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COLOR ENHANCEMENT OF NIMBUS HIGH RESOLUTION INFRARED RADIOMETER DATA

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GSFC — GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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ABSTRACT

Two examples of Nimbus High Resolution Infrared Radiometer (HRIR) data processed by a color display enhancement system demonstrate possible meteorological, oceanographic, and geomorphological applications of this technique for geophysical research. A commonly used means of displaying radiation temperatures mapped by the HRIR has been a black-and-white photofacsimile film strip. However, the human eye can distinguish many more colors than shades of gray, and this characteristic permits an analyst to evaluate quantitatively radiation values mapped in color more readily than in black and white.

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CONTENTS

COLOR ENHANCEMENT OF NIMBUS HIGH RESOLUTION INFRARED RADIOMETER DATA

I. INTRODUCTION

The Nimbus meteorological satellites, Nimbus I[1] and Nimbus II,[2] both contained a High Resolution Infrared Radiometer (HRIR) which was sensitive to radiation in the 3.5 - 4.2 micron atmospheric window region of the electromagnetic spectrum. The HRIR is sensitive to variations in the outgoing radiation from clouds and/or the earth's surface, and hence its measurements can be applied to specific research problems in meteorology, oceanography, and geomorphology. (For example, the reader is referred to Nordberg, et al;[3] Allison, et al;[4] Warnecke, et al;[5,6,7] and Pouquet.[8])

The HRIR data are ordinarily available in two display forms. The first is a black-and-white photofacsimile image produced from the original analog recor of the data. The second display form is a computer product which may be a contoured, uncontoured, or line-drawn grid print map. This form is a transformation of the data into a standard geographical map projection. Although the facsimile shows qualitative radiance features, the finer details cannot be detected because the analyst is unable to discriminate more than about six steps in the gray scale.

The contoured and line-drawn computer products assist the analyst in his task of data interpretation; however, pattern recognition is still a difficult prob lem. The addition of color tends to accentuate the features and simplifies the analysis process.

This report describes the Nimbus HRIR experiment and the ATS ground station equipment; presents some general color principles and relates how they apply to display enhancement; and demonstrates the unique advantages of the color presentation compared to the conventional forms of HRIR data display.

II. THE NIMBUS HIGH RESOLUTION INFRARED RADIOMETER EXPERIMENT

The High Resolution Infrared Radiometer (HRIR) experiment on Nimbus II was essentially the same as that flown on Nimbus I. The single-channel scanning radiometer is shown in Fig. 1. It contains a lead selenide (PbSe) photoconductive cell which is radiation cooled to -75C and operates in the 3.5 to 4.2 micron atmospheric window region. The aperture of the instrument is 0.5 degrees; thus the area viewed from the average satellite altitude of 1100 kilometers has the approximate dimensions 9 by 9 kilometers at the subsatellite point. The radiometer scan mirror continuously rotates the field of view of the detector through 360 degrees in a plane normal to the orbital path. The detector, therefore, views the housing cavity, outer space, earth, outer space, and returns again to view the housing cavity. The outer space level serves as a zero reference and, together with the radiometer housing (typically having a temperature of 290K), provides for an in-flight check of calibration.

The satellite radiometer measurements differ from satellite television pictures in that the radiometer measures outgoing emitted radiation, while the television pictures depict variations in reflected solar radiation. In the 3.5 - 4.2 micron, near-infrared region of the Nimbus HRIR, only nighttime measurements detect pure thermal radiation. Atmospheric and terrestrial features are detected also by daytime measurements, but a separation of the emitted thermal radiation from the near-infrared reflected solar radiation is not possible because of their approximately equal radiances. Hence, a unique physical interpretation of the measurements, in meteorological terms, is not possible for daytime data. During the nighttime the detected thermal radiance alone can be interpreted meaningfully in terms of an equivalent blackbody temperature, T_{BB}, defined as the temperature of an isothermal blackbody filling the field of view which causes the same response from the radiometer as does the generally non-Planckian spectral distribution of the radiation emerging from the top of the atmosphere in the direction of the satellite. This permits the derivation of earth or ocean surface temperatures, under clear sky conditions, and cloud top heights when an opaque, plane cloud surface fills the field of view of the radiometer. In the atmospheric window region of the HRIR instrument, there is still present slight atmospheric attenuation, primarily by water vapor and carbon dioxide, and a correction of up to +5.8 ±2.0K may have to be applied to a measured equivalent blackbody temperature to yield the thermometric temperature of a viewed surface (Warnecke, McMillin, and Allison[7]). These corrections are directly proportional to the scan nadir angle and the variable atmospheric water vapor content.

III. CONVENTIONAL HRIR DATA DISPLAY

The Nimbus HRIR data are normally available in two display forms. One is a black-and-white photofacsimile image formed scan by scan from the original analog record of the data. This results in a pictorial view of the cloud and surface temperature structure. Normally, absolute values of either temperature or temperature differences can not be derived from this display, because reproductions from the master negatives are exposure controlled. However, with microdensitometric techniques, temperature features can be obtained from the original archival negatives which were not exposure-controlled. These data may be obtained only through special request from the National Space Science Data Center, Greenbelt, Maryland. Figure 2 is an example of a portion of a nighttime orbital film strip showing the area approximately from 30N to 50N latitude and 100W to 130W longitude. The warmer (dark gray) T_{BB} values over such areas as the Gulf of California and the Sacramento Valley can be distinguished from the colder (light gray) T_{BB} values of the higher ranges of the Sierra Nevada and the white cloud patches along the right edge of the picture. In this form of presentation the analyst is limited by his inability to distinguish more than about 6 of the 10 available gray shades in the photofacsimile picture. Even the 10 available gray shades are not sufficient to depict the much finer structure which is inherent in the HRIR data.

The second form of data display is the grid print map, which is a computer transformation of the data, in terms of the equivalent blackbody temperature, T_{BB}, into a standard geographical map projection. In this type of data display, absolute values are presented and the researcher is able to obtain the significant small-scale features. Figure 3 depicts a hand analysis of the grid print map corresponding to a portion of the area that is shown in the pictorial display of Fig. 2. The analysis was performed by Pouquet[8] for a study that demonstrates the usefulness of the Nimbus HRIR data for geomorphological studies in sub-arid lands. In this demonstration of the geological usefulness of satellite HRIR measurements, Pouquet points out that the principal value of the measurements lies in their aid in preselecting sites to be investigated and studied using conventional methods, that is field work, and subsequent laboratory analysis of soils and rock samples. The geologist, is thus frustrated in his task of site preselection by having to rely upon his ability to distinguish between shades of gray on the film strip pictorial display of HRIR data, or by having to expend time in studying the machine contoured or hand analyzed grid print maps. Of great value would be an enhanced presentation which would be more discernable than is possible with black-and-white techniques and allow for a more rapid initial interpretation.

