McIDAS

Man computer Interactive Data Access System

Navigation Manual

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PREFACE

Navigation refers to the geometric transformation from a nominal satellite coordinate system to an earth reference system, varying as a continuous function of time, to account for the dynamical effects of the satellite's orbit and attitude. This manual covers the navigation model and the McIDAS commands used to determine the variables and maintain the files associated with the navigation system. Many programs within McIDAS utilize the data in these files for coordinate transformations of the following projections and satellites:

- GOES geostationary
- NOAA polar orbiters
- polar stereographic
- Lambert conformal
- Mercator
- Meteosat
- radar
- Voyager spacecraft (Jupiter, Saturn, Uranus)
- Pioneer Venus

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1. NAVIGATION MODEL

GEOSYNCHRONOUS SATELLITE NAVIGATION MODEL

The transformation of radiance values from an image frame position of a near geosynchronous satellite to an earth reference system requires a model to account for a number of individual satellite parameters necessary to form the complete transformation. Such a Geosynchronous Satellite Navigation model* has been developed at the Space Science and Engineering Center to handle sequences of image frames from ATS, SMS, and GMS satellites over extended time periods. Spacecraft attitude determination uses a time sequence of landmark references. This technique is immediately adaptable to any spin stabilized satellite. The primary focus of the model is the geometric transformation from a nominal satellite coordinate system to an earth reference system, varying as a continuous function of time, to account for the dynamical effects of the satellite's orbit and attitude.

Describing the vagaries incurred in transforming frame sweep coordinates (line-element) of the data imagery to the nominal satellite coordinate system has been of secondary consideration since these vagaries are relatively stable with respect to time and since the cataloging of these errors lies in the area of satellite instrumentation. Parameters have been included in the navigation model on the basis that they could be measured or inferred and that including these parameters would improve the accuracy of the transformation to an earth reference system. Table 1 lists the parameters considered in the model. These parameters are illustrated in a satellite-earth relationship in Figure 1.

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*Geosynchronous Satellite Navigation Model; D. Phillips, E. Smith, January 1974

Orbit Parameters

Transforming the nominal satellite coordinate system to the earth coordinate system requires two dynamical aspects of the satellite: the orbit and the attitude. Orbit parameters are available in the following form:

- orbit inclination
- orbit period
- longitudinal position and time of southern equatorial excursion
- orbit eccentricity
- time and height of orbit apogee

The orbit position vector in earth coordinates is given by s(t) in equation (1).

$$\vec{S}(t) = \begin{pmatrix} x(t) \\ y(t) \\ z(t) \end{pmatrix} = \begin{Bmatrix} \cos(EQC) & -\sin(EQC) & 0 \\ \sin(EQC) & \cos(EQC) & 0 \\ 0 & 0 & 1 \end{Bmatrix} \cdot$$

$$\begin{Bmatrix} \cos(2\cdot\pi\cdot(t-t_{eqc})/P_e) & \sin(2\cdot\pi\cdot(t-t_{eqc})/P_e) & 0 \\ -\sin(2\cdot\pi\cdot(t-t_{eqc})/P_e) & \cos(2\cdot\pi\cdot(t-t_{eqc})/P_e) & 0 \\ 0 & 0 & 1 \end{Bmatrix} \cdot$$

$$\begin{Bmatrix} 1 & 0 & 0 \\ 0 & \cos(I) & \sin(I) \\ 0 & -\sin(I) & \cos(I) \end{Bmatrix} \cdot \begin{Bmatrix} H(t)\cdot\cos(2\cdot\pi\cdot(t-t_{eqc})/P_s) \\ H(t)\cdot\sin(2\cdot\pi\cdot(t-t_{eqc})/P_s) \\ 0 \end{Bmatrix} \qquad (1)$$

where EQC = Longitude of satellite's position during an equatorial crossing (southward)

t_{eqs} = Time of equatorial crossing

I = Inclination of the orbital plane with respect to the equatorial plane

Table 1

Model Parameters

- Frame Definition (see Figure 2)

  A_e = Angular Sweep-Elements

  T_e = Total Elements in Frame

  $R_e = A_e/T_e$ = Radians per Element

  A_ℓ = Angular Breadth-Lines

  T_ℓ = Total Lines in Frame

  $R_\ell = A_\ell/T_\ell$ = Radians per Line

- Spin Rate

  ω_I = Initial Spin Rate

  ω_F = Final Spin Rate

  Spin Rate at Line i = $\omega_i = (\omega_I-(\omega_I-\omega_F) \cdot (L_i/T_\ell))/3600000$

- Orbit

  Inclination

  Eccentricity

  Period

  Longitudinal Drift

- Satellite Spin Axis

  Attitude

  1. Declination
  2. Right Ascension
  3. Picture Center Line

     (Spin Axis Precession)

  Spin Axis Precession

  Spin Axis Nutation

- Earth Element Positioning (λ)

  Position at $t_o = \beta$

  Drift Rate = $\dot{\beta}$

- Camera Mount Misalignment from Projected Spin Axis

  Pitch

  Yaw

  Roll

- Atmosphere

  Refraction

  Cloud Height

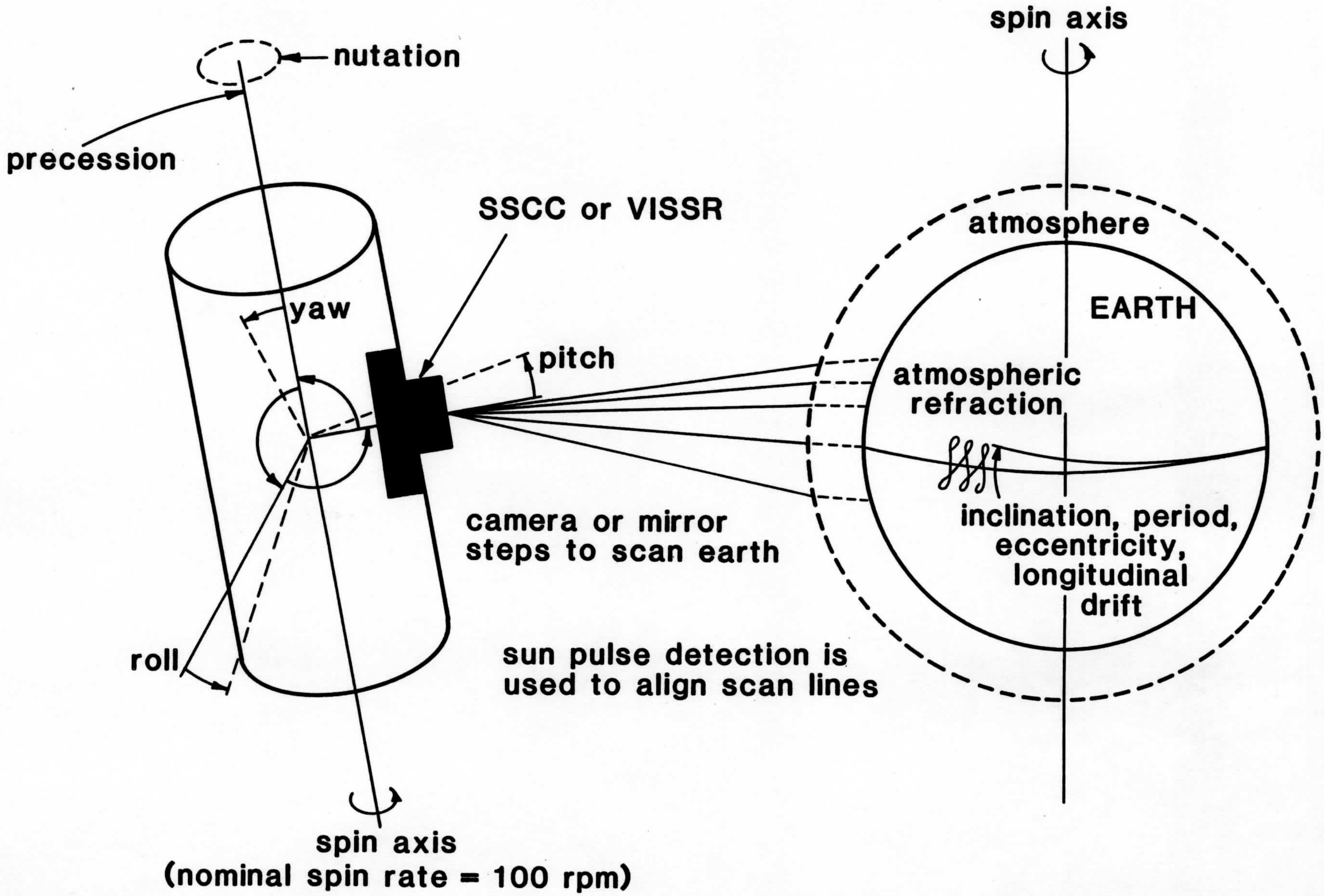

Figure 1. Satellite - Earth relationship

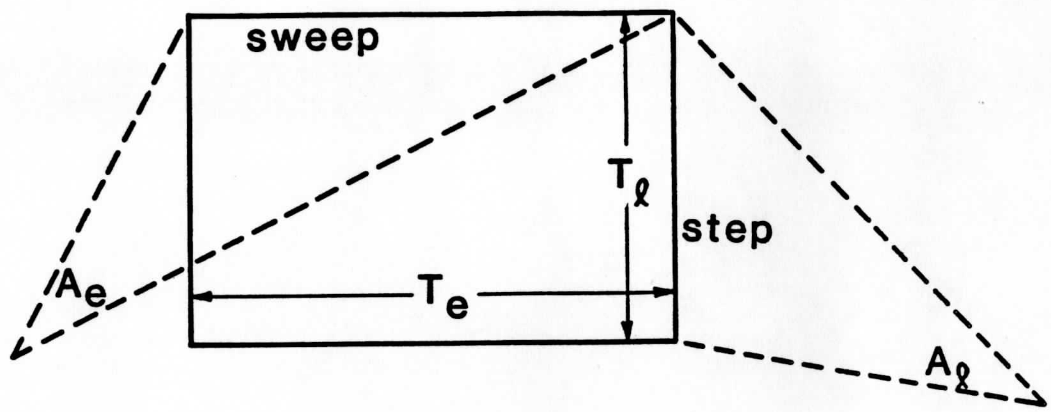

Figure 2. Image frame.

$H(t)$ = Height of satellite at time t

P_s = Orbital Period

P_e = Length of celestial day

and

$$H(t) = (H_{max} - e \cdot H_{max})/1 + e \cdot \cos((t - t_{min}) \cdot 2 \cdot \pi / P_s)) \qquad (2)$$

where

e = Orbital eccentricity

H_{max} = Maximum height of satellite

H_{min} = Minimum height of satellite

t_{min} = Time of minimum height

Attitude Determination

Orbit parameters and landmark measurements are used to calculate spin axis coordinates (attitude) from image data. The spin axis is defined by two parameters and one camera reference as seen in Figure 3.

- D = Declination
- RA = Right Ascension
- PC = Orthogonal Reference (Picture Center Line)

The orbit parameters enable the translation of landmark measurements $\vec{K}_i$ and their corresponding step angles ψ_i to a relationship between the spin axis and the celestial sphere. $\vec{K}_i$ and ψ_i are given by:

$$\vec{K}_i = \begin{pmatrix} r_i \cdot \cos\theta_i \cos\lambda_i \\ r_i \cdot \cos\theta_i \sin\lambda_i \\ r_i \cdot \sin\theta_i \end{pmatrix} \qquad (3)$$

where

r_i = Radius of oblate sphere at landmark i

θ_i = Latitude of landmark i

λ_i = Longitude of landmark i

and

$$\psi_i = R_\ell \cdot (L_i - PC) \qquad (4)$$

where

R_ℓ = Radians per scan line

L_i = Image line coordinate

The position of the satellite in space is found for the time a landmark is viewed by the spin scan camera. The vectors from the center of the earth to the landmark and to the satellite are rotated in a celestial coordinate system according to the time the landmark was scanned. The vector from the satellite to the landmark is then found in celestial coordinates by subtracting the two resultant vectors. This vector is normalized to a unit pointing vector. This yeilds a celestrial coordinate unit vector $\vec{C}_i$ for each landmark measurement defined as follows:

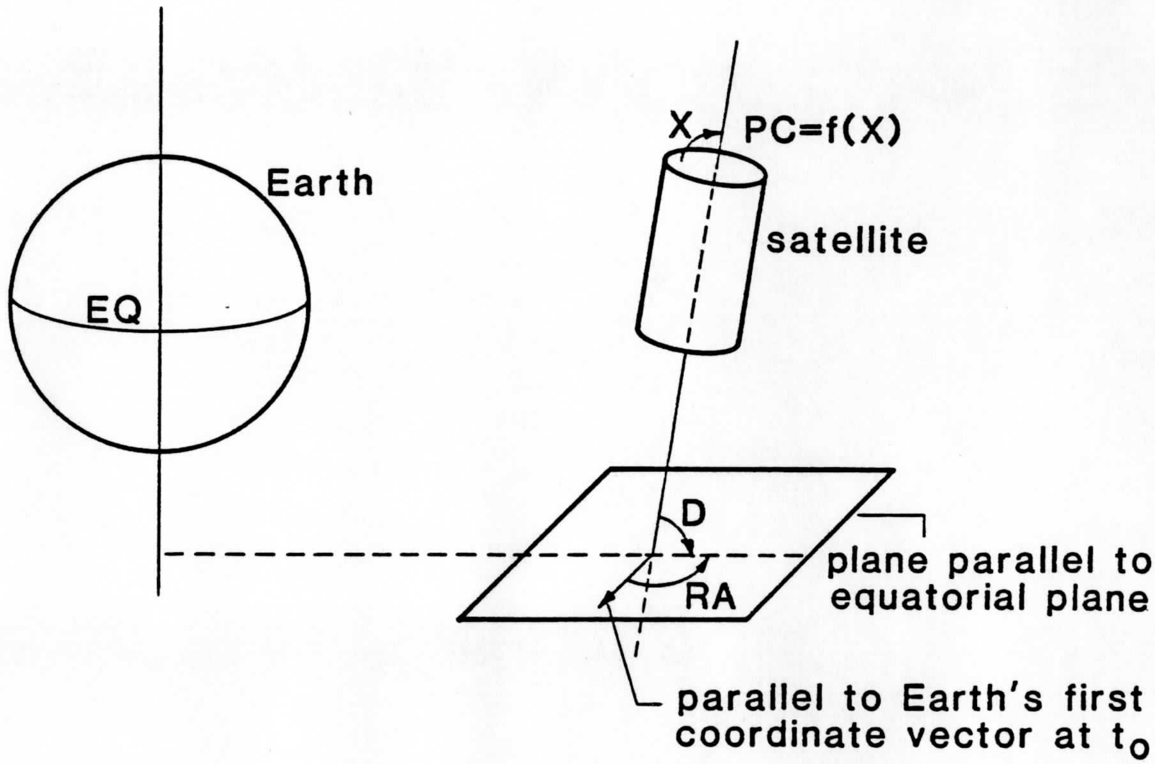

Figure 3. Satellite spin axis.

$$\vec{C}_i = (C_x, C_y, C_z)_i \qquad (5)$$

where

$$\vec{C}_i = \begin{pmatrix} \cos((t-t_o)/P_s) & -\sin((t-t_o)/P_s) & 0 \\ \sin((t-t_o)/P_s) & \cos((t-t_o)/P_s) & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$(\vec{K}_i - \vec{S}(t))/||\vec{K}_i - \vec{S}(t)|| \qquad (6)$$

The angle between the spin axis and the pointing vector $\vec{C}_i$ is determined by the step angle ψ_i corresponding to the scan line at which the landmark occurred. This angle and pointing vector (determined by the landmark and the satellite's position), determine a circular loci of points on the celestial sphere as is illustrated in Figure 4. The spin axis is necessarily restricted to this loci within the limit of the available landmark measurements and the accuracy of the satellite's orbit.

Two landmark measurements determine an attitude position at the intersection of the circular loci on the celestial sphere. You can distinguish which of the two intersections represent the satellite's attitude by knowing that the true spin axis position is the closest to the north pole of the celestial sphere. More than two measurements necessitate a least square procedure in order to obtain a best fit of the attitude position. The least square procedure minimizes the sums of squares of differences between the cosines of step angles (of the camera from the spin axis of the satellite) and the cosines between the celestial pointing vectors (determined by a landmark and the satellite's position) and the unit vector representing the spin axis position. The expression is given in equation (7).

$$g(\alpha, \delta, \phi) - \sum_{i=1}^{n} ((\sin\alpha, \cos\alpha\cdot\cos\delta, \cos\alpha\cdot\sin\delta)\cdot(C_x, C_y, C_z)_i - \cos(\psi_i+\phi))^2 \quad (7)$$

This solution can be found by steepest descent to where partials $\partial g/\partial\alpha$, $\partial g/\partial\delta$, $\partial g/\partial\phi$ are sufficiently close to 0. The iteration technique uses a steepest descent method with a convergence criteria dependent on the step size. Thus,

$$\partial g/\partial\alpha = \sum_{i=1}^{n} (C_x)^2\cdot\cos\alpha\cdot\sin\alpha + \sum_{i=1}^{n} (C_x\cdot C_y)\cdot\cos\delta\cdot(2\cdot\cos\alpha^2-1)$$

$$+ \sum_{i=1}^{n} (C_x\cdot C_z)\cdot(2\cdot\cos\alpha^2-1)\cdot\sin\delta - \sum_{i=1}^{n} (C_y)^2\cdot\cos\alpha\cdot\sin\alpha$$

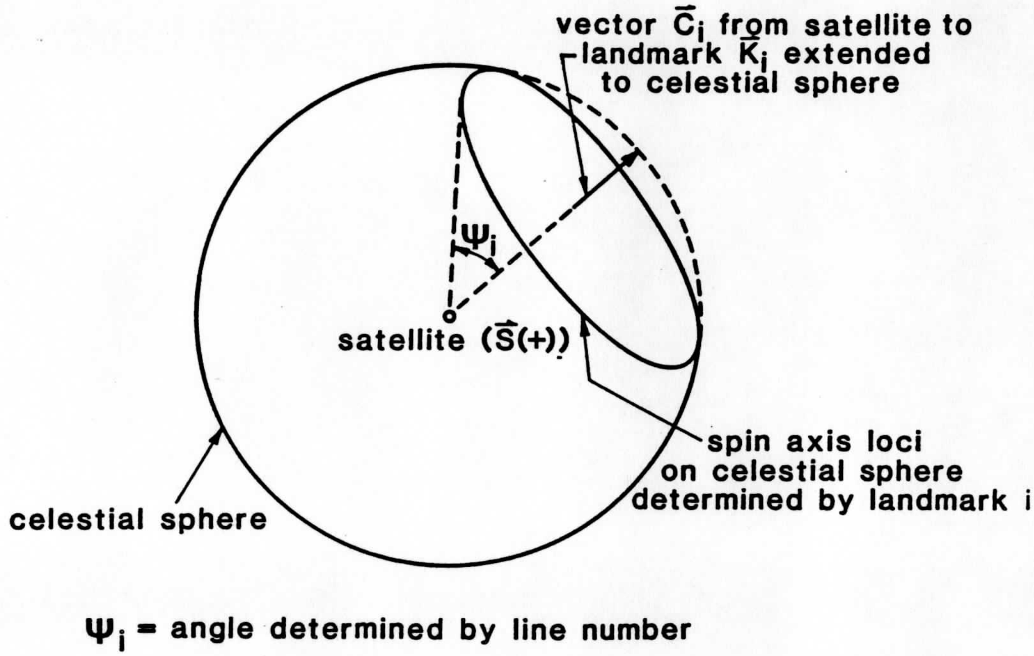

Figure 4. Attitude determination using landmark measurements.

