative ways of obtaining the information may be used. Some of these are discussed in References 7 and 8.

From one or more of these sources, and procedures such as those given in References 7 and 8, the station can determine the track of the satellite across the earth, and the time the satellite is above any point along its subsatellite track.

4.3.2 Time of Data Acquisition

Since the DRIR broadcast is continuous and lacks absolute time signals, stations receiving the data must make their own annotations of times of observation on the facsimile paper. If a time mark could be placed beside a scan line exactly at the time the image was being formed in the facsimile, there would be no problem. A mark could be made along the edge of the data at each integral minute, and the time noted in terms of GMT. The subsatellite latitude* at this time, which can be obtained in any of several ways (Refs. 7, 8), would then be the latitude of the point where this scan line crossed the center line of the DRIR data.

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* This part of the discussion is written in terms of latitude because, over most of the earth, this is the geographical coordinate which varies most rapidly along the centerline of the DRIR data. Even for stations near the poles, the data will normally extend far enough equatorward to make it feasible to use latitude in determining the along-track match of the data and the grid.

** This is a replacement page for that in the original report. It was made necessary by revision of procedures in Section 4.3.1 subsequent to that report.

A complication arises from the fact that the facsimile stylus is covered to avoid the danger of electrical shock and the image is first accessible for marking about 6.35 cm (2.5 inches) after formation, which is over the heater bar in the Fairchild recorder. The function of the heater bar is to dry the moist facsimile paper. It is approximately 1.5 cm (0.6 inches) wide and stretches across the width of the paper. As suggested slightly later, the paper can conveniently be marked here on either or both sides. Thus, in general the only time marks that can feasibly be applied will be offset from the scan lines to which they apply. Hence, in determining latitude and fitting the grid to the data, this offset must be taken into consideration.

A suggested technique to handle this problem is as follows: With the facsimile shut off, uncover the stylus and carefully measure (say, for the Fairchild facsimile) 6.35 cm (2.5 inches) from the image forming line of the facsimile in the direction toward which the paper feeds. This is directly over the heater bar.† At this exact distance, scribe a mark on the case to each side of the paper. (For the convenience of later operators, it would also be well to place a notation stating that this mark is 6.35 cm from the stylus.) During an interrogation, at several integral minutes (GMT), place marks each side of the paper exactly opposite these points and label the marks with the times at which they were made.

As soon as the paper is removed from the facsimile recorder, measure backwards (in the direction opposite to the feed of the paper) from each of these marks 6.35 cm (2.5 inches) and place an "offset" mark. Connect each offset mark to its corresponding original mark by a lightly drawn arrow (see Fig. 3). If the times were carefully noted when the original marks were made, and if the measurements were made with precision, the offset marks are now beside the scan lines depicting the data being observed at the times the original marks were made.

4.3.3 Along the Track Matching

From the plotted subsatellite track (and the times that are plotted along it), determine the subsatellite latitude at each time a mark was made on the facsimile paper. For future reference (see Section 4.4), the longitudes of these points can easily be determined concurrently and should be noted. (The procedures for these latitude and longitude determinations are described in such manuals as Ref. 7 and 8, and

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† Other situations or most appropriate distances to be measured may exist for different facsimile recorders.