Another example of the hand analysis required for the interpretation of the HRIR grid print data is shown in Fig. 4 (Warnecke, et al[7]). This figure demonstrates the value of the hand analyzed grid print map in the interpretation of the data for oceanographic and meteorological research. The small-scale temperature features observed in the ocean surface allow one to depict such properties as the north wall of the Gulf Stream, shown by the two heavy isotherms for 290K and 300K between 35N and 37N. Also, the cloud structure is shown by the colder isotherms in the lower right portion of the figure. However, again in this example, considerable hand analysis was required before interpretation of the data could be done, and hence the need of another form of data display is again suggested.

IV. DISPLAY ENHANCEMENT

The term "display enhancement" is used to denote the use of computers and photographic techniques to modify and display the data from sensors in a manner that can be most readily interpreted by the user.

The present method of black and white display has certain deficiencies. One of these results from the use of a limited resolution film recorder in the conversion of digital data samples to a film record. Another deficiency results from the limited number of gray levels which can be discerned on film or photographic paper.

Correction of the first limitation can be achieved by direct means, such as linear expansion by computer processing of selected areas of interest. The second problem, however, is not easily solved using black and white display techniques because of the limited intensity values obtainable on photographic materials. One approach to the solution of this problem, known as "contrast enhancement", is to replace each intensity value V_i of the data with a second value $I(V_i)$, a function of V_i, selected to provide a picture with the desired contrast enhancement. A second approach, which is an extension of contrast enhancement, is the generation of "pseudo-color" displays. The basis for this approach is the fact that the human eye can distinguish many more colors than gray levels. The generation of a color enhanced display entails a decision upon a color function whereby an intensity value is transformed into a color. The generation of pseudo-color pictures requires only a rudimentary knowledge of color theory.

V. GENERAL COLOR PRINCIPLES

A diffuse body under specified illumination reflects light which can be classified as having hue, saturation and brightness. Each of the spectral colors, for example, red, orange, or yellow, has a different hue but the same saturation. The saturation of a color can be reduced by adding white to it; pink, for example, has the same hue as red but less saturation. If the spectral characteristic of the illuminant are not changed, a body retains its hue and saturation but the brightness will change as the intensity of illumination falling on the body is varied.

The following describes how it is possible to produce an unlimited number of colors. Assume that we have three tungsten light projectors each with a different colored filter — one blue, one green, and one red. Now project these lights so that they exactly overlap on a screen and adjust the light intensities of the projectors so that a white (or gray) light is formed. In front of each color filter place a neutral density filter with a light transmission T which may be varied from 0 to 100%. Finally, add the contraint that $T_b + T_g + T_r = 100\%$ (where the subscripts refer to the color of the associated color filter). Then, by varying the transmission of each colored filter an unlimited number of colors can be produced. Table I includes a number of examples of the resulting color for various transmissions of the blue, green, and red filters. All the colors which can be so generated may be plotted on the familiar triangular coordinate system shown in Fig. 5, where the intersecting lines are isopleths of percent transmission for the three colors, red, green, and blue, at 10% intervals. The examples listed in Table I are also shown in Fig. 5 at the intersection of the appropriate transmission isopleths. For example, at the intersection of 50% transmission for red and 50% transmission for green, yellow is obtained. It is noted that colors near the periphery of the triangle are most saturated and that those closer to the center are more pastel.

Table I

Sample Transmission - Color Relationship

BLUE T_b (%)	GREEN T_g (%)	RED T_r (%)	Resulting Color
100	0	0	Blue
0	100	0	Green
0	0	100	Red
0	50	50	Yellow
50	0	50	Magenta
50	50	0	Cyan
33 1/3	33 1/3	33 1/3	White (Gray)

The concept of the color triangle is useful, but it cannot be used in practice for the final color selection because equal spacing on the triangle does not connote equal color change to the eye and cross coupling between the dye layers of photographic material causes position shifts of points in the triangle. To circumvent these and other possible problems, the generation of a color selection chart, from which the final selection of colors is made, is desirable.

The generation of pseudo-color pictures may be accomplished by the direct application of these principles. For example, three black-and-white films, each with the desired transmission properties, can be created. Then a light source (in practice an enlarger is used) is employed to project, in sequence, each of these films, with its respective colored filter, onto a photo-sensitive material in order to create the final color picture. A second method of obtaining pseudo-color pictures is to merely automate the first method by successive exposures through blue, green, and red filters through the use of a color film recorder which does this for one line at a time instead of for the entire picture frame, as done in the first method. This second technique virtually eliminates registration problems which may be encountered when using the three films method. Both of these techniques have been used for color display enhancement of Nimbus HRIR data (Westinghouse Electric Corporation[9]).

VI. ATS COLOR RECORDING EQUIPMENT

To display the Nimbus HRIR data on the Applications Technology Satellite (ATS) color recorder, it is necessary to convert the Nimbus digital data to a digital data tape in a format which is compatible with the ATS ground station system software.

The Nimbus HRIR data are provided on the Nimbus Meteorological Radiation Tape (NMRT), which is a multi-file, binary tape containing documentation and data records. For a complete description of the NMRT, the reader is referred to the Nimbus I High Resolution Radiation Data Catalog and User's Manual, Volume 2,[10] and the Nimbus II User's Guide.[2]

The large volume of data associated with the Nimbus HRIR experiment makes it necessary to conserve as much space on the NMRT as is possible; hence the latitude and longitude is given for a number of "anchor" points for various viewing nadir angles and the latitude and longitude for each data point is obtained by interpolation between the anchor points. Thus, two computer programs are required to convert the NMRT data to the ATS color recording equipment tape format. The first program locates the data and arranges them into the desired Mercator projection in the ATS format. The second program then produces a compatible digital tape for the ATS color machine.

The ATS color system consists of a digital playback unit, a data timing unit, and a color photofacsimile recorder. The photofacsimile recorder that was used to produce color pictures from the Nimbus HRIR data is a modified Electronic Image Systems recorder that was previously modified for use with the ATS-III Multicolor Spin Scan Cloud Camera (MSSCC) Experiment. The significant features of this film recorder include an appropriate cathode ray tube (CRT), a movable color filter in the field of the lens and the associated electronics and optical system to form an image on a film plane. This system is shown schematically in Fig. 6.

