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ON THE PROVISION OF 5-MINUTE SATELLITE DATA FOR AWIPS-90

Harry R. Glahn

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1. INTRODUCTION

The Definition Phase Systems Requirements Specification (SRS) for AWIPS-90 (U.S. Government, 1986) states that several sectorized and remapped Geostationary Operational Environmental Satellite (GOES) products will be prepared and provided to the AWIPS contractor for distribution to Weather Forecast Offices (WFO's). Products for a particular continental U.S. (CONUS) Sector will be provided every 5 min whenever one or more WFO's within that sector are in the Warning Mode of operations. These same products will be made available but less frequently when no WFO in the sector is in the Warning Mode. (Warning Mode is defined as that mode of operations when hazardous weather exists or is imminent (op. cit., p. 587). When this SRS was prepared, the sector definitions were not finalized. However, for planning purposes, sectors were defined on a Mercator map projection (op. cit., p. 1125). An East CONUS Sector was defined for which GOES East would provide data, and a West CONUS Sector was defined for which GOES West would provide data. East and West CONUS Sectors were the same size on the Mercator map, being between 20° and 55° N latitude and between 105° and 60° W longitude for the East Sector and 135° and 90° for the West Sector. It was estimated that each GOES could scan its respective sector in about 3.3 min. Sectors defined to provide data for Hawaii, Puerto Rico, and Alaska could be scanned in about 1.7 min each. A north polar stereographic map composed of data from both GOES East and GOES West would be provided twice per hour and would require a scan time of 10 min each for GOES East and GOES West. It was recognized that the various requirements for data from the satellites might preclude data being provided <u>each</u> 5-min period; that is, the 5-min cycle might have to be broken occasionally.

In the AWIPS outphases SRS (U.S. Government, 1989), the sectors are defined in accordance with rather firm requirements regarding areas and map projections. The East and West CONUS Sectors are now defined on a Lambert conformal map projection, with vertical longitudes of 85° and 110° W, respectively. Alaska is to have a polar stereographic map aligned on 150° W longitude, and Puerto Rico and Hawaii will stay with the Mercator projection. The question arose as to whether the new CONUS sectors could be supported with 5-min data.

In order to help answer the question, software was developed that would prepare maps for display on the Automation of Forecast Operations and Services (AFOS) equipment and compute scan times for the various sectors. This office note briefly describes the software, presents maps bearing on the questions involved with providing high frequency satellite data, and discusses the scan times relative to the feasibility of meeting the expectations embodied in the AWIPS SRS. In order that the reader may be able to judge the method of attack and reasonableness of data presented, certain information regarding GOES imaging operations is included for easy reference.

2. GOES I-M SCAN CAPABILITIES

This section is not meant to be an exhaustive treatment of GOES imager scan capabilities. However, information pertinent to the rest of this document has been taken from three sources--"The Imager/Sounder to Operations Ground Equipment (OGE) Interface Control Document of the GOES I,J,K,L, & M Spacecraft" (Integral Systems, 1988), "Imaging Subsystem Performance Specification" (Ford Aerospace, 1986), and "Users Manual for a Program to Calculate GVAR Data Vomumes" (Komajda, 1988).

At any given time, the GOES imager is in one of seven operational modes (Integral Systems, 1988, p. 2-63):

1. Normal Scan Frame - The Imager is scanning some portion of the earth/space within commanded rectangular scan limits.

2. Priority 2 Scan Frame - This mode is identical to a normal scan frame, but typically occurs as a higher priority interrupt of a normal scan frame. Once the priority 2 scan frame is completed, the normal scan frame resumes from the point of interruption.

3. Priority 1 Scan Frame - This mode is identical to a normal scan frame, but typically occurs as a higher priority interrupt to either a normal scan frame or a priority 2 frame. Once the priority 1 scan frame is completed, the interrupted scan frame resumes from the point of interruption.

4. Star Sense/Sequence - The imager slews to just beyond the location of a star, and holds that position for a commanded period of time as the star drifts across the field of view. Star viewing is either performed by commanding individual star senses (star sense mode) or as a sequence of star senses (star sequence mode). The star sense operation is classified at the highest level of priority because it is capable of interrupting a normal and any priority frame operation (op. cit., p. 2-2).

5. Space Look - Based on the expiration of a timer, some other operation is interrupted while the instrument slews to space, collects data for a fixed period of time, and resumes the interrupted operation.

6. Blackbody Calibration - Based on the expiration of a timer, the instrument performs a space look followed by a view of the internal blackbody.

7. Idle - The imager remains in idle mode whenever no other operation is being performed.

Any of the above modes can be terminated by a scan reset command, resulting in a blackbody calibration and entry to idle mode.

The worst case scenario of nested operations that the OGE could handle would be the interruption of a normal frame operation by either one of the priority frames, beginning the priority frame operation, and interrupting the priority frame to execute a star sense/sequence operation (op. cit., p. 2-2).

The imager scans a rectangle (a rectangle to it, not on the earth) in response to commands that, in effect, define the "left and right" edges of the rectangle (here called azimuth) and the "bottom and top" edges of the rectangle (here called elevation). At the start of a scan, the imager starts at a corner of the rectangle (the corner depending on the order of input information) and scans alternate E-W and W-E lines (azimuth) until the north to south (elevation) extent is covered. Although the imager is capable of scanning from either north to south or south to north, the OGE is designed to ingest, process, and monitor data generated only from a north to south scan (op. cit., p. 2-5).

The configuration of the detectors is shown in Fig. 1 reproduced from Fig. 2.1 in the Integral Systems (1988) document. The detector characteristics are (op. cit., p. 2-3):

Visible, Channel 1 - resolution 1 km - eight detectors arranged in a linear, north-south fashion.

IR, Channel 3 - resolution 8 km - one primary and one redundant detector.

IR, Channels 2, 4, and 5 - resolution 4 km - three sets of two primary detectors with three redundant sets.

Each of the visible detectors provides an Instantaneous Geometric Field of View (IGFOV) that is 28 microradians on a side. At the subsatellite point, this corresponds to a square pixel whose dimensions are 1 km on a side. The IR Channel 3 provides an IGFOV of 224 microradians, and the IR Channels 2, 4, and 5 each provide an IGFOV of 112 microradians (op. cit., p. 2-12); these correspond to squares of 8 and 4 km on a side, respectively, at the subsatellite point.

A "line" should be in even multiples of 64 microradians and is scanned at the rate of 20° (azimuth) per second. The "step" between lines (scan reversal) requires about 0.2 sec. Given the azimuth and elevation extents, the scan time can be calculated.

Computing the times required for other imager operations is more of a problem. First, the time for some operations is variable, and second, some operations are performed upon command and, therefore, may or may not occur during a scan of a particular duration. Komajda (1988) prepared a program which calculates times required for various imager operations, given the latitudinal and longitudinal extents of the area on the earth to be viewed. Certain assumptions were made, and I have tried to follow the same procedures. The times used are:

Star Sequence - 1 min every 30 min of scan time, starting 15 min after the start of the scan.

Space Looks - 1 sec each plus three invalid scans every 2 min of scan time, starting 1 min after the start of the scan.

Blackbody Calibration - 40 sec every 10 min starting 5 min after the start of the scan.

In accordance with Komajda's program GVAR, each of these operations was started halfway into its respective "cycle" rather than waiting until a full cycle had passed. From the GOES documentation, it seems a scan of several minutes could be done without interruption, but then several operations might be needed before the next scan. The procedure used by Komajda, and used here, helps one to not forget about the time required by these operations.

3. DEFINITION OF THE SATELLITE SCAN RECTANGLE

If one is interested in scanning all latitudes and longitudes within specified ranges, as is the case when the region on the earth is a rectangle on a Mercator projection, then these limits of latitudes and longitudes are sufficient for calculating scan times. However, if the projection is not Mercator, then a correct satellite rectangle cannot be computed without more information concerning the earth rectangle extent and map projection.

Given the map projection and corner points of the earth rectangle (in terms of latitude and longitude), the limits of satellite azimuth and elevation can be calculated to cover those four points. However, even this is not sufficient to guarantee all the earth rectangle will be scanned. Rather, one has to also consider the points on the lines connecting the corner points. I could discover no existing software that performed this function.

4. MAPS OF SCANNED AREAS

It seemed that it might be useful in understanding why certain areas would require more or less scan time than other areas and also in planning GOES scan strategies, that the area actually scanned by the satellite, in order to cover the specified area, be mapped. This was done by drawing, on the AFOS Graphics Display Module (GDM), the boundaries of the scanned area and the boundaries of the area required to be covered on the particular map projection being used. In addition, lines of equal azimuth and lines of equal elevation were plotted within those boundaries. The increment between these lines was computed on the basis that "boxes" bounded by those intersecting lines would, on the average, require N sec to scan, N being a variable to the computer program. This "average" was determined by computing the interval (the same for azimuth and elevation) between lines to define enough boxes at N sec each to equal the total scan time (scan time only, not including blackbody calibrations, etc.). For all hemispheric maps shown, the boxes represent 10 sec scan time; for all other maps, the boxes represent 2.5 sec.

The software can handle Mercator, polar stereographic, and Lambert conformal maps, and can compute the scan time for any sector (or an accumulation of sectors) that can be defined by four corner points with straight lines between them on the map projection being used. It also turns out that a pie-shaped sector of a hemispheric polar stereographic map can be accommodated with a suitable arrangement of the four input points. The continental outlines, international boundaries, state boundaries, and major lakes (the "geography") were taken from the National Meteorological Center's (NMC's) files of World Data Bank data (see Appendix I for more details). The mapping equations are described in Appendix II.

A. East CONUS Sector

The original East CONUS Sector defined on the Mercator projection along with the scanned area is shown in Fig. 2. As is the case with all maps relating to a two-GOES situation, GOES East is assumed to be over the equator at 75° W. The computed scan time is 3.1 min with another 0.1 min for a space look. The small boxes defined by equal elevation and azimuth lines take, on the average, 2.5 sec. (For verification, there are about 77 boxes; at 2.5 sec each, this is 3.2 min.) At the east and north edges, the boxes may be "smaller" than the others, as the incrementing is started at the lower left corner, and the boxes are constrained to the limits of the viewed area.

One might think that by eliminating the lower tier of boxes, that about 11 X 2.5 = 27.5 sec could be saved, and that is essentially true. However, a similar saving is not true for the western column. Since the step between lines must be done no matter what the width of the sector, the full 2.5 sec per box cannot be saved. The time for the step is a significant part of the total. In this particular case, there were 340 lines; therefore, of the total scan time of 3.1 min, 1.1 min is due to these steps.

The Lambert East CONUS Sector is shown in Fig. 3. The total scan time is 4.4 min including less than 0.1 min for space looks.

If one were to compute the scan time based on covering <u>all</u> latitudes and longitudes between the corner points of the Lambert East CONUS Sector, Fig. 4 with a scan time of 5.5 min (plus 0.2 min for space looks and 0.7 min for a blackbody calibration for a total of 6.3 min) would result. Obviously, this is not the time needed. (Fig. 4 is on a Mercator map because the area scanned is a rectangle on that projection.)

B. West CONUS Sector

The original West CONUS Sector defined on the Mercator projection along with the scanned area is shown in Fig. 5. As is the case with all maps relating to a two-GOES situation, GOES West is assumed to be over the equator at 135° W. The computed scan time is 3.0 min. Even though the East and West Mercator Sectors are the same size, GOES West is, on the average, farther from the West Sector than GOES East is from the East Sector, so the West Sector scan time is slightly less than the East Sector scan time.

Fig. 6 shows the Lambert West CONUS Sector. The scan time is 3.4 min with an additional 0.1 min for space looks for a total of 3.5 min.

C. Alaska, Hawaii, and Puerto Rico Sectors

The polar stereographic Alaska Sector viewed from GOES West is shown in Fig. 7. The scan time is 1.8 min including a single space look of less than 0.1 min. The two thin lines crossing the upper left of the map are the limit of the satellite's view within the elevations scanned (upper line) and the line representing 75° from the subsatellite point on the earth (lower line). This lower line may be near the limit of useful data. Note that the upper left corner of the sector is slightly beyond the satellite's view.

The Mercator projection Hawaii and Puerto Rico Sectors are shown in Figs. 8 and 9, respectively. For each, the scan and total times are between 1.3 and 1.4 min.

D. MARD Sector

Initially, instead of East and West CONUS Sectors, there will be a single "MARD" Sector. Figs. 10 and 11 show the east and west portions of that sector that would be scanned, respectively, by GOES East and GOES West. The respective scan times are 2.0 min (2.1 min with a space look) and 1.7 min (1.8 min with a space look). Note that the seam along 105° W (equidistant from GOES East and GOES West) is not parallel to the east and west edges of the MARD area.

E. One-GOES Scenario for East and West CONUS Sectors

In the case of only one GOES in operation, it is planned for it to be at 98^{o} W in the summer and at 108^{o} W in the winter. Fig. 12 shows the area it would have to scan to cover both East and West CONUS Sectors, which are the two rectangles in the figure. The scan time is 5.4 min from the summertime (98^{o} W) position (Fig. 12) with another 0.1 min for space looks and 0.7 min for a blackbody calibration for a total of 6.2 min. The total time for the wintertime position is also 6.2 min (Fig. 13).

F. One-GOES Scenario for MARD Sector

In the case of only one GOES in operation, the MARD Sector can be scanned in 2.5 min. This is indicated in Figs. 14 and 15 for GOES in its summertime and wintertime positions, respectively.

G. Polar Stereographic Composite

When two GOES satellites are in operation, there will be a northern hemispheric polar stereographic map produced as a composite with the seam at 105^{o} W (equal distance from GOES East at 75^{o} W and GOES West at 135^{o} W). The areas scanned by GOES East and West are shown in Figs. 16 and 17, respectively. The scan times for GOES East is 8.9 min with 0.2 min for space looks and 0.7 min for blackbody calibration, giving a total time of 9.8 min. The corresponding times for GOES West are 10.0, 0.3, 0.7, and 10.9 min, respectively.