$$\cdot \cos\delta^2 - \sum_{i=1}^{n} (C_y \cdot C_z) \cdot 2 \cdot \sin\alpha \cdot \cos\alpha \cdot \sin\delta \cdot \cos\delta$$

$$- \sum_{i=1}^{n} (C_z)^2 \cdot \sin\alpha \cdot \cos\alpha \cdot \sin\delta^2 - \sum_{i-1}^{n} (C_x \cdot \cos\psi_i) \cdot \cos\alpha$$

$$\cdot \cos\phi + \sum_{i=1}^{n} (C_x \cdot \sin\psi_i) \cdot \cos\alpha \cdot \sin\phi + \sum_{i=1}^{n} (C_y \cdot \cos\psi_i)$$

$$\cdot \sin\alpha \cdot \cos\delta \cdot \cos\phi - \sum_{i=1}^{n} (C_y \cdot \sin\psi_i) \cdot \sin\alpha \cdot \cos\delta$$

$$\cdot \sin\phi + \sum_{i=1}^{n} (C_z \cdot \cos\psi_i) \cdot \sin\alpha \cdot \sin\delta \cdot \cos\phi$$

$$- \sum_{i=1}^{n} (C_z \cdot \sin\psi_i) \cdot \sin\alpha \cdot \sin\delta \cdot \sin\phi \qquad (8)$$

$$\partial g/\partial\delta = -\sum_{i=1}^{n} (C_x \cdot C_y)\cdot\cos\alpha\cdot\sin\alpha\cdot\sin\delta + \sum_{i=1}^{n} (C_x \cdot C_z)\cdot\sin\alpha\cdot\cos\alpha$$

$$\cdot\cos\delta - \sum_{i=1}^{n} (C_y)^2\cdot\cos\alpha^2\cdot\cos\delta\cdot\sin\delta + \sum_{i=1}^{n} (C_y \cdot C_z)$$

$$\cdot\cos\alpha^2\cdot(2\cdot\cos\delta^2-1) + \sum_{i=1}^{n} (C_z)^2\cdot\cos\alpha^2\cdot\sin\delta\cdot\cos\delta$$

$$+ \sum_{i=1}^{n} (C_y \cdot\cos\psi_i)\cdot\cos\alpha\cdot\sin\delta\cdot\cos\phi - \sum_{i=1}^{n} (C_y \cdot\sin\psi_i)$$

$$\cdot\cos\alpha\cdot\sin\delta\cdot\sin\phi - \sum_{i=1}^{n} (C_z \cos\psi_i)\cos\alpha\cdot\cos\delta\cdot\cos\phi$$

$$+ \sum_{i=1}^{n} (C_z \cdot\sin\psi_i)\cos\alpha\cdot\cos\delta\cdot\sin\phi \qquad (9)$$

$$\partial g/\partial\phi = \sum_{i=1}^{n} (C_x \cdot\cos\psi_i)\sin\alpha\cdot\sin\phi + \sum_{i=1}^{n} (C_x - \sin\psi_i)\sin\alpha\cdot\cos\phi$$

$$+ \sum_{i=1}^{n} (C_y \cdot\cos\psi_i)\cos\alpha\cdot\cos\delta\cdot\sin\phi + \sum_{i=1}^{n} (C_y \cdot\sin\psi_i)\cos\alpha\cdot\cos\delta\cdot\cos\phi$$

$$+ \sum_{i=1}^{n} (C_z \cdot\cos\psi_i)\cos\alpha\cdot\sin\delta\cdot\sin\phi + \sum_{i=1}^{n} (C_z \cdot\sin\psi_i)\cos\alpha\cdot\sin\delta\cdot\cos\phi$$

$$- \sum_{i=1}^{n} (\cos\psi_i)^2\sin\phi\cdot\cos\phi + \sum_{i=1}^{n} (\sin\psi_i)^2\sin\phi\cdot\cos\phi$$

$$+ \sum_{i=1}^{n} (\sin\psi_i \cdot\cos\psi_i)\cdot(2\cdot\sin\phi^2-1) \qquad (10)$$

In response to the fact that the step number (picture center line), at which the spin scan camera is perpendicular to the spin axis of the satellite, is not necessarily known, a parameter corresponding to this step number PC has been incorporated in the model. This makes finding the spin axis position a three parameter problem. We solve for D, RA, PC from the three angles

$$D = \mathrm{asin}(\cos\tilde{\alpha}\cdot\sin\tilde{\delta}) \tag{11}$$

$$RA = \mathrm{atan}(\cos\alpha\cdot\cos\delta/\sin\alpha) \tag{12}$$

$$PC = PC_n-(\tilde{\phi}-\pi/2)R_\ell \tag{13}$$

where $\tilde{\alpha}$, $\tilde{\delta}$, and $\tilde{\phi}$ are the respective values of α, δ, and ϕ after the last iteration and PC_n is the nominal picture center line.

<u>Nominal Satellite Coordinate System</u>

The nominal satellite coordinate system is determined by the spin axis pointing vector and the position of the earth in each scan line. The z axis coincides with the spin axis of the satellite. The x axis is perpendicular to the earth. The y axis completes a right handed coordinate system as illustrated in Figure 5. The position of the earth in each line sweep determines the x, y coordinates of the pointing vector of each sample on that line. Hence, a transformation from the raw image frame coordinates to the satellite's nominal reference frame is needed.

Consequently, in transforming from the satellite's raw image frame to the satellite's nominal reference frame it is necessary to measure the earth position in each scan line. In the model the deviation of the earth from its nominal position is determined from landmarks measurements. Any deviation from the nominal position can be approximated as a linear function of time. For this reason a regression line is fitted to the residuals obtained from measured landmark sample positions and their positions in the nominal frame of reference. The y intercept of the regression line is referred to as β at time t_o and the slope of the line is referred to as $\dot{\beta}$ as seen in Figure 6. The equations for deriving the regression line follow. Let

$$\gamma(t) = \beta + \dot{\beta}t \tag{14}$$

where

γ = Drift in radians from frame center.

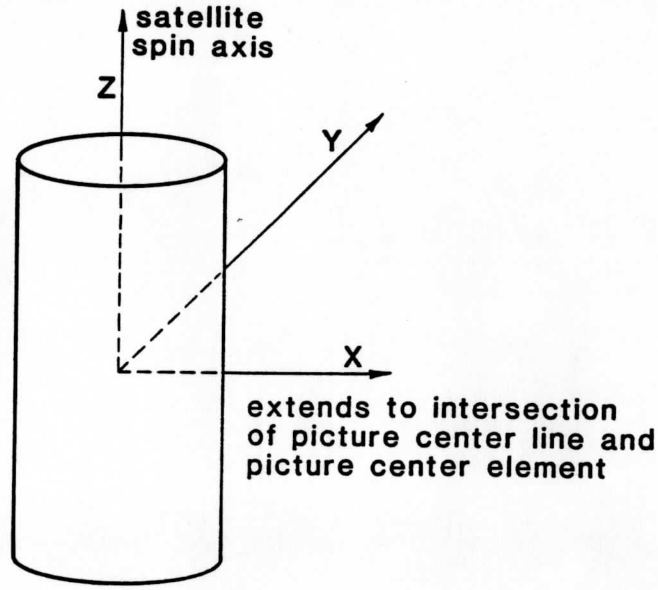

Figure 5. Nominal satellite coordinate system.

Minimize the expression

$$\sum_{i=1}^{n} (\beta_i - \beta - \dot{\beta} t_i)^2 \qquad (15)$$

where

PICTIM = Frame start time

n = Number of landmarks

$$\beta_i = R_e(E_i^{\gamma_o} - E_i^m) \qquad \text{where } \gamma_o = 0 \qquad (16)$$

$$t_i = PICTIM + \omega_i \, (L_i + (E_i \cdot A_e)/(T_e \cdot 360)) \qquad (17)$$

Using the following sums,

$$S\gamma = \sum_{i=1}^{n} \gamma_i \qquad (18)$$

$$S_{\gamma t} = \sum_{i=1}^{n} \gamma_i t_i \tag{19}$$

$$S_t = \sum_{i=1}^{n} t_i \tag{20}$$

$$S_{t^2} = \sum_{i=1}^{n} t_i^2 \tag{21}$$

solve for β and $\dot{\beta}$

$$\beta = (S_{t^2} S_\gamma - S_t S_{\gamma t})/nS_{t^2} - S_t^2) \tag{22}$$

$$\dot{\beta} = (nS_{\gamma t} - S_\gamma S_t)/nS_{t^2} - S_t^2) \tag{23}$$

Satellite-Earth Coordinate Transformation

We desire a transform f such that

$$f(L,E) = (\theta,\lambda) \tag{24}$$

and

$$f^{-1}(\theta,\lambda) = (L,E) \tag{25}$$

where L = Line (satellite coordinate)

E = Element (satellite coordinate)

θ = Latitude (earth coordinate)

λ = Longitude (earth coordinate)

The ability to transform to an earth frame of reference (θ,λ) from satellite imagery coordinates (L,E) results from the ability to transform vectors in the satellites nominal coordinate system to an earth reference frame, and vice versa (see Figure 7). The transformation is a rigid Euclidean rotation and displacement. The displacement vector from the earth's reference frame to the satellite's nominal coordinate system is determined by the satellite's position at that particular time in the earth's reference frame. The third column of the rotational matrix is the pointing vector of the spin axis in the earth's frame of reference given in equation (26) and (27).

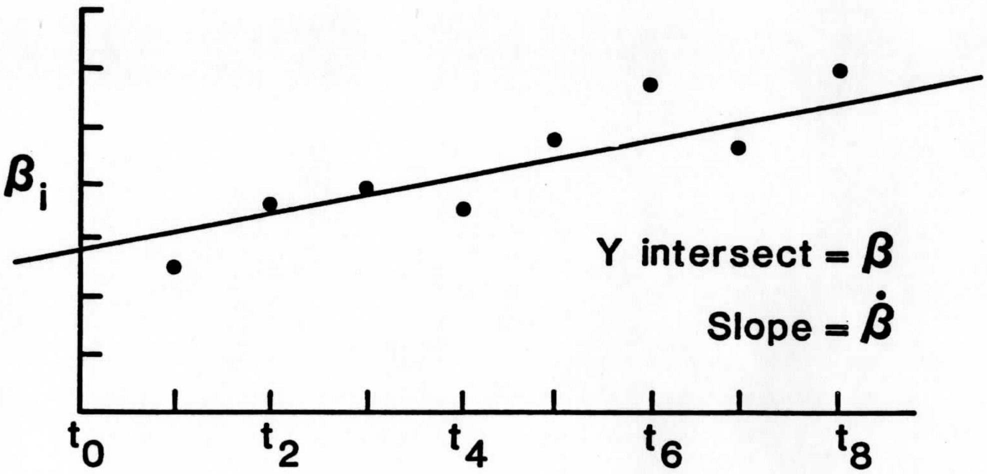

Figure 6. Beta and beta-dot calculation.

$$\overrightarrow{SPAX}(t) = \begin{Bmatrix} \cos[(t-t_o)\cdot 2\pi/P_e] & \sin[(t-t_o)\cdot 2\pi/P_e] & 0 \\ -\sin[(t-t_o)\cdot 2\pi/P_e] & \cos[(t-t_o)\cdot 2\pi/P_e] & 0 \\ 0 & 0 & 1 \end{Bmatrix} \cdot \begin{Bmatrix} \cos D & \sin RA \\ \cos D & \sin RA \\ \sin D & 0 \end{Bmatrix} \quad (26)$$

$$\overrightarrow{AROT_3}(t) = \overrightarrow{SPAX}(t) \quad (27)$$

where

D = Declination of satellite spin axis

RA = Right Ascension of satellite spin axis

$\overrightarrow{SPAX}(t)$ is assumed to have been adjusted for precession and nutation by the respective equations (28) and (29).

$$\overrightarrow{SPAX}(t) = \overrightarrow{SPAX}(t)\cdot\cos[P_{rate}\cdot(t-t_o)] + P_{dir}\cdot\sin[P_{rate}\cdot(t-t_o)] \quad (28)$$

where

P_{rate} = Precession Rate

P_{dir} = Precession Direction

and

$$\overrightarrow{SPAX}(t) = \overrightarrow{SPAX}(t) \cdot \cos[N_{mag}] + N_{dir} \cdot \sin[N_{mag}] \qquad (29)$$

where

N_{mag} = Nutation Magnitude at time t

N_{dir} = Nutation Direction at time t

The first column of the rotational matrix is perpendicular to the third column and lies in the same plane as the spin axis pointing vector and the satellite position vector:

$$\overrightarrow{AROT}_1(t) = \frac{\dfrac{\vec{S}(t)}{||\vec{S}(t)||} - \dfrac{\vec{S}(t)}{||\vec{S}(t)||} \cdot \overrightarrow{SPAX}(t) \cdot \overrightarrow{SPAX}(t)}{\left|\left|\dfrac{\vec{S}(t)}{||\vec{S}(t)||} - \dfrac{\vec{S}(t)}{||\vec{S}(t)||} \cdot \overrightarrow{SPAX}(t) \cdot \overrightarrow{SPAX}(t)\right|\right|} \qquad (30)$$

The second column is a cross product of the third and first columns, resulting in an orthogonal rotational matrix

$$\overrightarrow{AROT}_2(t) = \overrightarrow{AROT}_3(t) \times \overrightarrow{AROT}_1(t) \qquad (31)$$

The rotational matrix and displacement vector enables a conversion of vectors from an earth reference frame to the nominal satellite reference system.

$$AROT(t) = \begin{pmatrix} \overrightarrow{AROT}_1(t) \\ \overrightarrow{AROT}_2(t) \\ \overrightarrow{AROT}_3(t) \end{pmatrix} \qquad (32)$$

In transforming from the image frame coordinates to the nominal satellite reference system, an adjustment has to be made for misalignment between the camera axis and the spacecraft spin axis. This is done with a

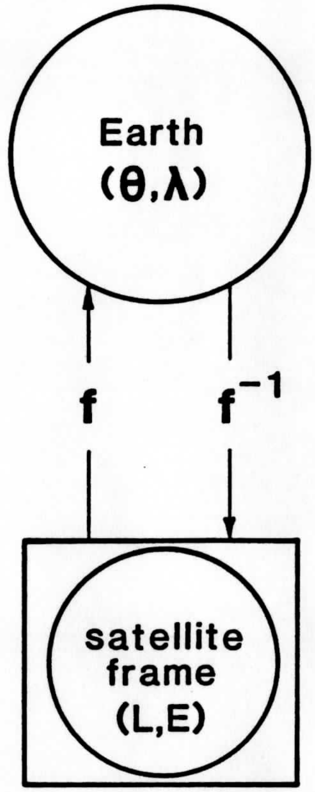

Figure 7. Satellite-Earth Transformation

rotational matrix defined in terms of the three angles of misalignment (ξ, η, κ) given by equation (33).

$$ROT = \begin{matrix} (\cos\kappa\cdot\cos\xi) & 0 & (\sin\eta\cdot\sin\kappa\cdot\cos\xi + \cos\eta\cdot\sin\xi) \\ (-\sin\kappa) & 0 & (\sin\eta\cdot\cos\kappa) \\ (\cos\kappa\cdot\sin\xi) & 0 & (\cos\eta\cdot\cos\xi - \sin\eta\cdot\sin\kappa\cdot\sin\xi) \end{matrix} \qquad (33)$$

where

ξ = pitch misalignment (North-South displacement)

η = yaw misalignment (Total skew effect)

κ = roll misalignment (East-West displacement)

The Euler angles of this rotation are referred to as roll, pitch and yaw. This rotation actually accounts for two effects: the misalignment of the camera axis from the principle axis of the satellite and the misalignment of the principle axis from the spin axis of the satellite. Both misalignments can be modeled as one effect. The values of these parameters are expected to remain constant over long time periods and will be extractable from the imagery data.

Satellite to Earth - $(\theta,\lambda) = f(L,E)$

The background is now set to examine the transformation from satellite image coordinates to earth latitude and longitude coordinates in detail. First a pointing vector, $\vec{V}_s(t)$, is found in nominal satellite coordinates with adjustment for principle axis anomalies

$$\vec{V}_s(t) = \begin{pmatrix} \cos E & \sin E & 0 \\ -\sin E & \cos E & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} \mathrm{ROT} \end{pmatrix} \cdot \begin{pmatrix} \cos L \\ 0 \\ -\sin L \end{pmatrix} \quad (34)$$

Next, $\vec{V}_s(t)$ is rotated into a pointing vector $\vec{V}_e(t)$ in earth coordinates.

$$\vec{V}_e(t) = (\mathrm{AROT}(t))^{-1} \cdot \vec{V}_s(t) \quad (35)$$

where

$$\begin{matrix} x'(t) \\ y'(t) \\ z'(t) \end{matrix} = \vec{V}_e(t) \quad (36)$$

and

$$\begin{matrix} x(t) \\ y(t) \\ z(t) \end{matrix} = \vec{S}(t) \quad (37)$$

The pointing vector $\vec{V}_e(t)$ is extended to an intersection with an oblate sphere representing the earth's surface at the proper atmospheric level with the parameter d in equation (38).

$$1 = \frac{[x(t)-d \cdot x'(t)]^2 + [y(t)-d \cdot y'(t)]^2}{a^2} + \frac{[z(t)-d \cdot z'(t)]^2}{b^2} \quad (38)$$

where

a = equatorial radius of earth

b = polar radius of earth

This intersection determines an earth coordinate vector $\vec{EC}(t)$:

$$\vec{EC}(t) = [EC_x(t), EC_y(t), EC_z(t)] = \vec{S}(t) - d_1 \cdot \vec{V}_e(t) \quad (39)$$

where d_1 (the smallest root of equation (39)) is the distance from the satellite to the intersection with the earth's surface at that atmospheric level. A correction for atmospheric refraction can be made by the following three steps:

1. Determine the intersection of the pointing vector $\vec{V}_e(t)$ with the appropriate oblate sphere at the top of the atmosphere.
2. Perturbate the pointing vector by the refraction angle determined from Snell's principles of refraction.
3. Solve for a new pointing vector $\vec{V}_e(t)$ and then proceed to determine the earth coordinate vector $\vec{EC}(t)$.

The final step solves for θ and λ.

$$\theta = \text{atan}(EC_z/\sqrt{EC_x^2 + EC_y^2}) \quad (40)$$

$$\lambda = \text{atan}(EC_y/EC_x) \quad (41)$$

This completes the satellite image coordinate (L,E) tranformation to earth coordinates (θ,λ).

Earth to Satellite - (L,E) = $f(\theta,\lambda)$

The transformation from earth coordinates to satellite image coordinates is easier. First an earth coordinate vector is generated.

$$\overline{EC}(t) = \begin{pmatrix} r(\theta) \cdot \cos\theta \cdot \cos\lambda \\ r(\theta) \cdot \cos\theta \cdot \sin\lambda \\ r(\theta) \cdot \sin\theta \end{pmatrix} \quad (42)$$

where $r(\theta)$ = radius of oblate sphere at the specified atmospheric level at latitude θ

The vector from the earth's surface to the satellite is given by equation (43).

$$\vec{W}(t) = (\overrightarrow{EC}(t) - \vec{S}(t)) \quad (43)$$

Normalize this vector to a pointing vector $\vec{V}_e(t)$ in earth coordinates,

$$\vec{V}_e(t) = \vec{W}(t) / |\vec{W}(t)| \quad (44)$$

Note that an atmospheric refraction correction can be applied in an inverse manner as before.

Rotate $\vec{V}_e(t)$ into a pointing vector in satellite coordinates

$$\vec{V}_s(t) = (AROT(t)) \cdot \vec{V}_e(t) \quad (45)$$

where

$$\begin{pmatrix} x''(t) \\ y''(t) \\ z''(t) \end{pmatrix} = \vec{V}_s(t) \quad (46)$$

The final step solves for L and E corrected for principle axis anomalies

$$L = PC - [\mathrm{asin}(z''(t)/\sqrt{ROT_{3,1} + ROT^2_{3,3}}) - \mathrm{atan}(ROT)_{3,1}/ROT_{3,3})]R_\ell \quad (47)$$

$$E = PE - [\mathrm{atan}[(ROT_{2,1} \cdot CL + ROT_{2,3} \cdot SL)/(ROT_{1,1} \cdot CL + ROT_{1,3} \cdot SL)] - \mathrm{atan}[y''(t)/x''(t)]]/R_e \quad (48)$$

where PC = Picture Center Line

PE = Picture Center Element

$$SL = \frac{z''(t)}{\sqrt{ROT^2_{3,1} + ROT^2_{3,3}}}$$

$$CL = \sqrt{1-SL^2}$$

The transformation from earth to satellite coordinates requires an iterative procedure because t is not known exactly for the earth coordinate (θ,λ), thus $\vec{S}(t)$ and AROT(t) are not known. Five iterations are sufficient to converge to the proper t. The picture start time is used as an initial guess. This completes the model's ability to achieve satellite imagery coordinates (L,E) from earth reference coordinates (θ,λ).

