NOAA Technical Memorandum NESS 65

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

GRAPHICAL RELATIONS BETWEEN A SATELLITE AND A POINT VIEWED PERPENDICULAR TO THE SATELLITE VELOCITY VECTOR (SIDE SCAN)

Irwin Ruff
Arnold Gruber

Washington, D.C.
March 1975

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / National Environmental Satellite Service

NOAA TECHNICAL MEMORANDUMS

National Environmental Satellite Service Series

The National Environmental Satellite Service (NESS) is responsible for the establishment and operation of the environmental satellite systems of NOAA.

NOAA Technical Memorandums facilitate rapid distribution of material that may be preliminary in nature and so may be published formally elsewhere at a later date. Publications 1 through 20 and 22 through 25 are in the earlier ESSA National Environmental Satellite Center Technical Memorandum (NESCTM) series. The current NOAA Technical Memorandum NESS series includes 21, 26, and subsequent issuances.

Publications listed below are available from the National Technical Information Service, U.S. Department of Commerce, Sills Bldg., 5285 Port Royal Road, Springfield, Va. 22151. Prices on request. Order by accession number (given in parentheses). [illegible] listed below can be obtained from Environmental Data Servic[illegible]C. 20235.

[illegible]

NESS 31 Publications and Final Reports on Contracts and Grants, 1970. NESS, December 1971, 6 pp. (COM-72-10303)

NESS 32 On Reference Levels for Determining Height Profiles From Satellite-Measured Temperature Profiles. Christopher M. Hayden, December 1971, 15 pp. (COM-72-50393)

NESS 33 Use of Satellite Data in East Coast Snowstorm Forecasting. Frances C. Parmenter, February 1972, 21 pp. (COM-72-10482)

NESS 34 Chromium Dioxide Recording--Its Characteristics and Potential for Telemetry. Florence Nesh, March 1972, 10 pp. (COM-72-10644)

NESS 35 Modified Version of the Improved TIROS Operational Satellite (ITOS D-G). A. Schwalb, April 1972, 48 pp. (COM-72-10547)

NESS 36 A Technique for the Analysis and Forecasting of Tropical Cyclone Intensities From Satellite Pictures. Vernon F. Dvorak, June 1972, 15 pp. (COM-72-10840)

NESS 37 Some Preliminary Results of 1971 Aircraft Microwave Measurements of Ice in the Beaufort Sea. Richard J. DeRycke and Alan E. Strong, June 1972, 8 pp. (COM-72-10847)

NESS 38 Publications and Final Reports on Contracts and Grants, 1971. NESS, June 1972, 7 pp. (COM-72-11115)

NESS 39 Operational Procedures for Estimating Wind Vectors From Geostationary Satellite Data. Michael T. Young, Russell C. Doolittle, and Lee M. Mace, July 1972, 19 pp. (COM-72-10910)

NESS 40 Convective Clouds as Tracers of Air Motion. Lester F. Hubert and Andrew Timchalk, August 1972, 12 pp. (COM-72-11421)

NESS 41 Effect of Orbital Inclination and Spin Axis Attitude on Wind Estimates From Photographs by Geosynchronous Satellites. Linwood F. Whitney, Jr., September 1972, 32 pp. (COM-72-11499)

NESS 42 Evaluation of a Technique for the Analysis and Forecasting of Tropical Cyclone Intensities From Satellite Pictures. Carl O. Erickson, September 1972, 28 pp. (COM-72-11472)

NESS 43 Cloud Motions in Baroclinic Zones. Linwood F. Whitney, Jr., October 1972, 6 pp. (COM-73-10029)

NESS 44 Estimation of Average Daily Rainfall From Satellite Cloud Photographs. Walton A. Follansbee, January 1973, 39 pp. (COM-73-10539)

NESS 45 A Technique for the Analysis and Forecasting of Tropical Cyclone Intensities From Satellite Pictures (Revision of NESS 36). Vernon F. Dvorak, February 1973, 19 pp. (COM-73-10675)

NESS 46 Publications and Final Reports on Contracts and Grants, 1972. NESS, April 1973, 10 pp. (COM-73-11035)

(Continued on inside back cover)

NOAA Technical Memorandum NESS 65

GRAPHICAL RELATIONS BETWEEN A SATELLITE AND A POINT VIEWED PERPENDICULAR TO THE SATELLITE VELOCITY VECTOR (SIDE SCAN)