H. Polar Stereographic Map from One GOES

If a single GOES is in operation located at 98^{o} W, the area scanned will be from 175^{o} W to 30^{o} W and is shown in Fig. 18. The total time is 13.0 min including 0.4 min for space looks and 0.7 min for blackbody calibration. With GOES at its wintertime position of 108^{o} W, the scan will be from 175^{o} E to 30^{o} W, and the scan time is increased slightly to 13.2 min (Fig. 19). Note that some of the area at the eastern and western extremes (as well as to the north) are beyond 75^{o} from the subsatellite point.

5. DISCUSSION

A summary of the information contained in the last section regarding scan times for sectors defined in the AWIPS outphases SRS is given in Table 1. Also included in the table are the minimum and maximum azimuth and elevation angles used to compute the values. Once again, the times for space looks, star sequences, and blackbody calibrations seem, according to available documentation, not to be fixed and could be mostly done outside the actual imaging; however, they must be done at some time. None of the scans was long enough to invoke the star sequence algorithm. In the following discussion, I will use the total times given in Table 1.

According to the AWIPS SRS, two northern hemispheric composites will be furnished each hour. For GOES East (West), this will require 19.6 (21.8) min per hour. These same scans should also provide the data necessary for remapping the CONUS, Alaska, Puerto Rico, and Hawaii Regional Sectors as required for the Normal Mode of WFO operations. If data for <u>all</u> these five sectors were to be provided twice more per hour, as they would if one or more WFO's were in the

Alert Mode in each sector, then GOES East would be occupied 4.4 X 2 (East CONUS) + 1.4 X 2 (Puerto Rico) = 11.6 min more, and GOES West would be busy 3.5 X 2 (West CONUS) + 1.3 X 2 (Hawaii) + 1.8 X 2 (Alaska) = 13.2 min more. This seems reasonable from a total imaging time standpoint, although the simultaneous processing of the data and the providing of the sectors to the AWIPS contractor so that the product can be made available for use on station within 6 min from the start of the image scan (see U.S. Government, 1989, p. SRSI-K-35) could be a problem.

When a WFO in a CONUS Sector is in Warning Mode, and especially if it is in the East CONUS Sector, it will surely be quite difficult to maintain a 5-min schedule, even if a single sector could be provided within 5 min as specified in the AWIPS SRS, especially since the presently defined East CONUS Sector on the Lambert map projection will require, on the average, 4.4 min to image, not including required star sequences.

The plan to image the whole East CONUS Sector every 5 min when a single WFO in that sector is in the Warning Mode may not be feasible. However, it should be possible to define a few subareas such that one or more of these could be imaged as necessary in much less than 4.4 min. The management/coordination structure necessary for this would surely not be unduly cumbersome. For instance, given information concerning each WFO's operational status (e.g., Warning Mode), the instruction to the National Environmental Satellite and Data Service (NESDIS) regarding GOES East might be "provide data for areas B and D each 5 min" rather than just "provide data for the East CONUS Sector each 5 min." (Of course, this would be in addition to other required data.) The processing software might have to be more sophisticated. But again, this should be doable and have a small cost to benefit ratio.

The maps shown in this office note allow one to see where some imaging time could be saved with little loss of data. For instance, for the one GOES imaging of both East and West CONUS Sectors from the wintertime position (Fig. 13), the time can be cut from 6.2 to 4.4 min--almost a 30% reduction--by imaging the reduced area shown in Fig. 20. Since much of the image "rectangle" represented in Fig. 13 does not cover the desired sectors and because of the relationship of the area actually scanned to the position and shape of the conterminous United States, the reduced coverage might be adequate and allow other necessary satellite operations to be done. This reduced area still follows the rules used for defining the East and West CONUS areas--that data be provided 1200 km to the west of the CONUS land mass, 800 km to the east, and 1000 km to the north and south (U.S. Government, 1989, p. SRSI-K-9).

6. CONCLUSIONS

As stated in the AWIPS SRS, there is a need to provide imagery over areas not specifically addressed in the SRS in order to support the operational requirements of the National Centers, of the WFO in Hawaii for a portion of the southern hemisphere, and of other non-NWS users of GOES imagery. (There is also a need for GOES soundings, but these can be obtained while imaging is being done.) In order to meet all these requirements as well as the requirement for 5-min images useful for WFO operations, it may be necessary to image one or more subareas rather than the complete East (or West) CONUS Sector when WFO's in only a small area (such as a two or three state area in the Midwest) are in the Warning Mode. A few subareas could be defined, each one capable of providing data over the Local Area of several WFO's. For instance, the small area in

Fig. 21 will likely cover the Local Areas of all WFO's in Kansas, Oklahoma, and northern Texas and can be imaged in 0.9 min as compared to 4.4 min for the whole East CONUS Sector. (The Local Area is a 750 X 750 km area, considerably larger than a WFO's area of responsibility.)

The maps in this office note and the software used to prepare them and compute scan times should be useful in further refining the requirements for GOES data.

ACKNOWLEDGMENTS

I am indebted to several people who assisted me in various ways in the preparation of this paper. I wish to thank Marcus Shellman, Ben Watkins, and Jamie Hawkins of NESDIS for providing GOES documentation; Ray Komajda of MITRE Corporation for information on the use of his GVAR software; Chuck Hoffeditz of the Office of Hydrology for information on the use of the World Data Bank data for preparing maps on AFOS; Dave Shimomura and Fee Jing Yen of NMC for information on the use of the World Data Bank files; Wendy Wolf of the Techniques Development Laboratory (TDL) for guidance on preparing graphics on the AFOS GDM; Dave Unger and Tim Chambers of TDL for assistance in transferring data from the National Oceanic and Atmospheric Administration's (NOAA's) Central Computer Facility to AFOS; and especially Jack Jalickee of the Office of Systems Development for his helpful suggestions, mathematical expertise, and the mapping equations in Appendix II. Some of the software used had its origin in the work of John Stackpole of NMC; Jack Pellett, then of TDL; Wendy Wolf of TDL; and Sandy MacDonald, then of the NWS Western Region.

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Ford Aerospace, 1986: Imaging subsystem performance specification. Specification No. 565056, Rev. A, Ford Aerospace & Communications Corporation, Western Development Laboratories Division, Palo Alto, Calif., 113 pp.

Komajda, R. J., 1988: Users Manual for a Program to Calculate GVAR Data Volumes, Mitre Working Paper No. WP-88W00352, Mitre Corporation, McLean, Va., 27 pp.

Table 1. Summary of scan information concerning the areas that are defined in the draft AWIPS-90 outphases SRS (U.S. Government, 1989). The minimum and maximum of the azimuth and of the elevation are also given in microradians (mrad). The total imaging time is the sum of scan time, space looks, star sequences, and blackbody calibrations; each value is rounded to tenths of minutes. The entry spanning two lines labelled "MARD Composite" represents a composite from GOES East and West for the MARD area. Another such entry labelled "Hemispheric Composite" represents a composite for the northern hemisphere. "E-W CONUS" is the area that covers both the East and West CONUS Sectors. The planned longitudes of GOES East and West are 75° W and 135° W, respectively. With only one GOES, the plan is for it to be at 98° W in the summer and 108° W in the winter.

Sector	Scanned by	Satellite Longitude (deg W)	Azimuth Minimum (mrad)	Azimuth Maximum (mrad)	Elevation Minimum (mrad)	Elevation Maximum (mrad)	Scan Time (min)	Space Looks (min)	Star Sequences (min)	Blackbody Calibration (min)	Total Imaging (min)
East CONUS	GOES East	75	-99252	35853	41869	141549	4.4	0.1	0.0	0.0	4.4
West CONUS	GOES West	135	-16409	103527	53387	136939	3.4	0.1	0.0	0.0	3.5
Alaska	GOES West	135	-79717	46108	109970	150962	1.7	0.0	0.0	0.0	1.8
Hawaii	GOES West	135	-87997	-34109	31892	81172	1.3	0.0	0.0	0.0	1.3
Puerto Rico	GOES East	75	-6126	49106	27564	77740	1.3	0.0	0.0	0.0	1.4
MARD	GOES East	75	-79026	3278	66596	129764	2.0	0.0	0.0	0.0	2.1
Composite	GOES West	135	19090	79058	65237	128181	1.7	0.0	0.0	0.0	1.8
E-W CONUS	One GOES	98	-96587	92597	43265	141377	5.4	0.2	0.0	0.7	6.2
E-W CONUS	One GOES	108	-73615	112753	43498	141162	5.3	0.2	0.0	0.7	6.2
MARD	One GOES	98	-55028	54028	65045	130677	2.5	0.0	0.0	0.0	2.5
MARD	One GOES	108	-31365	78395	65592	130328	2.5	0.0	0.0	0.0	2.5
Hemispheric	GOES EAST	75	-86769	119183	0	151872	8.9	0.2	0.0	0.7	9.8
Composite	GOES West	135	-150836	86796	0	151872	10.0	0.3	0.0	0.7	10.9
Hemispheric	One GOES	98	-151340	147540	0	151872	11.9	0.4	0.0	0.7	13.0
Hemispheric	One GOES	108	-151340	151572	0	151872	12.1	0.4	0.0	0.7	13.2

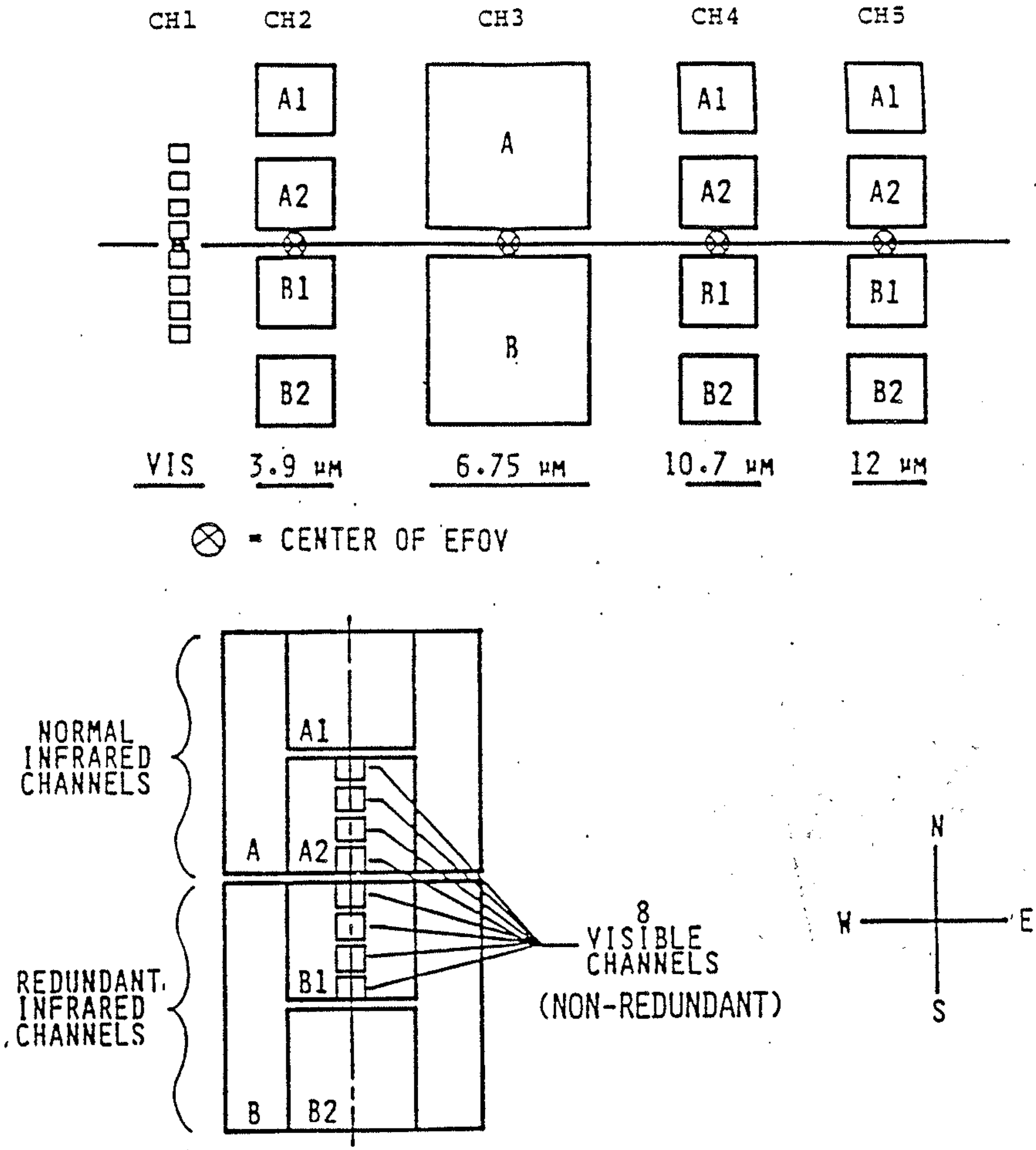

Figure 1. The configuration of the imager detectors of GOES I through M reproduced from Integral Systems (1988).