Image Frame Coordinates Irregularities

The irregularities involved in registering image data in the time dependent coordinate system of the satellite's camera sweep across the earth's surface have been ignored in the model. These irregularities result from electronic timing errors, signal sampling errors and sun pulse detection errors during the data acquisition process. However, as has been explained, any steady linear shear of the picture with respect to the earth is modeled with an initial value and slope term. Finally, the spin rate and angular sample resolution are included in the model, thereby completing the set of parameters needed to describe the sweep coordinate of the imagery frame.

The scan line step coordinates in the imagery frame are dependent upon camera step measurements, with respect to the principle axis, made before launch. Any non-repeatable stepping irregularities from one image frame to another or post launch line stepping distortions within the same frame are not considered in this model. However, frame coordinate irregularities can be easily implemented in such a model by using camera step-sweep increment lookup tables.

2. DAILY NAVIGATION

DAILY NAVIGATION

In order to navigate satellite imagery you need to understand the interrelationship of coordinate transformations, spacecraft orientation and landmark measurements.

Coordinate Transformations

The variables needed for coordinate transformations are divided into five areas:

- frame geometry
- camera geometry
- spacecraft orientation
- spacecraft orbit
- satellite-earth-Sun related variables.

There are four frame geometry parameters defining the line and element resolution of a satellite image: total scan lines (LINTOT), total elements in scan line (ELETOT), total sweep angle in line direction (DEGLIN), total sweep angle in element direction (DEGELE). They are constant over time for a given satellite but may vary with satellite design.

Five camera geometry variables define the relationship between VISSR mirror and the spacecraft: pitch is the forward-leaning misalignment causing a line position bias, yaw is the sideways leaning misalignment causing element direction skew as a function of line number, roll is the rotation misalignment causing element direction bias, PICLIN is the picture center line determined from scan frame geometry, ISEANG is the angle between the VISSR and sun sensor. Pitch and piclin are different forms of the same expression for the same variables. They usually change at the time of a spacecraft manuever due to a change of on-board mass distribution when fuel is expended. The change in mass distribution causes a change in the spacecraft spin axis relative to the physical axis.

The spacecraft orientation parameters are spin axis declination, right ascension and spin rate; these three vary daily. The first two are attitude parameters which cannot be measured directly, but must be computed using landmarks or starmarks in the images. The spacecraft attitude affects the location of the Earth image in the line direction (North - South) only. The spin rate also varies daily, however, the algorithms are designed to be insensitive over the normal range of variation.

Orbit Parameters

Eight orbit parameters describe the position and velocity of the satellite at a particular time (epoch time):

- epoch date the orbit is valid, year, month, day, ETIMY
- epoch time the orbit is valid, hour, minute tenths, ETIMH
- semi major axis of the elliptical orbit of the satellite, SEMIMA
- orbit eccentricity coefficient is the ratio of the distance between foci of the ellipse and the semi-major axis, ECCEN
- orbit inclination is the angle between the plane of the satellite's orbit and the earth's equator, ORBINC
- mean anomaly is the angle between a line from the satellite to the earth at a given moment and a line from the earth to the satellite's perigee passage, MEANA
- argument of perigee is the angle from the ascending node measured in the satellite's orbit plane and the direction of motion to the perigee point, PERIGEE

- longitude of ascending node is the angle between the Vernal Equinox and the line defining the equatorial and orbit planes intersection where the satellite crosses the equator going north, ASNODE.

The spacecraft constantly has many small forces acting on it which are not included in the simple orbit model used by McIDAS. Therefore, these parameters should be updated on a daily to weekly basis. If a maneuver (station keeping) is executed, the orbit parameters must be updated (usually within hours) to maintain accurate navigation. These parameters can be obtained from several sources. They can be computed from landmarks or starmarks or gotten from the responsible government agency. NASA measures GOES orbits once every two weeks and sends a TWX of the parameters, these are filed in the SSEC computer room.

Betas and Gammas

The GOES satellites have a sun sensor on-board which is used to determine when the Earth will be in view of the camera (mirror) and consequently, when to start taking data for each scan line. The angle between the start of Earth view and the Sun is called beta. The Earth and satellite rotate 15 degrees per hour, therefore, a beta/time (beta-dot) is used to maintain the Earth in the center of the frame as an image is scanned. Betas stored in McIDAS are used to compute gamma and gamma-dot parameters. Gamma and gamma-dot are the variables which determine the East-West navigation for an image. If they are not present in the navigation file for a specific image, McIDAS will use a set from an earlier time as a first guess. The betas provide one basis for computing gammas, they can also be computed for an image using the element position of two landmarks in the image.

Landmarks

Each day a set of landmarks is collected and measured. The measurement consists of selecting a land feature (usually a point on a coast line) and accurately defining the latitude-longitude and the satellite line-element for that point in a series of pictures. From the Earth coordinate of the landmark and an orbit description, a unit vector from the satellite to the landmark is computed. From the image coordinate line number and an orbit description, a second unit vector from the satellite to the landmark is computed. By allowing the spin axis attitude of the satellite to vary, the difference between the two vectors is minimized. A plane has now been defined normal to this vector and passing through the center of the satellite. A second vector provides a second plane intersecting the first and defining the spin axis by the resulting line of intersection. The larger the angle between these planes the more likelihood of a correct solution; thus, daily navigation requires a minimum of two landmark measurements.

Noise, from a variety of sources (measurement error, nutation, etc.), requires that a number of measurements be made and a least squares solution be used for the spin axis attitude. The attitude is expressed as two angles: declination and right ascension. The right ascension is the angle between the vernal equinox and the projection of the spin axis onto the Equatorial plane. Declination is the angle between this projection and the spin axis.

The implications of the above discussion are:

- One landmark is inadequate to produce a solution.
- Two landmarks will produce a solution; however, in our imperfect world more than two measurements are necessary.
- The two landmarks can be from one image or from different images.

- The greater the time difference between images the better the solution.
- No two landmarks need be the same.
- Five careful measurements from successive images would normally be adequate to eliminate measurement noise.
- Two addition landmarks (total seven) will normally suffice when nutation is present.

North-South and East-West Component

The attitude determination takes care of the North-South component of the navigation problem and Iajust-gamma have been introduced to deal with the East-West navigation. The start of data collection for each scan is determined from the sun pulse generated by the satellite's sun sensor and beta. Beta and beta-dot are input to the S/DB at the ground station to correct and keep the earth image centered in the frame. Since the values used don't necessarily agree with those expected by our satellite-earth-Sun orbit models, we compute correction factors for each image. The correction factors are gamma and gamma-dot. The final correction is IAJUST, which is the difference between the computed element location and the measured element location for the first landmark of the day.

There are additional considerations in the daily navigation which impact the 24-hour prediction and orbit adjustment processes. Using the same geographic location for primary landmarks throughout the day as well as for subsequent days makes the orbit adjustment process much simpler for reasons to be discussed later. Establishing a standard primary landmark also helps the quality control of the measurements, since a time sequence loop with each frame centered on the measured points will detect measurement errors in a relative sense. It is less important to the orbit adjustment process for the secondary landmark to be fixed, but the quality control benefit still applies.

Daily Navigation Procedures

The navigation procedures can be divided into four sub-tasks:

- landmark collection
- landmark measurement
- attitude-IAJUST determination
- quality control.

A detailed flow diagram (Figure 8) and sample output (Figure 9) are included. The landmark collection process is set up by any one of several data ingest commands. For real time GOES imagery AA is the basic command.

Measuring Landmarks

Normally, the primary landmark is selected for seven consecutive images beginning in early morning and the secondary landmark is selected for first, fourth, and seventh images. After the landmark set is collected and displayed at four times enlargement, the measurement phase begins. Since the landmark coordinates are frequently used, you should determine the latitude and longitude of the landmark and enter its value into a string table entry with command TE. A plastic overlay should be traced from the clearest image and the latitude/longitude point marked with a cross hair. Starting with the primary landmark align the plastic overlay to the entire pattern on the TV monitor, not just a single point, and place the cross hair cursor under the overlay cross hair and enter the NE_L command.

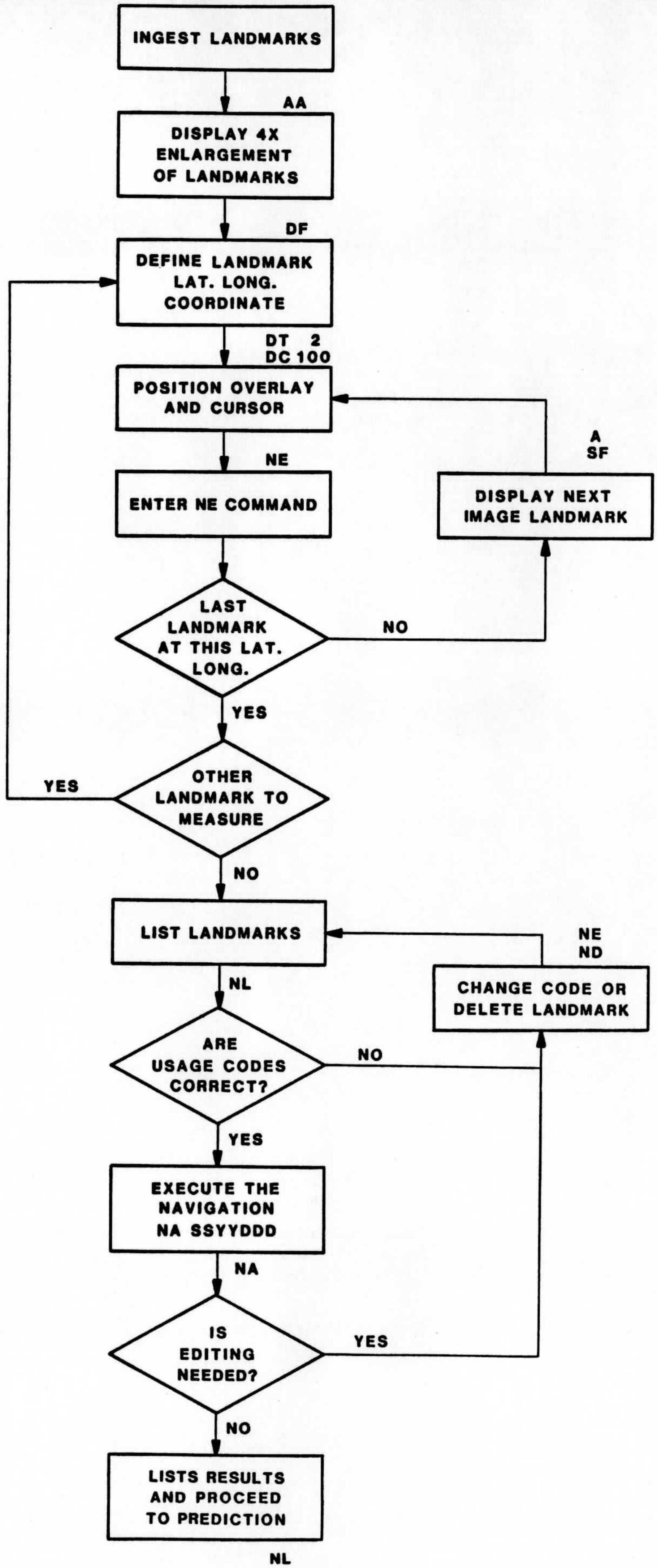

Figure 8. Daily Navigation.

When all landmarks have been measured, the images should be redisplayed (DF command) with the measured landmark at the center of each frame and looped. This will help evaluate measurement errors, but caution must be exercised because you are attempting to align the entire landmark area not a single point. The single point can move around considerably from one image to the next because of nutation, jitter, etc. Remeasure on any images when the landmark pattern does not match the majority; you may need to shift images by two or more pixels.

Use NL to list the landmarks and ensure all have the proper code (i.e., primary are code Ø, secondary are code 3Ø1, tertiary are code 3Ø2, etc.), if not, use NE to change codes. Now the measurement phase is complete. Compute the attitude and IAJUST with command NA. Pages_to_ explain the format and the evaluation of a typical navigation run. When the results are satisfactory, another NA run with the print and punch options will provide a permanent record for future reference.

SAMPLE NAVIGATION RUN

The following pages provide examples of output from command NA for a typical day. The original listing generated by NA_1279Ø24_X_ON_DEV=P is shown in Figure 9.

General Description of the Output

The output in Figure 9 is a product of the NA command. The first half of the output ("Landmarks" through "Keplerian orbit parameters") lists the input data from which the attitude, East-West adjustment, gammas, and landmark residuals were computed.

Under the heading LANDMARKS:

- N is the landmark number in the landmark file.
- LTIME is the nominal start time of the image from which the landmark was measured.
- LINE and ELEM are the sensor line number and element number (full resolution satellite coordinates) at the location of the landmark feature.
- LAT and LON are the geodetic latitude and longitude of the same landmark feature defined by LINE and ELEM.

Under the heading BETAS:

- N is the number of betas in the file.
- BTIME is the nominal start time of the image from which the betas were taken.
- SCN1 is the first observed scan number,
- STIM1 is the time in hours, minutes and seconds,
- M1 is the time in milliseconds
- BETA1 is the beta from the IR documentation
  SCN2, STIM2, M2 and BETA2 are the last observed set of the same parameters.

FIGURE 9. Sample Navigation Run

NAVIGATION FROM FILE # 100 FOR: JAN. 24, 1979 SSYYDDD: 1279024

LANDMARKS

N	LTIME	LCODE	LINE	ELEM	LAT	LON
1	83300	0	2517	6604	351500	-1394430
2	100300	0	2478	6614	351500	-1394430
3	103300	0	2464	6616	351500	-1394430
4	110300	0	2446	6618	351500	-1394430
5	113300	0	2427	6620	351500	-1394430
6	153300	0	2265	6630	351500	-1394430
7	173300	0	2212	6623	351500	-1394430
8	173300	301	7703	6385	-330000	-1374700
9	203300	0	2218	6609	351500	-1394430
10	203300	301	7717	6407	-330000	-1374700
11	220300	0	2257	6600	351500	-1394430
12	220300	301	7759	6415	-330000	-1374700
13	223300	0	2274	6596	351500	-1394430
14	223300	301	7777	6417	-330000	-1374700
15	230300	0	2293	6593	351500	-1394430
16	233300	0	2314	6589	351500	-1394430

BETAS

N	BTIME	SCN1	STIM1	M1	BETA1	SCN2	STIM2	M2	BETA2
1	53300	3	53214	488	2450071	2400	55609	199	2345625
2	83300	3	83212	27	1664042	785	84000	31	1629973
3	100300	3	100219	87	1270512	785	101007	90	1236646
4	103300	3	103420	57	1130721	785	104208	61	1096654
5	110300	3	110400	56	1001168	785	111148	68	967104
6	113300	3	113404	207	869834	2400	115759	906	765424
7	153300	3	153245	17	6117643	785	154033	20	6083587
8	173300	3	173218	46	5595712	2400	174613	750	5491312
9	203300	3	203227	77	4809122	2124	205336	22	4716721
10	220300	3	220220	56	4416588	2124	222329	9	4324175
11	223300	3	223417	64	4277038	2124	225526	17	4184619
12	230300	3	230400	34	4147188	785	231148	38	4113113
13	233300	3	233411	937	4015376	2400	235806	625	3910926

KEPLERIAN ORBIT PARAMETERS

ETIMY	ETIMH	SEMIMA	ECCEN	ORBINC	MEANA	PERIGEE	ASNODE
790116	0	4216508	80	125	323537	170800	120334

ATTITUDE AND EAST-WEST ADJUSTMENT

DECLIN	RASCEN	PICLIN	NL	SPINP	IAJUST	IAJTIM
893242	151958	5003	12	600000	-9044	83300

SATELLITE GEOMETRY

DEGLIN	LINTOT	DEGELE	ELETOT	PITCH	YAW	ROLL	ISEANG
200342	402501	182227	13376	-2132	0	0	90000

GAMMAS

N	GTIME	GAMMA	GAMDOT
1	53300	189.58	-17.95
2	83300	83.25	-0.38
3	100300	100.36	-1.81
4	103300	107.58	-2.46
5	110300	85.10	-0.41
6	113300	-534.45	53.33
7	153300	87.08	-1.08
8	173300	-899.64	55.29
9	203300	234.45	-7.81
10	220300	240.10	-7.46
11	223300	236.93	-7.11
12	230300	127.94	-2.32
13	233300	579.52	-20.18

LANDMARK RESIDUALS

N	SSYYDDD	HHMMSS	LCODE	LINDIF	ELEDIF	SUBLAT	SUBLON
1	1279024	83300	0	9.28	0.11	-733	1395237
2	1279024	100300	0	5.46	0.67	-650	1395234
3	1279024	103300	0	8.47	-1.36	-619	1395231
4	1279024	110300	0	7.88	-3.01	-544	1395228
5	1279024	113300	0	7.86	1.17	-437	1395223
6	1279024	153300	0	3.52	-3.49	220	1395154
7	1279024	173300	0	0.02	4.01	557	1395142
8	1279024	173300	301	-0.23	9.25	557	1395142
9	1279024	203300	0	4.32	15.90	730	1395141
10	1279024	203300	301	7.06	1.07	730	1395141
11	1279024	220300	0	7.75	20.16	636	1395148
12	1279024	220300	301	11.49	0.57	636	1395148
13	1279024	223300	0	7.63	20.41	602	1395151
14	1279024	223300	301	11.83	0.48	602	1395151
15	1279024	230300	0	9.07	18.27	541	1395153
16	1279024	233300	0	10.87	45.14	434	1395159

RMS ERROR OF LANDMARK RESIDUALS BY CODE

CODE	NUMBER	RMSLIN	RMSELE
0	12	7.42	17.05
301	4	8.97	4.67

The "Satellite Geometry" parameters are:

- DEGLIN is the total angle swept by the mirror from north limit to south limit.
- LINTOT is an encoded total number of lines in the angle DEGLIN.
- DEGELE is the total angle swept by the mirror from east limit to west limit.
- ELETOT is an encoded total number of elements in the angle DEGELE.
- PITCH is the angle between the north-south center position of scanning mirror and the normal to the satellite's spin axis passing through the mirror center. This angle changes during a maneuver because the change in mass distribution in the satellite moves the spin axis. A ray coming from the sensor reflected by the mirror out to space will define a plane as the mirror steps. This plane will rotate with the satellite.
- YAW is the angle between this plane and the spin axis
- ROLL is the difference between the nominal angle from the sun pulse detector and the VISSR and the actual angle. This angle is added and subtracted in GOES navigation, therefore, it is transparent to the process. It will change the absolute value of IAJUST.
- SPINP is the mean spin period of satellite for the day in microseconds.

The Keplerian orbit parameters are:

- ETIMY is the epoch year month day.
- ETIME is the epoch hour, minute tenths, and hundredths of minute.
- SEMINA is the semi-major axis.
- ECCEN is the eccentricity.
- ORBINC is the inclination.
- MEANA is the mean anomaly.
- PERIGEE,argument of perigee.
- ASNODE, longitude of ascending node.

The "Attitude and East-West adjustment" parameters are:

- DECLIN is the declination angle of the satellite's spin axis.
- RASCEN is the right ascension of the spin axis.

- PICLIN is the picture center line which is nominally the expanded.
- LINTOT divided in half (i.e. (8 x 1821. 2) + 1 = 7285).
- NL is the number of landmarks used to compute the attitude.
- IAJUST is the IAJUST parameter.
- IAJTIM is time of landmark from which IAJUST was computed.

