A PROGRAM FOR COMPUTER GRIDDING OF SATELLITE PHOTOGRAPHS FOR MESOSCALE RESEARCH

by

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The research reported in this paper has been partially supported by the National Aeronautics and Space Administration under grant NASA NsG 333 and by the National Weather Satellite Center, U. S. Weather Bureau, under grant CWB WBG - 6.
A computer program is described which performs the coordinate transformations used in Fujita's graphical method for gridding TIROS photographs. Output is a matrix of picture coordinates of latitude-longitude intersections to be plotted on a distortion-free grid. Total time required to grid a series of photographs is greatly reduced compared to the original graphical technique.

1. Introduction

Because TIROS is a spin-stabilized rather than an earth-oriented vehicle, the geometry for gridding of TIROS photographs is fairly complicated. Small errors in the attitude of the satellite can produce significant errors in the location of individual clouds or cloud elements on the photographs. For example, estimating the tilt to be 43° when it is actually 40° produces an error of approximately 40 n mi in the computed position of the principle point of the photograph. Even more serious errors arise from inaccuracies in picture start time of tape mode photographs on TIROS satellites—especially TIROS I, II and III. If a high degree of accuracy in the picture gridding is required, it is necessary to check the programmed picture start time through the use of landmarks on the photographs or, in the absence of landmarks, by matching satellite nadir angles as a function of time with the photogrammetrically determined tilts of individual photographs (Fujita, 1963).

Fujita (1963) describes a concise method for gridding satellite photographs which

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has been successfully applied in a number of meso- and synoptic-scale studies. He uses a series of tilt and height grids to transform latitude and longitude intersections on an OEC (oblique equidistant cylindrical projection) chart to distortion-free grids constructed for each TIROS camera. He then transforms to fiducial grids constructed for each photograph. This method of processing TIROS photographs is apparently the most accurate developed to date (Fujita, 1964). It is, however, a time-consuming job which must be carefully and conscientiously carried out.

This report describes a computer program which duplicates Fujita’s graphical procedure. It differs from previous programs in that the mathematics is simplified by employing projective geometry and spherical trigonometry throughout. It was not designed to perform the entire gridding operation but only that part which can best be performed by machine. Input data is assumed to have been checked or determined by graphical techniques. The output is in terms of the distortion-free grid. Thus, hand operations are required at the beginning and end of the procedure and only the coordinate transformations are carried out by machine.

The program is written for an IBM 7094. It has been employed routinely for research studies at SMRP using the facilities of the Computation Center of the University of Chicago. Computer time for gridding all 32 pictures of a single TIROS orbit is approximately 45 sec. As with most programs, small refinements are continually being made. Although it was designed for research purposes, the program could easily be transformed to a fully operational scheme by the addition of subroutines to generate the satellite orbit and to correct for mean radial distortion.

2. Input

The following preliminary data are required:

a. Latitudes and longitudes of the subsatellite points and satellite altitudes at one-min intervals for the duration of the picture sequence plus at least one min on either side.

1Among these are SMRP Reports 9, 12, 14, 25, 28 and 35, available from SMRP, 5736 S. Woodlawn Avenue, Chicago, Illinois 60637.

2Dean (1961), Frankel and Bristor (1962), Mach and Gardner (1962).
b. Latitude and longitude of the spin-axis point at the initial time -- the first min of subpoint data.

c. Picture start time in min past the initial time.

Subpoint latitudes and longitudes and satellite altitudes are given in the Definitive AT Map published by NASA. Goldshlak (1962-) summarizes TIROS spin-axis data. Fujita (1963) gives spin-axis positions for TIROS I through V. The most accurate approach is to determine a fixed-earth spin-axis point directly from the photographs (Fujita, 1963).

A gridding scheme can be no better than the quality of the input data; therefore, it is important to get an accurate estimate of the spin-axis point and the picture start time by preliminary analysis on the OEC chart.

Fig. 1 shows the form used at SMRP for summarizing the input data. The information is entered on punched cards according to a format shown in the Appendix.

3. Mathematics

The program computes the tilt of each photograph from the spin-axis point and the position of the subpoint. Subsatellite points are interpolated at the time of the picture from the information at one-min intervals. Latitude of the spin-axis point is assumed constant during the time of a single sequence, however, its longitude is decreased by 0.25° per min because of the rotation of the earth. Fig. 2 shows the geometry for determining tilt $\tau$ and the azimuth of the principal line $\alpha_{pp}$. From spherical triangle I in Fig. 2, we have

$$\cos \tau = \sin \phi_{sa} \sin \phi_{sp} + \cos \phi_{sa} \cos \phi_{sp} \cos (\Delta \theta)$$

(1)

where $\theta$ refers to longitude, $\phi$ to latitude and subscripts sa and sp to spin-axis and subpoints respectively.

The azimuth of the principal line, measured clockwise from true north, is given by

$$\sin(\pi - \alpha_{pp}) = \cos \phi_{sa} \frac{\sin \Delta \theta}{\sin \tau}$$

(2)

We determine the latitude and longitude of the principal point from the picture tilt and the azimuth of the principal line. Thus, the great circle arc $\delta_{pp}$ between
subpoint and principal point is given by

\[ \sin(\delta_{pp} + \tau) = \frac{H + R}{R} \sin \tau \]  

(3)

where \( R \) is the mean radius of the earth and \( H \) is the satellite height (Fujita, 1963).