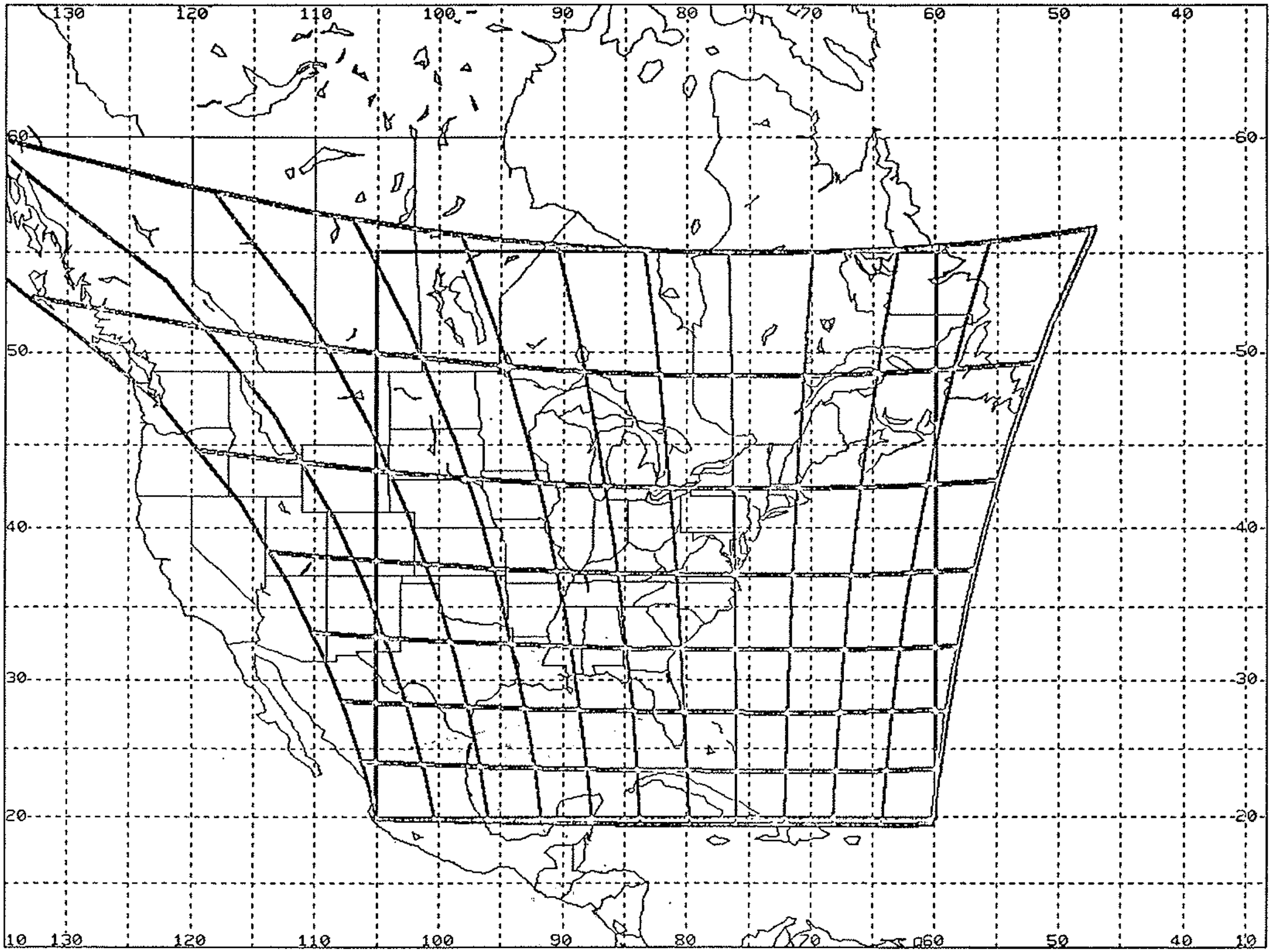

Figure 2. The "original" East CONUS Sector as defined in U.S. Government (1986) on the Mercator projection (20° to 55° N latitude, 60° to 105° W longitude). In this and following maps, the dark, relatively horizontal arcs are lines of equal elevation for the imager. The dark, relatively vertical arcs are lines of equal azimuth. The total imaging time is calculated to be 3.2 min.

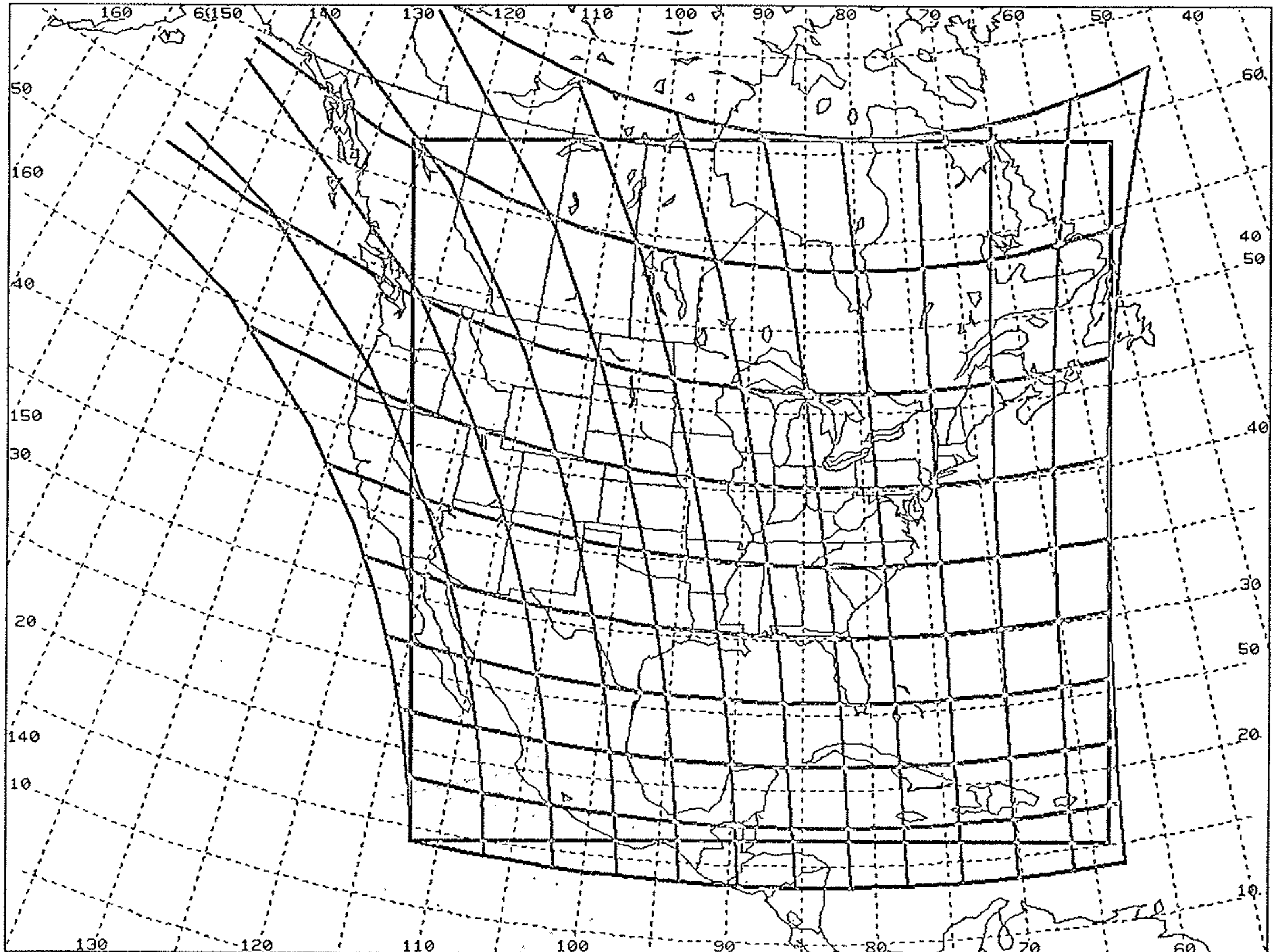

Figure 3. The "new" East CONUS Sector as defined in U.S. Government (1989) on the Lambert map projection. The termination of the azimuth and elevation lines at the upper left is essentially the limit of the satellite's view. The total imaging time is computed to be 4.4 min.

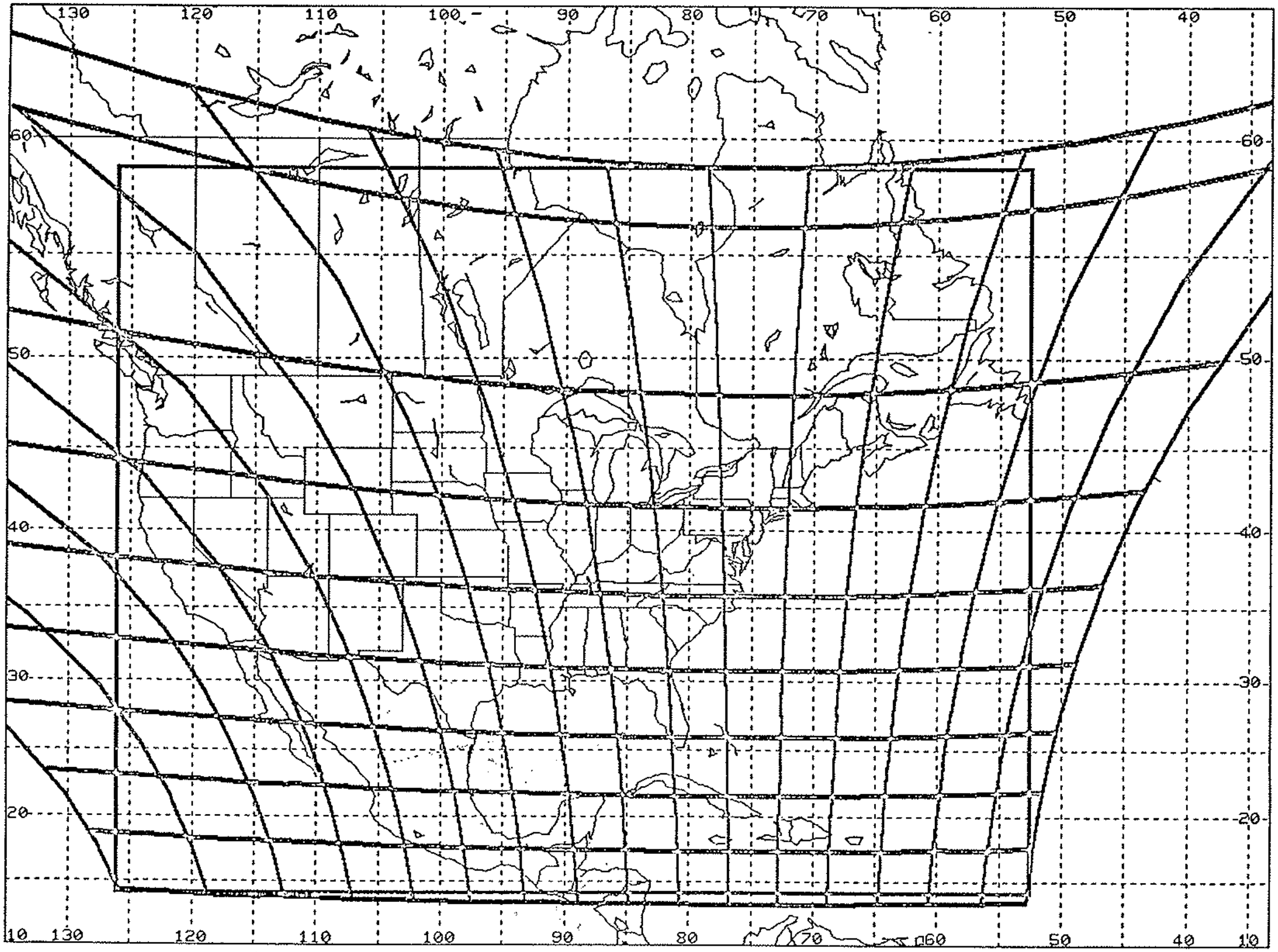

Figure 4. The area that would be scanned based on scanning all latitudes and all longitudes between the minima and maxima latitudes and longitudes defined by the corner points of the "new" East CONUS Sector. The total imaging time is calculated to be 6.3 min.

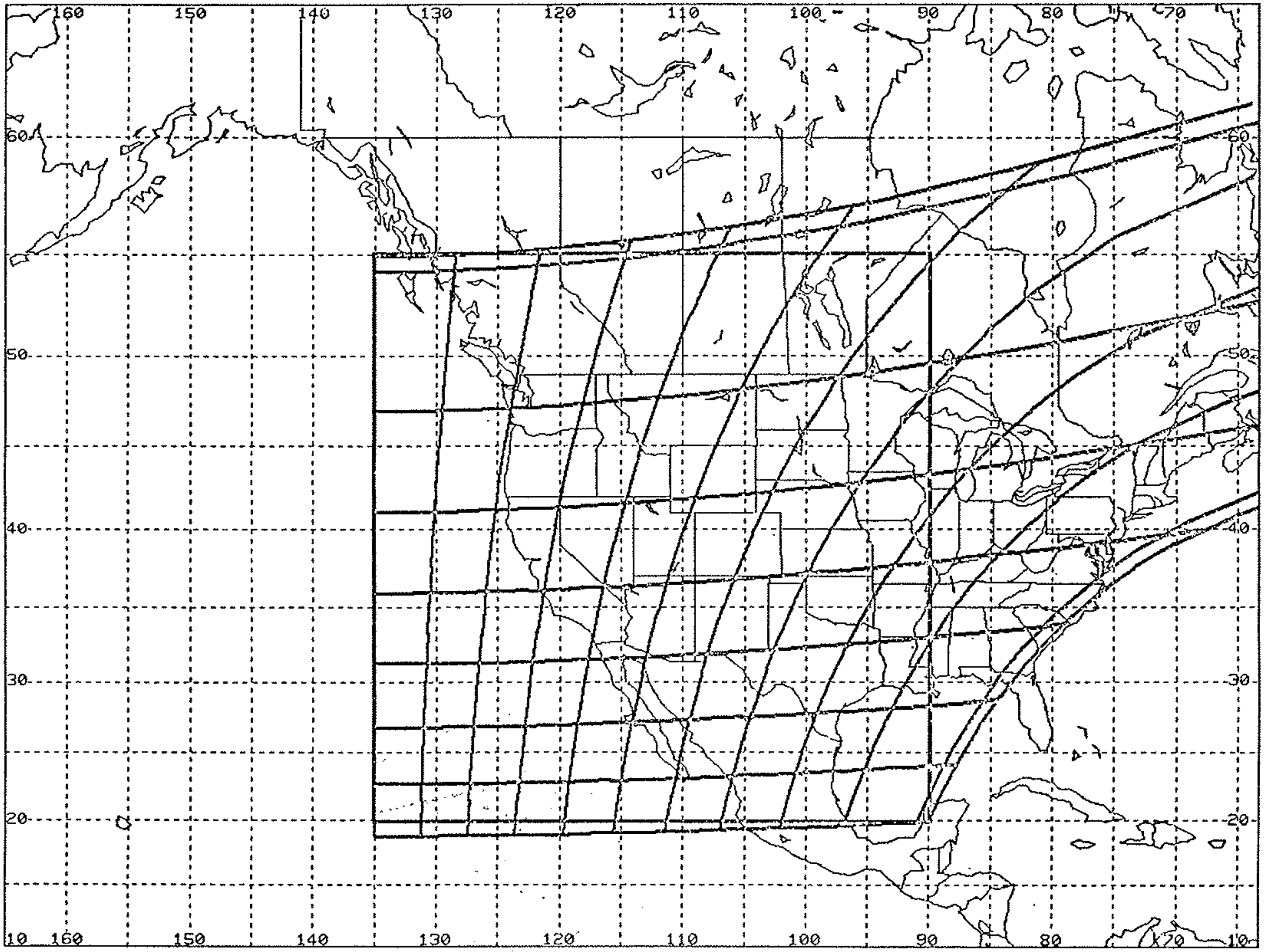

Figure 5. The "original" West CONUS Sector defined on the Mercator map projection. The total imaging time is computed to be 3.0 min.