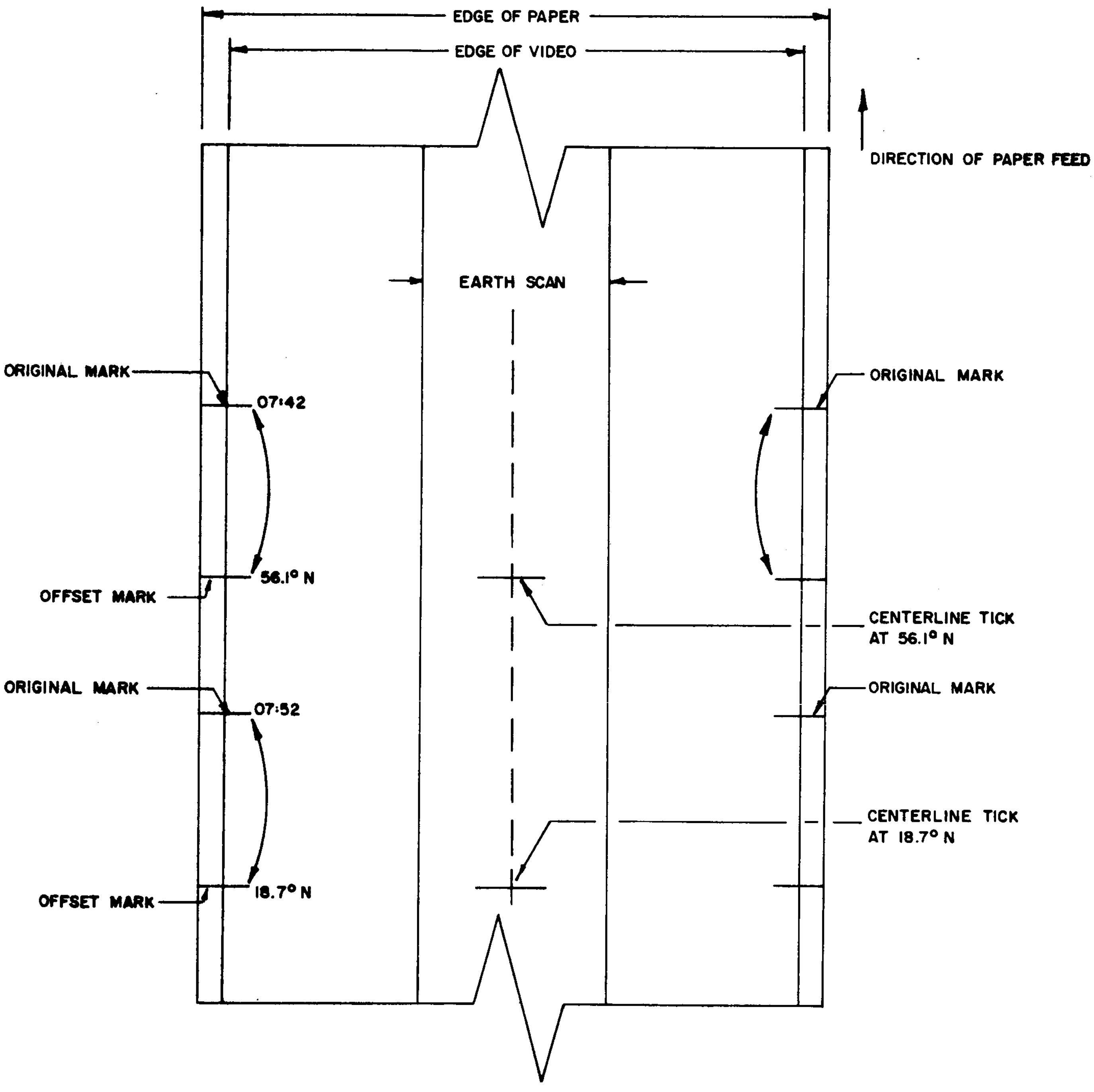

Figure 3. Example of Original and Offset Time Marks

are identical to those used for determining the latitudes and longitudes of the centers of APT pictures.) Write these latitudes beside the corresponding offset marks; these latitudes are those of the center line of the DRIR data at points opposite the corresponding offset marks (i.e., where a straight line connecting a pair of offset marks crosses the center line). The center line should be lightly marked with a small tick mark at these points (see Fig. 3).

Place the latitude-longitude grid on a light table in the proper orientation (see Section 4.2). Place the DRIR over it, approximately positioned in the across-track direction (see 4 under Section 4.3), and slide it up or down (in the along track dimension) until the latitudes on the grid correspond to the latitudes on the center line, opposite the offset marks, determined as described just above. (If an exact concurrent match cannot be achieved at all of these points, it should be resolved as either a best fit compromise, or by favoring the area of greatest interest when making the match.)

If clearly identifiable landmarks can be identified on the data, it is well at this point to check their known latitudes with those shown by the grid and further adjusting the grid as necessary to match the latitudes of the landmarks. Again, a best fit compromise may be required.