The same CRT is used to generate all three primary colors by means of the filter wheel which is synchronized with the video intensity signal. In order to obtain the three primary colors from the same light source, the light must have sufficient spectral energy in each of the primary colors. The face of the CRT used was coated with P24 silicate phosphor because it resembles white light with sufficient spectral energy to generate the primary red, green, and blue colors. A set of narrow band filters is then used to obtain the three primary color components. To generate a color picture, 4096 spots of each of the three primary colors are placed on every line. Thus, to complete one line of color recording, three horizontal sweeps of the CRT are required. The filter wheel and color synchronizer operate in the following manner. The filter wheel is positioned in front of the lens so that one color component, say red, is written. A horizontal sweep is initiated on the CRT causing the film to be exposed to the red component. Without the beam being stepped vertically, the filter wheel is rotated so that the green filter is now in front of the lens. The sweep is initiated again and the film now exposed to the green component. For the third horizortal sweep without moving the CRT beam vertically, the filter wheel is rotated again, bringing the blue filter in front of the lens, and the sweep is initiated exposing the film to the blue component. After these three horizontal sweeps, the CRT beam is stepped vertically one line and the procedure is repeated. The end result is a section of film exposed to the three primary colors which can be developed and printed in a conventional manner.

VII. COLOR DISPLAY ENHANCEMENT OF HRIR DATA

The first example of color display enhancement of Nimbus HRIR data is shown in Fig. 7. The area covered includes the south-western section of the United States, and the northern portions of Baja California and the Gulf of California. This print was generated using the technique of initially producing three black-and-white transparencies and then creating the color picture from them. Basic documentation data for this picture are given in Table II. A portion of the data depicted in black-and-white in Fig. 2 was used in producing Fig. 7.

The color scale, at the top of Fig. 7, represents the color-temperature (T_{BB}) relationship, where each color is assigned to an interval 2K wide. The temperature range, from 273K or less (black) to 304K or more (purple), was selected for this particular case to correspond to the two degree isotherms used in the analysis, Fig. 3, by Pouquet.[8] The sequence of colors and the temperature range per color, however, may be selected as desired.

The color cell size used in this example is 1/8 degree of latitude by 1/8 degree of longitude and corresponds closely to the grid mesh interval of 1/8 degree longitude for the grid print map from which the analysis shown in Fig. 3 was made. The two degrees per color and the cell size used in Fig. 7 were selected to facilitate its comparison with the grid print data over the same area (but at a different time) shown in Fig. 3.

Table II

Basic Documentation Information for Nimbus II HRIR Data of Figure 7

Data Orbit Number	1491
Date	4 September 1966
Begin/End Times of Data	0753/0758 GMT
Latitude Range	30N - 40N
Longitude Range	111W - 119W

The second HRIR color print shown in Fig. 8 involved the use of the ATS color film recorder at the NASA Data Acquisition Facility, Rosman, North Carolina, by the second technique discussed above. The area shown includes the Gulf Stream, and parts of Delaware, Maryland, Virginia, and North Carolina; it corresponds to the area and data depicted in the hand analyzed grid print map of Fig. 4. The colors selected for the land areas were chosen to provide contrast with the adjacent coastal water. Table III lists the basic documentation information for this picture.

Table III

Basic Documentation Information for Nimbus II HRIR Data of Figure 8

Data Orbit Number	238
Date	2 June 1966
Begin/End Times of Data	0457/0504 GMT
Latitude Range	33N - 40N
Longitude Range	70W - 78W

The temperature range was selected to emphasize the large sea surface temperature gradient across the north wall of the Gulf Stream. In order to have a temperature interval of 2K per color over the range of the warmer ocean temperatures, all temperatures below 277K were assigned a gray color. If, however, the cloud patterns (colder T_{BB}) had been of primary interest, a color-temperature relationship could have been selected to emphasize these meteorological features. The color cell size used in Fig. 8 is 0.1 degree of latitude by 0.1 degree of longitude, while the grid mesh interval of Fig. 4 is 0.25 degree longitude.

VIII. SUMMARY

The authors have presented data to substantiate their conviction that the color enhanced Nimbus HRIR data are more interpretable than a black and white presentation. In this respect the superiority of the color-enhanced data is principally due to the ability of the human eye to distinguish colors more readily than shades of gray.

Future possible applications of color display enhancement techniques would be the real time production of HRIR data directly from the analog data into the form of color film strips, similar to those now done in black-and-white. This would eliminate the need for digitizing the HRIR data prior to obtaining a color display and would allow for real time use of the satellite infrared data for meteorological and geophysical operations.

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REFERENCES

1. Staff Members, Nimbus I High Resolution Radiation Data Catalog and User's Manual, Volume 1, Photofacsimile Film Strips, Goddard Space Flight Center, Greenbelt, Maryland, January 1965.

2. Nimbus Project, Nimbus II User's Guide, prepared by Allied Research Associates, Inc., Concord, Massachusetts, for the Nimbus Project, Goddard Space Flight Center, Greenbelt, Maryland, July 196C.

3. W. Nordberg, A. W. McCulloch, L. L. Foshee, and W. R. Bandeen, "Preliminary Results from Nimbus II," Bull. Amer. Meteor. Soc., 47, 857 (1966).

4. L. J. Allison, G. W. Nicholas, and J. S. Kennedy, "Examples of the Meteorological Capability of the High Resolution Infrared Radiometer on the Nimbus I Satellite," J. Appl. Meteor., 5, 314 (1966).

5. G. Warnecke, L. J. Allison, and L. L. Foshee, "Observations of Sea Surface Temperatures and Ocean Currents from Nimbus II," Space Research VIII, North Holland Publishing Company, Amsterdam, Holland, 1968.

6. G. Warnecke, L. J. Allison, E. R. Kreins, and L. M. McMillin, "A Satellite View of Typhoon Marie 1966 Development," NASA Technical Note D-4757, National Aeronautics and Space Administration, Washington, D. C., November 1968.

7. G. Warnecke, L. M. McMillin, and L. J. Allison, "Ocean Current and Sea Surface Temperature Observations from Meteorological Satellites," NASA

Technical Note D-5142, National Aeronautics and Space Administration, Washington, D. C. (In press, 1969).

8. J. Pouquet, "An Approach to the Remote Detection of Earth Resources in Sub-Arid Lands," NASA Technical Note D-4647, National Aeronautics and Space Administration, Washington, D. C., December 1968.

9. Westinghouse Electric Corporation, "ATS-I SSCC Data Reduction and Analysis," Contract No. NAS5-11513, Final Report, Defense and Space Center, Baltimore, Maryland, prepared for NASA, Goddard Space Flight Center, Greenbelt, Maryland, May 1968.

10. Staff Members, Nimbus I High Resolution Radiation Data Catalog and User's Manual, Vol. 2, Nimbus Meteorological Radiation Tapes - HRIR, Goddard Space Flight Center, Greenbelt, Maryland, July 1966.