And from triangle II, Fig. 2, we have

\[ \sin \phi_{pp} = \sin \phi_{sp} \cos \delta_{pp} + \cos \phi_{sp} \sin \delta_{pp} \cos \alpha_{pp} \]

and

\[ \theta_{pp} = \theta_{sp} + \sin^{-1} \left[ \frac{\sin \delta_{pp} \sin \alpha_{pp}}{\cos \phi_{pp}} \right] \]  

(4)

The position of the principal point is a part of the output; it is, however, extraneous information as far as the coordinate transformations are concerned. Neglecting distortion, the parameters \( \phi_{sp}, \theta_{sp}, \tau, \alpha_{pp}, \) and \( H \) are sufficient to determine picture coordinates of arbitrary points on a spherical earth.

Coordinate transformations from latitude and longitude on the earth to Cartesian coordinates on the distortion-free grid are summarized in Figs. 3, 4, and 5. Three transformations are involved:

a. Latitude and longitude on the earth transform to nadir angle \( \eta \) and horizontal angle \( \psi \) measured from the principal line (Fig. 3). The equations used in this transformation are

\[ \cos \delta = \sin \phi_{sp} \sin \phi_p + \cos \phi_{sp} \cos \phi_p \cos(\Delta \theta), \]

\[ \sin \alpha = \frac{\cos \phi_p \sin(\Delta \theta)}{\sin \delta}, \]

\[ \tan \eta = \frac{\rho \sin \delta}{\rho (1-\cos \delta) + H}, \]

and

\[ \psi = \alpha - \alpha_{pp}. \]  

(5)

b. Coordinates (\( \eta, \psi \)) transform to the angles (\( \rho, \gamma \)) on a unit sphere centered at the perspective center of the photograph (Fig. 4). We have

\[ \cos \rho = \cos \eta \cos \tau + \sin \eta \sin \tau \cos \psi \]

and

\[ \sin \gamma = \frac{\sin \eta \sin \psi}{\sin \rho} \]  

(6)
c. Coordinates \((\rho, \gamma)\) transform to Cartesian coordinates on the image plane (Fig. 5). Here

\[
x = f \tan \rho \sin \gamma
\]

and

\[
y = f \tan \rho \cos \gamma
\]

(7)

where \(f\) is the principal distance of the distortion-free grid.

The rather special geometry at the horizon is described in Fig. 6. As a condition for the appearance of a horizon on the photograph we have

\[(90 - \delta_h) \leq (\tau + B)\]

where \(\delta_h\) is the dip (Fig. 6) and \(B\) is the camera field of view. Picture coordinates of the horizon are obtained by setting \(\eta = 90 - \delta_h\) in (6) and then assuming increasing values of \(\psi\) until the computed \(\rho\) exceeds the camera field of view \(B\).

Fig. 7 summarizes the sequence of operations carried out by the machine in solving (1) through (7).

4. Output

The machine output is in three parts:

a. A summary of the input data.

b. A series of coordinate matrices for all gridded frames within a single orbit.

c. A table giving computed position and attitude data for each frame.

A sample matrix is shown in Fig. 8. Row and column headings are latitude and longitude respectively. Matrix elements are \(x\) (upper) and \(y\) (lower) coordinates in millimeters of the indicated intersections projected onto the distortion-free grid. The principal distance \(f\) in (7) is 94.7 mm which enables the output to be plotted directly onto Fujita's (1963) grids. Zeroes in the matrix indicate that the particular intersection is outside of the camera field of view or else beyond the horizon. In order to avoid packing of grid points near the actual horizon, a fake horizon is assumed at a nadir angle that is 98 per cent of the complement of the dip angle. This is the same procedure used by Frankel and Bristor (1962) except that their percentage is 95.

If there is a visible horizon in a particular frame, horizon coordinates will be written above the longitude headings of the matrix. Since the horizon is symmetrical
about the principal line, only positive values of \( x \) are computed and the complete horizon curve is obtained by plotting the points \((x, y)\).

The standard matrix is 18 x 18. The number of rows, however, increases in stages as the latitude of the subpoint increases in order to encompass a greater number of meridians. The grid increment is also variable: when the subsatellite latitude passes beyond 60°, the longitude increment increases from 2 to 4°. At 70° the increment becomes 8°. Thus, near-polar orbits from TIROS and Nimbus satellites can be handled with the existing output format. A latitude-longitude grid for one frame of a simulated TIROS orbit is shown in Fig. 9.

Once the matrix output has been obtained for a desired orbit, grid the pictures in the following way:

a. Construct a fiducial grid for each frame. Usually two or three fiducial grids will fit closely enough to all pictures in a single orbit.

b. If there is a horizon in a particular photograph, transfer it to the distortion-free grid. If there is no horizon, determine the principal line from a plot of the principal point track (Fujita, 1963) and sketch the principal line on the distortion-free grid.

c. Plot the picture matrix on millimeter graph paper.

d. Place the translucent distortion-free grid for the particular frame on the graph paper and match the principal points and the horizon curves or principal lines.

e. Transfer latitude and longitude intersections by hand to the fiducial grid on the photograph.

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I wish to thank Mrs. G. Baralt for her assistance in "de-bugging" various phases of the program and Mr. James Arnold for useful discussions concerning the form of the output. Thanks are due, of course, to Prof. Fujita upon whose work the entire gridding procedure is based.
REFERENCES


APPENDIX

THE FORTRAN PROGRAM

The program was written in FORTRAN II for the IBM 7090 or 7094. With minor changes it should be adaptable to smaller machines. Inverse trigonometric functions are an essential part of the program, however, and these are not always included as library subroutines in the smaller systems.