"Gammas" parameters include:

- N is the number of the entry in the file.
- GTIME is the nominal start time of the first picture used to compute gamma-gammadot.
- GAMMA is value of gamma for the GTIME picture extrapolated back to ØØ GMT.
- GAMDOT is the change in gamma per hour.

GAMMA is expressed in elements per hour. Gamma and gamma-dot are computed first from the landmark's element location. The parameter LCODE in the landmark file allows gamma grouping by assigning the same number in the thousands place. When this is done, all landmarks with the same code number will be used to compute a gamma-gammadot which will be listed with the GTIME of the earliest picture in the group. One landmark per group is sufficient to compute gamma and two are sufficient to compute gamma and gammadot.

"Landmark Residuals" provide feedback on the quality of the computed parameters and indirectly the orbit and geometry constants used.

- N is the number of the landmark in the file.
- SSYYDDD is the satellite source, year, and day number of the data set.
- HHMMSS is the hour, minute, and seconds of the nominal start time of the images and is equal to "LTIME" from the "LANDMARKS" list.
- LCODE is the landmark code.

- LINDIF and ELEDIF are the residuals. They are obtained by using the computed parameters to determine the expected location of the landmarks in satellite coordinates and subtracting that form the measured location.

- SUBLAT and SUBLON are latitude and longitude of the sub-satellite point at the picture start time.

Ingested Navigation at SSEC

Navigation is ingested with each satellite image. Figure 10 illustrates the flow of SSEC ingested navigation. The signal is picked up by the antenna, passed through a receiver, and sent to the PSK Demodulator where the signal is converted from phase encoded to NRZ (non return zero), similar to a standard FM signal. Inside the computer room the signal is processed by an SSEC built Frame Synchronizer. From the Frame Sync the signal goes to a Preprocessor, also known as an Ingestor. If you record GOES data on video cassettes, the signal is split upon exiting the Frame Sync. One signal is sent to the recorders; the other to the Ingestor. From the Ingestors, data is sent to the CPU and stored on disk; to restore data from the video cassettes it must also be processed by an Ingestor.

Navigation data is found in the 'common doc' located in the beginning of each IR image scan line. Twenty lines of common doc are needed to obtain the Orbit and Attitude data (O&A) and betas necessary to navigate one GOES image. The twenty lines are comprised of two major frames consisting of 10 minor frames (major and minor frames are a NESDIS definition). The INGExxx software checks the common doc for good copies before it is actually stored in spool files. The ingested data is stored temporarily in digital areas or permanently on cassette tape.

If noise interrupts the transmission of data the next 20 lines of common doc are read in search of a good data set. Once found the good set

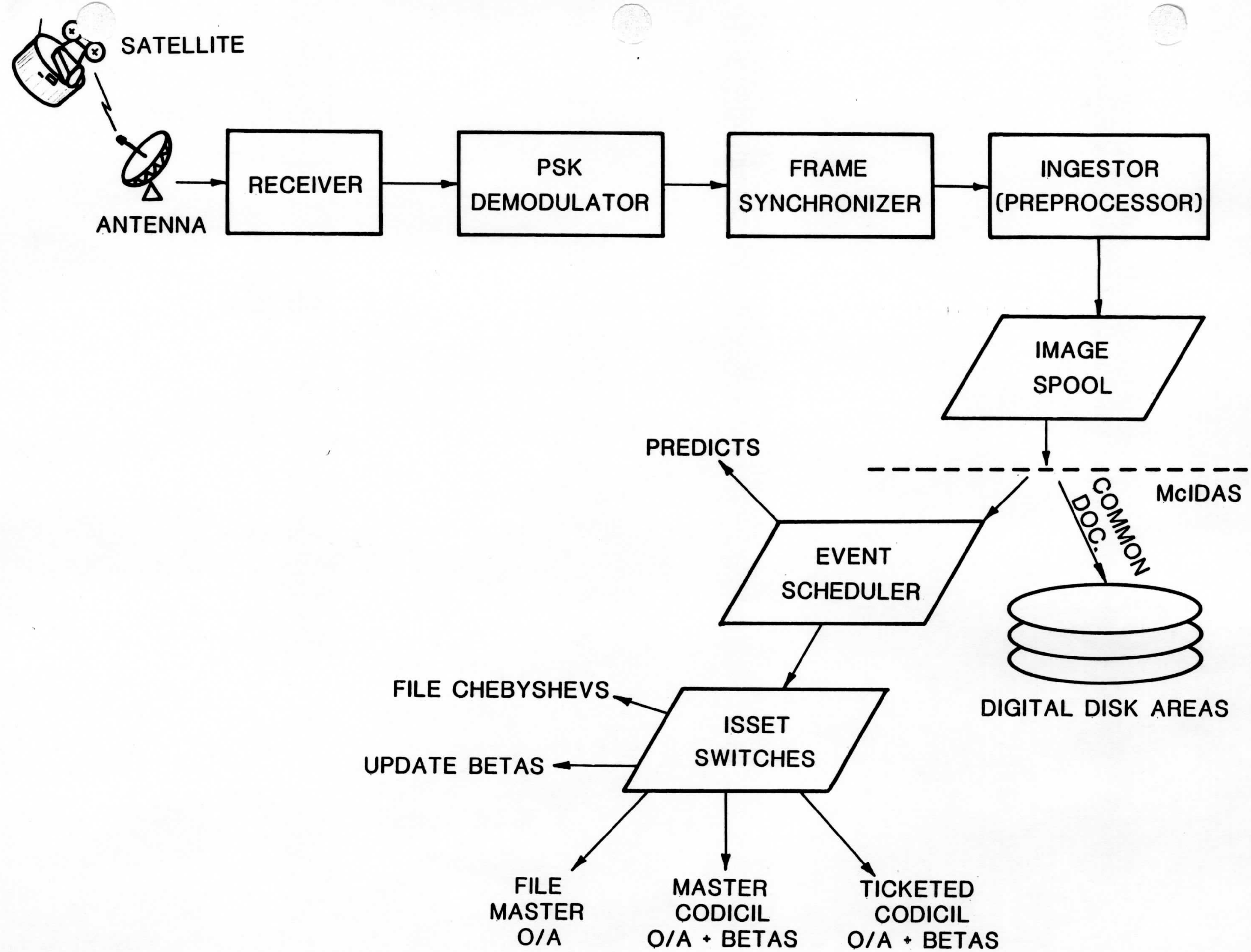

FIGURE 10. FLOW OF NAVIGATION DATA FROM SATELLITE TO DISK.

of common doc is passed on to the image spool file. The spool file number usually corresponds to the ingestor number.

Now within McIDAS the Event Scheduler commands determine how navigation parameters will be stored.

The following McIDAS commands manipulate the data:

- CHEB generates Chebyshev polynomials if none were sent.
- NK generates navigation codicils from the GOES master file.
- FNVGOE handles the processing of beta and O&A data.
- FOAA calculates the next day's prediction.

Command ISSET sets the following options for image spool processing.

- update betas
- file master O&A
- file ticketed codicil
- file master navigation codicil

In master navigation codicils the KEYS used to match images with data are SSYYDDD and HHMMSS. In ticketed codicils the ticket number is located in the SSYYDDD space and the HHMMSS is Ø; the ticket number is directly associated with the image area.

See the McIDAS Operator's Manual chapter on Ingestion for more information.

TABLE 2

SS Code	Sensor Source
Ø	Non-Image Derived Data
1	Test Patterns
2	Graphics
3	Miscellaneous
4	PDUS Meteosat Visible
5	PDUS Meteosat Infrared
6	PDUS Meteosat Water Vapor
7	Radar
8	Miscellaneous Aircraft Data (MAMS)
12	GMS Visible
13	GMS Infrared
14	ATS 6 Visible
15	ATS 6 Infrared
16	SMS-1 Visible
17	SMS-1 Infrared
18	SMS-2 Visible
19	SMS-2 Infrared
2Ø	GOES-1 Visible
21	GOES-1 Infrared
22	GOES-2 Visible
23	GOES-2 Infrared
24	GOES-3 Visible
25	GOES-3 Infrared
26	GOES-4 Visible (VAS)

SS Code	Sensor Source
27	GOES-4 Infrared and Water Vapor (VAS)
28	GOES-5 Visible (VAS)
29	GOES-5 Infrared and Water Vapor (VAS)
30	GOES-6 Visible
31	GOES-6 Infrared
32,33	GOES-7 Visible, GOES-7 Infrared
36-40	NOAA Series Satellites
41	TIROS-N
42	NOAA-6
43	NOAA-7
44	NOAA-8
45	NOAA-9
46	Venus
47	Voyager 1
48	Voyager 2
50	Hubble St.
60	NOAA-10
61	NOAA-11
70	GOES-I (IMAGER)
71	GOES-I (SOUNDER)
72	GOES-J (IMAGER)
73	GOES-J (SOUNDER)
74	GOES-K (IMAGER)
75	GOES-K (SOUNDER)
76	GOES-L (IMAGER)

SS Code	Sensor Source
77	GOES-L (SOUNDER)
78	GOES-M (IMAGER)
79	GOES-M (SOUNDER)
8Ø	ERBE
9Ø	RAW METEOSAT

AUTOMATIC NAVIGATION

INTRODUCTION

Satellite image navigation uses a set of transformation functions for computing earth coordinates (latitude and longitude) from image coordinates (line and element) and image coordinates from earth coordinates. These functions are supplemented by a set of navigation parameters (orbital, attitude, camera geometry, etc.) which are common for all points on a given image.

The quality of navigation is determined by the correctness of the satellite motion model that is implemented in the transformation functions, and the precision of the navigation parameters. Satellite design determines the model of the satellite motion and some of the navigation parameters. However, most navigation parameters are time-dependent and are determined daily.

Navigation parameters are usually provided with the satellite data stream, but for some applications their precision may not be sufficient. This situation can be corrected by upgrading the navigation using landmarks. The automatic navigation software (AUTONAV) collects landmarks and upgrades navigation from them.

Navigation from the AUTONAV system replaces the data stream navigation as long as a sufficient number of landmarks is available. It is a good idea, however, to save the data stream navigation in case automatic navigation fails due to a lack of landmarks (i.e., when the system is down for an extended time or after a maneuver).

The master navigation file holds navigation from the satellite data stream. It is referred to as nav file #1 in the examples in this document. The landmark navigation file holds the landmarks and the navigation computed from them (nav file #3 in the examples).

FUNCTIONS OF AUTOMATIC NAVIGATION

The AUTONAV system performs four major functions:

- collecting landmark data for every visible image
- evaluating the quality of existing navigation
- upgrading navigation parameters
- predicting navigation for the next few days

The AUTONAV system performs landmark measurement by matching a template to a satellite image in the subsection where the landmark is expected. The quality of matching is evaluated by cross-correlation. If the maximum correlation exceeds the threshold value, the landmark is assumed to be found and its position on the image is stored in the navigation file. If the cross-correlation does not reach the threshold value, the landmark cannot be found. Cloudiness is usually the reason.

The quality of navigation is evaluated by residuals and some statistical values calculated from them. Residuals are differences between the computed position of a landmark (i.e., image line and element computed from latitude and longitude of a landmark) and the landmark position (image line & element) on an image. Therefore, line and element residuals are computed for each landmark.

Perfect navigation has all residuals close to zero. The most important statistical variable computed from residuals is RMS (root mean square). It provides a global measure of navigation quality.

Navigation parameters are upgraded by optimizing the parameters to get minimum residuals for all good landmarks measured during the period under consideration. The result is stored in the navigation file from which codicils are generated to navigate particular images.

Navigation for the next few days is predicted daily by extrapolating the navigation parameters.

MAJOR PROGRAMS IN AUTONAV

The major programs in AUTONAV are:

AUTOLM
NVAUTO
NVFOR
NVSTAT
NVUP
TPLATE

These programs are discussed in the NAVIGATION COMMANDS section of this manual.

SET-UP

Use the following steps to set up the AUTONAV program. Included as an example is SSEC's set-up of AUTONAV for the GOES EAST satellite.

1. Use the TPLATE program to create landmark templates (according to the input latitude and longitude) and store them in areas. Template preparation is done manually. Replacements or new templates can be added at any time. SSEC prepared nine templates from full resolution visible images and stored them in disk areas 161-169.

   Choosing the landmark location is a very important step in the successful application of AUTONAV. Choose landmark locations according to the number of cloud-free days over an area, and easily recognized shapes with good contrast. Islands, peninsulas, lakes and coastlines provide good landmarks. Landmarks should be far from each other. For example, if navigation for the entire USA is of interest, choose landmarks at the east and west coasts and somewhere in South or Central America. Choosing two or three landmark locations in each area makes the landmark collection less dependent on cloudiness. If only part of an image needs better navigation, one or two landmarks can provide good navigation in a circle or an ellipse, respectively, around the landmark locations.

The location of SSEC's landmarks (code, latitude and longitude) are listed below.

10	29.0000	113.1417	Baja area
11	24.0667	109.8250	Baja area
12	20.7833	105.5500	Baja area
20	27.9167	12.9667	West coast of Africa
21	26.4000	14.1667	West coast of Africa
30	-15.6667	69.7167	Titicaca Lake
31	-43.0000	64.2917	Valdes Peninsula (South America)
32	-40.8167	64.9000	Punta Villarino (South America)
40	42.0333	70.2000	Cape Cod

2. To collect landmarks from the satellite image, prepare the areas around the locations where the landmarks are expected. Depending on landmark locations, it may be necessary to extend the existing ingesting schedule (with the SSKE command) to include a few additional areas with sizes comparable to landmark windows.

3. Enter the landmark data into the auxiliary landmark file using AUTOLM with option ADD. SSEC's landmark file is called AUTOEAST. The data includes landmark codes (PRIORITY), area numbers from which landmarks are collected, template area numbers, the range of areas where landmarks will be searched, line and element lag, threshold values for correlation to store landmarks, band (for IR landmarks only), the navigation file number to store landmark data, and the number of the information file about the landmark collection process (card file number). Below is the SSEC AUTOEAST file as an example.

ENTRY	PRIORITY	AREA1	AREA2	TEMPLATE	LAGL	LAGE	THRESHOLD	BAND	NAVF	CARDF
1	10	101	104	168	20	20	20		3	5
2	11	101	104	166	20	20	20		3	5
3	12	101	104	164	20	20	20		3	5
4	20	155	156	169	25	25	15		3	5
5	21	155	156	167	25	25	15		3	5
6	30	157	158	165	20	20	20		3	5
7	31	159	160	162	20	20	20		3	5
8	32	159	160	163	20	20	20		3	5
9	40	101	104	161	20	20	20		3	5

4. Enter an event scheduler entry for AUTOLM, with option RUN, to collect landmarks when satellite images come in. At SSEC entries 4999, 5001 and 5002 in the event scheduler start the AUTOLM program and set flag 940 to indicate that collection for a given nominal time has been made. The event scheduler entries for AUTOLM at SSEC are:

   1. F22=1&F23=8&F940=0&F44<>4
      AUTOLM_RUN_AUTOEAST_DEV=NNN_GUESS=9

   2. F22=1&F23=8&F940=0&F44<>4
      SETF_F940_1

   3. F22=1&F23=1
      SETS_F940_0

See edit member DNEFLAGS for more information about flags.

5. Set the filing of some navigation data from the satellite data stream into the landmark navigation file, and the generation of navigation codicils from the landmark navigation file. Both of these functions require additional entries in the event scheduler. See the DNFNVDOC file for SSEC set-up.

6. When AUTONAV runs the first time, navigation from the satellite data stream must be copied from the master navigation file to the landmark navigation file. It will be overwritten when navigation is upgraded the first time.

7. Time scheduler entries are needed for NVUP to upgrade navigation from landmarks. The period of time between two subsequent upgradings should not exceed 24 hours. If upgrading is necessary only once daily, use NVFOR to upgrade navigation and make predicts at the same time. Scheduling NVUP to automatically upgrade attitude during the day is recommended only if landmark collection always warrants a sufficient number and variety of landmarks. Use additional care after maneuvers to exclude landmarks collected before maneuvers.

   At SSEC, there is no entry in the time scheduler to upgrade attitude during the current day. Navigation for the current day is based on the predict. The best navigation for the current day is available at the end of the day after running the NVFOR program.

8. Set the time scheduler entry for the NVFOR program to predict navigation for the next few days. As a byproduct, NVFOR generates the best navigation from landmarks for a given day. Three entries must exist in the time scheduler (within a few hour time period) to provide continuation of AUTONAV when the computer is down. At SSEC entries 1691, 1693 and 1695 in the time scheduler start NVFOR three times daily. This occurs indirectly through file MBNV, which sets the execution of NVFOR as a background job in class M at 22:30Z, 23:30Z and 2:00Z the next day. The three entries in the time scheduler are listed below. File NVUP32 is generated by the NVFOR program to provide information about the prediction process. The printout of the file is used for documentation purposes.

```
 *** SCHEDULER IS ON  ***               MESSAGE DEVICE IS: C
T#  ID  XS  NEXT  EXECUTN  # REM  INTERVAL  TOL  NAME  PROJ  COMMAND TEXT ...

Ø  1691     88259  223ØØØ   MANY  1ØØØØØØ   3ØØØ  OPER  6999  SUBMIT  MBNV
Ø  1693     88259  233ØØØ   MANY  1ØØØØØØ  1ØØØØ  OPER  6999  SUBMIT  MBNV
Ø  1595     8826Ø   2ØØØØ   MANY  1ØØØØØØ  3ØØØØ  OPER  6999  SUBMIT  MBNV
```

9. Use the MANEUV program to introduce maneuver data into the maneuver file. The last maneuver date and time is copied into the auxiliary file NVA(sat#) used by NVFOR. The file also keeps the day and time for the next NVFOR execution so that you can check if NVFOR has already worked in a given day. At SSEC, file NVA32 is used by NVFOR for the GOES EAST satellite. The nominal time for NVFOR execution is set in file NVA32 for 22:30Z.

10. Three navigation files must be reserved for AUTONAV. The master navigation file stores navigation from the data stream. The landmark navigation file stores landmark data and navigation computed by the AUTONAV system. NVFOR needs an auxiliary navigation file to store intermediate results during prediction computation. At SSEC, the master navigation file is file #1. File #3 is the landmark navigation file. File #4 is reserved for NVFOR.

DAILY MAINTENANCE

AUTONAV needs daily monitoring. Maintenance consists of the following:

- checking the prediction process
- checking landmark collection (number and variety)
- checking navigation quality
- upgrading attitude, if necessary
- turning AUTONAV off/on at maneuver
- copying the landmark navigation file

1. Check file NVUP(sat#) to examine yesterday's predict generation. The file is generated by NVFOR (see p. 3-44.1) around 22:30Z and is retained on the system until the next program execution (about 24 hours). For GOES-EAST, you would enter the following command either at the end of the day or early morning of the next day.

   SEE_NVUP32_132_DEV=S

   Small global RMS values (1-2 pixels) mean the predicting process was satisfactory and predicts for the current day should be correct. If RMS values are larger, the predicted navigation may be unsatisfactory. Go to step 2.

2. Check landmark collection. Call NVUP with option RES=1 to compute residuals only. For GOES-EAST you would enter:

   NVUP_32#Y_0_0_24_NAVF=3_RES=1

   Although this check may be done at any time, 15Z is recommended. If landmarks are not present or their number is small (less than 10), go to step 3. If landmark collection is satisfactory, go to step 4.

3. Visually check navigation quality by displaying at least 3 of the selected full resolution images (using DF), and overlaying a map on them (using MAP). Choose locations over varying parts of the earth to get an accurate sample, as quality of navigation may be good at one location but not at another. SSEC uses the following coordinates for this purpose:

   EC 27 81 (Florida)
   EC 29.3 113.2 (Baja)
   EC 42 70 (Cape Cod)
   EC 43 89 (Wisconsin)

   If the map lines up with the images displayed, stop at this point and return to step 2 in 2-3 hours. Otherwise, go to step 7.