FIGURE CAPTIONS

Figure 1. Nimbus I High Resolution Infrared Radiometer.

Figure 2. Photofacsimile of Nimbus II HRIR, orbit 1491, 4 September 1966 (After Pouquet[8]).

Figure 3. Analysis of Nimbus II HRIR nighttime measurements (orbit 519) on 23 June 1966, over southwestern United States, based on a computer grid print map with 0.125 degrees longitude per grid interval (After Pouquet[8]).

Figure 4. Analysis of Nimbus II HRIR nighttime measurements (orbit 238) over the Gulf Stream taken on 2 June 1966. Isotherms are drawn in 10K intervals; additionally the 295K isoline is shown (After Warnecke, et al[7]).

Figure 5. Color triangle, where the intersecting lines are isopleths of percent transmission for the three colors, red, green, and blue, at 10% intervals.

Figure 6. Schematic diagram of the ATS color facsimile recorder.

Figure 7. Color enhancement of Nimbus II HRIR nighttime measurements (orbit 1941) on 4 September 1966, over the southwestern United States, processed by the ATS color facsimile system.

Figure 8. Color enhancement of Nimbus II HRIR nighttime measurements (orbit 238) taken on 2 June 1966, over the Gulf Stream, processed by the ATS color facsimile system.

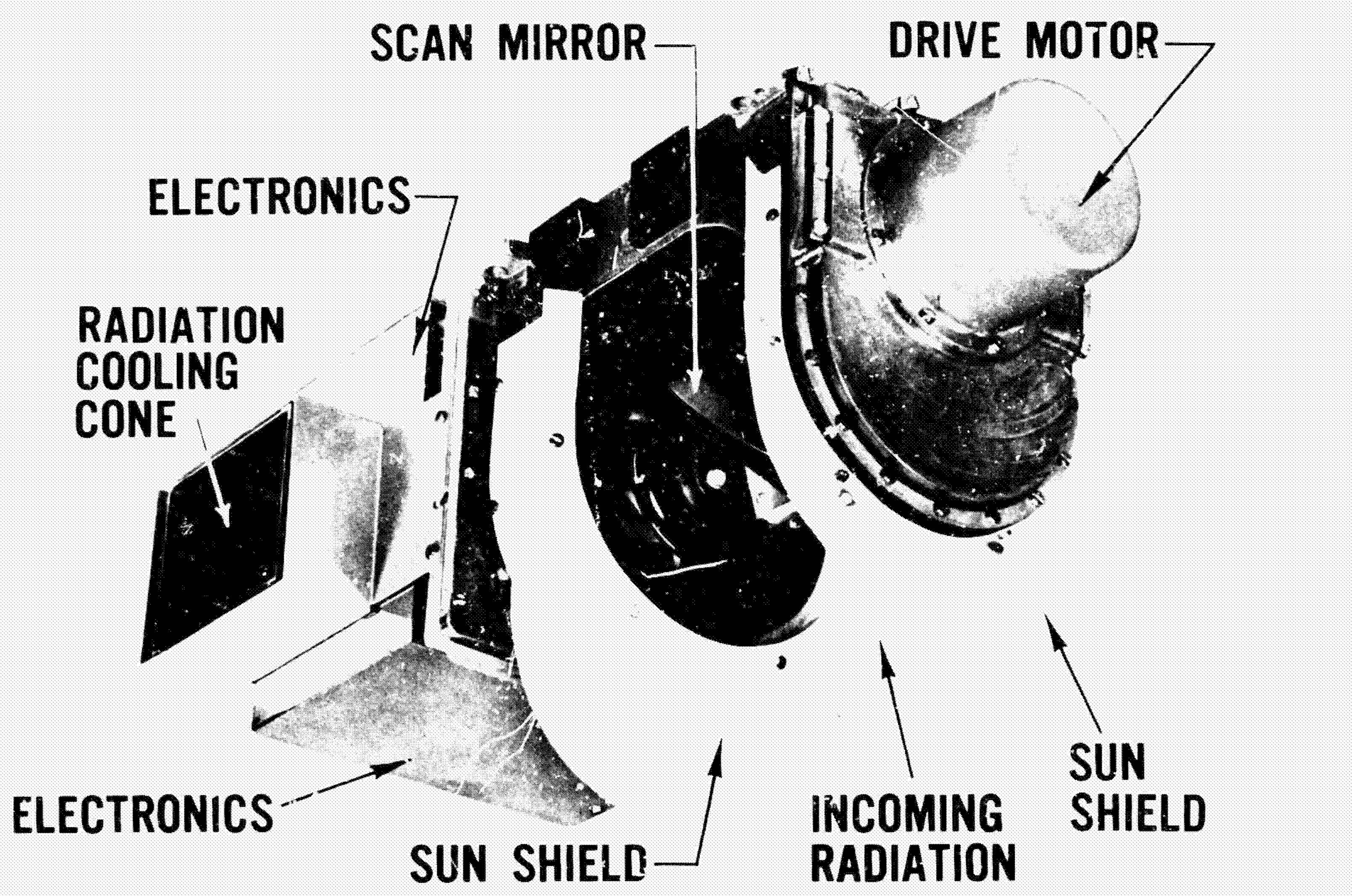
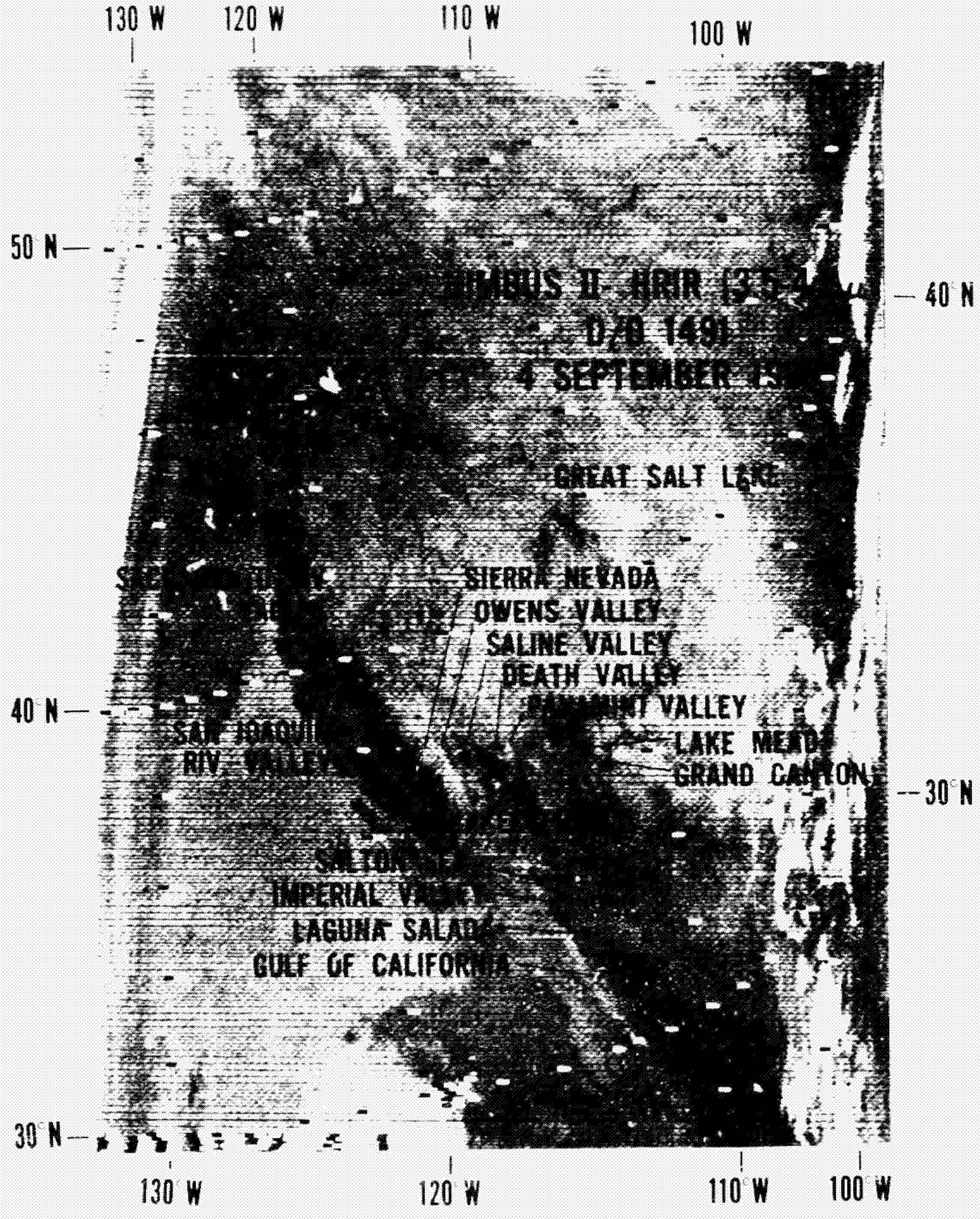