4.3.4 Across the Track Matching

The data and grid should then be precisely matched in the across-track direction by matching the two sets of horizons. If the orbit is nearly circular and the orbit altitude is close to that marked on the grid, the match should be close, except where roll affects the horizon image. Matching horizons along the total length of the available data automatically rotates the grid to the best position. Again, a best fit compromise may be required.

If the distances between the data horizons and grid horizons are not the same, the match should be made with the horizons parallel and with the same discrepancies between the two sets of horizons along both sides of the data. This procedure matches the subsatellite tracks of the grid and the data.

If the horizons do not coincide, this indicates there will be some gridding error (except along the subsatellite track, or center line) which will increase toward the horizon. The magnitude of this gridding error, at a given distance from the subsatellite track, can be estimated by linear interpolation between the zero error along the subsatellite track and the amount of image-grid mismatch at the horizon, and by then converting this estimated mismatch to distance as determined from the grid network at that point.

After the best across-track match has been achieved, the along track (latitude) match should be rechecked to insure it was not disturbed in the process. When the best fit in both dimensions has been concurrently achieved, the grid and data should be taped together to hold them in their proper relative positions. The latitude lines can now be lightly traced on the DRIR data, and labeled; the tracing should be done lightly and as thin lines, to prevent obscuring small but significant features in the data.

4.4 Determination of Absolute Values of Longitude from the Latitude-Longitude Grid

A brief discussion of how absolute values of longitude are assigned to the longitude lines of the latitude-longitude grid was included in Section 2. In general, tracing of the longitude lines of the grid onto the image is not desirable, since the longitude lines on the grid will seldom correspond to longitudes which are integral multiples of five. This section discusses the general case of determining integral five degree longitude lines and drawing them on the data.

Assume the procedures of Sections 4.1 - 4.3 have been completed, and the grid has been matched to the film. Use the longitude of one of the points along the subpoint track for which the time of observation, and subsequently the latitude and longitude, were determined (see Section 4.3.3). From interpolation between the one degree tick marks, determine the distance in degrees of longitude from this point to the nearest longitude line. The absolute longitude of this line is then the longitude of the point on the subsatellite track $\pm$ the distance from the point to the grid longitude line in degrees of longitude, and all other longitude lines on the grid have absolute values equal to the longitude of this line $\pm n\, 5^{\circ}$ (where n = 1, 2, 3, - - -).

At this point, it is well to make two checks to be sure the best possible values of absolute longitude are assigned:

1. The above procedure should be repeated for all center line points for which observation times were determined to see if they lead to the same absolute values for the longitude grid lines. If there are differences (small differences of the order of one degree or less are almost inevitable), an average of them should be taken.

2. The known longitudes of a reasonable number of clearly identifiable landmarks (if any are visible) should be compared to those determined from the absolute values assigned to the longitude lines on the grid. If discrepancies are noted, the absolute values of the grid longitude lines should be appropriately adjusted. Again, a best fit

compromise may be necessary. (For this purpose, landmarks near the edges of the data should be avoided, because of errors that can result from foreshortening.)

Once the best possible values of the absolute longitudes of the grid longitude lines are established, determine the distance (in degrees longitude) that an integral five degree longitude line will be east (or west) of one of the grid longitude lines. It is usually most convenient to use a grid longitude line that crosses the center line about halfway from the top to the bottom of the available data. The other integral five degree longitude lines will be an equal distance (in degrees of longitude) east (or west) of the other grid longitude lines. This distance should then be determined (in degrees of longitude, using interpolation between the one degree tick marks) along each latitude line, and the absolute longitude lines traced lightly on the data by connecting the points. In tracing these lines, they should run more or less parallel to (i.e., parallel the curvature of) the grid longitude lines. These five degree absolute longitude lines should then be labeled.

4.4.1 A Simplified Example of the Longitude Determination Procedure

Suppose the coordinates of a subsatellite point on a southbound pass, at the time determined and marked on the DRIR data were 43.9°N, 94.4°W. On the grid, this subsatellite point would be at approximately the point indicated in Figure 4. This point is approximately 2.2° of longitude west of the next grid longitude line to the east. Since the 95.0°W longitude line would be 0.6° of longitude west of this subsatellite point, the 95.0°W line would be 2.8° west of the grid longitude line just east of the indicated subsatellite point. Correspondingly, points 2.8° west of the other grid longitude lines would also be along integral five degree longitudes such as 105°W, 100°W, 90°W, 85°W, etc. Hence, with the grid underlying and matched to the facsimile image, and by using the one degree "tick marks" on the latitude lines of the grid, marks corresponding to the desired integral five degree longitude lines can be entered along each latitude line. These marks can then be connected as described above (and shown in Fig. 4), and labeled. The DRIR data have thus been geographically referenced with five degree latitude-longitude lines.