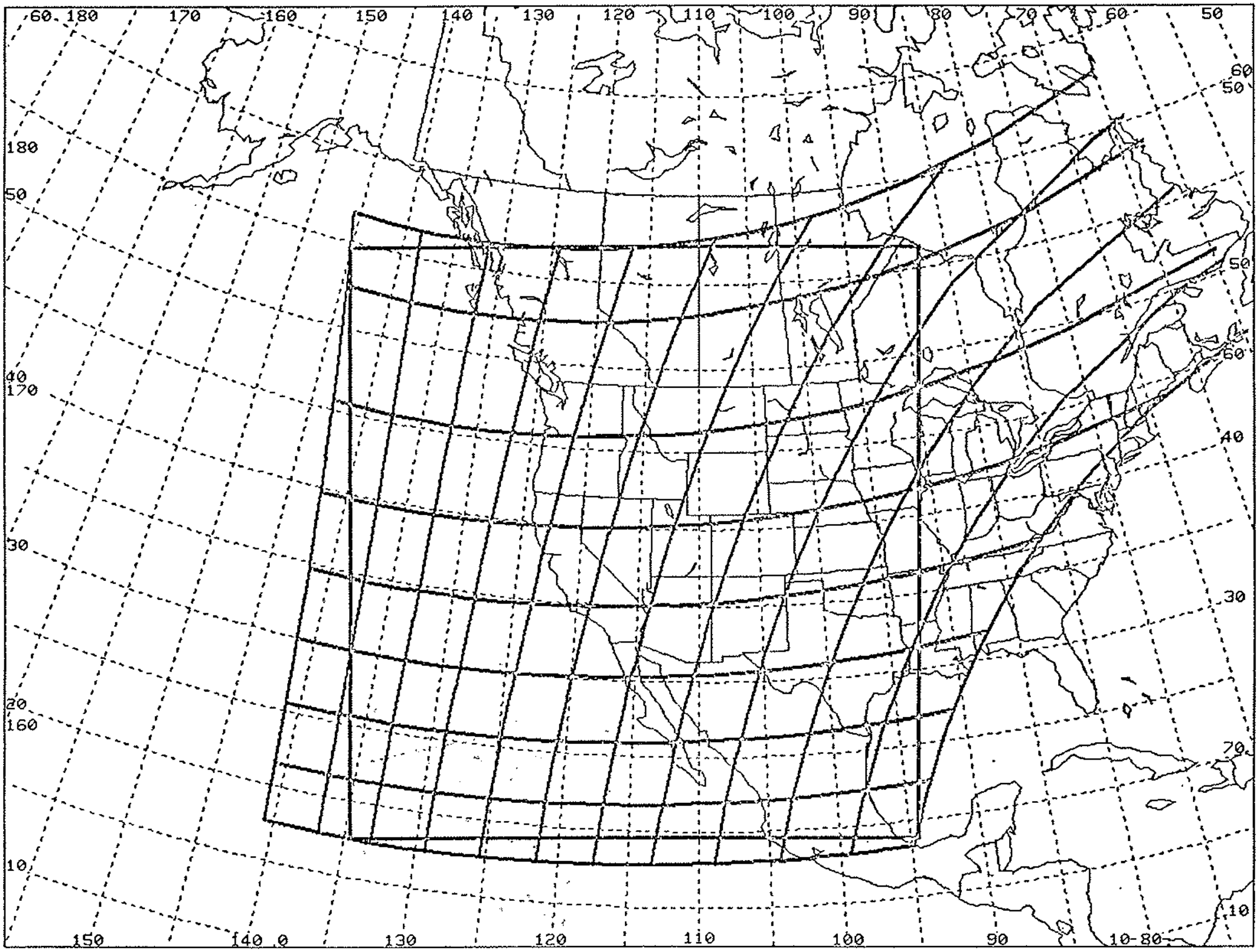

Figure 6. The "new" West CONUS Sector defined on the Lambert map projection. The total imaging time is computed to be 3.5 min.

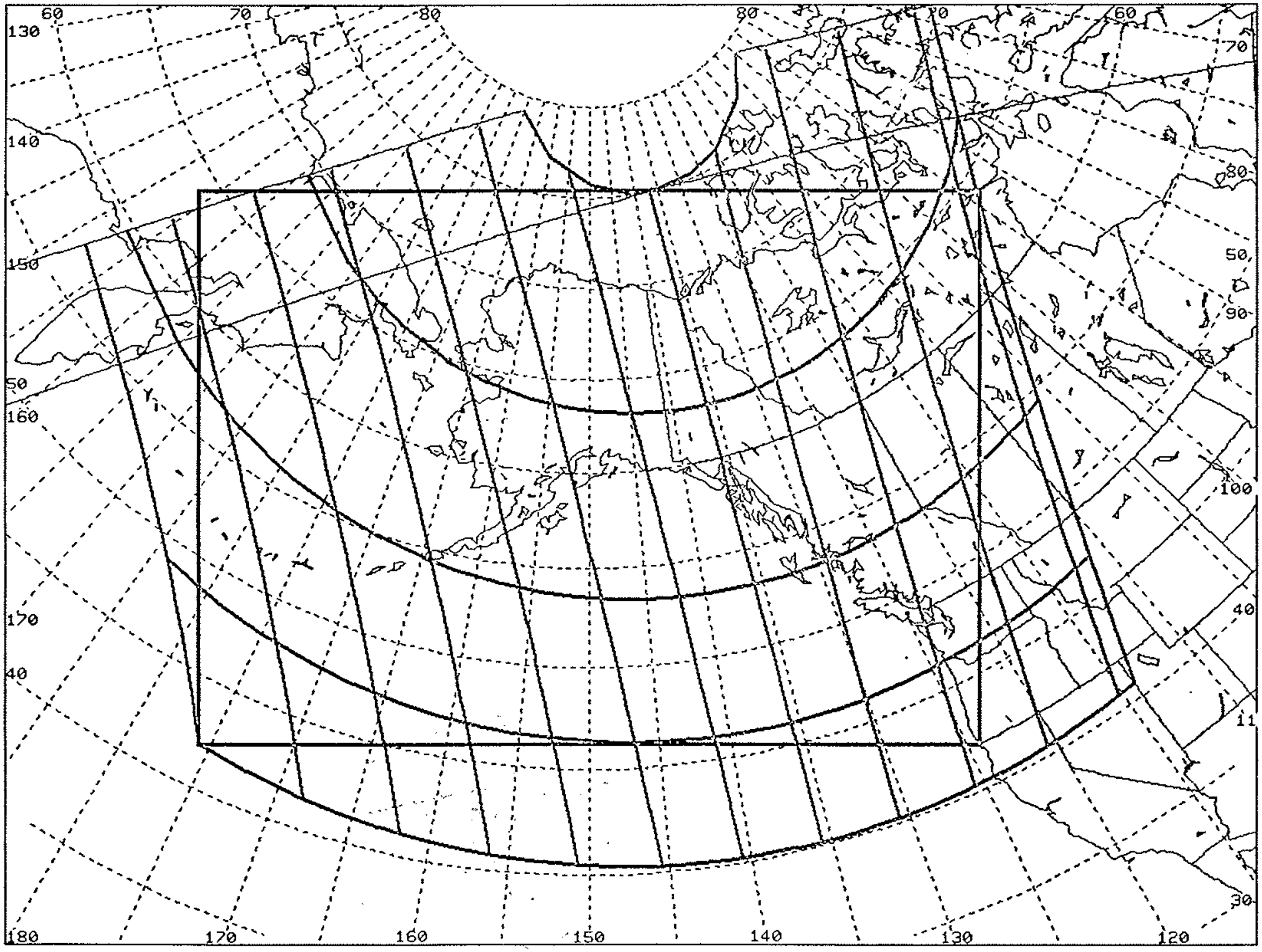

Figure 7. The Alaska Sector defined on the polar stereographic map projection. The thin lines arcing across the top of the map represent the edge of the earth as viewed by the satellite over the range of elevation scanned (upper) and the 75° line on the earth from the subsatellite point. The total imaging time is computed to be 1.8 min.

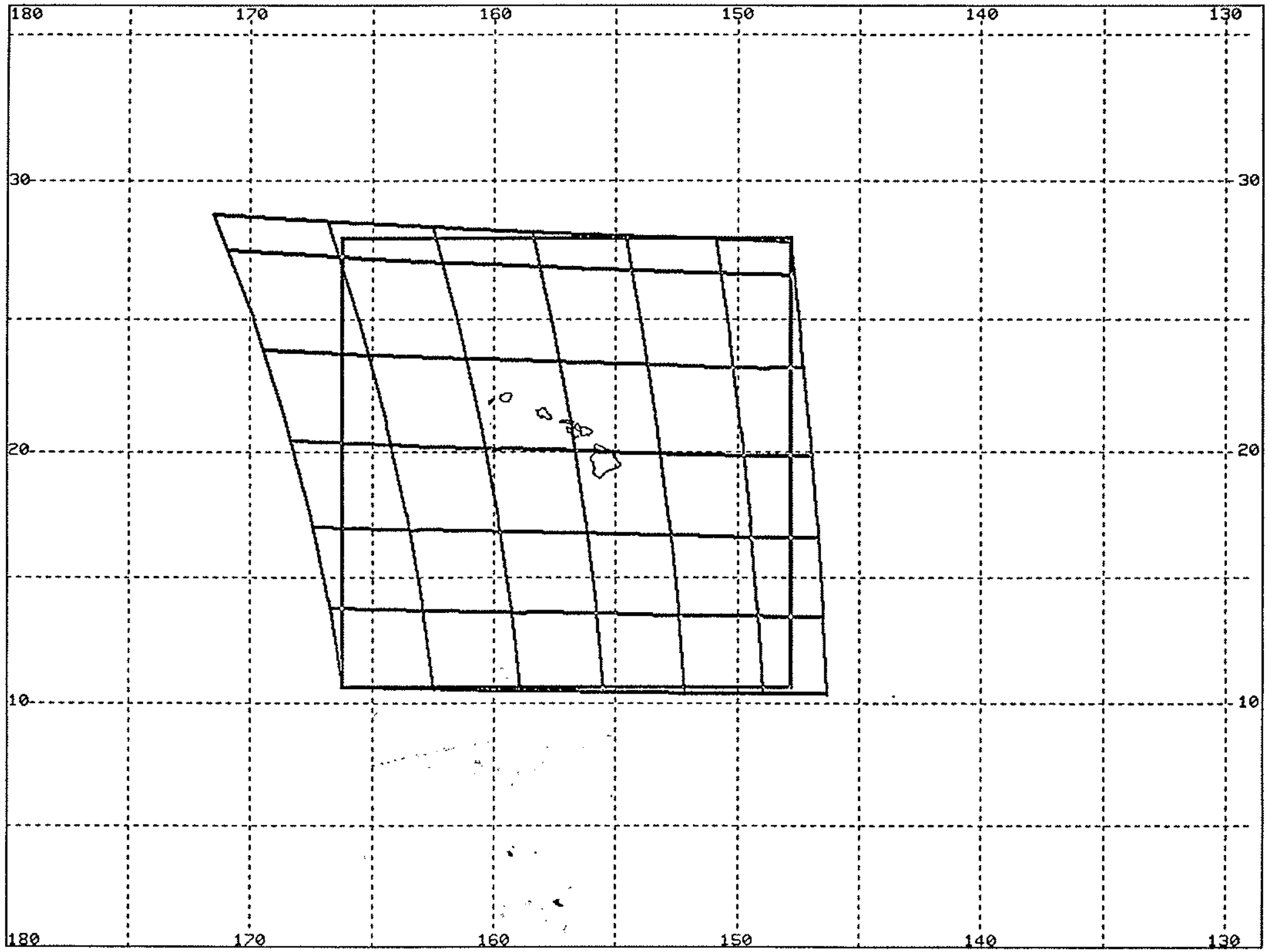

Figure 8. The Hawaii Mercator Sector. The total imaging time is computed to be 1.3 min.