4. Small RMS and residual values indicate good navigation. Large RMS values may be caused by a few bad landmarks and do not necessarily indicate a navigation problem. Review the list of individual landmark residuals or run NVUP again with option FLU=1.5. Enter:

   ```
   NVUP_32#Y_Ø_Ø_24_NAVF=3_RES=1_FLU=1.5
   ```

   Check the landmark variety. Fluctuation testing may exclude all landmarks from one area. If this is the case go to step 3. If global RMS values are in the expected range, stop at this point. If RMS values are high after the above test, it may mean unsatisfactory navigation. Go to step 5.

5. If there are 1Ø or more landmarks from at least 3 locations, upgrading the attitude may correct navigation. Such options can be checked without changing the current navigation parameters by displaying the results of the upgrade. Enter:

   ```
   NVUP_32#Y_Ø_Ø_24_NAVF=3_VAR=DE_RA_RO
   ```

   If resulting RMS values are in the expected range, go to step 6. Otherwise, go to step 7.

6. Run the NVUP program again to store the final result. Enter:

   ```
   NVUP_32#Y_Ø_Ø_24_NAVF=3_3_VAR=DE_RA_RO
   ```

   Gamma recomputing is automatically performed after the new navigation is stored in the navigation file. If attitude upgrading corrects navigation, stop here. Otherwise, go to step 7.

7. At this point, it is assumed that navigation from AUTONAV is unsatisfactory and AUTONAV has to be turned off. Before switching it off, you may return to step 3 (if you have not already done so) to visually verify that navigation is unsatisfactory. Also check the satellite data stream by combining navigation from the master navigation file with landmarks from the landmark navigation file into a temporary navigation file. Enter:

   ```
   NM_1_5_ALL_32#Y;NM_3_5_L_32#Y
   ```

   Now run NVUP:

   ```
   NVUP_32#Y_Ø_Ø_24_NAVF=5_RES=1
   ```

   If the RMS values are significantly better, it justifies turning AUTONAV off. If RMS values are in a similar range, it may indicate a more serious problem, i.e. satellite motion instability, a ground station problem, etc. Wait for more landmarks and repeat the procedure starting with step 2. If you decide to turn AUTONAV off, enter:

   ```
   NVAUTO_OFF
   ```

NOTE: If AUTONAV has been continuously operational but landmarks have not been collected (i.e., the system was down), global RMS values may be high indicating bad navigation. In such cases, upgrading the attitude is usually satisfactory, but it does not have to provide navigation in the 1-2 pixel range. If landmarks are already known for at least 6-8 hours and their variety is satisfactory, then upgrading more variables may yield significantly better navigation. To do this, enter:

NVUP_32#Y_Ø_Ø_24_NAVF=3_3_VAR=EC_AS_PE_OR_EA_DE_RA_RO_PI_YA

Depending on the circumstances, landmarks from the past day may also be included.

Upgrading 1Ø variables can be time consuming. Note that the semi-major axis and picture center line are not upgraded.

SATELLITE MANEUVERS

Maneuvers change navigation parameters. Turn AUTONAV off just before the first post-maneuver image is collected. Enter:

NVAUTO_OFF

The first post-maneuver image is navigated by data stream navigation. This navigation also collects landmarks after maneuver. It is assumed that the ground station provides navigation in the range of 2Ø pixels so landmarks can be found.

If a maneuver is performed in the middle of a day it is possible to collect three distant landmarks from one image. In this case the attitude can be upgraded immediately. First the navigation from the master navigation file has to be moved to the landmark navigation file. Enter:

NM_1_3_day_32#Y

Now upgrade the attitude. Note that only post-maneuver landmarks should be included in the upgrading process. If, for example, maneuver was performed just before 17Z, you would enter:

NVUP_32#Y_Ø_17_24_NAVF=3_3_VAR=DE_RA_RO

Now AUTONAV can be turned on:

NVAUTO_ON

If AUTONAV is turned on after collecting landmarks from the first image, the quality of navigation may be satisfactory only for a short period of time. Attitude upgrading will be needed again in 2-3 hours. Usually it takes a longer time to collect landmarks but the sequence of commands to turn the AUTONAV on is the same as above.

If the first upgrade is performed several hours after a maneuver and the number of landmarks is greater than 1Ø, the navigation after upgrading may be good for a longer time (about half a day). Checking navigation quality is recommended every 2-3 hours. The first upgrade of all parameters and predicts by NVFOR should result in satisfactory navigation predicts, provided landmarks were collected for at least 8 hours after a maneuver. Otherwise the upgrading may be excellent but the predict may be unsatisfactory. Such a predict may be satisfactory just after midnight, but it usually deteriorates quickly.

The recommended procedure is to turn AUTONAV off the first night after a maneuver if the landmark collection time between the manueuver and NVFOR execution is less than 7-8 hours, or if the number and variety of landmarks are insufficient. AUTONAV can be turned on the next day using the procedure described above.

In summary, turning AUTONAV on immediately after a maneuver will give you good navigation to the end of the day. However, it needs more supervision. Waiting until the next day is simplest. If the maneuver is performed close to the end of the day, waiting is the only solution.

NAVIGATION COMMANDS

NAVIGATION COMMANDS

AUTOMATIC LANDMARK LOCATOR

```
AUTOLM_RUN_file [keywords]
AUTOLM_DEL_file_entry
AUTOLM_LIS_file
AUTOLM_ADD_file_code_barea_earea_tp_lagl_lage_thresh_band_navf_cardf
```

PARAMETERS

RUN	→	run the automatic landmark finder
DEL	→	delete a file entry
LIS	→	list the file entries
ADD	→	add a file entry
file	→	LW file containing landmark information
entry	→	an entry number (automatically assigned by the add option). Each entry contains all the information needed to process a landmark measurement (see the ADD option).
code	→	a 2 digit number for the landmark code. The first digit represents a particular landmark area. The second digit area. The second digit is a priority ranking from Ø (high) to 9 (low). A list of landmark codes can be found on page 2-21.
barea	→	beginning range of areas to find landmarks
earea	→	ending range of area to find landmarks
tp	→	area number of template image
lagl	→	outer window expansion to search for landmark, lines (default=2Ø pixels)
lage	→	outer window expansion to search for landmark, lines for elements (default=2Ø pixels)
thresh	→	threshold for correlation that determines good landmark (default=2Ø)
band	→	spectral band (default=not used, for visible images)
navf	→	navigation file to file landmark location (default=don't file information)
cardf	→	card file (1-999) to file landmark information. If the number 1 is input, the data will be written to file CARDFØØ1 which can be viewed with the SEE command or use NVSTAT for error summary. (default=don't file)

KEYWORDS (for RUN option only)

OPT=ALL	→	to process all images (default=latest image time). This keyword is for testing purposes only and should not be used operationally.
DELTIM=	→	the amount of time after sunrise and before sunset that an attempt will be made to find landmark (default=1 hr).
GUESS=	→	lagl and lage. Use this keyword if a smaller lagl and lage value is desired. If a match fails, the number from the file is used. This greatly speeds up processing if navigation is within the GUESS window size, as the speed is proportional to the product of lagl and lage.

REMARKS

AUTOLM is an automatic landmark finder. It is called by the event scheduler when image ingesting is finished. The landmark search is organized according to the data gathered earlier in the auxiliary landmark file. A range of areas is searched to find the most current one. Then templates are matched in subsections of images (windows) which are determined by landmark latitude and longitude. The window size is equal to the template plus a lag value added at each site (i.e., if a template is 4Ø x 4Ø pixels and a lag value in the line and element direction is 2Ø, then the window is 8Ø x 8Ø pixels). Note the correlation between the program's ability to find a landmark and existing navigation. If navigation is shifted at one position more than the lag value, a landmark cannot be found.

The following information is needed to run AUTOLM for real time evaluation of navigation quality.

- Range of areas that contain real time visible images for GOES East
- Location of template image (restored from PUT tape from SSEC)
- LW file for AUTOLM to use (ex. EASTQC)
- Landmark code (1Ø is usually used for Baja)

The command would be entered as follows at SSEC:

AUTOLM_ADD_EASTQC_1Ø_1Ø1_1Ø4_43Ø_X_X_X_X_X_1

When you enter this command:

AUTOLM_RUN_EASTQC

The latest visible image in the 1Ø1 to 1Ø4 range is searched for the landmark stored in template image 43Ø. The result is sent both to the screen and to file CARDFØØ1 (which can be listed with SEE). The following last 4 columns are of most interest:

line error *element error* *correlation* *landmark code*

If the correlation is higher than 2Ø, the line and element error will not be correct. When the correlation is lower than 2Ø, the line and element errors are expressed in full resolution pixels. NVSTAT will print a summary of the RMS error and standard deviation for all good landmarks.

For constant measuring of landmark errors, this command should be entered into the event scheduler. An event flag (F94Ø) has been issued for use with automatic navigation process. This flag is set when AUTOLM has been run on the latest image and is reset when a new image begins.

REMARKS (cont.)

Information needed to setup AUTOLM in event scheduler:

- Ingestor number for real-time full resolution visible images that will contain the landmark of interest (in this case Baja)
- 3 unused ID numbers in event scheduler

For example, at SSEC the visible images are ingested through ingestor 1, and there are 3 ID numbers available in the 45ØØ's.

```
ESKE ID=45Ø1 "F22=1&F23=8&F94Ø=Ø&F44<>4 "AUTOLM RUN EASTQC DEV=NNN
ESKE ID=45Ø2 "F22=1&F23=8&F94Ø=Ø&F44<>4 "SETF 94Ø 1
ESKE ID=45Ø3 "F22=1&F23=1 "SETF 94Ø Ø
```

You may want to add the keyword TERM=Ø to the above 3 commands (if most of the system scheduled entries run under terminal Ø).

Use NVSTAT to list a quick summary of navigation errors for the current day, any other day or the last N days.

COMPUTE OR LIST ORBIT AND ATTITUDE DATA INCLUDING CHEBYSHEV POLYNOMIAL COEFFICIENTS

CHEB_ssyyddd_hh:mm:ss_opt

DEFAULT

CHEB_ssyyddd_hh:mm:ss

- list orbit and attitude day for given satellite, day and time

PARAMETERS

ssyyddd → satellite ID, year and day of data to be computed
hh:mm:ss → time of image for which data is to be computed
opt→ LIST → list orbit and attitude data (default)
FILE → generate and file orbit and attitude data in a Chebyshev polynomial navigation codicil

REMARKS

To get a complete listing of a Chebyshev polynomial, route the command to a printer (DEV=S). Data that is displayed on the CRT is only a summary.

To view existing Chebs use the NLC command.

EXAMPLES

CHEB_2684298_12:3Ø
Display the Chebyshev polynomial coefficients for sensor 26 at 12:3ØZ, 1984, day 298.

CHEB_248Ø325_11_FILE
Generate and file orbit and attitude data for sensor 24 at 11Z, 198Ø, day 325.

CHANGE OR DELETE BETAS

CHGBET_ssyyddd_oldtime_newtime_[keyword]

DEFAULT

CHGBET_ssyyddd_oldtime

- delete all betas for given sensor, day and time

PARAMETERS

ssyyddd → sensor source, year and Julian day of betas to be changed or deleted
oldtime → original time of betas to be changed, HH:MM:SS
newtime → time betas are to be changed to. If new time is omitted all betas for old time are deleted, HH:MM:SS

KEYWORD

NAVF= . → navigation file number in which betas are to be changed (default=current file)

REMARKS

Use NVU_SET to point at a navigation file.

EXAMPLES

CHGBET_3Ø85Ø28_16:Ø1_16
On the current navigation file, change the 16Ø1Z betas to 16ØØZ for satellite 3Ø, day 28 of 1985.

CHGBET_2885198_21:11_NAVF=28
Delete all 2111Z betas for satellite 28, day 198 of 1985 from navigation file 28.

DELETES UNREFERENCED CODICILS FROM THE SYSTEM NAVIGATION FILE

CLRNAV SHOW
CLRNAV KILL

PARAMETERS

SHOW → lists the codicils to be deleted (default)
KILL → deletes the codicils

REMARKS

CLRNAV generates a list of navigation codicils referenced by area or frame. Any navigation codicil not appearing on the list (i.e., with no area or frame directories on disk) is deleted.

Output from the SHOW parameter goes to the system printer. The KILL parameter is usually run just after the monthly purge.

CLRNAV allocates storage for up to 32000 navigation codicil references. If the system references more than 32000 codicils (either online image files or frame directories), CLRNAV will terminate with the error message MAXLST OVERFLOW. If this occurs, the operator can either delete image files from the system or increase the internal buffer size within CLRNAV to allow for the excess codicil sets.

EXAMPLES

CLRNAV SHOW
This entry lists the unreferenced navigation codicils to be deleted and directs the output to the system printer.

CLRNAV KILL
This entry deletes all unreferenced navigation codicils.

FILES NAVIGATION DATA FROM THE GOES SATELLITE DATA STREAM

FNVGOE_spool_block_word_beta_cheb_code_gamma_oa_[keyword]

DEFAULT

No default, you must specify the parameters.

PARAMETERS

```
spool → spool number (equals the ingestor number)
block → spool block number, range 1-256
word  → number of the first word from the block
beta  → 0 → does not store betas (default)
        1 → stores betas
cheb  → 0 → does not make a Chebyshev codicil (default)
        1 → makes a Chebyshev codicil
code  → 0 → does not create a codicil (default)
        1 → makes a master codicil
        2 → makes a ticketed codicil
gamma → 0 → does not store or compute gammas (default)
        1 → computes and stores gamma and gamma-dot
oa    → 0 → does not store the Orbit and Attitude (O&A) block
            (default)
        1 → stores the Orbit and Attitude block
        2 → reads the Orbit and Attitude spool block but does not
            store the O&A block; obtains betas from the Orbit and
            Attitude spool block; has to be used with flag beta=1
```

KEYWORD

NAVF= → navigation file number to store navigation (default=current)

REMARKS

Below are the error codes sent to the log file if the betas aren't filed.

1 SCAN1<=Ø
2 (YDAY1,TIME1)-(NOMYD,NOMHMS)>18 MINUTES OR <Ø
3 SCAN2<=SCAN1
4 TIME2<TIME1 OR (YDAY2,TIME2)-(NOMYD,NOMHMS)>18 MINUTES OR <Ø
5 BETA1-BETA2>(NINT((TIME2-TIME1)*6Ø.)+1)*BTPMIN

The FNVGOE program reads data from the ingestor spool and stores it in a navigation file with the correct format. It also generates codicils, upgrades the area directory with the new codicil and computes gammas. FNVGOE entries in the event scheduler are set differently depending on whether AUTONAV is on, off or not installed at all. See the DAFNVDOC file for a description of the current setup.

FNVGOE is used in place of commands OANDA and BETAS.

ADD/DELETE LANDMARK TO/FROM LANDMARK FILE

```
LNDMRK_ADD_[keywords]_"text
LNDMRK_DELETE_[keywords]_"text
```

DEFAULT

No default; you must specify the landmark to add or delete.

PARAMETERS

option	→	ADD	→	add a landmark (default)
		DELETE	→	delete a landmark
"comment	→	descriptive information about the landmark location		

KEYWORDS

LNAME=	→	3-letter landmark name, listed with command NAVMAP; for example, TAN is Tanganyika, Zaire (no default)
LAT=	→	landmark latitude, DD:MM:SS (no default)
LON=	→	landmark longitude, DDD:MM:SS (no default)

REMARKS

Comment input should be descriptive of a location, for example, Madison, Wisconsin.

Command LNDMRK allows you to add a landmark location to the landmark file or delete a location from the landmark file.

EXAMPLE

```
LNDMRK_ADD_LNAME=TPA_LAT=27:57:36_LON=82:31:48_"TAMPA BAY,_FLORIDA
```

Add landmark Tampa Bay, Florida to the landmark file and name it TPA.

GENERATE NAVIGATION CODICIL FOR AN AREA

MAKNAV_area_[keywords]

DEFAULT

MAKNAV_[keywords]

- generate a navigation codicil for designated projection

PARAMETERS

area → area number to navigate (default=Ø)

KEYWORDS

```
PS=npl_npe_slat_qlon_size_pole      →  Polar stereographic
LAMB=npl_npe_slat1_slat2_qlon_size  →  Lambert conformal
MERC=eql_eqe_slat_qlon_size         →  Mercator
RADR=cenl_cene_clat_clon_size_rot   →  Radar
RECT=lin_lat_ele_lon_deglin_degele  →  Rectilinear
     npl   → image line for north pole
     npe   → image element for north pole
     eql   → image line for equator
     eqe   → image element for equator
     slat  → standard latitude (PS default=6Ø, MERC default=Ø)
     slat1,slat2 → standard latitudes for LAMB (default=3Ø_6Ø)
     qlon  → normal or center longitude
     size  → size in km of one pixel
     pole  → N → north pole (default)
           → S → south pole
     cenl  → center line of radar site
     cene  → center element of radar site
     clat  → radar lat
     clon  → radar lon
     rot   → rotation of image (default=Ø)
     lin   → image line number
     lat   → latitude of image line
     ele   → image element number
     lon   → longitude of image element
     deglin→ degrees of line
     degele→ degrees of element
PLANET=planet to be navigated (default=EARTH)
```

REMARKS

Use MAKNAV to generate a navigation codicil for typical map projections. A ticketed codicil number is assigned to the area (if specified) and this ticket number is also entered in the string table under the name NAVNUM. If area was not entered, CA can be used to attach the navigation to an area (CA_area_NAV=#NAVNUM or CA_area_NAV=ticket#). Use REMAP to remap into the map projection generated by MAKNAV.

EXAMPLE

Take a current satellite image in area 12 and remap into a Mercator projection in area 6ØØØ.

1. GA_6ØØØ_5ØØ_64Ø
   Generate an area to put remapped image
2. CA_6ØØØ_3Ø_85Ø58_123ØØØ_1_1_8_8
   Change area directory to get satellite day, time, upper left line, element and resolution.
3. MAKNAV_6ØØØ_MERC=2ØØØ_2ØØØ_Ø9Ø_1
   Generate a Mercator projection codicil entry for area 6ØØØ.
4. REMAP_112_6ØØØ
   Remap area 112 into 6ØØØ.

INPUTS/EDITS SATELLITE MANEUVER DATA AND UPDATES THE NVAss FILE

MANEUV_option_ss_day_time_code

DEFAULT

MANEUV

- lists all maneuvers in LW file MANEUVER

PARAMETERS

option → ADD → adds satellite manueuver data
CHA → changes satellite maneuver data; can only change time and kind
LIST → lists satellite maneuver data for satellite only (default)
DEL → deletes satellite maneuver data, specify ss and day only
ss → satellite number
day → day of maneuver, YYDDD
time → time of maneuver, HH:MM:SS
code → code for type of maneuver; codes and their priorities are:

Code	Description	Grade of Importance
NS	Inclination Change	1
EW	In place Station Change	2
SK	Station Keeping	3
REOR	Spin Axis Reorientation	4
RPM	Spin Rate	5

If more than one maneuver is done at the same time or at different times the same day but with no other images sent between them, enter only the time and information for the maneuver with the highest grade of importance.

REMARKS

DEL and CHA search by satellite number and maneuver day. The search starts at the end of the file. If multiple entries for a given satellite and day are in LW file MANEUVER, only the last entry can be deleted or changed at one time.

An NVA LW file is used with AUTONAV. See page 2-19 in this manual for more information.

EXAMPLES

MANEUV_LIST_32
This entry lists maneuvers for satellite 32.

MANEUV_CHA_32_90231_11:15:45_EW
This entry changes the maneuver for satellite 32 on day 90231 to 11:15:45 and code EW.

MEASURE LANDMARKS FOR NAVIGATION

ML_LIST
ML_ssyyddd_lat_lon_[keywords]

DEFAULT

ML_LIST

- list contents of landmark file

PARAMETERS

LIST	→	list contents of landmark file
ssyyddd	→	sensor source name, year, and day of image (default= current image if you have an image displayed)
lat	→	landmark latitude, DD:MM:SS (no default)
lon	→	landmark longitude, DDD:MM:SS (no default) Use 'lat' and 'lon' parameters if the landmark is not in the landmark file.