At times, the latitude and longitude lines drawn on the image might obscure small but significant meteorological features. This can be minimized by first determining whether there are any such features, and then leaving a small gap in any latitude and/or longitude lines that would cross these features. This is especially desirable if the lines are later to be traced over more heavily than they should originally be drawn.

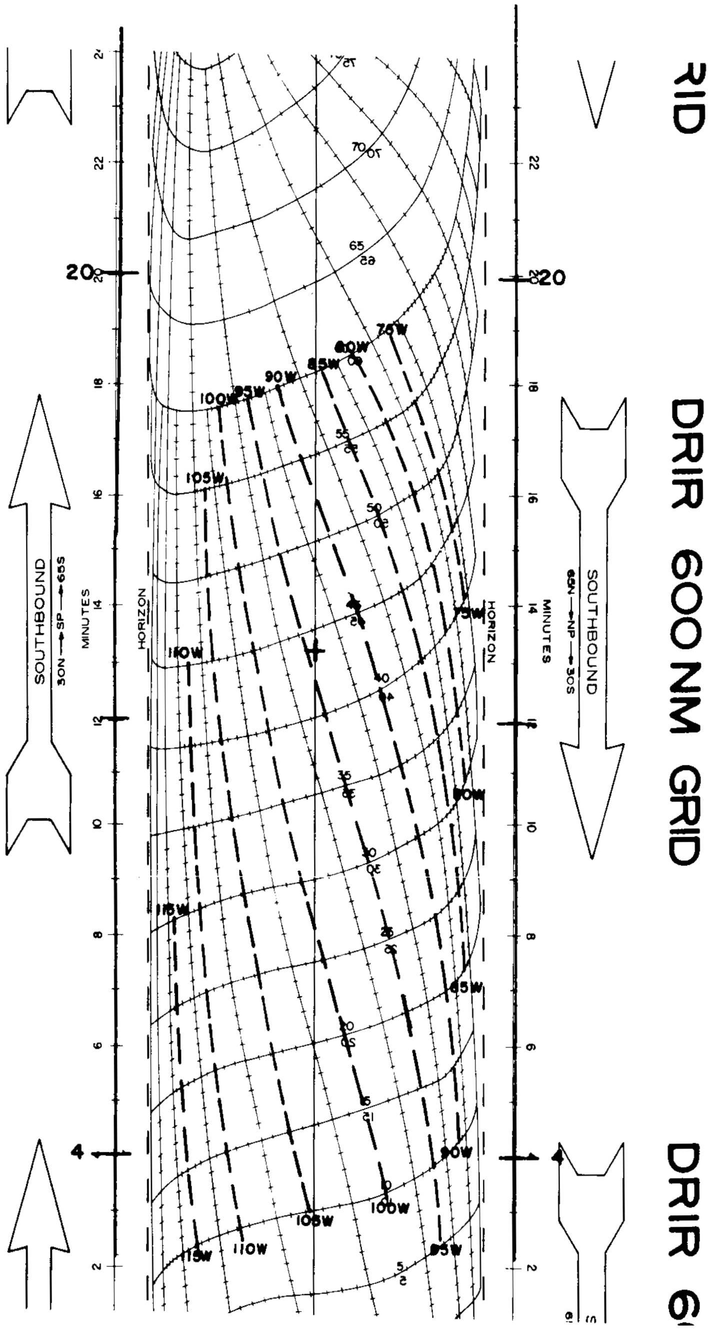

Figure 4. DRIR Grid Labeled from Known Subsatellite Coordinates

4.5 An Example of the Geographic Referencing of DRIR Data

The example of geographic referencing presented in this section (Fig. 5), uses a portion of the Nimbus I HRIR data from data orbit 351 (Ref. 1). The scale of the data has been modified to approximately match a DRIR latitude-longitude grid for 600 n.mi., but the effect of the eccentricity of the Nimbus I orbit is apparent in the changes of the width of the data along the film strip.