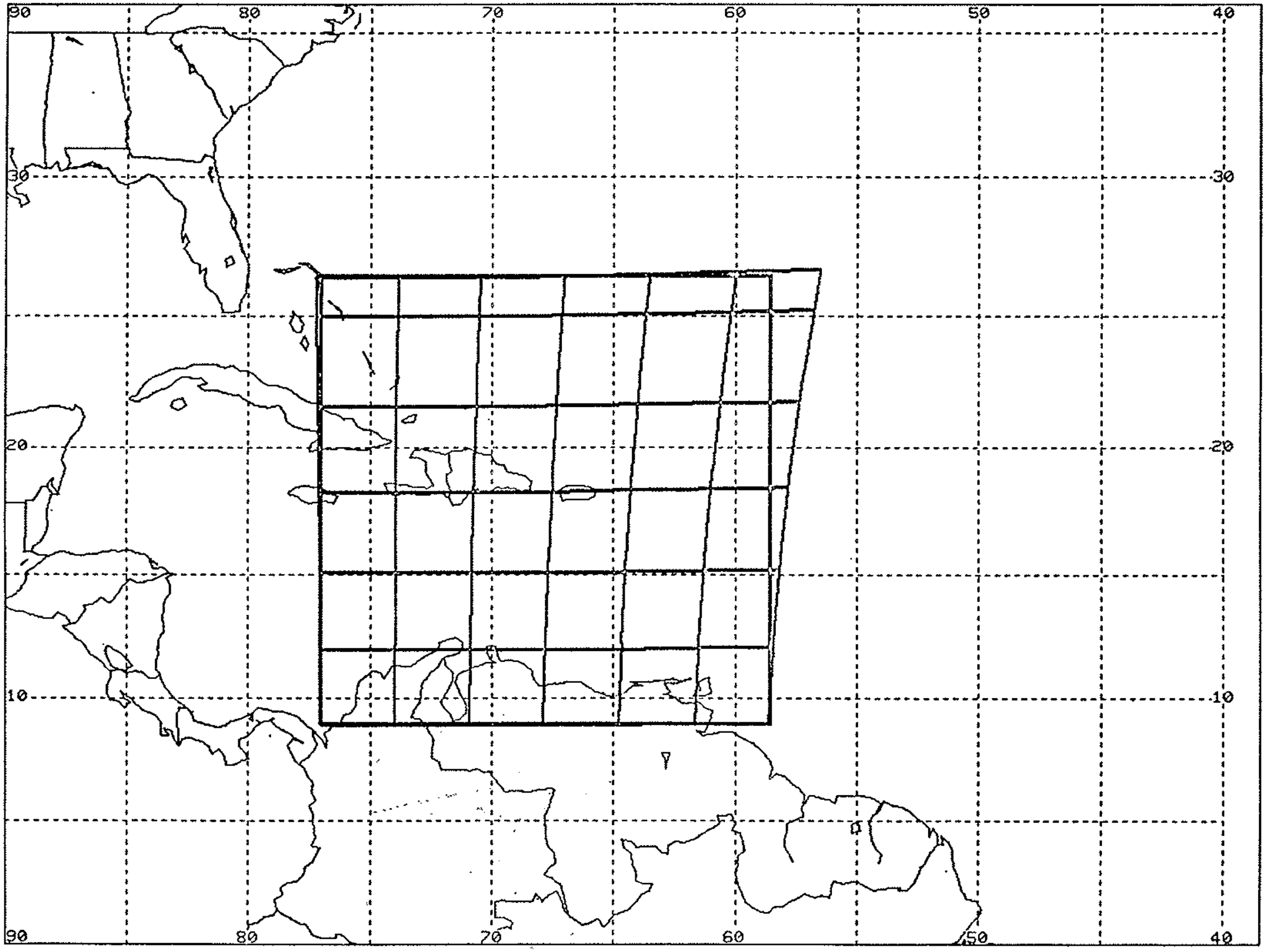

Figure 9. The Puerto Rico Mercator Sector. The total imaging time is computed to be 1.4 min.

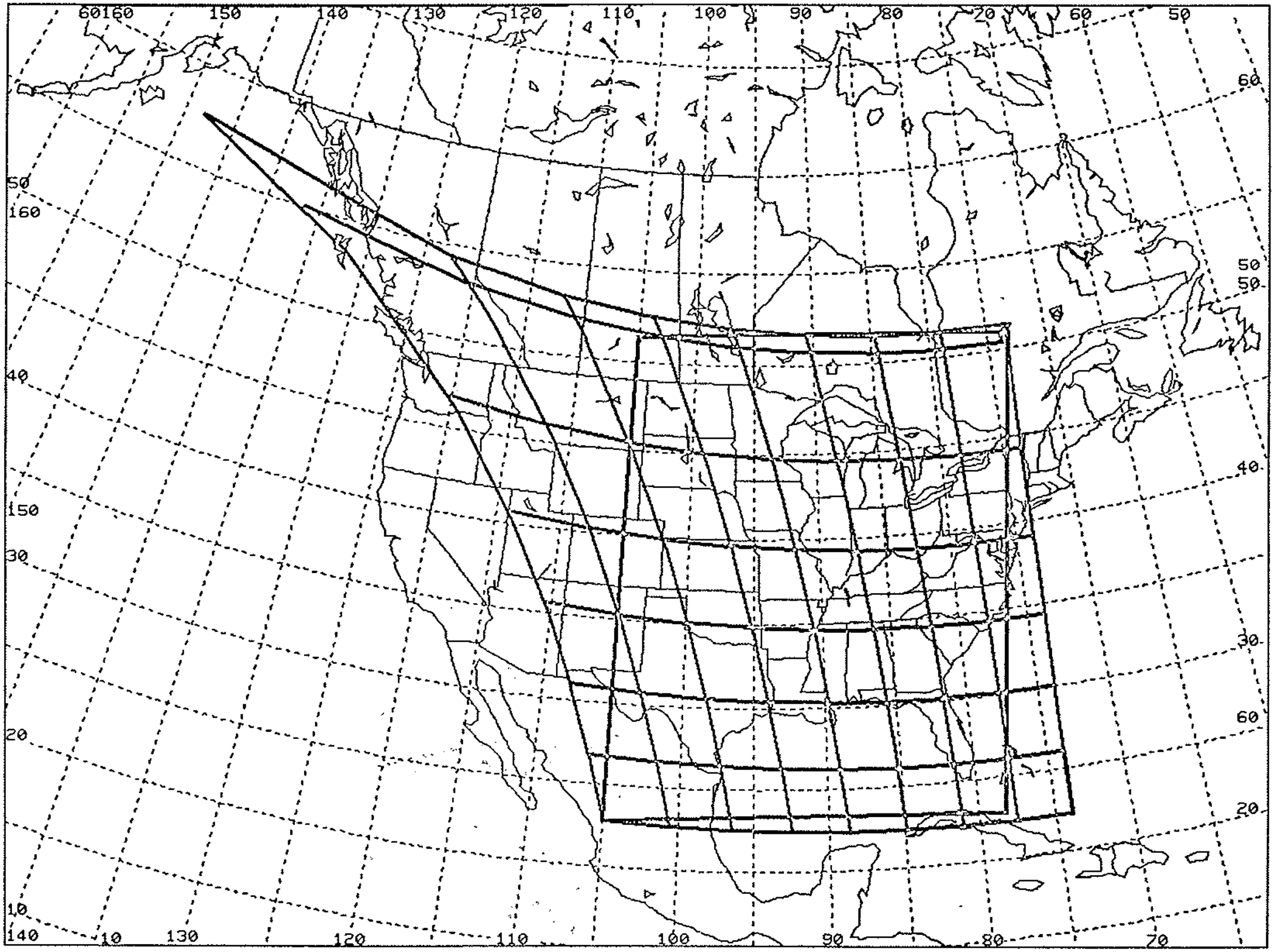

Figure 10. The portion of the MARD Sector that would be scanned by GOES East. The total imaging time is computed to be 2.1 min.

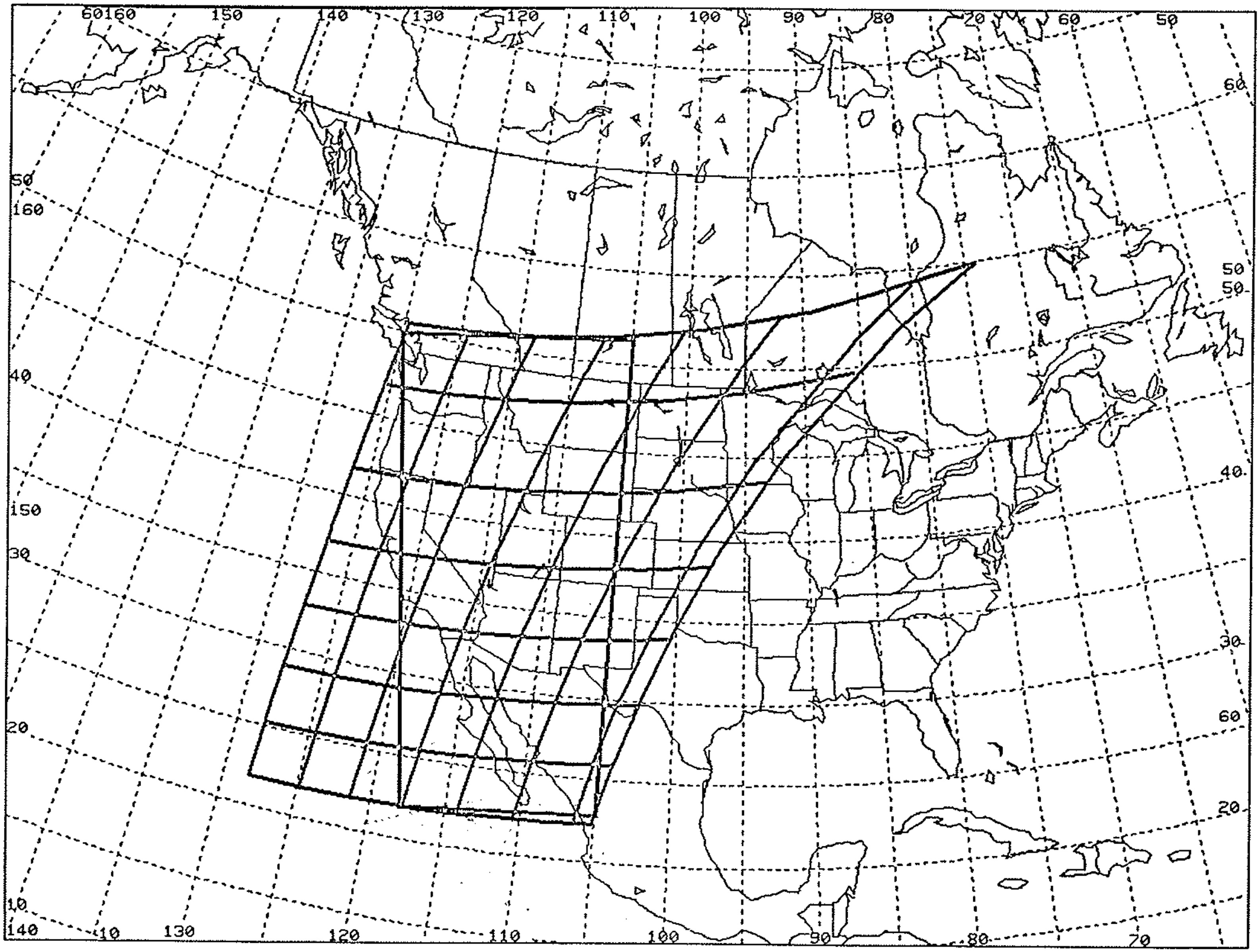

Figure 11. The portion of the MARD Sector that would be scanned by GOES West. The total imaging time is computed to be 1.8 min.