Figure 1 – NIMBUS I HIGH RESOLUTION INFRARED RADIOMETER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110 W
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30 N
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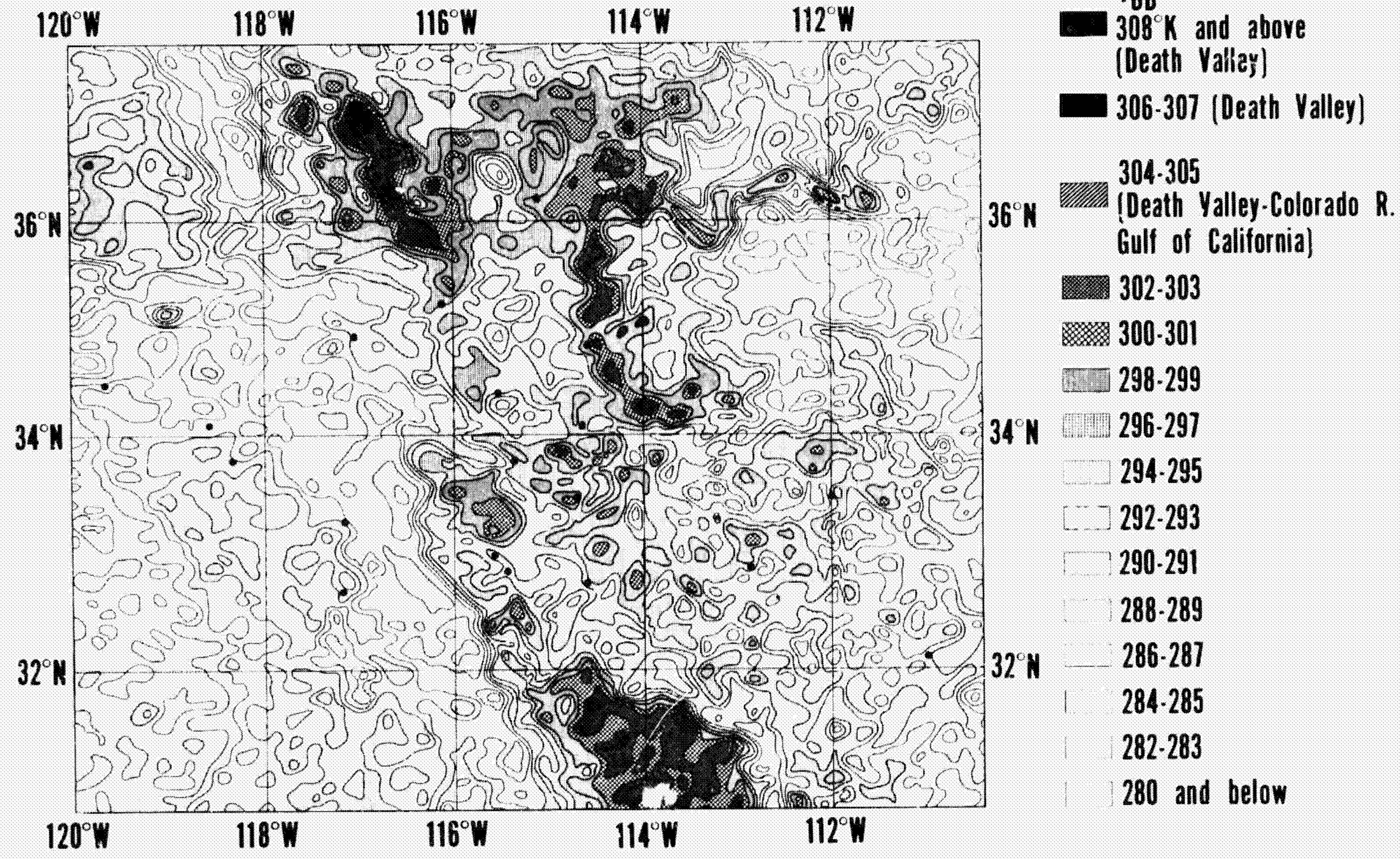