At SMRP radiation data are typically analyzed in conjunction with the photographs and a separate program has been written which locates geographically the analog radiation readings. Radiation and photo-gridding routines are actually subroutines called for by a short main program. However, the photo-gridding program given here is complete in itself. The program is separated into logical units. A short summary of the purpose of the unit precedes the program statements and definitions of the FORTRAN names for variables, constants and subroutines follow.
A. Read the identifier and subpoint cards. Summarize the input data.

F=94.7
C1=.0174532925
C2=57.2957795
C3=6367.65
PI=3.1415927536
DIMENSION LAT(20),LONG(30),CDIF2(30),SDIF2(30),CLAT(30),SLAT(20),
NXHOR(10),NYHOR(10),NX(20,30),NY(20,30),TABLE(9,50),SPDATA(3,50)
100 READ INPUT TAPE 5,1,JTIROS,JORBIT,JM,JD,JY,SA1,REFSA2,REFT,NO,
1 NFORK
1 FORMAT (I2,I5,3I2,2F5.1,F5.0,2I2)
200 READ INPUT TAPE 5,2,((SPDATA(M,N),M=1,3),N=1,NO)
2 FORMAT (2F5.1,F5.0)
300 WRITE OUTPUT TAPE 6,3,JTIROS,JORBIT,JM,JD,JY,SA1,REFSA2,REFT,
1 ((SPDATA(M,N),M=1,3),N=1,NO)
3 FORMAT (1H1,15X,31HSUMMARY OF INPUT DATA TIROS NO.,I2,16H ORBIT N
1 0.(A/O),I5,5X,5HMTHN,M,5X,5H DAY ,I3,9H YEAR 19,12/,/28X,18HSPIN
2 AXIS LATITUDE,F5.1,3HDEG,24H SPIN AXIS LONGITUDE,F6.1,3H AT,
3 F6.0,1HZ/,/43X,35HORBITAL DATA FROM DEFINITIVE AT MAP/20X,80HONE-MI
4 NUTE TIME INTERVALS STARTING FROM THE TIME OF THE SPIN AXIS DETERM
5 INATION.//48X,24H LAT. LONG. HT.//(4X,2F8.1,F8.0))

Definitions

F  --------------  Principal distance of distortion-free grid or photo.
C1  --------------  Conversion factor degrees to radians.
C2  --------------  Conversion factor radians to degrees.
C3  --------------  Mean radius of the earth.
JTIROS  --------------  TIROS Number.
JORBIT  --------------  Orbit Number (Actual Orbit).
JM,JD,JY  --------------  Month, Day, Year.
SA1  --------------  Latitude of spin-axis point.
REF SA2,REFT  --------------  Long. of spin-axis point at initial time, REFT.
NO  --------------  Number of minutes of subpoint data to follow.
SPDATA (1,N)  ------------  Latitude of subpoint at time REFT plus (N-1) minutes.

SPDATA (2,N)  ------------  Longitude of subpoint.

SPDATA (3,N)  ------------  Altitude of satellite in km.

B. Read the "picture" card. Write identifying information and explanation of format.

READ INPUT TAPE 5,1,IMAGE, START, TDIF, NUMBER, MODE
1 FORMAT (I2,F5.2,F3.2,2I2)
ISTEP = 2
DVVIEW=50.0
SINSA1=SINF(C1*SA1)
COSA1=SQRTF(1.-SINSA1**2)
VIEW=C1*DVIEW
500 WRITE OUTPUT TAPE 6,5,JIROS,JORBKIT,JM,JD,JY,ISTEP,F
5 FORMAT (1H1,20X,5HJIROS,13,55X,12HORBKIT NUMBER,15/47X,5HMONTH,12,3
1 X,3HDAY,12,3X,7HYEAR 19,12//32X,20HIMAGE COORDINATES OF,12,41H DE
2 G LATITUDE AND LONGITUDE INTERSECTIONS/,40X,37HCARTESIAN COORDINAT
3 ES CENTERED AT THE,40X,40HPRIMARY POINT, Y AXIS ALONG PRIMARY LINE.
4 /40X,41H(UPPER) AND Y(LOWER) IN MM TO BE PLOTTED/40X,40HON DISTOR
5 TION-FREE GRID OR PHOTO WITH F=, F5.1, 3HMM.)

Definitions

IMAGE  ------------  Number of the first frame. Will typically be 32 for tape mode, 1 for direct.

START  ------------  Picture start time in minutes (tenths and hundredths) past the initial time.

TDIF  ------------  Time interval in minutes between successive frames.

NUMBER  ------------  Number of photos to be gridded.

MODE  ------------  Plus 1 for direct, -1 for tape.

ISTEP  ------------  Latitude increment for photo grids.