Assume an APT/DRIR readout site at Denver, Colorado (40°N, 105°W). The descending node of this orbit was at 124.1°W at 075705 GMT. Suppose the satellite was acquired at 074036, when it was at about 61.3°N, 103.9°W and a time mark placed on the facsimile paper (over the heater bar) at 0746 GMT. As described in Section 4.3.2, the mark would be 6.35 cm (2.5 inches) north from the line being scanned at that time. The subsatellite coordinates at 0746 GMT are known to have been 41.1°N, 113.7°W. On the facsimile paper, measure 6.35 cm (2.5 inches) opposite to the direction of paper feed (i.e., southward along the paper from the first mark). The point on the center line opposite this offset mark (the subsatellite point) then has a latitude of 41.1°N. Match this point to the 41.1°N latitude line where it crosses the center line of the grid, with the grid in its approximate proper orientation. After adjusting the grid and data for the proper across track match, the latitude referencing of the data has been established, and the latitude lines can be traced and labeled.

From interpolation using the one degree tick marks, the subsatellite point at 41.1°N, 113.7°W is approximately 1.8° of longitude east of a grid longitude line, which makes the longitude of that grid line 115.5°W. Other grid lines therefore represent 110.5°W, 120.5°W, etc.

The longitude lines can then be drawn, by connecting marks made 0.5° of longitude east of the longitude lines of the grid. These lines are then labeled. Figure 5 shows the result with the DRIR transparent grid lines shown by solid lines, and the absolute longitude lines shown dashed to differentiate them. After a check for accuracy, consistency and completeness, the gridded data are ready for meteorological analysis and interpretation.

4.6 Geographic Referencing with Only Landmarks Available

There is some very slight chance that a station might acquire DRIR data, but lack precise subpoint track data. In such a case, if identifiable landmarks are available, the use of the latitude-longitude grids is still straightforward. Select