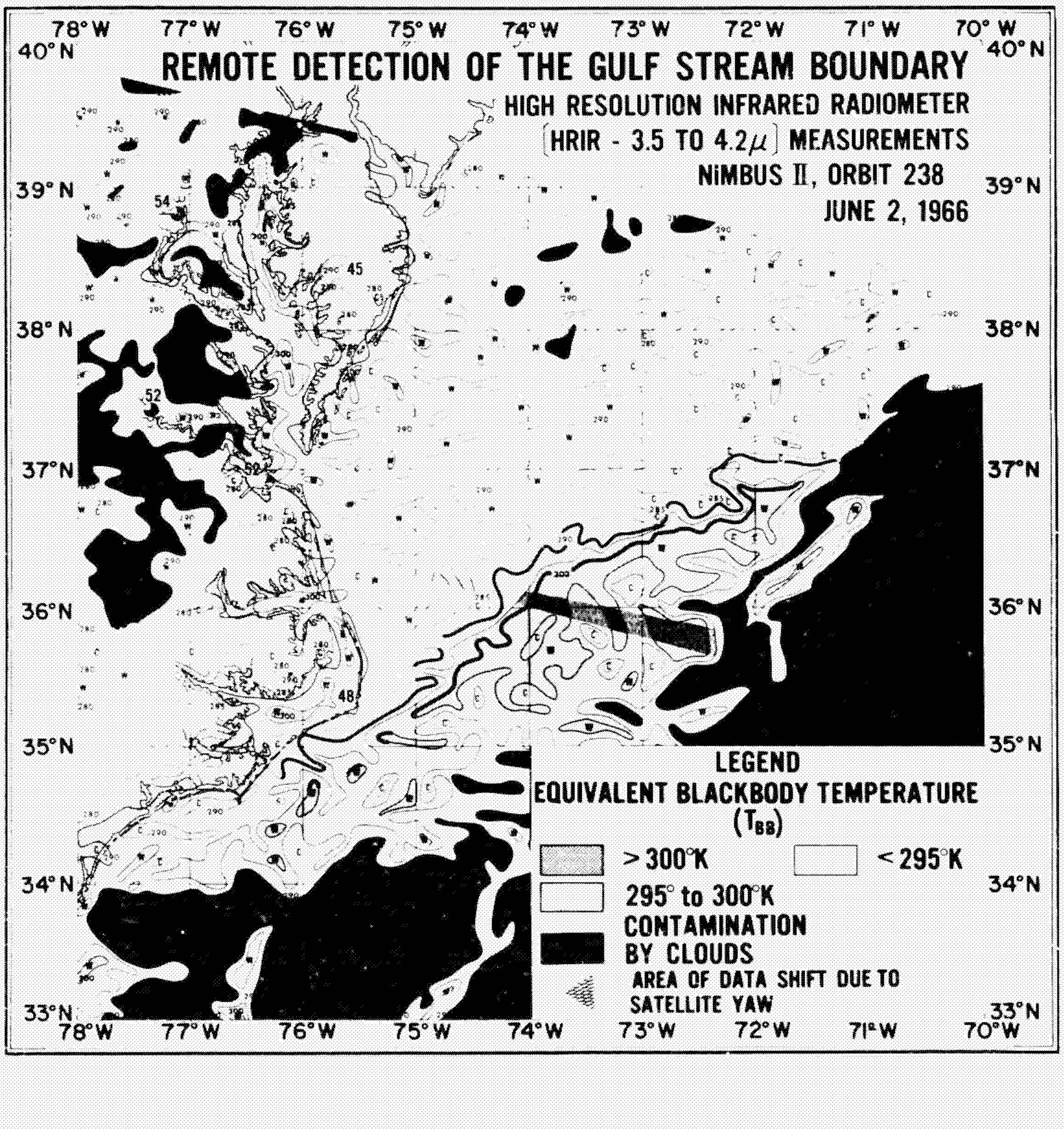
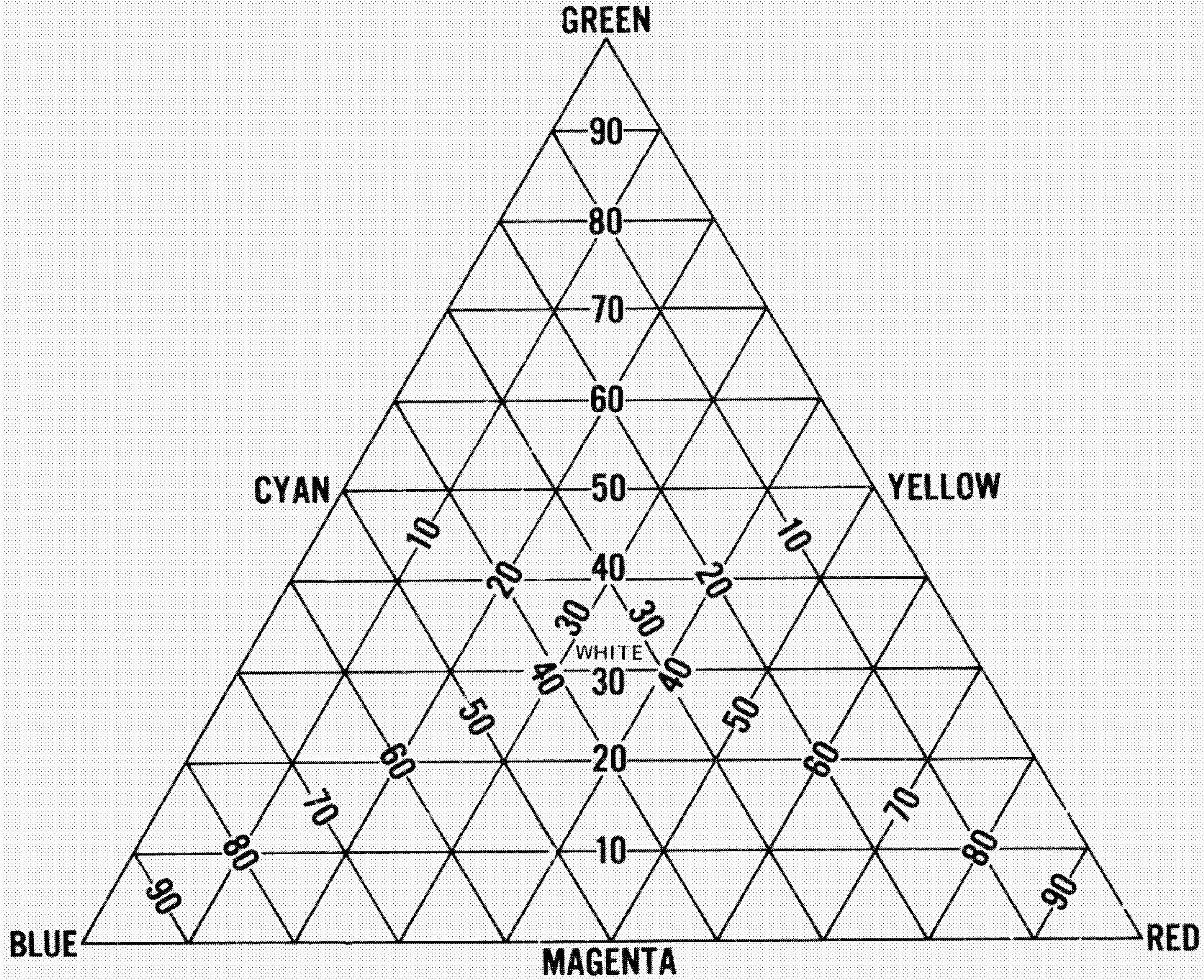
SIERRA NEVADA
OWENS VALLEY
SALINE VALLEY
DEATH VALLEY
LAKE MEAD
GRAND CANYON
RIV. VALLEY
LAGUNA SALADA
GULF OF CALIFORNIA
130 W
120 W
110 W
100 W