DVVIEW  ------------  Field of view of camera in degrees.
C. Set up a two-dimensional array TABLE giving frame number, time (with respect to initial time), subpoint latitude and longitude and satellite altitude for each picture to be gridded. Latitude, longitude and altitude are obtained by linear interpolation in matrix SPDATA.

```
DO 6 J=1, NUMBER
  TABLE(1,J)=IMAGE+(J-1)*MODE
  DUMMY=J-1
  TABLE(2,J)=START+(DUMMY*TDIF)
  DUMMY=INTF(TABLE(2,J))
  R=TABLE(2,J)-DUMMY
  INDEX=DUMMY+1.
  TABLE(3,J)=SPDATA(1,INDEX)+R*(SPDATA(1,INDEX+1)-SPDATA(1,INDEX))
  IF(ABSFS(SPDATA(2,INDEX+1)-SPDATA(2,INDEX))<100.)4,2,2
    D1=SPDATA(2,INDEX)
    D2=SPDATA(2,INDEX+1)
    IF(D1-D2)<210,210,212
    TABLE(4,J)=D1+R*(D2-D1)
    IF(TABLE(4,J)<220,6,6
    GO TO 6
  210 D2=360.
    TABLE(4,J)=D1+R*(D2-D1)
    IF(TABLE(4,J)<220,6,6
    GO TO 6
  212 D2=D2+360.
    TABLE(4,J)=D1+R*(D2-D1)
    IF(TABLE(4,J)<360.)6,222,222
    TABLE(4,J)=TABLE(4,J)-360.
    GO TO 6
  220 TABLE(4,J)=TABLE(4,J)+360.
  GO TO 6
  222 TABLE(4,J)=TABLE(4,J)-360.
  GO TO 6
4  TABLE(4,J)=SPDATA(2,INDEX)+R*(SPDATA(2,INDEX+1)-SPDATA(2,INDEX))
6  TABLE(5,J)=SPDATA(3,INDEX)+R*(SPDATA(3,INDEX+1)-SPDATA(3,INDEX))
```

Definitions

| TABLE (1,J) | Table number of jth frame. |
| TABLE (2,J) | Picture time in minutes past initial time. |
| TABLE (3,J) | Subpoint latitude at picture time. |
| TABLE (4,J) | Subpoint longitude at picture time. |
| TABLE (5,J) | Satellite altitude in km at picture time. |
D. Keep a count of the number of pictures that have been gridded. Define the frame number, time, subpoint latitude and longitude and satellite altitude for the particular frame to be gridded. Do the preliminary calculations for computing tilt and the azimuth of the primary line.

```
200 JCOUNT=JCOUNT+1
   IF(JCOUNT-NUMBER)8,8,800
8  IMAGE=TABLE(1,JCOUNT)
   DELTAT=TABLE(2,JCOUNT)
   SP1=TABLE(3,JCOUNT)
   SP2=TABLE(4,JCOUNT)
   H=TABLE(5,JCOUNT)
   JSTEP=2
10  SA2=REFSA2-.25*DELTAT
   IF(SA2)11,17,17
11  SA2=SA2+360.
17  DUMMY=C1*SP1
   COSSP1=COSF(DUMMY)
   SINSP1=SINF(DUMMY)
   DIF2=C1*ABSF(SA2-SP2)
   FSP2=SP2
   FSA2=SA2
   IF(DIF2-PI)16,12,12
12  IF(SA2-SP2)13,14,14
13  FSP2=SP2-360.
   GO TO 15
14  FSA2=SA2-360.
15  DIF2=2.*PI-DIF2
```

Definitions

- **JCOUNT**
  - Position in array TABLE of data referring to particular frame being gridded.

- **IMAGE**
  - Number of particular frame being gridded.

- **DELTAT**
  - Picture time in minutes past REFT.

- **DIF2**
  - Difference in radians between subpoint and spin-axis longitudes.

- **H**
  - Satellite height in km.

- **SP1**
  - Subpoint latitude.

- **SP2**
  - Subpoint longitude.
SA2  --------------  Spin-axis longitude and picture time.
JSTEP  --------------  Longitude increment of photo grid.

E. Compute the picture tilt and the azimuth of the principal line.

16 CTILT = (SINSP1*SINSA1) + (COSSA1*COSSP1*COSF(DIF2))
       IF(ABSF(CTILT) - 1.) 20, 18, 18
18 CTILT = 1.
       STILT = 0.
       TILT = 0.
       AZPL = 0.
       GO TO 30
20 STILT = SQRTF(1. - CTILT**2)
       TILT = ACOSF(CTILT)
       ARG = COSSA1*SINF(DIF2)/STILT
       IF(ARG - 1.) 22, 21, 21
21 AZPL = PI/2.
       GO TO 30
22 AZPL = ASINF(ARG)
       IF(SINSP1*CTILT - SINSA1) 24, 21, 26
24 AZPL = PI - AZPL
26 IF(FSA2 - FSP2) 30, 30, 27
27 AZPL = 2.*PI - AZPL

Definitions

TILT  --------------  Picture tilt, \( \tau \).
AZPL  --------------  Azimuth of the principal line, \( \alpha_p \).
F. Determine whether or not the principal point of the photo will be on the earth. If not, set its latitude and longitude equal to minus zero. If it is on the earth, compute its latitude and longitude.

30  RATIO=C3/(C3+H)
    COMDIP=ASINF(RATIO)
    CAZPL=COSF(AZPL)
    SAZPL=SINF(AZPL)
    IF(COMDIP-TILT) 32, 32, 31
32  PM1=-0.
    PM2=-0.
    GO TO 33
31  D=ASINF(STILT/RATIO)-TILT
    SIND=SINF(D)
    SINPM1=(SINSP1*COSF(D))+(COSSP1*SIND*CAZPL)
    COSPM1=SQRTF(1.-SINPM1**2)
    PM1=C2*ASINF(SINPM1)
    DIF2=C2*ASINF(SIND*SINF(AZPL)/COSPM1)
    THETA=SP2+DIF2
    PM2=DCHK(THETA)

Definitions

COMDIP: Complement of the dip, $\delta_H$.

PM1: Latitude of the principal point.

PM2: Longitude of the principal point.

D: Great circle distance subpoint to principal point.

DIF2: Difference in degrees between subpoint and principal point longitudes.