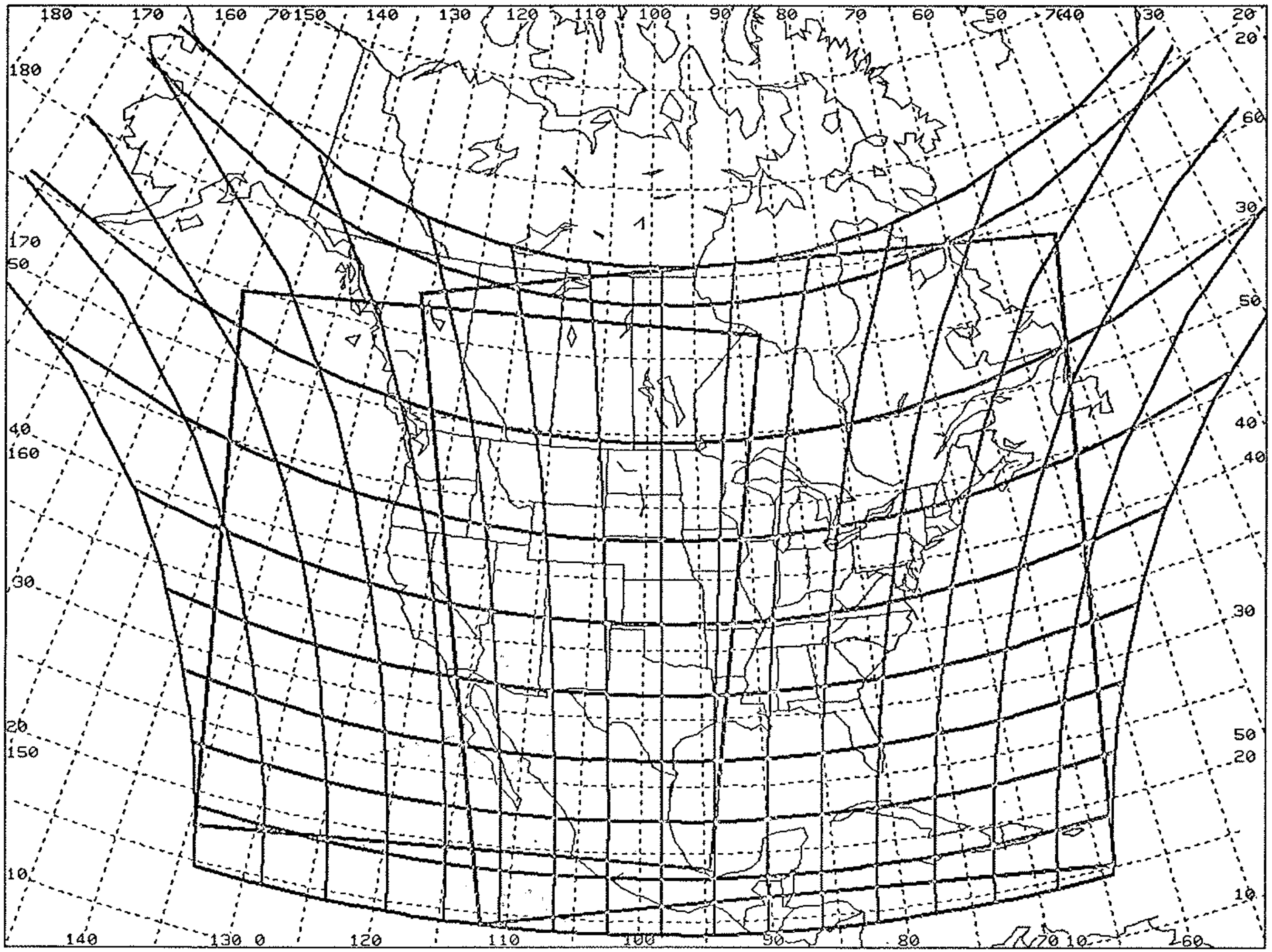

Figure 12. The area that would be scanned by a single GOES located at its summertime position of 98° W. The two rectangles are the East and West CONUS Sectors. The map is oriented with the satellite longitude, 98° W. The total imaging time is computed to be 6.2 min.

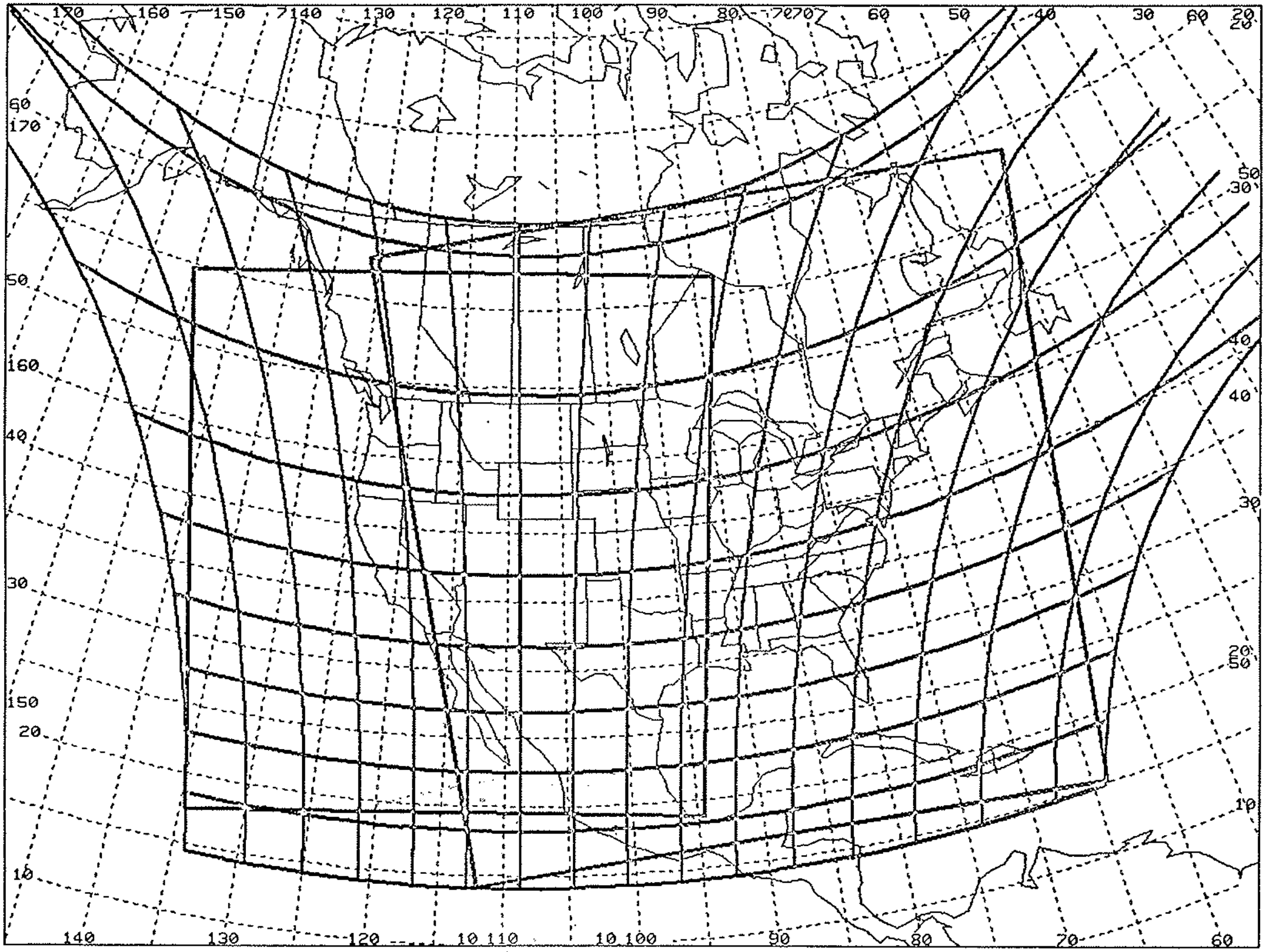

Figure 13. Same as Fig. 12, except for GOES at its wintertime position of 108° W. The total imaging time is computed to be 6.2 min.

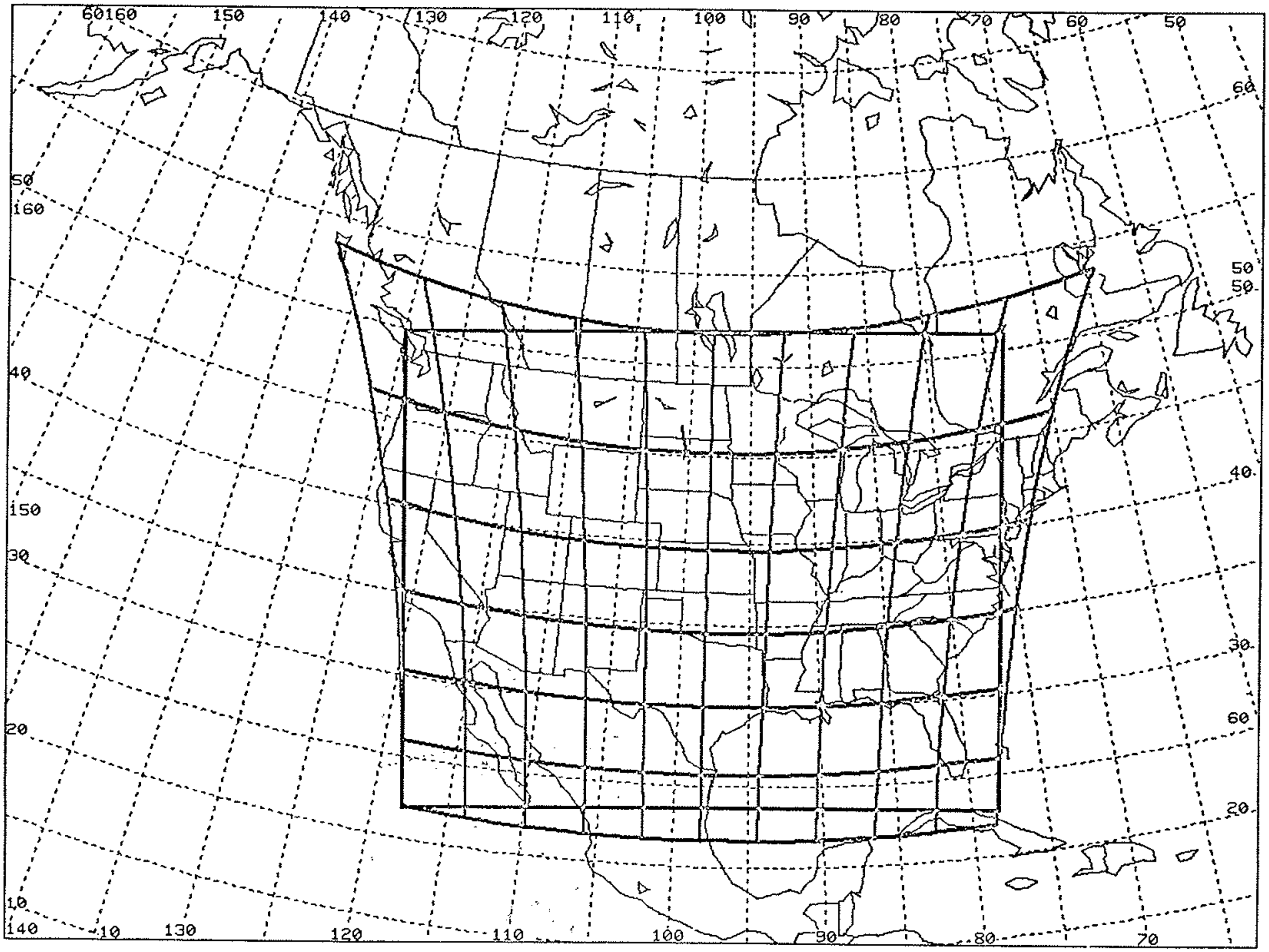

Figure 14. The MARD Sector scanned from a single GOES in its summertime position of 98° W. The total imaging time is computed to be 2.5 min.

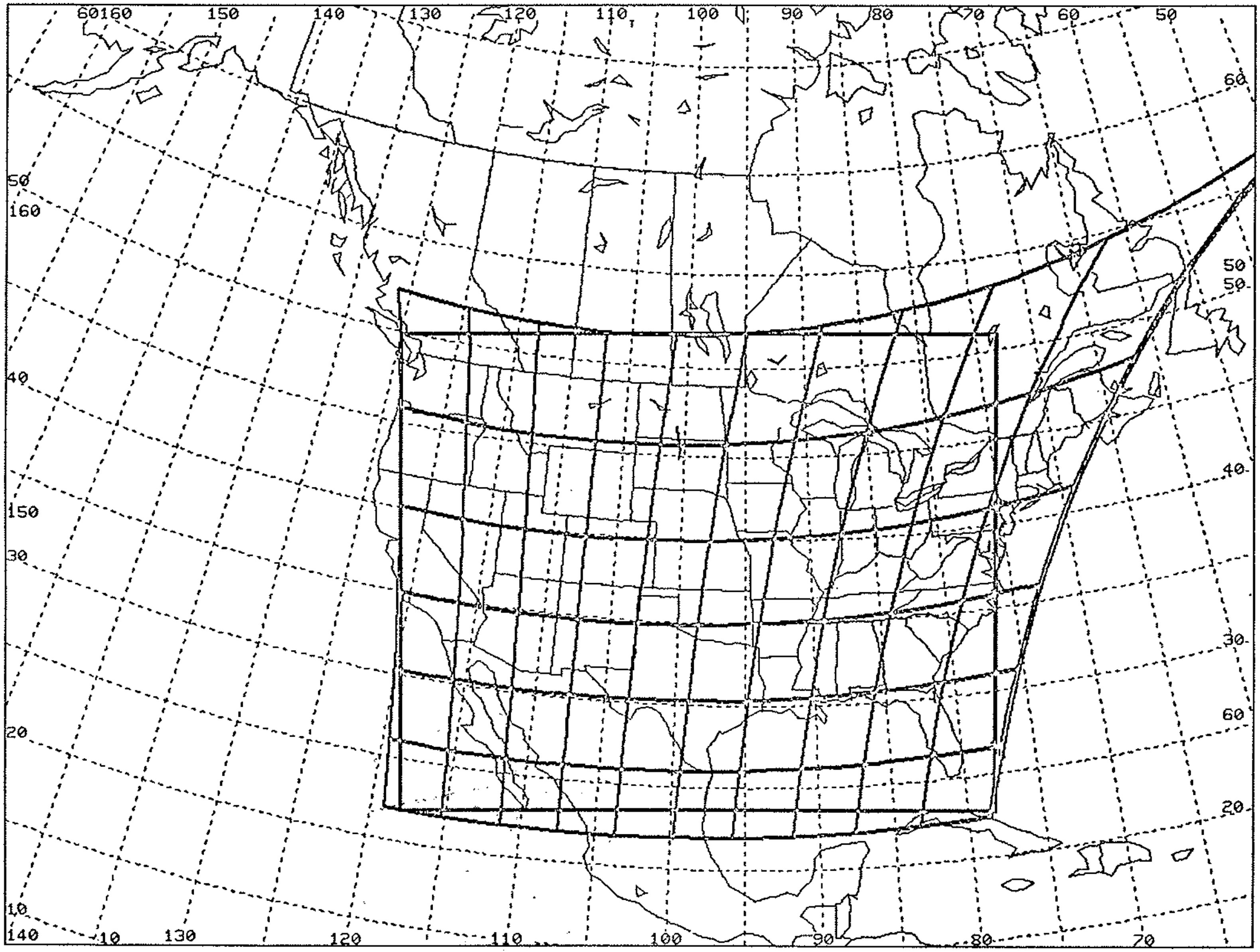

Figure 15. Same as Fig. 14, except for GOES in its wintertime position of 108° W. The total imaging time is computed to be 2.5 min.