KEYWORDS

LCODE=	→	landmark number code, listed with command NE (default=Ø, primary landmark)
LNAME=	→	3-letter landmark code name, from ML_LIST (default=blank) If LNAME is specified, 'lat' and 'lon' parameters are not necessary.
LOAD=YES	→	reload image after measurement
NO	→	do not reload image after measurement; move on to next image (default)
CALC=YES	→	calculate attitude, landmark residuals, Gamma, IAJUST
NO	→	do no calculate attitude, etc. (default)

REMARKS

Use command ML either to list the contents of the landmark file or measure landmarks for navigation.

Move the cursor to a landmark location and press the spacebar to enter latitude, longitude, line, and element locations (uses command NE_L). Use the period key (.) to exit ML.

If you specify keyword LNAME, it is not necessary to enter latitude and longitude parameters.

EXAMPLES

ML_LIST
List contents of landmark file.

ML_3Ø8718Ø_LNAME=MAC_LCODE=Ø
Output:

LNAME	LAT	LON	LOCATION
MAC	4551Ø4	8442Ø6	STRAITS OF MACKINAC, MICHIGAN

CALCULATE ATTITUDE, GAMMAS, IAJUST AND RESIDUALS

NA_ssyyddd_option_print_piclin

DEFAULT

NA_ssyyddd

- compute AGIR for ssyyddd

PARAMETERS

```
ssyyddd → sensor source, year and day of data, SSYYDDD
option  → A → compute S/C attitude from landmark measurements in
              navigation file
        → G → compute new gammas from landmarks and, where
              possible, from IAJUST and betas.  If I has been
              selected G will automatically be done
        → I → compute IAJUST, which is the east-west adjustment
              value (in visible elements) determined from the first
              valid landmark measurement of the day
        → R → compute landmark residuals
              (default=AGIR)
        Note: more than one can be specified (e.g., AIR, GR, etc.)
print   → OFF → do not print calculations (default)
        → ON  → suppressed output is listed on the CRT along with
                the normal output.  The suppressed output consists
                of landmark and beta entries from the navigation
                file, and newly computed gammas.
piclin  → -1  → compute the picture center line (the visible line
                at which the camera view angle is perpendicular to
                the spin-axis) as part of the attitude computation.
                The landmark measurements are used as input.
        →  Ø  → nominal value is used as the picture center line.
                The nominal value is determined by the frame
                geometry and is equal to the total number of
                visible lines divided by 2. (default)
        → N>Ø → forces piclin to be the value entered into the
                navigation file.  It is assumed that you have
                entered a reasonable value.
```

EXAMPLES

NA_18852ØØ_R
Calculate residuals for day 2ØØ, 1985, sensor 18.

NA_1279Ø24_X_ON_-1
Calculate A, G, I and R for day 24, 1979, sensor 12. The picture center line is computed from the landmarks. The new calculations are printed.

CHECKS THE BETAS AND GAMMAS IN A NAVIGATION FILE

NAVCHK_file_ssyyddd_check

DEFAULT

NAVCHK

- checks the betas and gammas for the current navigation file, sensor source 32, current day

PARAMETERS

```
file    → navigation file number (default=current)
ssyyddd → sensor source, year and day (default=32 plus current day)
check   → B → beta check
          G → gamma and dot check
          (default=checks betas and gammas)
```

REMARKS

NAVCHK checks for bad betas by comparing beta values, times and scan lines to see if they are logical. Error messages for "bad betas" are:

```
BETA1 GREATER THAN PREVIOUS BETA2
LATE BETA MISSED
SCAN1.LE.0
TIME1-NTIME.GT.19 MINUTES.OR.LT.0
SCAN2.LE.0
SCAN2.LE.SCAN1
SCAN2-SCAN130
TIME2.LE.TIME1
BETA1-BETA2 DOES NOT MATCH TO TIME2-TIME1
```

The error message for a "bad gamma" is:

```
WRONG GAMMMA OR GAMMA DOT
```

If no errors are detected, the number of betas and gammas checked is listed.

EXAMPLE

NAVCHK_1_3288034

This entry checks the betas and gammas for navigation file 1, satellite ID 32, day 88034. The output is:

```
TEST OF BETA BLOCKS IN NAV FILE #   1   SYD   3288034
64800/  TIME2.LE.TIME1
64800/  BETA1-BETA2 DOES NOT MATCH TO TIME2-TIME1
104800/ BETA1 GREATER THAN PREVIOUS BETA2
221800/ LATE BETA MISSED
```

Bad betas were detected for image times 648Z, 1048Z, and 2218Z. 648Z generated two error messages.

NAVIGATION QUALITY CONTROL

NAVQC_area_template_lagl_lage_[keywords]

DEFAULT

No default, you must specify 'area' and 'template'.

PARAMETERS

```
area     → source area (no default)
template → landmark template (no default)
lagl     → line lag in pixels (default=20)
lage     → element lag in pixels (default=20); parameters 'lagl'
           and 'lage' indicate how far outside the template
           bounds to look for the specified image navigation
```

KEYWORDS

```
BAND=     → band number; must be specified for IR data
            (default=ALL)
CARDF=    → card image file number for statistics (default=0)
CUT=      → cross-correlation coefficient threshold that
            determines a good landmark, range is 1-100
            (default=20); used in AUTOLM
NAVF=     → navigation file number for landmarks (default=0)
PLAG=YES  → print correlation matrix
    =NO   → do not print correlation matrix (default)
```

REMARKS

NAVQC computes the cross-correlation matrix between an area and a specially prepared template area (see TPLATE for details on creating a template). By default, NAVQC reports the data normally stored in the card file by AUTOLM. This data includes satellite number, date and time of image, longitude/latitude and line/element of the reference point in the area, line and element error, correlation, and template identification number ("priority").

Keywords NAVF and CARDF can ask NAVQC to make a landmark entry in a navigation file (as input to the NVUP program), or store the default output in a card file (to monitor landmarking with SEE or NVSTAT). Keyword PLAG can print the correlation matrix scaled from 0 to 9, with 0 indicating the best match.

REMARKS (cont.)

Command NAVQC serves the same purpose as command SEQNAV (page 3-48.2). However, with NAVQC, you specify an image. SEQNAV checks the navigation quality of the most recent image.

EXAMPLES

NAVQC_1Ø4_171_PLAG=YES
This entry displays a correlation matrix and prints the line/element errors and correlation value between template 171 and real time image 104.

NAVQC_1Ø4_171_NAVF=3_CARDF=5
This entry adds this landmark to the system navigation.

DELETES DATA FROM A NAVIGATION FILE

ND_option_satellite day_time_code_[keywords]

DEFAULT

ND_ALL_satellite day_time

- deletes all data for 'day' and 'time'

PARAMETERS

```
option → ALL  → deletes day and image dependent data including
                orbit and attitude (default)
         BLEG → deletes all B, L, E and G data
         B    → deletes betas
         E    → deletes earth edge
         G    → deletes gamma
         L    → deletes landmark
satellite day → sensor source and day of navigation, SSYYDDD or
                SSYY/MM/DD
time          → time of data (default=deletes all data when using ALL
                option)
code          → 1 or 2 → for deleting first or second betas
                (default=deletes all data when using ALL option)
              → landmark code for deleting landmarks
```

KEYWORDS

```
NAVF=         → navigation file number to delete from (default=current
                navigation file)
PASS=YUK      → password required to deleted data from navigation
                files 1-100
```

REMARKS

When deleting navigation, specify the NAVF keyword; file 1 is the system navigation file which cannot be altered.

You can point to a different navigation file by using NVU_SET.

EXAMPLES

ND_B_2883265_12:30_1_NAVF=4_PASS=YUK
This entry deletes betas (1) in navigation file 4 at 1230Z day 265, 1983, satellite 28.

ND_ALL_1882100_PASS=YUK
This entry deletes all navigation from the current navigation file on day 100, 1982, satellite 18.

DELETE RANGE OF DAYS FROM NAVIGATION FILE

NDD_file_ss_begday_endday_[keyword]

DEFAULT

NDD_file_ss_begday

- delete navigation for satellite ss in specified navigation file
- only data for begday is deleted

PARAMETERS

file	→ navigation file to delete from
ss	→ sensor source number (satellite) of navigation to be deleted, range 1 to 99
begday	→ beginning day to be deleted, YYDDD
endday	→ ending day to be deleted, YYDDD (default=begday)

KEYWORDS

PASS=YUK → password to delete from master navigation file

EXAMPLE

NDD_28_3Ø_791ØØ_791Ø8
Delete all navigation for satellite 3Ø, 1979, days 1ØØ through 1Ø8, from navigation file 28.

DEFINE ATTITUDE

NE_A_ssyyddd_declin_rascen_piclin

DEFAULT

None, you must specify the parameters.

PARAMETERS

A → define the attitude
ssyyddd → satellite, year, day identifier, SSYYDDD
declin → declination in degrees, minutes and seconds, HHMMSS
rascen → right ascension in degrees, minutes and seconds, HHMMSS
piclin → picture center line

EXAMPLE

NE_A_1279Ø24_895427_229Ø436_7285
Define the attitude for sensor 12 day 24, 1979. The declination is 89°54'27"; right ascension is 229°Ø4'36"; picture center line is 7285.

DEFINE BETA

NE_B_ssyyddd_spicture_code_scan_hhmmss_ms_beta

DEFAULT

None, you must specify the parameters.

PARAMETERS

```
B        →  define betas
ssyyddd  → sensor source, year and day, SSYYDDD
spicture → nominal picture start time, HHMMSS
code     → 1 → first scan definition
         → 2 → last scan definition
scan     → scan line number when beta was recorded
hhmmss   → time beta is recorded
ms       → millisends * 1Ø of scan
beta     → beta count of scan
```

EXAMPLE

NE_B_1279Ø24_1631ØØ_1_1Ø1_1631Ø3_97_4459898
Define a 16:31Z beta for sensor 12, day 24, 1979: first scan definition, scanline 1Ø1 at 16:31:Ø3Z, 97 millisends * 1Ø with a beta count of 4459898.

DEFINE CAMERA GEOMETRY

NE_C_ssyyddd_pitch_yaw_roll

DEFAULT

None, you must specify the parameters.

PARAMETERS

```
C       → define camera geometry
ssyyddd → sensor source, year, day, SSYYDDD
pitch   → satellite pitch, DDDMMSS
yaw     → satellite yaw, DDDMMSS
roll    → satellite roll, DDDMMSS
```

REMARKS

NE_C is used to define the pitch, yaw and roll angles (DDDMMSS) of the camera axis with respect to the principle axis of a satellite.

EXAMPLE

NE_C_1279Ø24_414_83Ø_Ø
Define camera geometry for sensor 12, day 24, 1979: pitch is 414, yaw is 83Ø, roll is Ø.

CHANGE EARTH EDGE DEFINITION

NE_CE_ssyyddd_spicture_old_new

DEFAULT

None, you must specify the parameters.

PARAMETERS

CE	→	change Earth edge definition
ssyyddd	→	sensor source, year, day, SSYYDDD
spicture	→	nominal starting time of picture, HHMMSS
old	→	current code of the Earth edge, 3 digit code
new	→	new code of the Earth edge

REMARKS

The NE_CE command is used to change the current Earth edge code "old" to the entry "new". The "old" code specification must match exactly to the existing information for the change to occur. Use NE_E to list Earth codes.

EXAMPLE

NE_CE_1279Ø24_18ØØØØ_Ø31_131
Change the left Earth edge code Ø31 to the right edge code 131 for sensor 12, day 24, 1979.

CHANGE LANDMARK DEFINITION

NE_CL_ssyyddd_spicture_old_new

DEFAULT

None, you must specify the parameters.

PARAMETERS

```
CL       →  change landmark definition
ssyyddd  → sensor source, year, day, SSYYDDD
spicture → nominal starting time of picture, HHMMSS
old      → current code of the landmark
new      → new code of the landmark
```

REMARKS

The NE_CL command is used to change the current landmark code "old" of a day entry to a "new". The "old" code specification must match exactly to the existing definition for the change to occur. Use NE_L to determine old codes.

EXAMPLE

NE_CL_1279Ø24_1833ØØ_Ø_3Ø1
Change landmark code Ø at 18:33Z for sensor 12, day 24, 1979 to code 3Ø1.

DEFINE EARTH EDGE

NE_E_ssyyddd_spicture_code_line_ele

DEFAULT

None, you must specify the parameters.

PARAMETERS

```
E        → define Earth edge
ssyyddd  → sensor source, year, day, SSYYDDD
spicture → start time of picture, HHMMSS
code     → Earth edge code.  Format is ENN where:
             E  is the edge type (Ø or 1)
                Ø is left edge
                1 is right edge
             NN is the Earth edge number (Ø to 99)
line     → line coordinate satellite image coordinate of Earth edge
ele      → element coordinate
```

REMARKS

The NE_E command is used to define a navigation Earth edge for a specified image identified by "ssyyddd" and "hhmmss". The line coordinate "line" on which the actual edge element position "ele" occurs are defined. Use command NE_CE to change Earth edge codes.

EXAMPLE

NE_E_1279Ø24_13ØØØØ_155_216Ø_7785
Define 13Z Earth edge for sensor 12, day 24, 1979: right Earth edge 155, line 216Ø, element 7785.

DEFINE FRAME GEOMETRY

NE_F_ssyyddd_deglin_lintot_degele_eletot

DEFAULT

None, you must specify the parameters.

PARAMETERS

```
F       → define frame geometry
ssyyddd → sensor source, year, day, SSYYDDD
deglin  → define sweep angle in line direction, DDDMMSS
lintot  → define number of scan lines, NNLLLLL where:
          NN is number of sensors
          LLLLL is number of scans
degele  → define sweep angle in element direction, DDDMMSS
eletot  → define number of element samples
```

REMARKS

The navigation system determines the total number of actual lines by the product of NN and LLLLL. If any of these parameters are set to Ø, the previous definition is not changed.

EXAMPLE

NE_F_1279Ø24_2ØØ342_4Ø25Ø1_182227_13376
Define frame geometry for sensor 12, day 24, 1979: line sweep angle is 2Ø°3'42", 25Ø1 scanlines times 4 sensors, element sweep angle is 18°22'27", 13376 element samples.

DEFINE GAMMA

NE_G_ssyyddd_spicture_gamma_gammadot

DEFAULT

None, you must specify the parameters.

PARAMETERS

G → define gamma
ssyyddd → sensor source, year day, SSYYDDD
spicture → start time of image, HHMMSS
gamma → initial element * 1ØØ
gammadot → element drift per hour * 1ØØ

REMARKS

The DG command is used to define a navigation gamma condition for a specified "ssyyddd" and "hhmmss". The navigation software generates these definitions at navigation run time. This command is used only as a supplement to the normal navigation procedure. The "gamma" (γ) and "gammadot" ($\dot{\gamma}$) are given in decimal form. "Gamma" is given in terms of an initial element offset from a nominal frame reference and "gammadot" is given in terms of element drift per hour. The decimal form is NNNDD (NNN.DD).

EXAMPLE

NE_G_1279Ø24_1831ØØ_5471_-13Ø
Define 1831Z gamma for sensor 12, day 24, 1979: offset of gamma is 54.71 elements drifting in a negative direction at 1.3Ø elements per ΔT (ΔT is approximately 3Ø minutes).

DEFINE BETA CALCULATION PARAMETERS

NE_I_ssyyddd_iajust_iajtim_iseang

DEFAULT

None, you must specify the parameters.

PARAMETERS

```
I       → define beta calculation parameter (or IAJUST)
ssyyddd → sensor source, year and day, SS:YY:DDD
iajust  → controls the offset residual parameter
        → -1 → calculates offset from reference landmark
        →  Ø → set the actual offset residual, can be positive
               integer, too. (pictels*1ØØ)
iajtim  → time of first valid landmark
iseang  → angle between the VISSR and the sun sensor, DDDMMSS
```

REMARKS

The IAJUST is calculated from the betas. Element departure from the picture center element is calculated from the first valid landmark.

EXAMPLE

NE_I_1279Ø24_-9Ø44_833ØØ_9ØØØØ
Calculate the iajust for sensor 12, day 24, 1979: set actual offset residual to -90.44 pictels, time of first landmark is Ø833Z, VISSR/sun sensor angle is 9Ø°.

DEFINE LANDMARK

NE_L_ssyyddd_spicture_code_line_ele_lat_lon

DEFAULT

None, you must specify the parameters.

PARAMETERS

```
L        →  define landmark
ssyyddd  → sensor source, year and day, SSYYDDD
spicture → start time of image from which landmark was taken,
           HHMMSS
code → landmark code.  Indicate how landmark is to be used by
       navigation program.  Format is GGTNN where:
       GG is the gamma cutoff number (Ø - 99)
          T  is the landmark type (Ø - 3)
          Ø  is used for attitude and gamma calculation
          1  is used for attitude calculation only
          2  is used for gamma calculation only
          3  is used for neither attitude nor gamma calculations,
             but only as a navigational check
       NN is the landmark number (Ø - 99)

       A new gamma, gamma-dot set computed each time GG changes.
       If betas are defined, they override the effect of GG.

line   → satellite line position of landmark
ele    → satellite element position of landmark
lat    → latitude of landmark, DD:MM:SS
lon    → longitude of landmark, DD:MM:SS
```

REMARKS

The NE_L command is used to define the landmarks used by the NA command (navigation) for computing the satellite's attitude and gamma, gamma-dot sets.

EXAMPLE

NE_L_1279Ø24_1Ø33ØØ_Ø_2464_6616_35:15:ØØ_-139:44:3Ø
Define 1Ø33Z landmark for sensor 12, day 24, 1979; code is Ø, line position is 2464, element position is 6616, latitude is 35:15, longitude is -139:44:3Ø.

MEASURE LANDMARK

NE_M_lat_lon

DEFAULT

None, you must specify the parameters.

PARAMETERS

M → measure landmarks
lat → latitude of landmark, DD:MM:SS
lon → longitude of landmark, DD:MM:SS

REMARKS

Command NE_L could also be used to measure landmarks.

EXAMPLES

NE_M_35:15:ØØ_-139:44:3Ø
Define landmark at 35:15 N and -139:44:3Ø E.

ENTER ORBIT INCLINATION DATA

NE_O_ssyyddd_etimy_etimh_semina_eccen_orbinc_meana_perigee_asnode

DEFAULT

None, you must specify a group of parameters.

PARAMETERS

O	→	enter orbit inclination data
ssyyddd	→	specify sensor source, year and day, SSYYDDD
etimy	→	epoch year, month, day, YYMMDD
etimh	→	epoch hour, minute tenths, minute tenths-hundredths of minutes, HHMMSS
semina	→	semi major axis, Km
eccen	→	eccentricity coefficient, degrees/1ØØ
orbinc	→	inclination, NNDDD decimal degrees
meana	→	mean anomaly, NNNDD decimal degrees
perigee	→	argument of perigee, NNNDD decimal degrees
asnode	→	longitude of ascending node, NNNDDD decimal degrees

REMARKS

The NE_O command is used to define a navigation orbit for a specified satellite, year and day.

EXAMPLE

NE_O_1279Ø24_79Ø116_Ø_42165Ø8_8Ø_125_323537_17Ø8ØØ_12Ø334
Orbit inclination data is entered for sensor 12, day 24, 1979: epoch day 16, month 1, year 1979; epoch time Ø, semi major axis is 42165Ø8 km, eccentricity .8°, inclination is 12.5°, mean anomaly is 323.537°, perigee is 17Ø.8Ø°, ascending node is 12Ø.334°.

DEFINE SPIN PERIOD

NE_S_ssyyddd_spinp

DEFAULT

None, you must specify a group of parameters.

PARAMETERS

S → define satellite spin period
ssyyddd → specify sensor source, year and day, SS:YY:DDD
spin period → spin period of a satellite on the day specified by SSYYDDD, entered in microseconds. The spin rate in revolutions per minute x 1ØØØ can also be used. The format used is determined by its magnitude.

EXAMPLE

NE_S_1279Ø24_6ØØØØØ
Define spin period for sensor 12, day 24, 1979: spin period is 6ØØØØØ microseconds.