DCHK(THETA): Subroutine which insures that $0 \leq \Theta \leq 360$. 
G. Store the latitude and longitude of the principal point, the azimuth of the principal line and the picture tilt in their proper positions in array \textit{TABLE} for later output.

\begin{verbatim}
33 \text{TABLE}(6, JCOUNT)=PM1
   \text{TABLE}(7, JCOUNT)=PM2
   DAZPL=C2*AZPL
   DTILT=C2*TILT
   \text{TABLE}(8, JCOUNT)=MILT
   \text{TABLE}(9, JCOUNT)=DAZPL
\end{verbatim}

H. Determine whether or not there will be a horizon on the photo. If not, print out the heading for the picture grid, the orientation information and the words no visible horizon. If there is a visible horizon, compute \((x, y)\) coordinates of the horizon curve at \(10^\circ\) increments of horizontal angle, \(\psi\). Round to the nearest integer and write out the horizon coordinates along with the picture heading and the orientation data.

\begin{verbatim}
XANGLE=VIEW+TILT
YANGLE=VIEW-TILT
IF(COMDIP-XANGLE)35,35,50
35 A=COSF(COMDIP)
   B=SQRTF(1.-A**2)
   AZIM=0.
   DO 38 I=1,6
       COSRHO=(A*CTILT)+(B*STILT*COSF(AZIM))
       SQRHO=SQRTF(1.-COSRHO**2)
       SALFA=B*SINF(AZIM)/SQRHO
       CONST=1.
       IF(COSRHO*CTILT-A)36,37,37
       CONST=-1.
36       DUMMY=F*SINRHO/COSRHO
37       FIX=DUMMY*SALFA
       NYHOR(I)=I ROUND(FIX)
       FIX=CONST*DUMMY*SQRTF(1.-SALFA**2)
       NYHOR(I)=I ROUND(FIX)
38       AZIM=AZIM+10.*CI
40 WRITE OUTPUT TAPE 6,41,IMAGE,SP1,SP2,PM1,PM2,DTILT,DAZPL,
       (NXHOR(I),I=1,6),(NYHOR(I),I=1,6)
41 FORMAT ((1I1,10X,11HPICTURE NO.,I3,5X,3HSP1,F6.1,5X,3HSP2,F6.1,5X,3
       HPM1,F6.1,5X,3HSP2,F6.1,5X,4HTILT,F5.1,5X,4HAZPL,F6.1/50X,19HHORIZ
       2 ON COORDINATES/(30X,6I10))
       D2=PI/2.-COMDIP
       GO TO 60
50 WRITE OUTPUT TAPE 6,51,IMAGE,SP1,SP2,PM1,PM2,DTILT,DAZPL
51 FORMAT ((1I1,10X,11HPICTURE NO.,I3,5X,3HSP1,F6.1,5X,3HSP2,F6.1,5X,3
       HPM1,F6.1,4X,3HPM2,F6.1,5X,4HTILT,F5.1,5X,4HAZPL,F6.1/50X,18HNO VI
       2 SIBLE HORIZON//)
\end{verbatim}
Definitions

AZIM
---------
Horizontal angle $\psi$ measured in radians from the principal line. See Fig. 4 in text.

COSRHO
---------
$\cos(\rho)$ where $\rho$ is the radial angle on a unit sphere centered at the perspective center of the photograph.

SALFA
---------
$\sin(\gamma)$ where $\gamma$ is the azimuth on the unit sphere. See Fig. 4 in text.

IROUND(FIX)
---------
Subroutine which rounds to the nearest integer and converts to fixed point for output.

NXHOR
---------
x coordinate of horizon point.

NYHOR
---------
y coordinate of horizon point.

I. Compute the mid-point for the photo-grid array. This will be a point on the primary line roughly mid-way between the horizon (if one exists) and the bottom of the photo.

$$D2=\text{AS INF}(\text{S INF}(\text{XANGLE})/\text{RATIO})-\text{XANGLE}$$
$$D1=\text{AS INF}(\text{S INF}(\text{YANGLE})/\text{RATIO})-\text{YANGLE}$$
$$D3=(D2-D1)/2.$$ 
$$\text{SIND}=\text{SINF}(D3)$$
$$\text{SINP1}=(\text{SINSP1} \times \text{COSF}(D3))+(\text{COSSP1} \times \text{SIND} \times \text{CAZPL})$$
$$\text{COSP1}=\text{SQRRTF}(1.-\text{SINP1}^2)$$
$$P1=C2 \times \text{ASINF}($$SINP1$$)$$
$$\text{DIF2}=C2 \times \text{ASINF}($$SIND \times $$SAZPL/\text{COSP1})$$
$$\text{THETA}=P2+\text{DIF2}$$
$$P2=\text{DCHK}($$THETA$$)$$

Definitions

D1
---------
Great circle arc $d_1$ in Fig. 6 in text.

D2
---------
Great circle arc $d_2$ in Fig. 6 in text.

D3
---------
Great circle arc $d_3$ in Fig. 6 in text.
J. Select the proper grid dimension and longitude increment on the basis of the subpoint latitude.

\[
\text{DUMMY} = \text{ABSF(SP1)} \\
\text{IF(DUMMY-40.)68,64,64} \\
64 \quad \text{JP} = \text{INTF(DUMMY/10.)-3.} \\
\text{GO TO (641,642,643,644,644), JP} \\
641 \quad \text{MID}=13 \\
\quad \text{JNO}=11 \\
\quad \text{GO TO 69} \\
642 \quad \text{MID}=15 \\
\quad \text{JNO}=13 \\
\quad \text{GO TO 69} \\
643 \quad \text{MID}=15 \\
\quad \text{JNO}=13 \\
\quad \text{JSTEP}=4 \\
\quad \text{GO TO 69} \\
644 \quad \text{MID}=15 \\
\quad \text{JNO}=13 \\
\quad \text{JSTEP}=8 \\
\quad \text{GO TO 69} \\
68 \quad \text{MID}=10 \\
\quad \text{JNO}=8 \\
\quad \text{JP}=6
\]

Definitions

- **MID**
  - Column in the longitude, latitude matrix which will serve as the location for the starting longitude.