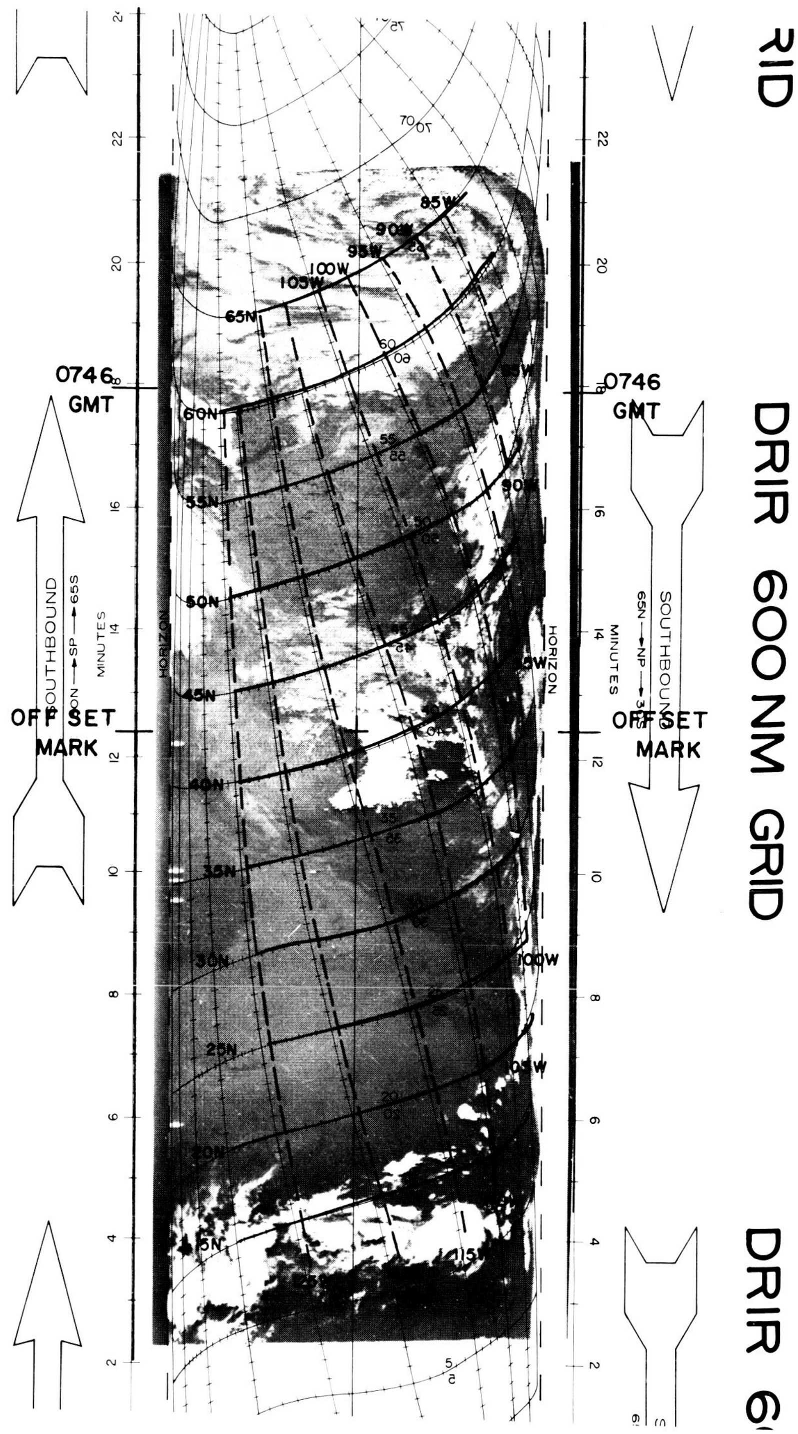

Figure 5. Simulated Geographically Referenced DRIR Data

the proper grid on the basis of estimated satellite height. Orient the grid properly, and place it in its approximate position relative to the across track direction. Move the grid along the strip until the grid latitude matches the known latitude of the landmark. Perfect the across track match. Trace and label the latitude lines. Use the longitude of the landmark to assign values of longitude to the grid longitude lines. Determine, draw, and label the five degree longitude lines.

5. SUMMARY

This report has presented a method for geographically referencing Direct Readout Infrared Radiometer (DRIR) data from the Nimbus C satellite, assuming no satellite attitude error. The procedure leads to geographically referenced DRIR data, with labeled five degree latitude-longitude lines drawn at the correct locations.

The method uses one of a set of transparent latitude-longitude grids, drawn for three heights: 1020 km (550 n.mi.), 1110 km (600 n.mi.) and 1200 km (650 n.mi.). The grids have fixed latitudes, at five degree intervals. Unassigned longitude lines are also at five degree intervals, except at latitudes greater than 60^{o}, where, due to convergence of the meridians, the interval is greater. Absolute values of longitude must be determined by reference to those of the subsatellite track of a particular orbit. Horizons indicated on the grids aid in positioning it relative to the DRIR data, and the subsatellite track is represented by a line down the middle. By suitable rotation and/or inversion, the grids may be used for both the northern and the southern hemispheres, and for either southbound or northbound passes.

APPENDIX A

BASIS OF DRIR GRID CONSTRUCTION

The DRIR grid described and illustrated in this report has been constructed as described below.

A subsatellite track for a circular sun-synchronous orbit at 600 n.mi. altitude was plotted on an OEC map,[9] with time marks at one minute intervals.

Coordinates of intersections of integral five degree latitude-longitude lines, relative to the subsatellite track, were determined from the OEC map in terms of time along the subpoint track, and degrees of great circle arc from the subsatellite point. The great circle arc measurements were made perpendicular to the instantaneous heading line, since that is the locus of HRIR mirror scan for no attitude error. (The instantaneous heading line is the intersection with the earth's surface of the orbital plane at the time in question.) The time along the track coordinate for a given latitude-longitude intersection was that for the point where a line from the intersection, and perpendicular to the instantaneous heading line, intersected the subsatellite track. (This is the subsatellite point from which the HRIR mirror would scan the given latitude-longitude intersection.)