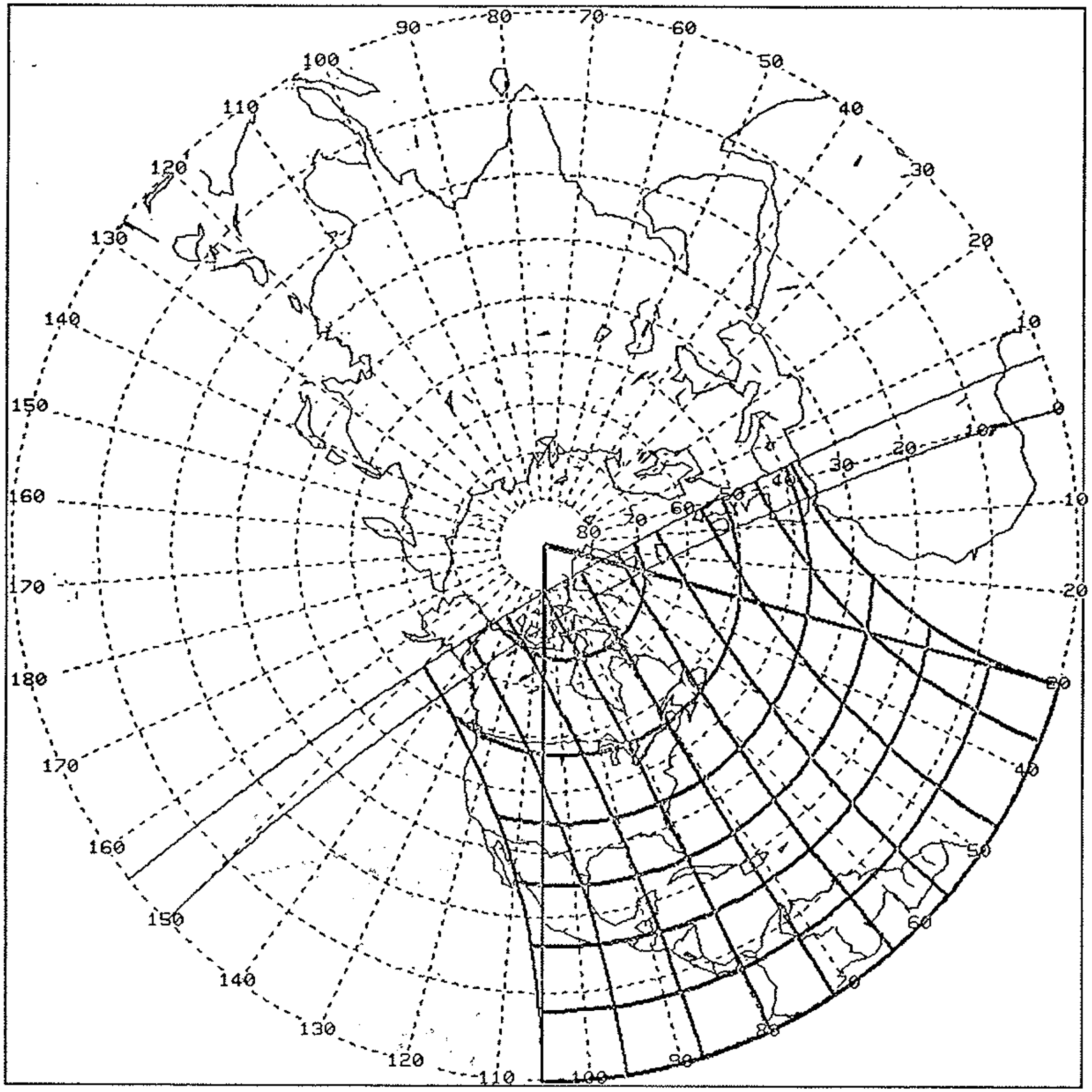

Figure 16. The portion of the northern hemispheric polar stereographic map scanned by GOES East. The fine-line arcs are the edge of the earth as seen from the satellite (upper) and the 75° line from the sub-satellite point. The total imaging time is computed to be 9.8 min.

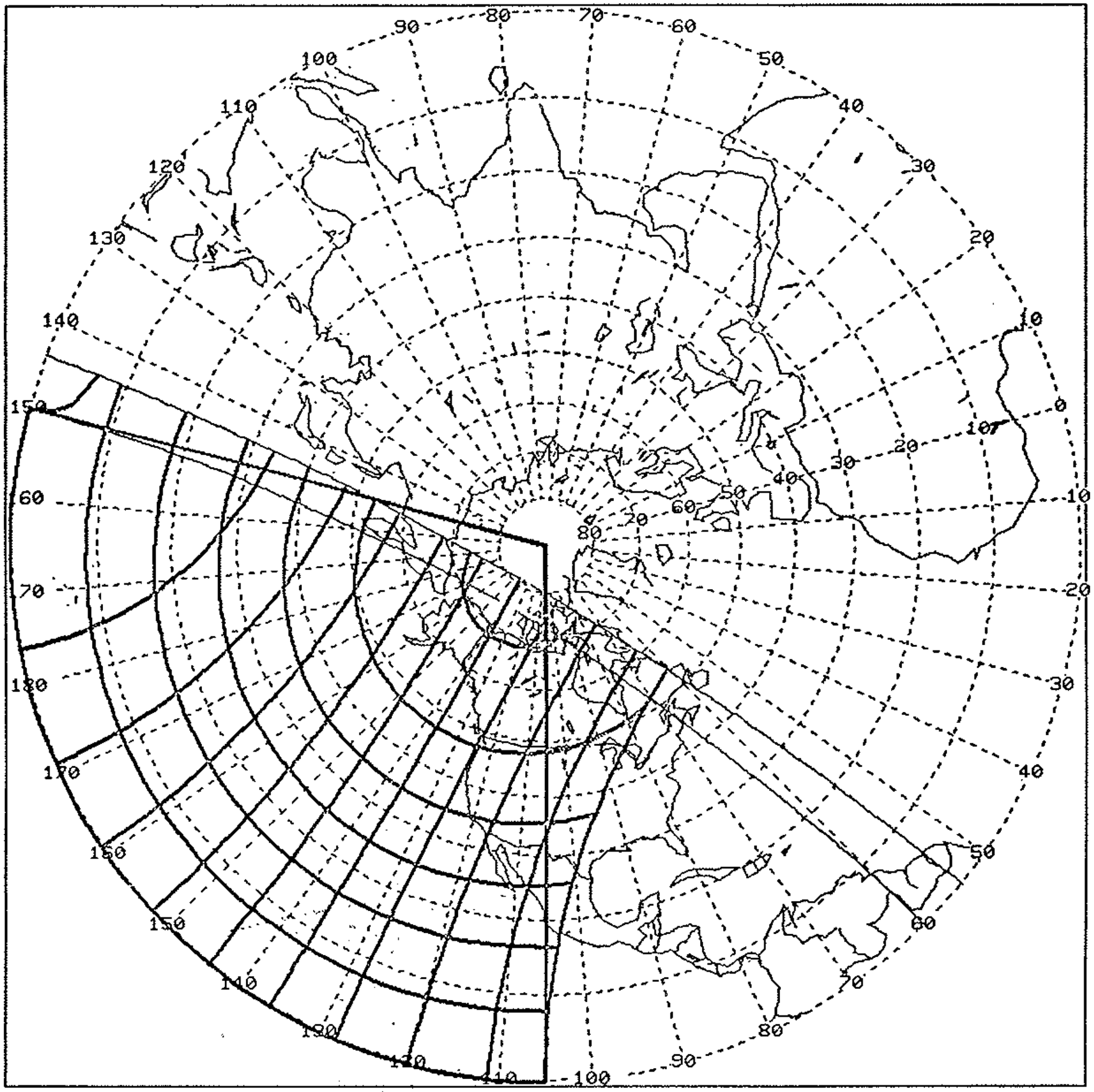

Figure 17. Same as Fig. 16, except for the area scanned by GOES West. The total imaging time is computed to be 10.9 min.

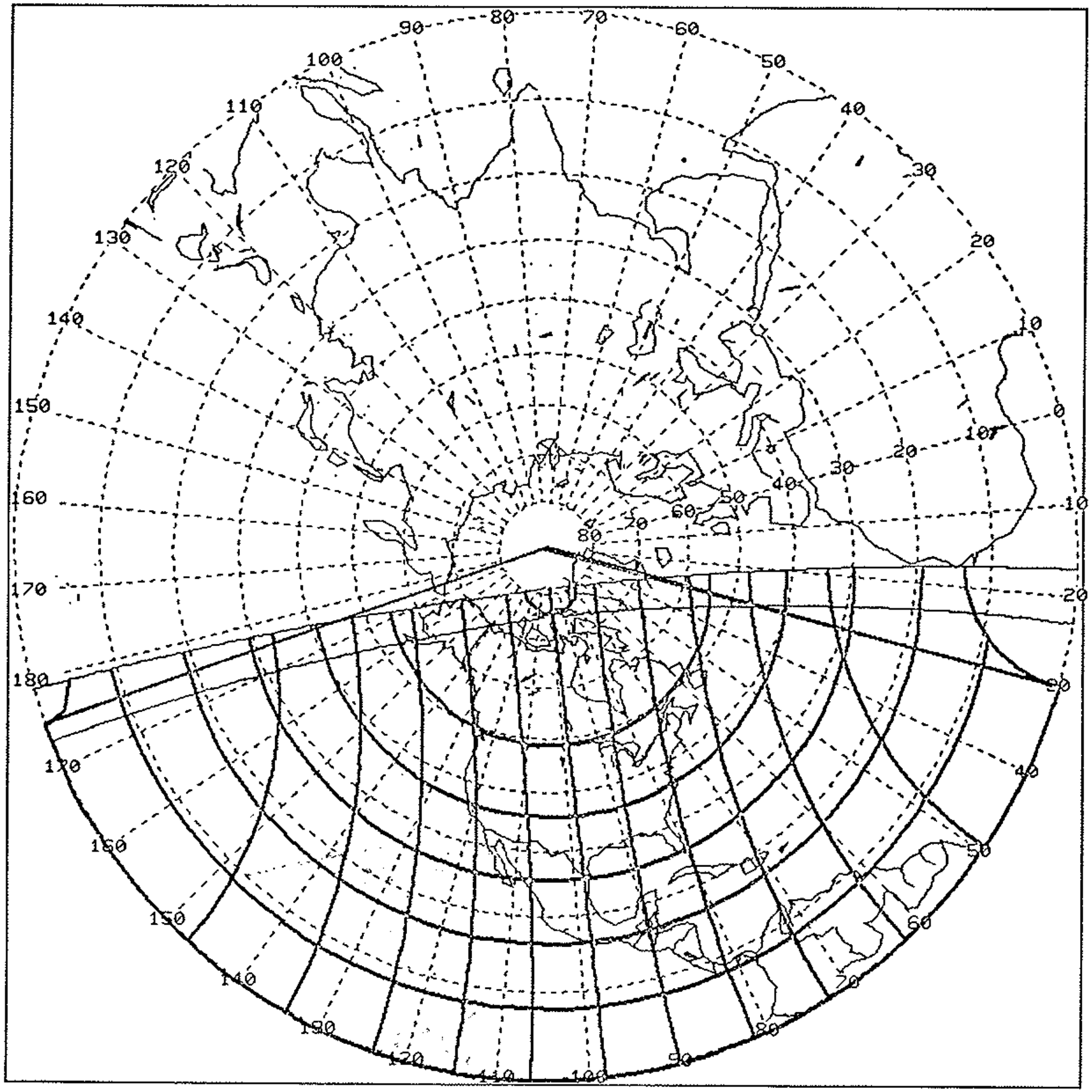

Figure 18. The hemispheric area over which data would be provided from a single GOES at 98^{o} W. The total imaging time is computed to be 13.0 min.