- **JNO**
  - Number of longitude columns beyond MID that the grid will extend.

- **JSTEP**
  - Longitude increment.
K. Set the central values of latitude and longitude for the photo-grid matrix equal to the even integers nearest to the latitude and longitude of the previously computed mid-point (P1,P2). Compute the sine and cosine functions for the central latitude and longitude required for the coordinate transformations to follow.

69\ P2=INTF(P2) \\
\ DuMMy=P2/2. \\
\ IF(INTF(DuMMy)-DuMMy)691,692,691 \\
691\ LONG(MID)=P2+1. \\
\ GO TO 693 \\
692\ LONG(MID)=P2 \\
693\ P1=INTF(P1) \\
\ DuMMy=P1/2. \\
\ IF(INTF(DuMMy)-DuMMy)694,695,694 \\
694\ LAT(10)=P1+1. \\
\ GO TO 70 \\
695\ LAT(10)=P1 \\
70\ DuMMy=LAT(10) \\
\ DuMMy=C1*DuMMy \\
\ SLAT(10)=SINF(DuMMy) \\
\ CLAT(10)=COSF(DuMMy) \\
\ DuMMy=LONG(MID) \\
\ DIF2=ABSF(DuMMy-SP2) \\
\ CDIF2(MID)=COSF(C1*DIF2) \\
\ SDIF2(MID)=SqrtF(1.-CDIF2(MID)**2)

Definitions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LONG</td>
<td>One-dimensional longitude array.</td>
</tr>
<tr>
<td>LAT</td>
<td>One-dimensional latitude array.</td>
</tr>
<tr>
<td>SLAT</td>
<td>Sine latitude array.</td>
</tr>
<tr>
<td>CLAT</td>
<td>Cosine latitude array.</td>
</tr>
<tr>
<td>CDIF2</td>
<td>Cosine of the longitude difference between subpoint and grid point. DIF2 corresponds to $\Delta \theta$ in Fig. 3 in text.</td>
</tr>
<tr>
<td>SDIF2</td>
<td>Sine of the longitude difference between subpoint and grid point.</td>
</tr>
</tbody>
</table>
L. Set up the latitude, cosine latitude, and sine latitude arrays.

```
DO 72 J=11,18
LAT(J)=LAT(J-1)-ISTEP
DUMMY=LAT(J)
DUMMY=C1*DUMMY
CLAT(J)=COSF(DUMMY)
72 SLAT(J)=SINF(DUMMY)
DO 74 J=1,9
M=10-J
LAT(M)=LAT(M+1)+ISTEP
DUMMY=LAT(M)
DUMMY=C1*DUMMY
CLAT(M)=COSF(DUMMY)
74 SLAT(M)=SINF(DUMMY)
```

M. Set up the longitude, CDIF2 and SDIF2 arrays.

```
JBOT=MID+1
JTOP=MID+JNO
DO 76 J=JBOT,JTOP
LONG(J)=LONG(J-1)+JSTEP
DUMMY=LONG(J)
DIF2=C1*ABS(F(DUMMY-SP2)
IF(LONG(J)-360)75,73,73
73 LONG(J)=LONG(J)-360
75 CDIF2(J)=COSF(DIF2)
76 SDIF2(J)=SQRT(F(1.-CDIF2(J)**2)
JTOP=MID-1
DO 80 J=1,JTOP
M=MID-J
LONG(M)=LONG(M+1)-JSTEP
DUMMY=LONG(M)
DIF2=C1*ABS(F(DUMMY-SP2)
IF(LONG(M))78,79,79
78 LONG(M)=LONG(M)+360
79 CDIF2(M)=COSF(DIF2)
80 SDIF2(M)=SQRT(F(1.-CDIF2(M)**2)
```
N. Compute the \((x, y)\) coordinates of the matrix of latitude, longitude intersections. Starting at \(\text{LAT}(10)\) and \(\text{LONG}(\text{MID})\), compute \((\eta, \psi)\) then \((\rho, \gamma)\) then \((x, y)\) coordinates on the image plane. Keeping the latitude constant, but increasing the longitude, continue the calculations until the horizon is reached or until \(\rho\) exceeds the field of view of the camera. When either of these occur, return to the starting longitude and repeat the calculation for decreasing increments of longitude, again, until the horizon or the edge of the field of view has been reached. Repeat the above procedure at each of the latitude lines until the central longitude is off the earth or off the picture.

```fortran
90  ISTART=10
    KFORK=1
92  ISTOP=ISTART+8
    DO 162 I=ISTART,ISTOP
        GO TO (94,96),KFORK
94  K=I
        GO TO 97
96  K=10-I
97  JSTART=MID
    MFORK=1
98  JSTOP=JSTART+JNO
    DO 151 J=JSTART, JSTOP
        GO TO (110,112),MFORK
    GO TO 114
110  M=J
    GO TO 114
112  M=MID-J
114  CDIST=SLAT(K)*SINSP1+CLAT(K)*COSSP1*CDIF2(M)
    IF(CDIST-1.)116,116,115
115  CDIST=1.
116  SDIST=SQRRTF(1. -CDIST**2)
    XNADIR=ATANF(C3*SDIST/(C3*(1.-CDIST)+H))
    IF(XNADIR-0.98*COMDIP)117,117,160
117  CNADIR=COSF(XNADIR)
    SNADIR=SINF@NADIR)
    SGAMMA=CLAT(K)*SDIF2(M)/SDIST
    IF(ABSF(SGAMMA)-1.)119,119,113
113  SGAMMA=1.
119  GAMMA=ASINF(SGAMMA)
    IF(CDIST*SINSP1-SLAT(K))120,120,118
118  GAMMA=PI-GAMMA
120  DUMMY=LONG(M)
    IF(SP2-DUMMY)124,124,122
122  GAMMA=2.*PI-GAMMA
124  PSI=GAMMA-AZPL
130  COSRHO=CNADIR*CTILT+SNADIR*STILT*COSF(PSI)
1301 RHO=ACOSF(COSRHO)
    IF(RHO-VIEW)132,132,160
132  SALFA=SINF(PSI)*SNADIR/SQRTF(1. -COSRHO**2)
    IF(ABSF(SALFA)-1.)136,136,134
134  SALFA=INTF(SALFA)
136  ALFA=ASINF(SALFA)
    IF(COSRHO*CTILT-CNADIR)140,150,150
140  IF(ALFA)142,144,144
142  ALFA=(-1.)*(PI+ALFA)
    GO TO 150
```
ALFA = PI - ALFA
DUMMY = F*TANF(RHO)
FIX = DUMMY*SALFA
NX(K, M) = IROUND(FIX)
FIX = DUMMY*COSF(ALFA)
NY(K, M) = IROUND(FIX)
IF(JSTART - MID) = 162, 154, 162
JSTART = 1
MFORK = 2
GO TO 98
IF(J - MID) = 152, 164, 152
CONTINUE
IF(IHAVE - 10) = 300, 165, 300
IHAVE = 1
KFORK = 2
GO TO 92