To construct a DRIR grid compatible in scale with DRIR data as recorded by a Fairchild facsimile recorder, the times along the subpoint track from an arbitrary reference (the equator) were converted to the distances the recording paper would advance, from the same reference, in the corresponding times. From the known facsimile line spacing of 0.0254 cm (0.01 inch), and a cycle rate of 44.7 RPM for the HRIR (to which the facsimile recorder cycle will correspond), a paper advance rate of 1.14 cm per minute was determined. Therefore, each minute along the subsatellite track corresponds to 1.14 cm along the recording paper.

To determine the appropriate scale of the grid perpendicular to the subsatellite track (the center line of the grid), it was noted that the nadir angle of the HRIR scanner is related to the distance, from the subpoint track, of an observed point by the relationship:[3]

$$B = 180^{\circ} - N - \sin^{-1} \left[\left(\frac{R + h}{R} \right) \sin N \right]$$

where

B = subpoint track distance in degrees of great circle arc

N = nadir angle of sensor view

R = radius of the earth

h = satellite altitude

and there is a constraint that:

$$\sin^{-1}\left[\left(\frac{R+h}{R}\right)\sin N\right] \geq 90^{\circ}$$

This relationship has previously been tabulated.[7]

Furthermore, the HRIR scanner revolves at a constant rate (44.7 rpm) while the facsimile stylus travels across the paper at a constant linear rate (960 cm per minute), synchronized to the HRIR scanner. The HRIR scanner has a zero degree nadir angle as the recorder crosses the center line (subsatellite track) of the image. Accordingly, from the tabulated values, great circle arc distance can be converted to nadir angle. Nadir angle can be converted to time from crossing the subsatellite track, which can be in turn converted to distance on the facsimile paper from the image center line. The appropriate distance on the paper, from the center line, can thus be determined from the relationship:

$$\text{Distance from center line (on the paper, cm)} = \frac{21.5 \text{ cm}}{360} \times \text{(nadir angle, in degrees)}$$

$$= 0.0597 \times \text{(nadir angles, in degrees)}$$

The coordinates of the five degree latitude-longitude intersections of the grid, relative to the equator and the center line (subpoint track) were computed and plotted using the relationships discussed above. The plotting and drafting were done on a two-to-one scale as a method of minimizing errors in the final product, after which the grid was photographically reduced to the proper scale to match that of the facsimile recorded image. (The grid as illustrated in Figure 1 has been further and arbitrarily reduced to fit the page size of this report.)

APPENDIX B

SELECTION OF DRIR GRID FROM WIDTH OF EARTH IMAGE

If information on satellite height is not received at a DRIR station, the image itself may be used to estimate satellite height, since the width of the earth in the recorded data is an inverse function of height.

Measure the distance between the horizons at a place where both horizons are sharply defined. The limits of applicability of each of the three DRIR latitude-longitude grids, in terms of this measured horizon distance, are presented in Table B.

Table B

Grid Selection from Horizon Width

Horizon width† (mm)	Assigned height of grid to be used (n. mi.)
>70.4	550
69.0 - 70.4	600
<69.0	650

† For Fairchild facsimile recorder, 8.45 inch total data width.

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February 1966

ERRATA SHEET
FOR
MANUAL GRIDDING OF DRIR FACSIMILE PICTURES
(Technical Note No. 7)
Contract No. NAS 5-3253

Page 1, Line 3

Put asterisk after "Nimbus C". In footnote add following sentence: The RCA manual on the change of gears on Fairchild facsimile recorders to receive DRIR refers to the equipment as HAX, standing for H(RIR) Automatic X(trans) mission system.

Page 3, Line 5

Replace "grographical" with "geographical".

Page 5, Line 4

Change 90^{o} to 85^{o}

Page 8, Line 3

Add asterisk after "track" and footnote beside asterisk below as follows: *See Section 4.3.1, p. 10, for an important correction to this statement.

Page 9, Last Paragraph, Line 3

Add "satellite attitude" between words "three" and "axes"

Page 24, Reference 7

After Reference 7, add (Out of Print)

Page 24, Reference 10

10. Goldshlak, L. and W.K. Widger, Jr., 1966: The Nimbus II Data Code Experiment, Technical Note No. 1, Contract No. NAS 5-10114, ARACON Geophysics Division, Allied Research Associates, Inc.