ENTER NEW SATELLITE DATA INTO NAVIGEOM FILE

```
NGE_L_ss
NGE_F_ss_deglin_lintot_degele_eletot
NGE_C_ss_pitch_yaw_roll
NGE_I_ss_iajust_iajtim_iseang
```

DEFAULT

No default, you must specify the parameters.

PARAMETERS

L	→	list data for satellite ss
F	→	enter frame geometry data
C	→	enter camera geometry data
I	→	enter beta calculation parameters
ss	→	new satellite sensor number (check existing list for available numbers)
deglin	→	total sweep angle in line direction, DDDMMSS
lintot	→	total number of scan lines, NNLLLLL; where NN is the number of sensors and LLLLL is the number of scan lines
degele	→	total sweep angle in the element direction, DDDMMSS
eletot	→	total number of elements in scan line
pitch	→	forward leaning misalignment caused by bias in line position, DDDMMSS
yaw	→	sideways leaning misalignment causing skew in element direction DDDMMSS
roll	→	rotation misalignment causing bias in element direction, DDDMMSS
iajust	→	east-west adjustment value, in positive or negative visible elements
iajtim	→	the time that IAJUST computed from first landmark of the day, HHMMSS
iseang	→	angle between VISSR and sun sensor, DDDMMSS

REMARKS

NGE is used when a new satellite is launched; a new sensor code is selected and the appropriate data is entered into the NAVIGEOM file. The data is collected from the appropriate responsible agency.

GENERATE NAVIGATION CODICIL FROM GOES MASTER FILE

NK_satellite day_time_type_[keywords]

DEFAULT

NK_satellite day_time

- generate navigation codicil for 'satellite day'
- generate ticketed codicil

PARAMETERS

satellite day → satellite and day, SSYYDDD

time → image time, HH:MM:SS

type → T → generate ticketed codicil (default)
M → generate master navigation codicil

KEYWORD

```
AREA=         →  area number to assign codicil
UPDATE=begday_begtime_endday_endtime_tinc → make master navigation
         codicil.   Use to do a backwards update of navigation.
     begday  → first satellite and day (SSYYDDD) of range to be
               updated (default=original satellite day)
     begtime → first time of range to be updated (HH:MM:SS)
     endday  → last satellite and day (SSYYDDD) of range to be
               updated (default=original satellite day)
     endtime → last time of range to be updated (HH:MM:SS)
     tinc    → time increment (default=Ø:3Ø)
NAVF=        → navigation file number
SENS=HIRS    → TIROS sensor HIRS
    =AVHRR   → TIROS sensor AVHRR (default)
    =MSU     → TIROS sensor MSU
    =ERB     → TIROS sensor ERB
```

REMARKS

The current GOES file (set by NVU) is used as the source.

If parameter type is T, the string NAVNUM is filled with the ticket value assigned to the navigation codicil and placed in your string table.

EXAMPLES

NK_3Ø85255_11:3Ø_AREA=6512
Generate a ticketed navigation codicil for area 6512, satellite 3Ø, day 255, 1985 at 11:3Ø GMT.

NK_3Ø84363_12
NK_3Ø84363_12_T
Both create a ticketed codicil for satellite 3Ø, 1984, day 363 12Z.

NK_16791ØØ_2Ø_M_UPDATE=16791ØØ_Ø_16791ØØ_23:3Ø:3Ø
NK_16791ØØ_2Ø_M_UPDATE=Ø_23:3Ø:3Ø
Both commands will use the navigation parameters for satellite 16, 2Ø2 of day 1ØØ of 1979 to update the codicils for every half hour from ØZ through 133ØZ.

GENERATE A POLAR ORBITER NAVIGATION ENTRY

NKTI_area_satellite_sensor_[keywords]

DEFAULT

No default, you must specify a group of parameters.

PARAMETERS

```
area       → area number to assign navigation
satellite  → satellite number (e.g., 1 for ERB, 5 for NOAA5, 6 for
             NOAA6, etc.)
sensor     → HIRS  → HIRS sensor type
             MSU   → MSU sensor type
             AVHRR → AVHRR sensor type
             ERB   → ERB sensor type
```

KEYWORDS

```
SCAN=POS → for scanning in positive direction (default)
     NEG → for scanning in negative direction
```

REMARKS

NKTI creates a polar orbiter navigation entry for an area. This allows typical McIDAS commands (e.g., IC, IGTV, E, MDX, REMAP, etc.) to operate on polar orbiter images. The ticket number is filed in the string table under the name NOAANUM.

EXAMPLE

NKTI_6ØØØ_8_AVHRR
Create navigation for AVHRR data from NOAA8 imagery in area 6ØØØ.

LISTS SPECIFIED DATA IN THE CURRENT NAVIGATION FILE

NL *type ssyyddd [keywords]*

PARAMETERS

```
type    → B       → lists betas
          G       → lists gammas
          L       → lists landmarks
          DAY     → lists the day block (default)
          ALL     → lists the day and image dependent data
          BD      → lists betas and the day block
          GD      → lists gammas and the day block
          LD      → lists landmarks and the day block
          ASNODE  → longitude of the ascending node, NNNDDD decimal
                    degrees
          DECLIN  → declination in degrees, minutes and seconds, HHMMSS
          DEGELE  → degrees of element
          DEGLIN  → degrees of line
          EANOM   → eccentric anomaly
          ECCEN   → eccentricity coeffecent degrees/100
          ELETOT  → defines the number of element samples
          IAJUST  → controls the offset residual parameter
                  → -1 → calculates the offset from the reference
                         landmark
                  → 0  → sets the actual offset residual; can be a
                         positive integer too (pictels*100)
          IAJTIM  → time of the first valid landmark
          ISEANG  → angle between the VISSR and the sun sensor, DDDMMSS
          LINTOT  → defines the number of scan lines, NNLLLLL where:
                    NN is the number of sensors
                    LLLLL is the number of scans
          PICLIN  → picture center line
          PERIGE  → argument of perigee, NNNDD decimal degrees
          PITCH   → satellite pitch, DDDMMSS
          RASCEN  → right ascension in degrees, minutes and seconds,
                    HHMMSS
          ROLL    → satellite roll, DDDMMSS
          SEMIMA  → semi major axis, Km
          SPINP   → spin period of a satellite on the day specified by
                    SSYYDDD, entered in microseconds; the spin rate in
                    revolutions per minute x 1000 can also be used;
                    the format is determined by its magnitude
          YAW     → satellite yaw, DDDMMSS
ssyyddd → sensor source, year, and Julian day to list (default=32#Y)
```

KEYWORDS

FORM=REAL → floating point format for the day block (default)
=INT → integer format for the day block as seen in the navigation file
NAVF= → navigation file number (default=current)
TIME= → begin end → range of times to list (default=ALL)

REMARKS

Use the McIDAS-MVS command NVU to list the valid times for GVAR and block 11 navigation.

EXAMPLES

NL
This entry lists the day block navigation parameters for sensor source 32 from the current day.

NL G 3294024 NAVF=100
This entry lists gammas for sensor source 32, day 94024, from navigation file 100.

NL ALL 3291304 TIME=12:01
This entry lists all navigation data for sensor source 32, day 91304, with orbit and attitude data from 12:01 UTC.

LIST NAVIGATION PARAMETERS FROM A NAVIGATION CODICIL

NLC_SSYYDDD_time_CHEB

NLC_ticket

DEFAULT

NLC_ticket

- list navigation parameters stored in 'ticket'

PARAMETERS

ssyyddd → satellite, year and Julian day of navigation to be listed
time → time of navigation to be listed, HH:MM:SS GMT
CHEB → list Chebyshev codicils
ticket → list navigation parameters from specified ticketed navigation codicil

REMARKS

DEV=C list a summary. DEV=S lists full Orbit and Attitude data on the system printer.

EXAMPLES

NLC_2482Ø65_2Ø
List the navigation parameters for satellite 24, 2ØZ of day 65, 1984.

NLC_2Ø84365_16:3Ø_CHEB_DEV=S
List the Chebyshev codicil for satellite 2Ø, 163ØZ of day 365, 1984 and send the list to the system printer.

NLC_62985
List the navigation parameters stored in ticket number 62985.

COPIES NAVIGATION DATA

NM *sfile dfile option ssyyddd password*

PARAMETERS

sfile → source navigation file number (default=current)
dfile → destination navigation file number; if it is 1 or 2, you must use the password JTY
option → B → moves betas
→ L → moves landmarks
→ E → moves earth edge
→ G → moves gammas
→ DAY → moves day data
→ ORBIT → moves orbit data
→ ALL → moves all data (default)
ssyyddd → sensor source, year and Julian day of the navigation data (default=current)
password→ JTY → required to move data to master navigation file 1 and 2.

REMARKS

Insert zero (0) for sfile or dfile to specify the current file. To point to files, use the NVU SET command.

ALL is the only valid option for moving GVAR or block 11 navigation.

EXAMPLES

NM 1 20 B 3294320
This entry copies the betas from file 1 to file 20 for sensor source 32, day 94320.

NM 0 1 ALL 3293316 JTY
This entry copies all the navigation information from the current file to file 1 for sensor source 32, day 93316.

COPIES NAVIGATION DATA FOR A RANGE OF DAYS

NMD *sfile dfile option ss bday eday password*

PARAMETERS

```
sfile     → source navigation file number(default=current)
dfile     → destination navigation file number(default=current)
option    → B    → moves betas
          → L    → moves landmarks
          → E    → moves earth edge
          → G    → moves gammas
          → DAY  → moves Orbit and Attitude information
          → ALL  → moves all navigation information (default)
ss        → sensor source of the data to be moved
bday      → first day of the range, YYDDD (default=current)
eday      → last day of the range, YYDDD (default=bday)
password  → JTY  → required to move data to master navigation file 1 or 2.
```

REMARKS

Use the NVU command to set the current navigation file. If sfile or dfile is zero (0), the current file is used.

NMD is a macro that calls NM.

ALL is the only valid option for moving GVAR and block 11 navigation.

EXAMPLES

NMD 1 3 ALL 32 94120 94124
This entry copies all navigation information for sensor source 32, days 120 through 124 of 1994 from file 1 to file 3.

NMD 0 1 L 32 93100 93104 JTY
This entry copies landmarks for sensor source 32, days 100 thru 104 of 1993 from the current file to file 1.

COMPUTE AND DISPLAY NAVIGATION TRANSFORMS

NT_SE_ssyyddd_hhmmss_line_ele_[keywords]

NT_ES_ssyyddd_hhmmss_lat_lon_[keywords]

NT_SP_ssyyddd_hhmmss

NT_ROT_ssyyddd_hhmmss

NT_ANG_ssyyddd_hhmmss_lat_lon_[keywords]

DEFAULT

No default, you must specify a group of parameters.

PARAMETERS

SE → satellite to earth transformation
ES → earth to satellite transformation
SP → sub-satellite position
ROT → satellite rotation
ANG → zenith angles
ssyyddd → satellite and day, SSYYDDD
hhmmss → time, HH:MM:SS
line → line number
ele → element number
lat → latitude
lon → longitude

KEYWORDS

THRU=end line_end element → calculate conversion through this line/element
THRU=end lat_end lon → calculate conversion through this latitude/longitude
N=n1_n2 → n1 is number of calculations between lines or latitudes, n2 is number of calculations between elements or longitudes (default=2_2)

REMARKS

The keywords allow you to make the transformation over a whole grid of points rather than just one.

EXAMPLE

NT_ES_3Ø84ØØ6_Ø_45_-89_THRU=5Ø_-99_N=6_3
Make 3 x 6=18 transformations. Make 6 between latitudes 45 and 5Ø (every degree), and 3 between longitudes -89 and -99 (every 5 degrees).

NAVIGATION TRANSFORM FROM NAVIGATION CODICIL

NTC_SE_primary_secondary_line_ele

NTC_ES_primary_secondary_lat_lon

DEFAULT

No default, you must specify a group of parameters.

PARAMETERS

SE → satellite to earth transformation (default)
ES → earth to satellite transformation
primary → the codicil number of the area listed by LA_area_FORM=ALL. The codicil number is listed after PRIMARY=
→ sensor source and day of data, SSYYDDD
secondary → time of data, HH:MM:SS
→ Ø → enter Ø if using a ticketed codicil
line → line coordinate
ele → element coordinate
lat → latitude
lon → longitude

EXAMPLES

NTC_ES_28851ØØ_12_36_9Ø
Calculate the earth to satellite transformation for satellite 28, day 1ØØ, 1985 at 12 GMT at 36°N and 9Ø°W.

NTC_SE_74769_Ø_1ØØ1Ø_2ØØØØ
Calculate the satellite to earth transformation for codicil 74769, line 1ØØ1Ø and element 2ØØØØ.

TURN AUTOMATIC NAVIGATION ON AND OFF

NVAUTO_option

DEFAULT

None, you must specify the parameters.

PARAMETERS

option → ON → turn AUTONAV on. Navigation codicils are generated from the landmark navigation file.
OFF → turn AUTONAV off and return to the master navigation file. Navigation codicils are generated from the master navigation file.

REMARKS

NVAUTO switches between the navigation from the AUTONAV system and the satellite data stream. NVAUTO operates on event scheduler entries for a FNVGOE program that distributes navigation data. See the DNFNVDOC file for more information.

NVAUTO can be used at any time. The OFF option does not stop landmark collection or navigation filing in the landmark navigation file. Upgrading and prediction take place as set in the time scheduler. In this manner, AUTONAV is hidden and can be used whenever the navigation from landmarks is better than navigation from the data stream.

COPY NAVIGATION FILE

NVCPY_sfile_dfile

DEFAULT

NVCPY

- copies current navigation file to file 11

PARAMETERS

sfile → navigation file number to be copied (default=current navigation file)
dfile → destination file number (default=11)

REMARKS

Use NVU to set the current navigation file.

EXAMPLE

NVCPY_3Ø_22
Copy the contents of navigation file 3Ø into navigation file 22.

UPGRADE AND PREDICT NAVIGATION FOR GOES

NVFOR_ssyyddd_pdays_fdays_mday_mtime_[keyword]

DEFAULT

NVFOR_32#y_3_7_mday_mtime_[keyword]

- generates predict and navigation upgrading for GOES EAST satellite, using current year and day
- predict is based on data from current day and past three days
- predict is computed for next 7 days
- maneuver day and time is taken from NVA32 file

PARAMETERS

ssyyddd	→	sensor source, year and day to upgrade (default=taken from NVA(sat#) file)
pdays	→	number of past days to include in upgrade (default=3 days)
fdays	→	number of future days to compute predict (default=7 days)
mday	→	last maneuver day, YYDDD(default=taken from NVA(sat#) file)
mtime	→	last maneuver time, HHMMSS(default=taken from NVA(sat#) file)

KEYWORD

NAVF= → lnavf → landmark navigation file (default=3)
anavf → auxiliary navigation file (default=4)

REMARKS

The NVFOR program is a part of the AUTONAV system. It upgrades navigation parameters and computes navigation predictions for the next few days based on all landmarks from the current day and a few past days. The program works in three steps. First, the best orbital parameters are computed with two camera angles (pitch and yaw) for the current day and past few days. The second step provides the best attitude (DE, RA, RO) for the current day and all past days. This step provides the best navigation for the current day and stores it in a landmark navigation file. All results are also stored in an auxiliary navigation file and are used in step three to obtain predict for the next few days. Orbital parameters are copied from the current day to a few future days. Attitude is extrapolated from its values in the past days and the predict is stored in the landmark navigation file. At the end of the program, gammas and gamma-dots are recomputed and the NVA(sat#) file is updated to indicate the next time for NVFOR execution.

Prediction deteriorates at a rate of about 100% per day. First day prediction usually provides navigation at 1-2 pixels, second day 2-4 pixels, and so on. After a four day break, AUTONAV may not have navigation satisfactory for landmark collection.

REMARKS (cont.)

NVFOR stores all intermediate results (i.e. residuals and navigations for all days under consideration) in a NVUP(sat#) file. This file is kept until the next execution of NVFOR. The data format in the file is identical to the NVUP program.

NVFOR is called by the time scheduler. All input data is read from the small LW file NVA(sat#). If necessary, the program can be used manually by entering the command sequence noted above.

SSEC runs NVFOR (with no parameters) three times daily. See page 2-22 for more information.

RMS ERROR AND STANDARD DEVIATION FROM LANDMARK MEASUREMENTS

NVSTAT_cardf_day_option_[keywords]

DEFAULT

NVSTAT

- list RMS error and standard deviation for current day from cardfile 1

PARAMETERS

cardf → card file number (1-999) to file landmark information (default=1)
day → YYDDD or negative number to denote number of past days (default=today)
option → STAT → navigation status (default)
LIST → list RMS error and standard deviation. List will list as the SEE command does.

KEYWORDS

CODE=code1 code2 <coden> → list of landmark codes (default=all)
CUT= → threshold that determines good landmark (default=2Ø)

EXAMPLES

NVSTAT_1
Summarize RMS errors in landmark collection for today.

NVSTAT_1_-4
Use the last 4 days and summarize RMS errors in landmark collection.

NVSTAT_1_882ØØ
Use data from day 2ØØ of 1988 and summarize RMS errors in landmark collection.

REMARKS

STAT output includes (for each line):

1. landmark code
2. RMS value of line residual
3. standard deviation of line residual
4. RMS value of element residual
5. standard deviation of element residual
6. number of measurements for a given landmark

Global values are also provided.

REMARKS (cont.)

LIST output includes (for each line):

1. number of position in card file
2. ssyyddd
3. nominal image time
4. landmark latitude
5. landmark longitude
6. landmark image line
7. landmark image element
8. line residual
9. element residual
10. correlation (zero=highest correlation: 100=lowest correlation)
11. landmark code

STAT output is also provided.

NAVIGATION FILE UTILITY

NVU LIST *[keywords]*
NVU SET *file*
NVU QUIT *file password*

PARAMETERS

LIST	→	lists navigation file entries (default)
SET	→	sets the navigation file pointer; responds with a message telling which file the pointer was set to and what it is now
QUIT	→	deletes a navigation file
file	→	navigation file number
password	→	JTY → password required for the QUIT option

KEYWORDS

DAY=	→	day of the year, yyddd
SATDAY=	→	ssyyddd ssyyddd → lists valid GVAR and block 11 navigation times
SS=	→	sensor source number
YY=	→	year of the navigation contained in the file

REMARKS

Use the NVU command to set the navigation file pointer, list the sensor source and days of the navigation contained in a file or delete a file.

Use the SATDAY keyword to list the times navigation was filed for GVAR or block 11 data for the specified sensor source and range of dates. You cannot use SATDAY with other keywords; it applies only to GVAR sensors.

EXAMPLES

NVU
This entry lists the navigation file entries in the current navigation file

NVU LIST SS=20
This entry lists the navigation available for sensor source 20 in the current navigation file.

NVU LIST SS=16 YY=79
This entry lists the navigation for 1979 for sensor source 16 contained in the current file.

NVU SET 100
This entry sets the navigation file pointer to file 100.

NVU LIST SATDAY=7095101
This entry lists the times that navigation was filed for sensor source 70 on day 95101.

UPGRADE SATELLITE NAVIGATION USING LANDMARKS

NVUP_ssyyddd_time_bhours_ehours_[keywords}

DEFAULT

None, you must specify the parameters.