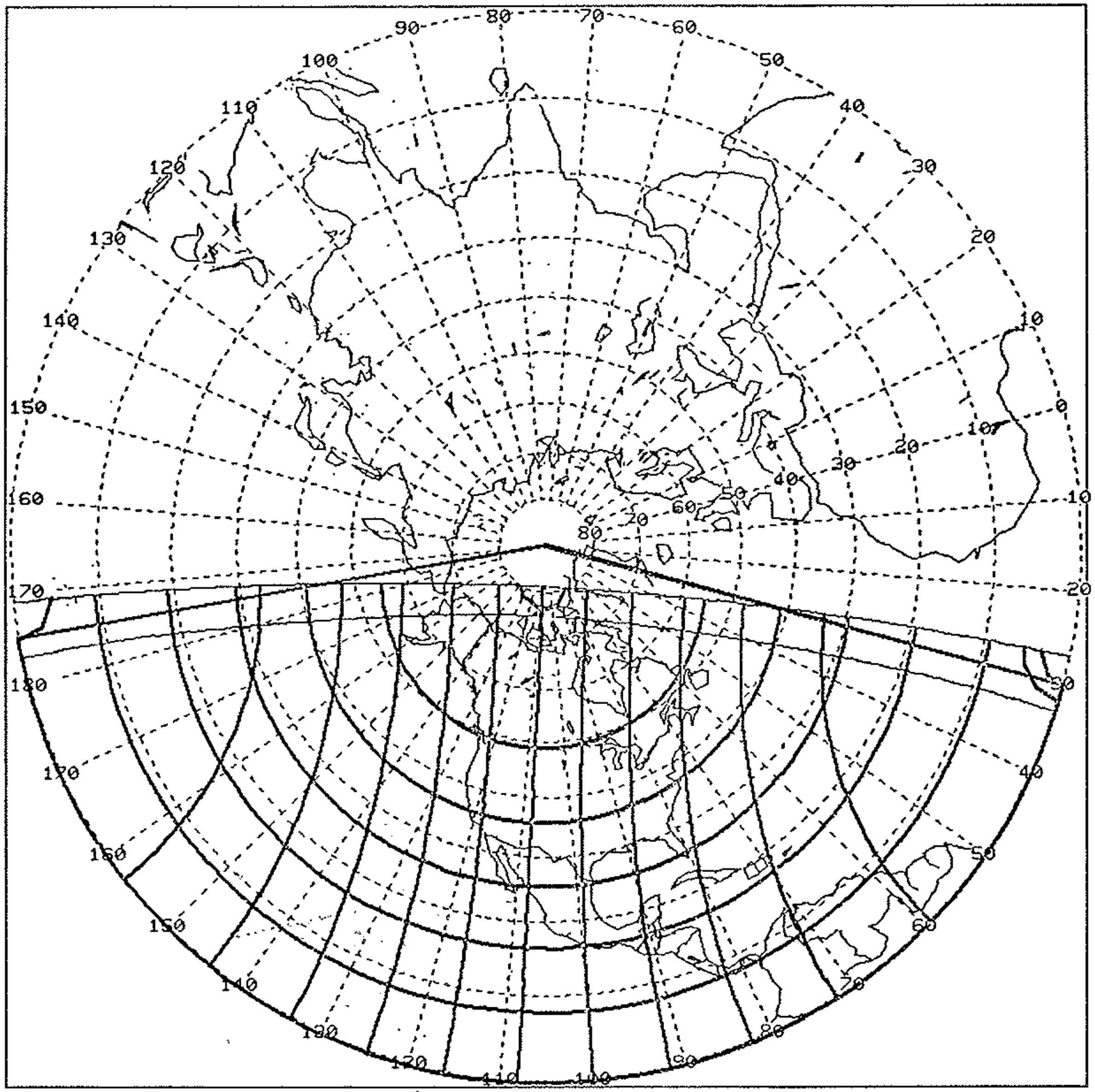

Figure 19. Same as Fig. 18, except for GOES at 108° W. The total imaging time is computed to be 13.2 min.

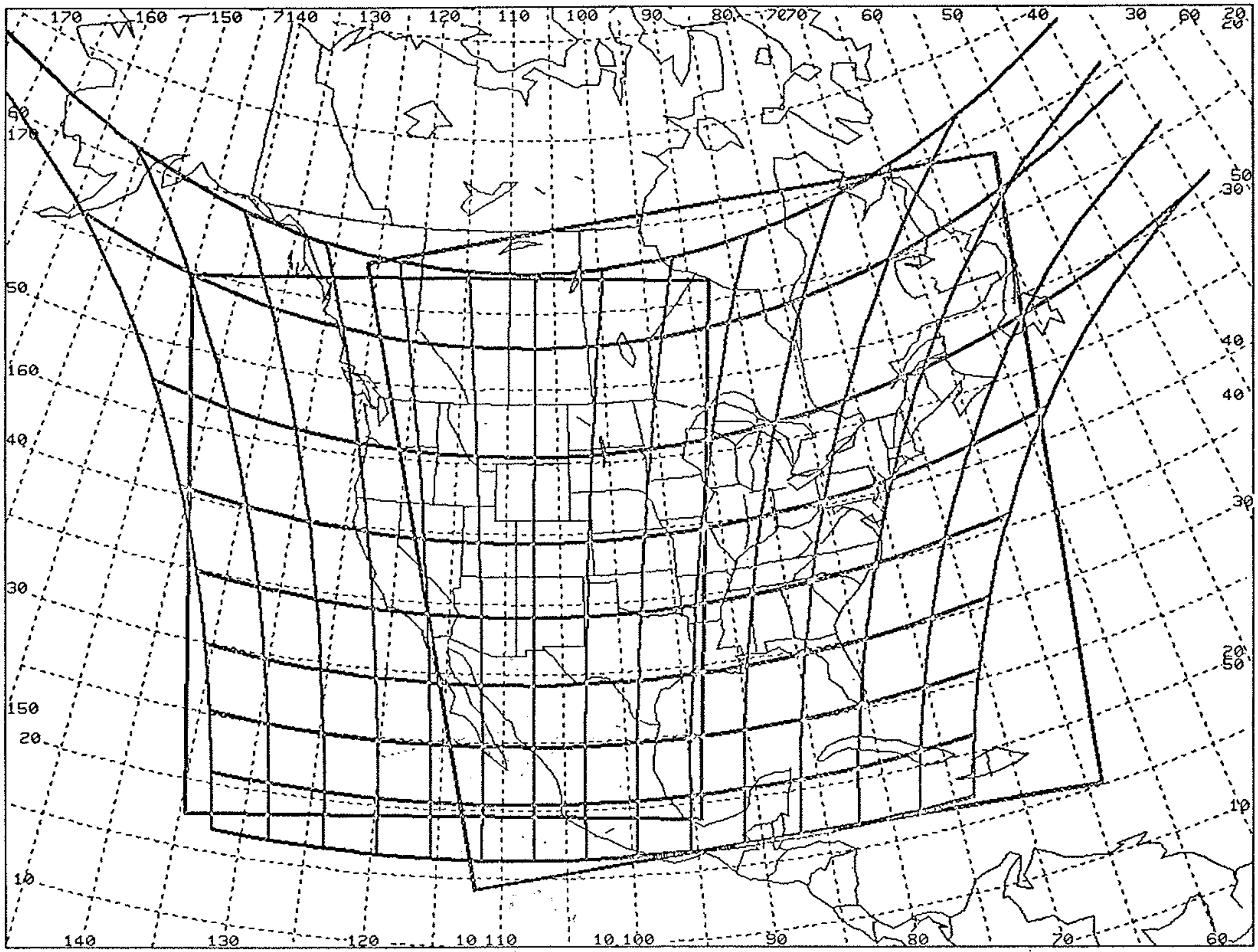

Figure 20. A reduced area that can be scanned by a single satellite from 108° W that covers much of the East and West CONUS Sectors. The total imaging time is computed to be 4.4 min.

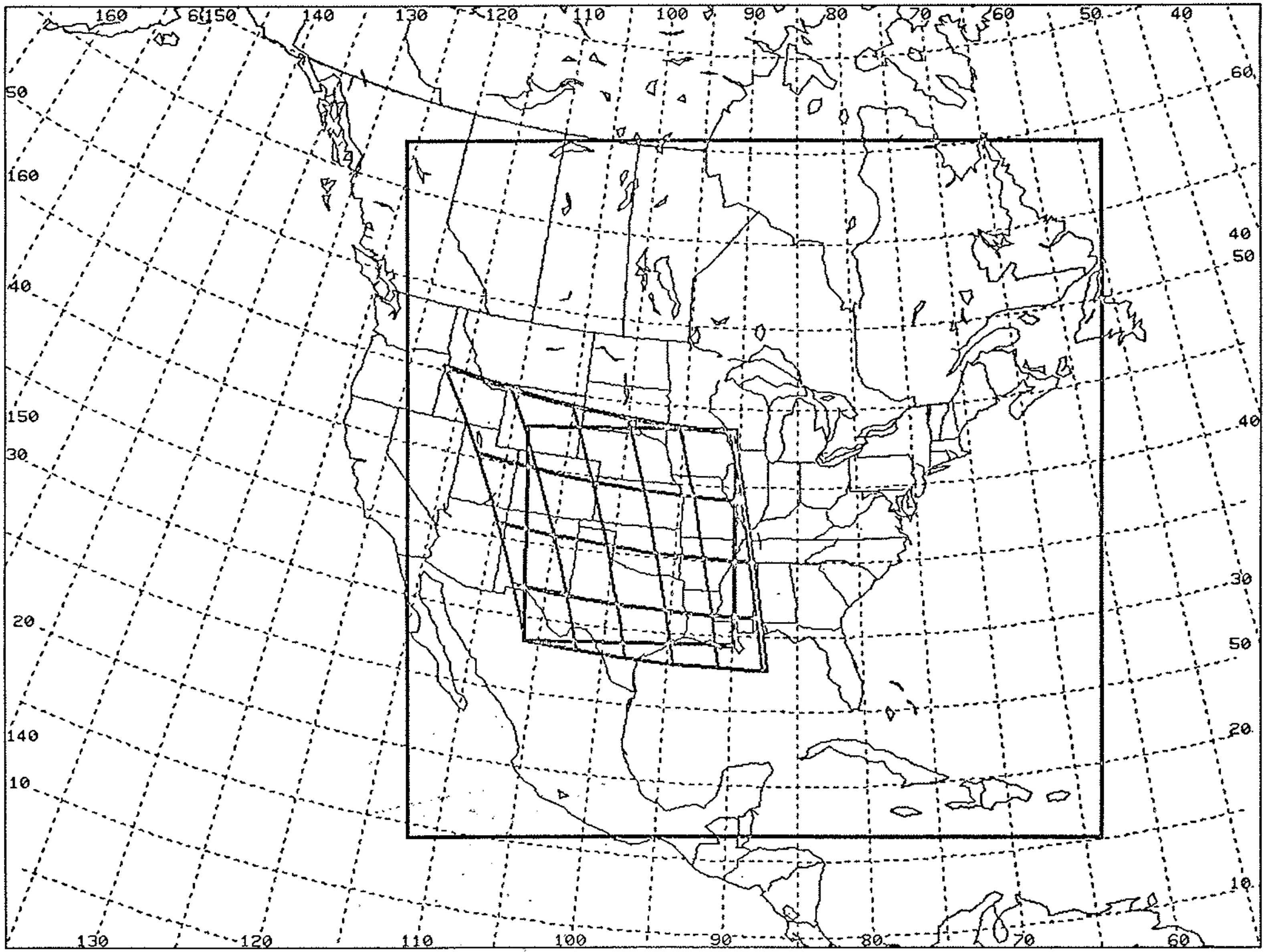

Figure 21. The small rectangle will likely cover the Local Areas of all WFO's in Kansas, Oklahoma, and northern Texas. The large rectangle is the East CONUS Sector. The total imaging time for the small rectangle is computed to be 0.9 min.

APPENDIX I

Mapping with the World Data Bank Geography

A detailed world geography of approximately 6 million points is maintained by NMC on NOAA's Central Computer Facility. For each of five areas--essentially North America, South America, Europe, Asia, and Africa--there are three files of data, one containing coastlines, islands, and lakes; one containing international boundaries; and one containing rivers. Each of these files also contains additional definition within the primary classification. For instance, lakes are further subdivided according to their importance and permanency. In addition, the North America area has an additional file containing U.S. state and Canadian province boundaries. (The unwary user may be surprised to find Mexico in "South America" and the Aleutian Islands in "Asia.")

These files contain records of data that define points along a particular geographic feature. These points may be less than one kilometer apart. For this particular task, the data were transferred via floppy disk to AFOS, and the volume of data was too large to deal with both in the transfer process and for use on AFOS. Therefore, for each record, the first and last points were transferred; for another point to be transferred, the cumulative distance from the previous point transferred and all other points in the record up to and including the next point to be transferred was required to be 50 km, except that for all latitudes north of 72° N, all latitudes south of 7° N, all west longitudes east of 53° W, and all east longitudes, the distance was required to be 100 km. By using this filtering process, by transferring only major features in all files, and by transferring rivers for only North America, the number of points was reduced to about 169,000--a manageable number.

Further filtering was necessary to not overflow the memory of the AFOS GDM. Besides beginning and ending points in each record, a point was plotted only if its distance from a previous plotted point exceeded a certain number of pixels. In addition, a closed contour was not plotted unless it exceeded a certain number of points. These two software parameters were adjusted as necessary to get desired detail (e.g., the Aleutian Islands on some maps) and to circumvent GDM memory overflow. Generally, a distance between points of 25 to 50 pixels was necessary to prevent overflow. Maps created after these two filtering processes are sufficient for the purpose at hand, but lack detail when zoomed on AFOS.

APPENDIX II

Mapping Equations

The set of equations for determining latitude and longitude on the earth given azimuth and elevation of the satellite imager and vice versa were provided by Jack Jalickee. For a satellite over the equator, the equations for the azimuth angle (az) and the elevation angle (el), given the latitude (lat), longitude relative to the satellite (long), radius of the earth (a), and distance from the satellite of the center of the earth (px), are:

$$az = \tan^{-1}\left[\frac{vy}{vx}\right]$$

$$el = \tan^{-1}\left[\frac{vz}{(vx^2 + vy^2)^{1/2}}\right]$$

where

$$rx = a \cdot \cos(lat) \cdot \cos(long)$$

$$ry = -a \cdot \cos(lat) \cdot \sin(long)$$

$$rz = a \cdot \sin(lat)$$

$$q = (px - rx)^2 + ry^2 + rz^2$$

$$vx = \frac{rx - px}{q}$$

$$vy = \frac{ry}{q}$$

$$vz = \frac{rz}{q}$$

The sign of the azimuth (elevation) will equal the sign of the longitude (latitude, where south latitude is negative).

The equations for the longitude and latitude, given az, el, a, and px, are:

$$long = \tan^{-1}\left[\frac{-ry}{rx}\right]$$

$$lat = \tan^{-1}\left[\frac{rz}{(rx^2 + ry^2)^{1/2}}\right]$$

where

$$vx = -\cos(el) \cdot \cos(az)$$

$$vy = -\cos(el) \cdot \sin(az)$$

$$vz = \sin(el)$$

$$q = -px \cdot vx - (px^2 \cdot vx^2 - px^2 + a^2)^{1/2}$$

$$rx = px + q \cdot vx$$

$$ry = q \cdot vy$$

$$rz = q \cdot vz$$

The signs correspond as in the previous equations.

The constants used in the calculations in this paper are a = 3961 mi and px = 26,198 mi, the same as those used by Komajda (1988).