Definitions

CDIST  ---------------  Cosine of the great circle distance \( \delta \) between subpoint and grid point. See Fig. 3 in text.

XNADIR ---------------  Nadir angle \( \gamma \) of grid point viewed from satellite. See Fig. 3.

GAMMA  ---------------  Horizontal angle of grid point measured from true North. Equivalent to the azimuth \( \alpha \) in Fig. 3.

PSI  ---------------  Horizontal angle \( \psi \) of grid point. See Fig. 3.

RHO  ---------------  Radial angle, \( \rho \). See Fig. 4 in text.

ALFA  ---------------  Azimuth \( \gamma \) of the projection of the grid point onto the unit sphere. See Fig. 4.

NX  ---------------  \( x \) coordinate of grid point.

NY  ---------------  \( y \) coordinate of grid point.
O. Select the output statement with the proper dimensions and the correct longitude increment and print out the picture matrix.

300 GO TO (310, 330, 330, 330, 330, 340), JP
310 WRITE OUTPUT TAPE 6, 311, (LONG(M), M=1, 24), (LAT(I), (NX(I,M), M=1,24),
1(NY(I,M), M=1, 24), I=1, 18)
311 FORMAT (14X, 24I4, 18(/10X, 25I4/14X, 24I4))
GO TO 400
330 WRITE OUTPUT TAPE 6, 331, (LONG(M), M=1, 28), (LAT(I), (NX(I,M), M=1, 28),
1(NY(I,M), M=1, 28), I=1, 18)
331 FORMAT (6X, 28I4, 18(/2X, 29I4/6X, 28I4)
GO TO 400
340 WRITE OUTPUT TAPE 6, 341(LONG(M), M=1, 18), (LAT(I), (NX(I,M), M=1, 18),
1(NY(I,M), M=1, 18), I=1, 18)
341 FORMAT (26X, 18I4, 18(/22X, 19I4/26X, 18I4)

P. Re-set all matrix elements equal to 0. Go back to compute the photo-grid for the
next frame stored in TABLE. If there are no more frames to be gridded on this
orbit, convert all times in TABLE to the proper form for output and print out the
entire table as a summary of the photo data. Read new data card. Exit if no
more data.

400 DO 175 I=1, 18
   DO 175 J=1, 30
      NX(I,J)=0
   175 NY(I,J)=0
   GO TO 200
800 DO 180 J=1, NUMBER
   ZTIME=REFT+TABLE(2, J)
   180 TABLE (2, J)=CONVRT(ZTIME)
   WRITE OUTPUT TAPE6, 801, JORBIT, JTIROS, JM, JD, JY, ((TABLE(I, J), I=1, 9)
1, J=1, NUMBER)
801 FORMAT (1H1, 15X, 38HSUMMARY OF PHOTO-GRID OUTPUT ORBIT NO., I5, 14H
1 TIROS NO., I2, 5X, 5HMONT, I3, 5H DAY, I3, 9H YEAR 19, I2//18X,
285HFRAME TIME SP1 SP2 HEIGHT PM1 P
3M2 TILT AZPL/(20X, F3.0, F10.2, 2F10.1, F10.0, 4F10.1))
GO TO 100
END(1, 0, 0, 0, 0, 0, 1, 0, 0, 1, 0, 0, 0, 0, 0, 0)

The program just described assumes the existence of certain built-in and
library functions. In addition, three FORTRAN functions were defined. Those
functions normally a part of the FORTRAN system are as follows:
The three handwritten FORTRAN functions are described below:

FUNCTION DCHK(THETA)

IF(THETA-360.) 4,2,2
2 DCHK=THETA-360.
RETURN
4 IF(THETA) 6,8,8
6 DCHK=THETA+360.
RETURN
8 DCHK=THETA
RETURN
END

I_ROUND(FIX). Takes a floating point argument FIX and rounds it off to the nearest fixed point integer.
FUNCTION IROUND(FIX)
  AFX=INTF(FIX)
  IF(ABS(FIX-AFX)-.5)10,5,5
  BFX=ABS(AFX)+1.
  IROUND=SIGNF(BFIX,AFX)
  RETURN
10 IROUND=AFX
  RETURN
END(1,0,0,0,0,1,0,0,0,0,0,)

CONVRT(ZTIME). Takes a time ZTIME in hours and minutes and makes certain that the minutes do not exceed 59 and the hours 23.