TERRESTRIAL FEATURES DERIVED FROM NIMBUS II, NIGHTIME HRIR MEASUREMENTS (3.5-4.2μ), AND FIELD CONTROL
ORBIT 0519, 23 JUNE 1966 WITH USE OF McMILLIN'S FILTER




REMOTE DETECTION OF THE GULF STREAM BOUNDARY
HIGH RESOLUTION INFRARED RADIOMETER
(HRIR - 3.5 TO 4.2μ) MEASUREMENTS
NIMBUS II, ORBIT 238
JUNE 2, 1966
78° W
77° W
76° W
75° W
74° W
73° W
72° W
71° W
70° W
40° N
39° N
38° N
37° N
36° N
35° N
34° N
33° N
LEGEND
EQUIVALENT BLACKBODY TEMPERATURE
(T_BB)
> 300°K
< 295°K
295° to 300°K
CONTAMINATION BY CLOUDS
AREA OF DATA SHIFT DUE TO SATELLITE YAW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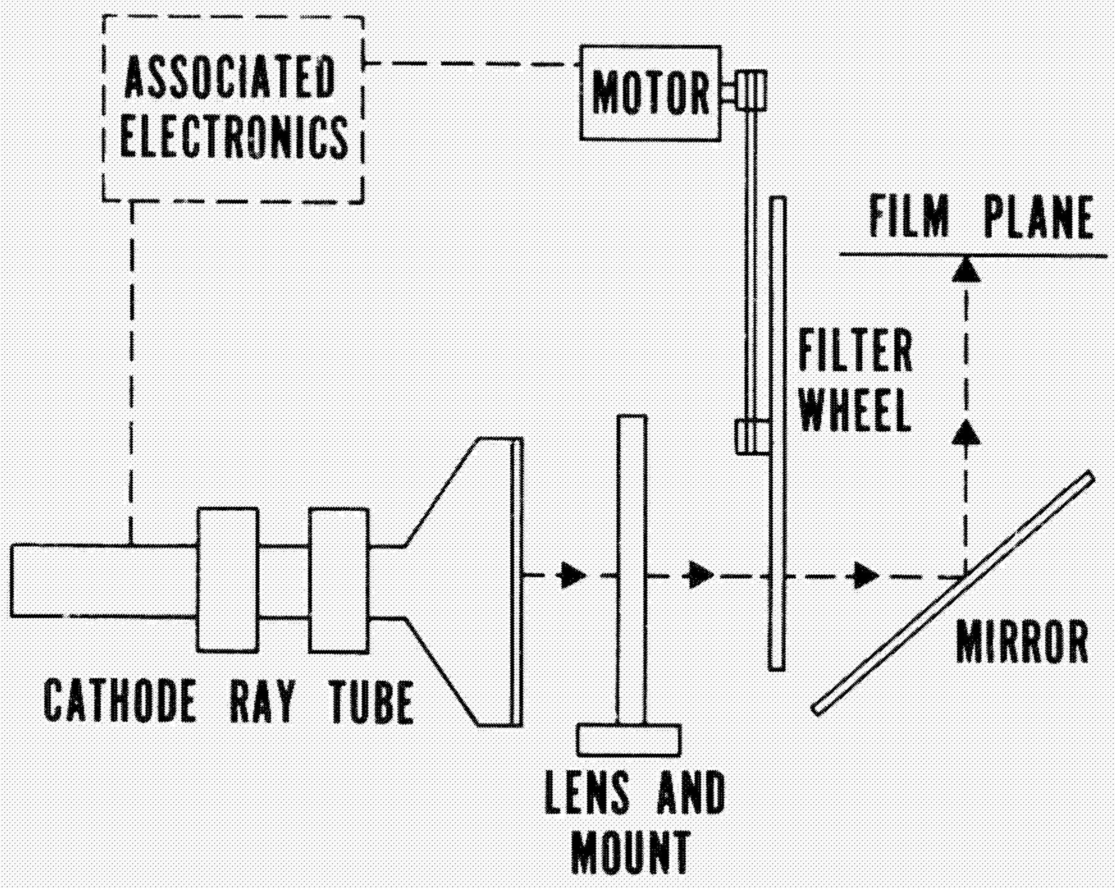
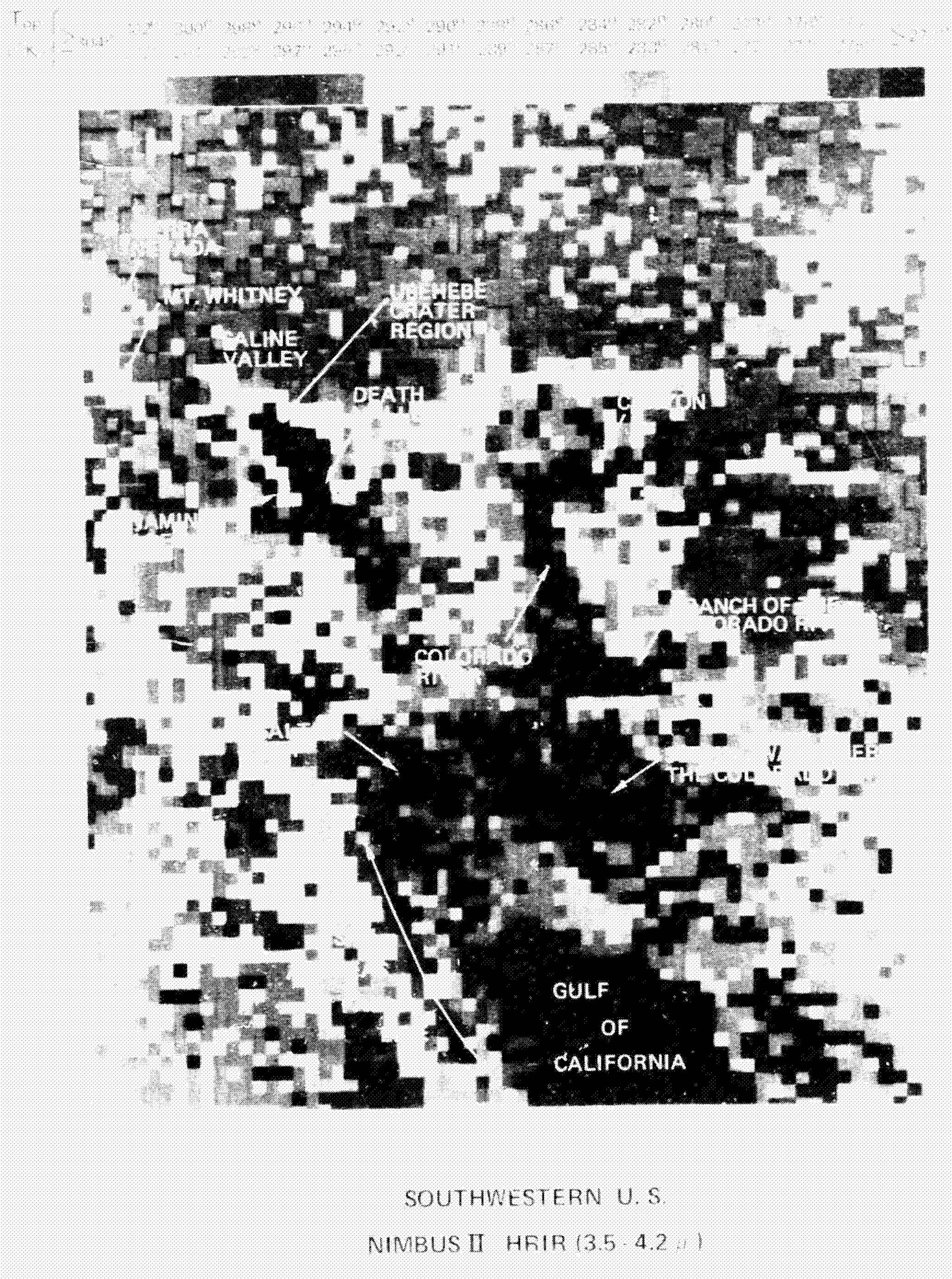