PARAMETERS

ssyyddd → sensor source, year and day of navigation data to upgrade
time → navigation time (the time the navigation block is assigned to). The navigation time must always be ØØZ. The navigation file structure doesn't store more than one set of navigation per day. (default=Ø)
bhours → number of hours to start before/after the input ssyyddd and time
ehours → number of hours to end before/after the input ssyyddd and time (bhours and ehours set the time interval for collecting landmarks and upgrading navigation)

KEYWORDS

NAVF=navf1_navf2 → input and output navigation file number (default= navf1=current navigation file; if navf2=Ø, program won't store navigation parameters to navigation file)
CODE= → codes of landmarks to be considered (max=14) (default=all available codes)
VAR= → two character abbreviations for variables to be upgraded (SE semimajor axis, EC eccentricity, AS right ascension of ascending node, PE argument of perige, OR orbit inclination, EA eccentric anomaly, DE attitude declination, RA attitude right ascension, PC picture center line, PI pitch, YA yaw, RO roll) (default=all variables)
DAY= → days to file results, yyddd or ssyyddd. Also (firstday) (lastday) 1, where "1" is a flag to indicate that all days between first and last day have to be included. Max=2Ø days. (default=day from input ssyyddd)
TOL=tol1_tol2 → optimization tolerances
  =tol1 → for functions and variables (default=1d-5)
  =tol2 → for derivatives (default=1d-5).
RES=Ø → to upgrade (default)
  =1 → to compute residuals only (to evaluate the quality of navigation and landmarks). Sets default of FLU= to zero.
GAM=Ø → to omit the gamma computation (can be used for testing)
  1 → to compute and use during upgrading process (default if navf2=Ø)
  2 → to compute, use during upgrading process, and store into navigation file navf2 (default if navf2 is not Ø). Use the default for operational purposes.

KEYWORDS (cont.)

FLU= → maximum allowed fluctuation value for landmarks to be included in the upgrading process (default=1.5). If RES=1, default=Ø.
NOP=1 → to neglect landmark table in output (default=Ø).

REMARKS

NVUP optimizes navigation parameters and evaluates navigation quality. The current version uses the navigation subroutine for all the GOES satellites. Optimization is performed by the MINPACK subroutines which are an integral part of NVUP. The NVUP program can be used manually or automatically (as part of the NVFOR program or called by the time scheduler). Manual application can upgrade navigation or check the quality of it without upgrading.

The variables (VAR=) listed in the keywords above can be divided into three groups:

- orbital parameters SE, EC, AS, PE, OR, EA
- attitude parameters DE, RA, RO, PC
- camera angles PI, YA, RO

where roll is also listed as an attitude parameter.

The orbital parameters change slowly. Changes that are significant for the satellite image navigation need correction every few days. The same is true for pitch and yaw. Attitude parameters change more often and need to be corrected daily. The picture center line can be optimized, but this procedure is not recommended because its change is compensated by camera angles.

FLU=1.5 with the option RES=1 shows those landmarks taken into account while upgrading and indicates the number of landmarks neglected because of high fluctuation values. If all landmarks must be used independently of fluctuation values, then fluctuation must be set to zero (FLU=Ø).

Tolerances are used by the MINPACK package and rarely need changed. Use value 1d-6 when there is no expected change in navigation parameters (i.e. parameters before and after upgrading are almost the same).

NVUP provides the following output:

- satellite-year-day, source navigation file, current day and time
- navigation time
- number of hours to start and end upgrading from navigation time (i.e. from ØØZ of day in ssyyddd)
- number of landmarks, number of landmarks excluded due to high error
- landmark table with the following columns

LD	landmark number
LDTIME	nominal time of image from which the landmark has been collected

REMARKS (cont.)

LCODE	landmark ID code
LINRES1	line residual before upgrading
LINFLU1	fluctuation for line residual before upgrading
LINRES2	line residual after upgrading
LINFLU2	fluctuation for line residual after upgrading
ELERES1	element residual before upgrading
ELEFLU1	fluctuation for element residual before upgrading
ELERES2	element residual after upgrading
ELEFLU2	fluctuation for element residual after upgrading
LINE	observed image line number for landmarks
ELEM	observed image element number for landmarks
LAT	landmark latitude
LON	landmark longitude

- averages and variances of residuals before and after upgrading
- number of landmarks from each location
- global RMS values and RMS values for landmarks from each location before and after upgrading
- navigation parameters before and after upgrading
- list of upgraded variables
- termination code for optimization by MINPACK, optimization tolerance
- number of navigation transformations during optimization.

If only residuals are computed (option RES=1), then data before and after upgrading is the same.

If the output navigation file number for keyword NAVF= is non-zero, then final navigation is stored to the navigation file. In this case, gammas are recomputed and stored to the same navigation file.

Review the output in the following order.

- number of landmarks
- number of landmarks from each location and number of landmark areas
- global RMS values
- RMS values for landmarks from each location
- individual residuals in the landmark table
- landmark fluctuations

Following is a description of some of the variables in the output.

Residuals measure the navigation shift at a landmark location. If non-zero, it may mean that navigation is not perfect or landmarks have not been collected properly. To distinguish between the two, compare the fluctuations of several landmarks.

Fluctuation variables in AUTONAV measure how much a given landmark residual differs from others. This variable is usually meaningful only if the number of landmarks is at least 10. A fluctuation of +/-1.5 can be used as a threshold value to recognize those landmarks that were collected improperly (i.e. by matching template to cloud). Landmarks with high fluctuation values are neglected in the upgrading process unless the default value is overwritten using keyword FLU=.

REMARKS (cont.)

The global RMS value is the most compact measure of navigation quality based on landmarks for an area covered by all landmarks and its vicinity. RMS values from each location have similar meaning for navigation around a given location. Low RMS values indicate good navigation. However, high RMS values do not always indicate bad navigation. One improperly collected landmark can raise the RMS value significantly, suggesting navigation problems. Therefore, the interpretation of RMS values must be done carefully. Landmarks collected late in the day often have better residuals than those collected early in the day.

When satellite motion is stable, good navigation leads to residuals and RMS values in the 1-2 pixel range. If they are in the 2-8 pixel range, navigation may still be satisfactory. Such precision is equivalent to a .5-2 pixel error on a resolution 4 image. If RMS values are higher than 8, the navigation may not be satisfactory.

NAVIGATION CODICIL DIRECTORY UTILITY

NXU_INFO_NAV_satellite day

NXU_LIST_NAV_satellite day_time_first word_last word

NXU_DEL_NAV_satellite day_time

DEFAULT

No default, you must specify a group of parameters.

PARAMETERS

INFO → list codicil directory
LIST → list navigation or CHEB parameters
DEL → delete specified codicil
NAV → type of codicil
satellite day → satellite and day of codicil, SSYYDDD
time → time of image for codicil, HHMMSS. Precede with 1 to list the CHEB codicil.
first word → first word to list (default=1)
last word → last word to list (default=first word + 18)

REMARKS

When using the INFO option, if an image start time is listed there is a navigation codicil for that image. If an image start time is listed with a 1 in front of it there is a Chebyshev codicil for that image.

The LIST option will list the navigation or CHEB parameters for the specified satellite, day and time in decimal, hex and EBCDIC. To list the CHEB parameters precede the image time with a 1. If the image hour is a single digit the first hour must be entered as Ø. For example, to list the CHEB parameters for 93ØZ enter the time as 1Ø93ØØØ. A sample list of CHEB parameters follows.

```
1.  DEC: -94222595Ø HEX: C7D6C5E2 EBCDIC: GOES
2.  DEC:    3Ø85226 HEX: ØØ2F13AA EBCDIC: ****
3.  DEC:    121Ø1ØØ HEX: ØØ1276F4 EBCDIC: ****
4.  DEC:      85226 HEX: ØØØ14CEA EBCDIC: ****
5.  DEC:    36ØØØØØ HEX: ØØ36EE8Ø EBCDIC: ****
6.  DEC:          Ø HEX: ØØØØØØØØ EBCDIC: ****
7.  DEC:          Ø HEX: ØØØØØØØØ EBCDIC: ****
```

EXAMPLES

NXU_INFO_NAV_3Ø85332
List the navigation and CHEB codicil directory for satellite 3Ø, day 332 of 1985. CHEBS are preceded by a 1.

NXU_LIST_NAV_3Ø85226_121Ø1ØØ
List the CHEB parameters for satellite 3Ø, day 226 of 1985.

NXU_DEL_NAV_3Ø86ØØ5_1631ØØ
Delete the navigation codicil for satellite 3Ø, day 5 of 1986, 1631Z.

FILE A PREDICTION BASED ON A MASTER NAVIGATION ENTRY

PRED_ss1_yyddd1_ss2_yyddd2_[keyword]

DEFAULT

No default; you must specify source and destination.

PARAMETERS

ss1 → source satellite ID (no default)
yyddd1 → source data's year and day (no default)
ss2 → destination satellite ID (no default)
yyddd2 → destination data's year and day (no default)

KEYWORD

NAVF= → navigation file number (default=1, master navigation file)

REMARKS

Use command PRED to predict navigation parameters, by copying today's master navigation data into tomorrow's.

EXAMPLE

PRED_3Ø_87224_3Ø_87225_NAVF=1ØØ
File prediction from source satellite 3Ø, day 224, 1987 for day 225, 1987; file prediction in navigation file number 1ØØ.

CHECK NAVIGATION QUALITY OF MOST RECENT IMAGE

SEQNAV_farea_larea_template_lag_[keywords]

DEFAULT

No default; you must specify at least one area to search and 'template'.

PARAMETERS

farea → first area number to search (no default)
larea → last area number to search (default=farea)
template → template area number, a clear, well-navigated image used to check the quality of other images (no default)
lag → number of pixels, in line and element directions. Parameter 'lag' determines how far outside the template bounds to look for the specified image navigation (default=2Ø); maximum is 45.

KEYWORDS

OPT=ALL → check all areas (default=check most recent area)
NAVF= → navigation file number for landmarks (default=Ø)
CARDF= → card file number for statistics (default=Ø)

REMARKS

Command SEQNAV looks at the most current image in the range 'farea' to 'larea' (must be a full-resolution visible image) and compares it to the template image. The template is a less than 6Ø x 6Ø pixel image centered on a landmark.

SEQNAV measures the offset between the current image and the template image. Data is filed as a landmark in a navigation file and is written into the card image file specified by keyword CARDF=.

EXAMPLE

SEQNAV_1Ø1_1Ø4_43Ø_NAVF=3_CARDF=3
Take the most recent image from areas 1Ø1 to 1Ø4 and determine the error in navigation based on the template (area 43Ø). File information in file CARDFØØ3 and file landmark measurement in navigation file 3.

Use command SEE_CARDFØØ3 to list card file. Use command NL to list landmarks filed.

CALCULATE NEXT JULIAN DATE

TC_#Y_+_1_ANS=TOMORROW

DEFAULT

No default, you must specify a group of parameters.

PARAMETER

#Y_+_1 → add 1 to today's Julian date (the value of the string table entry Y)

KEYWORD

ANS=TOMORROW → store the result of the above calculation in the string table entry TOMORROW

REMARKS

TC calculates the following day's Julian date for the purpose of filing predicted Orbit and Attitude (O&A) parameters.

This command is run once daily. After it has been run, #TOMORROW is entered in place of the date in the FOAA command to create a prediction for the next day. See FOAA.

Remember to use the appropriate number of pound signs (#) when entering a command that uses strings into the system scheduler (see SKE).

EXAMPLES

If the command

TC_#Y_+_1_ANS=TOMORROW

is run on 84218 the string TOMORROW is assigned the value 84219. This will then be used to create O&A data for 1984, day 219.

CREATE TEMPLATE FOR NAVIGATION QUALITY CONTROL AND AUTOMATIC NAVIGATION

TPLATE_area_lat_lon_code_elev

DEFAULT

No default; you must specify several parameters.

PARAMETERS

area → template area to generate (no default)
lat → latitude of a known point in the displayed image, DD:MM:SS (no default)
lon → longitude of a known point in the displayed image, DDD:MM:SS (no default)
code → navigation code, Ø to 999; unique for each landmark (no default)
elev → elevation of landmark, kilometers (default=topography file value)

REMARKS

Command TPLATE creates a template area with "perfect" navigation. The word "perfect" is used to indicate that the image coordinates are adjusted for this area based on the latitude/longitude of the known point in the image. This template is then used to compare to other images, to determine the error in navigation with command NAVQC. NAVQC uses a correlation algorithm for the comparison. Therefore, the template area should contain a unique feature (island, lake) that is cloud free and is well illuminated (near local noon). Also, the correlation performs better on three- or four-sided geographical features. Straight coastlines, for example, do not work well. For navigation, areas such as islands off Baja, Lake Titicaca (South America), and the west coast of Africa are used because they are cloud-free most of the time.

The procedure for creating a template is as follows:

1. Obtain high-resolution base map of area of interest.
2. Display a full-resolution, visible area over that area.
3. Type command TPLATE with a latitude/longitude for an easily identifiable feature in the image (such as tip of an island or tip of a coastline).
4. Position the cursor over a unique feature (island or lake). Make the cursor size a multiple of four but no larger than 6Ø x 6Ø pixels.
5. Type '.' (period).
6. You're instructed to move the cursor to the specific pixel that corresponds to the latitude/longitude in the command line. Type '.'.

REMARKS (cont.)

At this point, you're ready to use command NAVQC to determine errors in navigation or file landmarks. If you run NAVQC with the same area number that the template area was generated from, the error should be near zero pixels.

The navigation code is used only for automatic landmark determination. It is an arbitrary number (unique for each landmark location); the numbers Ø to 99 are used for finding real-time landmarks and should be avoided. Use numbers larger than 1ØØ.

EXAMPLES

Use the island near the Baja peninsula as a landmark. From a base map, we know that the eastern tip of the island is at 29.3 N and 113.2 W.

DF_1Ø1_1_EC_29.3_113.2
Load the current image.

CUR_6Ø_6Ø_1
Make the cursor 6Ø x 6Ø to fit island.

TPLATE_5742_29.3_113.2_1Ø1_Ø
Position the cursor to encompass the island. Type '.'. Move the cursor to the eastern tip of the island. Type '.'. Area 5742 contains only the island with "perfect" navigation. Note that the elevation entered is zero because it is an island.

UPGRADE ORBIT

UO_ssyyddd_hhmmss_nhours_epoch_ntrack_natt_orbplane_[keywords]

DEFAULT

UO_ssyyddd_hhmmss_nhours_epoch

- upgrade orbit for ssyyddd on hhmmss
- includes nhours landmarks and epoch orbit parameters

PARAMETERS

```
ssyyddd  → sensor source, year, day, SSYYDDD
hhmmss   → time of yyddd to start, hhmmss
nhours   → the number of hours; 24=1 day, 48=2 days, 72=3 days
           etc., of landmark measurements and beta counts which are
           to be included in the Upgrade Orbit calculation.
epoch    → epoch of the calculated orbit parameters
ntrack   → number of along track parameters (default=Ø)
natt     → number of attitude parameters to compute (default=Ø)
orbplane → YES → the orbit plane is found
         → NO  → the orbit plane is not found (default)
```

KEYWORDS

```
STO=YES → store data
   =NO  → do not store data (default)
SYD=ALL → store everyday landmarks were used
        → store navigation for specified SS:YY:DDD
```

REMARKS

Upgrade Orbit, is day oriented because its required data sets come in one day spans. Upgrade Orbit uses landmark measurements with associated beta counts to determine the orbit parameters which best track the satellite in its orbital plane.

GLOSSARY

GLOSSARY OF TERMS

Terms	Descriptions
Argument of Perigee	PERIGEE, angle from the Ascending Node, measured in the satellite's orbit plane and in the direction of motion to the perigee point (closest approach to earth), NNNDDD (degrees x 10^3).
Attitude	The pointing direction of the satellite's spin axis with respect to an earth centered inertial coordinate system. The attitude is commonly parameterized as declination (celestial latitude) and right ascension (celestial longitude).
Beta	The angle subtended at the satellite by the projection of the lines joining the sun and the earth to the satellite into the satellite's spin plane.
Camera geometry	Nominally the spin axis and the body axis of the satellite are expected to coincide; however, in practice, roll, pitch and yaw misalignments are observed.
Codicils	The Codicil structure is a generalized key-based data storage and retrieval system. Originally designed to provide an efficient means of producing variable length addenda to existing files, it may be used in any case where named data items of arbitrary size are required. Examples include the navigation and area codicils. The former contains all the information necessary to navigate a satellite image and is attached to the area directory, thus making the area self-contained.
DECLIN	Declination of satellite axis, DDDMMSS.
DEGELE	The total sweep angle in the element direction, DDDMMSS.
DEGLIN	The total sweep angle in the line direction, DDDMMSS.
Eccentricity	ECCEN, the ratio of the distance between foci of the ellipse and the semi major axis, DDDDDD X 10^5.
ELETOT	The total number of elements in a scan line.
Epoch date	ETIMY, date the orbit is valid, YYMMDD.
Epoch time	ETIMH, hour the orbit is valid, HHMMSS.

Frame geometry	Parameters LINTOT, ELETOT, DEGLIN, and DEGELE defining the resolution and range of the coordinate system in East-West and a North-South direction.
Gamma	Misalignment of the earth from the picture center element and is often determined from the sun pulse at the beginning of the scan line. Element offset x 1ØØ.
Gamma-Dot	Element drift of Gamma per hour x 1ØØ. $\sim\Delta G/\Delta T$ ($\Delta = \frac{G_2 - G_1}{T_1 - T_2}$)
Geostationary orbit	An equatorial, nearly circular orbit whose period of revolution is 1 day. The radius of this orbit is approximately 42,165 km (26,3Ø9 miles). With this type of orbit, the satellite moves slowly in an apparent figure eight motion with respect to the earth's surface.
IAJTIM	The time that IAJUST computed from the first valid landmark of the day, HHMMSS.
IAJUST	East-west adjustment value in visible elements determined from the first valid landmark of the day, positive or negative.
Inclination	ORBINC, the angle between the plane of satellite orbit and the Earth's equator, HHDDD (degrees x $1Ø^3$).
ISEANG	The angle between the VISSR and the sun sensor, DDDMMSS.
Landmark	An identified location on the earth's surface usually consisting of a natural geographic feature such as island, river valley, archipelago, etc.
LINTOT	The total number of scan lines. NNLLLLL where NN is the number of sensors and LLLLL is the number of scans. The line total is based upon the total number of visible sensors, per scan and the total number of scans.
Master Navigation Codicil	The orbital elements for exactly one set of images, visible and IR, are stored in the Master Codicil. These codicils comprise the Master Navigation File.
Master Navigation File	The Master Navigation File consists of a set of Master Navigation codicils. This permanent file, or set of files, contains all navigation data sent in the IR documentation. Two types of data are ingested: regular navigation parameters, as used commonly at SSEC, and Chebyshev polynomial orbital parameters. On the SSEC McIDAS, real time image navigation is automatically stored in the Master File via the event scheduler.

Mean Anomaly	MEANA, the angle between a line from the satellite to the earth at a given moment and a line from the earth to the satellite's perigee passage (assigned at the epoch times), NNNDDD (degrees x $1Ø^3$)
Orbit	The dynamic path of the satellite's motion. This motion is approximated by a Keplerian orbit which would be correct if this was actually a simple, two-body problem. The orbit type is always equal to one.
Orbit definition	The set of classical Keplerian parameters: Epoch date and time, eccentricity, inclination, mean anomaly, argument of perigee, right ascension of ascending node.
PICLIN	Picture center line determined from scan frame geometry.
Pitch	The forward-leaning misalignment causing a bias in the line position, DDDMMSS.
RASCEN	Right ascension of satellite axis, DDDMMSS.
Right Ascension of Ascending Node	ASNODE, the angle between the Vernal Equinox and the line defining the equatorial and orbit planes intersection where the satellite crosses the equator going north, NNNDDD x $1Ø^3$.
Roll	The rotation misalignment causing a bias in the element direction, DDDMMSS.
Semi-major axis	SEMIMA, semi major axis of the elliptical orbit of the satellite, NNNNNDD km*1ØØ.
SPINP	Either the period of a satellite on the given day, in microseconds, or the spin rate in revolutions/minute.
SPINRATE	The average rate of spin is approximately 1ØØ rpm. All GOES satellites are of the Spin Stabilized variety.
Ticketed Navigation Codicils	Ticketed codicils contain navigation data that has been manipulated by the user. Should you modify a Master Codicil via command NK, a new codicil is written and automatically assigns a ticket number; this protects an image from navigation version collisions as each image pair must specifically point at one codicil.
VISSR	Acronym for Visible-Infrared Spin Scan Radiometer.
Yaw	The sideways leaning misalignment causing skew in the element direction as a function of line number, DDDMMSS.