FUNCTION CONVRT(ZTIME)
  XTIME=ZTIME/100.
  YTIME=INTF(XTIME)
  DUMMY=XTIME-YTIME
  IF(DUMMY-.60)4,2,2
  2 DUMMY=DUMMY-.60
  XTIME=YTIME+1.+DUMMY
  4 IF(XTIME-24.)8,6,6
  6 XTIME=XTIME-24.
  8 CONVRT=100.*XTIME
  RETURN
END(1,0,0,0,0,1,0,0,1,0,0,0,0,0)
<table>
<thead>
<tr>
<th>TIROS No.</th>
<th>Month</th>
<th>Day</th>
<th>Year</th>
<th>SCAN POINT CALCULATION</th>
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<tbody>
<tr>
<td>A/O</td>
<td>Readout Orbit No.</td>
<td>R/O</td>
<td></td>
<td></td>
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</tbody>
</table>

| PHOTO GRID CALCULATION | Fig. 1. Form used at SMRP for listing the input data prior to punching. |

<table>
<thead>
<tr>
<th>TSA at the Initial Time</th>
<th>1-1</th>
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</thead>
<tbody>
<tr>
<td>Initial Time ($t_i$)</td>
<td>Z</td>
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<tr>
<td>Latitude (for south)</td>
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<tr>
<td>Longitude (east)</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Orbital Data from Definitive AT Map</th>
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</thead>
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<td>$t$</td>
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</table>

<table>
<thead>
<tr>
<th>Picture Start Time ($t_0$)</th>
<th>hr</th>
<th>min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure time of first direct or last tape picture (always positive)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$\Delta t_e = t_e - t_i$

$t_e$ is the exposure time of each frame

<table>
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<tr>
<th>CAMERA No.</th>
<th>$\Delta t_e$</th>
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<tr>
<td>Tape Direct</td>
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</table>

Fig. 1. Form used at SMRP for listing the input data prior to punching.
Fig. 4. Geometry for transformation from $(\eta, \psi)$ to coordinates $(\rho, \gamma)$ on a unit sphere centered at the perspective center of the photograph.
Fig. 5. Transformation from \((\rho, \gamma)\) to \((x, y)\) coordinates on the distortion-free image plane.

Fig. 6. Horizon geometry and midpoint calculation (see section I in Appendix).
STOP when no more data

START

READ
Identification card giving TIROS no., Orbit No., date, spin-axis data, etc.

READ
Subpoint data cards giving subpoint and altitude at one-minute intervals.

WRITE
Summary of input data.

READ
Picture card giving no. of grids, mode, etc.

Interpolate subpoint positions and satellite altitudes at picture time from subpoint data read into main program. Store in summary matrix TABLE

Set grid count \( m = 0 \).

Increase \( m \) by 1.

Have all grids been computed?

NO

Compute spin-axis point longitude for frame \( m \).

Compute tilt and azimuth of the primary line, \( \Omega_{PR} \).
Store in TABLE.

Compute lat. and long. of primary point.
Store in TABLE.

Is the primary point on the earth?

YES

Compute \((x, y)\) coordinates of points on the horizon.

WRITE
Time, frame no., tilt, etc. and horizon coordinates.

NO

Is there a horizon?

YES

WRITE
Time, frame no., tilt, etc., 'No visible horizon'.

NO

Select the proper grid dimension and longitude increment based upon the subpoint latitude.

Set up latitude, longitude arrays centered around the computed central point. Compute all trigonometric functions of \((\phi, \theta)\) which are required in the coordinate transformations.

Compute the \((x, y)\) coordinates of each grid point within a region of the earth bounded by the horizon and the camera field of view.

Set all \((x, y) = 0\)

WRITE
Matrix of \((x, y)\) coordinates for lat., long. intersections.

Fig. 7. Flow chart.
<table>
<thead>
<tr>
<th>PICTURE NO.</th>
<th>SP1 6.8</th>
<th>SP2 6.7</th>
<th>PM1 5.9</th>
<th>PM2 8.0</th>
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Fig. 8. Sample output matrix.
Fig. 9. Machine grid from simulated TIROS orbit.
Preliminary Result of Analysis of the Cumulonimbus Cloud of April 21, 1961 - Tetsuya Fujita and James Arnold

A Technique for Precise Analysis of Satellite Photographs - Tetsuya Fujita

Evaluation of Limb Darkening from TIROS III Radiation Data - S.H.H. Larsen, Tetsuya Fujita, and W.L. Fletcher

Synoptic Interpretation of TIROS III Measurements of Infrared Radiation - Finn Pedersen and Tetsuya Fujita

TIROS III Measurements of Terrestrial Radiation and Reflected and Scattered Solar Radiation - S.H.H. Larsen, Tetsuya Fujita, and W.L. Fletcher

On the Low-level Structure of a Squall Line - Henry A. Brown

Thunderstorms and the Low-level Jet - William D. Bonner

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