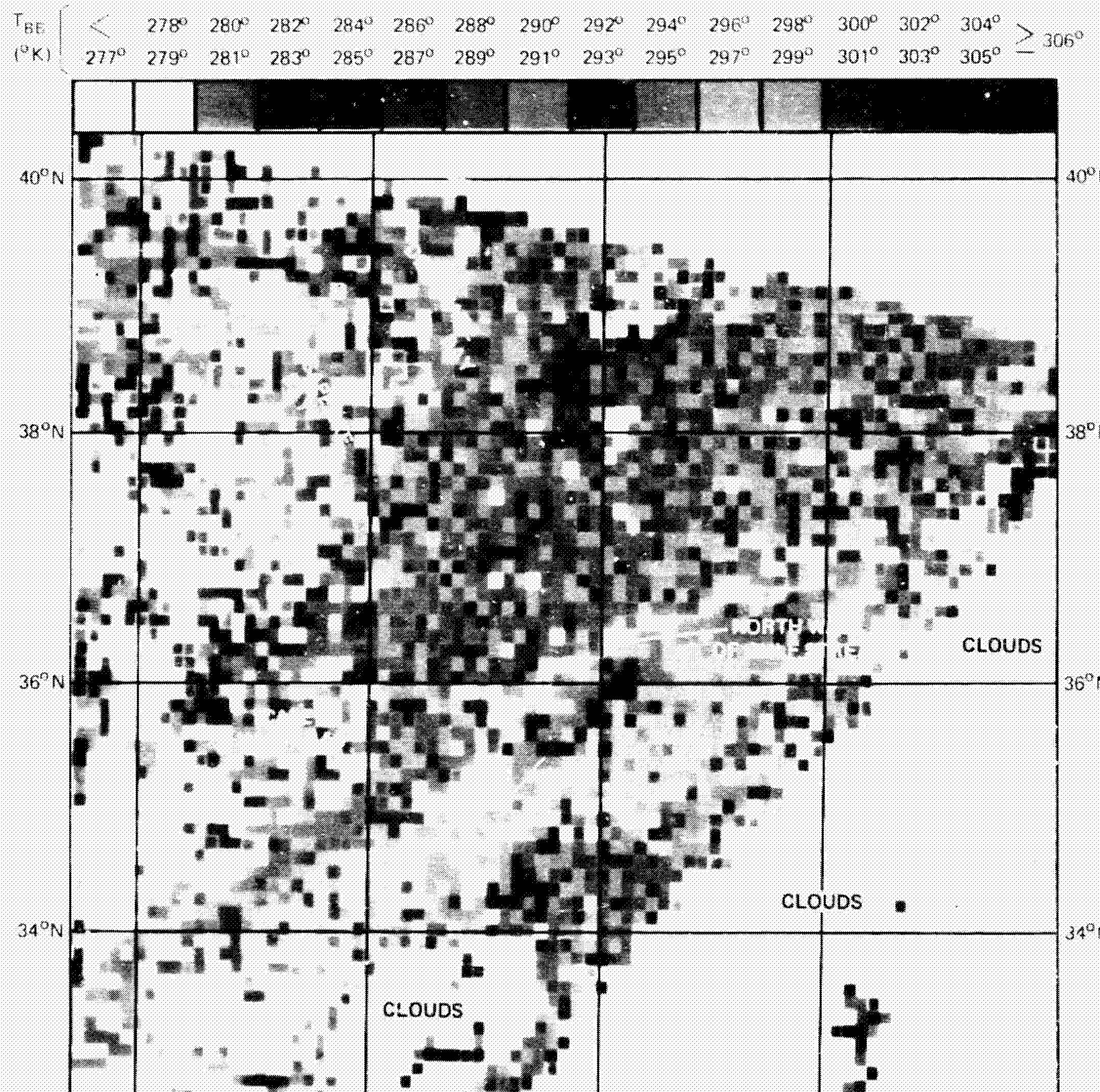
FIGURE 6 SCHEMATIC DIAGRAM OF COLOR FACSIMILE RECORDER



SOUTHWESTERN U. S.

NIMBUS II HRIR (3.5 - 4.2 μ)

ORBIT 1492 4 SEPTEMBER 1966



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36°N
34°N
78°W
76°W
74°W
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70°W
CLOUDS
CLOUDS
CLOUDS