Irwin Ruff
Arnold Gruber

Washington, D.C.
March 1975

UNITED STATES
DEPARTMENT OF COMMERCE
Frederick B. Dent, Secretary

NATIONAL OCEANIC AND
ATMOSPHERIC ADMINISTRATION
Robert M. White, Administrator

National Environmental
Satellite Service
David S. Johnson, Director

CONTENTS

GEOGRAPHICAL RELATIONS BETWEEN A SATELLITE AND A POINT VIEWED PERPENDICULAR TO THE SATELLITE VELOCITY VECTOR (SIDE SCAN)

Irwin Ruff
Arnold Gruber

National Environmental Satellite Service, NOAA
Washington, D. C.

ABSTRACT. This paper presents a procedure for calculating the position of an orbiting satellite when only the geographical coordinates of a point viewed by an instrument scanning perpendicular to the satellite velocity vector are known. This capability is valuable when using archived data, which do not include orbital specifics, to study, for example, angular patterns of reflected energy. The equations are derived and solved assuming a spherical Earth and a circular orbit. A brief discussion of the effects on the solutions of noncircular orbits and an ellipsoidal Earth is also presented.

INTRODUCTION

The ITOS scanning radiometer visible and infrared data from the NOAA satellite are archived in a mapped format on a polar stereographic projection. The archived data have been alined with the conventional numerical weather prediction grid on a 2048 x 2048 array per hemisphere (Conlan 1973). The mapping procedure consists, in part, of cropping the data from each orbit according to some prescribed satellite zenith angle and replacing data from preceding orbits by data from the succeeding orbit where overlap occurs.

The visible data are currently normalized to an overhead Sun by a simple solar zenith angle correction, although that is not a requirement of the mapping. When the scanning radiometer data are archived, information on the time of observation and satellite viewing angles (i.e., satellite zenith and azimuth angles) are not saved.

There are, however, occasions when that information is necessary. Such a case occurs when angular patterns of reflected energy are studied. It is then necessary to know solar zenith and azimuth angles as well as satellite zenith (or nadir) and azimuth angles. This note describes a procedure for recovering these angles from the mapped archive data. Derivation of the equations for a viewing direction perpendicular to the satellite velocity vector (the scanning radiometer case) and their solution are presented below. In the derivations, a circular orbit and a spherical Earth are assumed.

To solve the equations in an absolute time and geographic frame of reference it is necessary to know the orbit on which the mapped data were observed. Fortunately, this information, as well as the complete ephemeris of the orbit, is available from other sources.

Although the problem posed is the recovery of the orbital position of the satellite, given the viewed latitude and longitude, the derived equations are general, so that if the satellite's orbital position and viewing angles are known one can obtain the latitude and longitude of the viewed point.

RELATIONS OF VIEWING ANGLES

Prior to deriving the required equations it is useful to examine the relationship between various quantities in the plane of view. These relationships are shown in figure 1. The symbols have the following meanings:

VP = viewed point.

η = nadir angle of VP at satellite.

ε = zenith angle of satellite at VP.

SSP = subsatellite point

ψ = geocentric angle between SSP and VP.

R = Earth radius.

H = satellite height.

If either η or ε is known, the other may be obtained from:

$$\sin \varepsilon = \frac{R+H}{R} \sin \eta. \quad (1)$$

ψ , in degrees, is then given by

$$\psi = 180 - \eta - (180-\varepsilon) = \varepsilon-\eta. \quad (2)$$

If ψ is known,

$$S^2 = R^2 + (R+H)^2 - 2R (R+H) \cos \psi \quad (3)$$

$$\sin \varepsilon = \frac{R+H}{S} \sin \psi \quad (4)$$

$$\sin \eta = \frac{R}{S} \sin \psi. \quad (5)$$

DERIVATION OF EQUATIONS

Figure 2 is a polar map of the Northern Hemisphere that depicts the relationship between the orbital coordinate system and the surface of the Earth.

The "orbital coordinate system" is a spherical system on the surface of the Earth, in which the suborbital track forms the "Equator." The "orbital pole" (OP) used in the calculations is the pole of the orbital system located in the Northern (geographic) Hemisphere. The "orbital latitude" is termed ψ and the "orbital longitude" is τ. The orbital latitude is the geocentric angle between the subsatellite point and the viewed point.

The geographic latitude of a viewed point is ϕ and λ is its relative geographic longitude. Zero relative geographic longitude (as well as zero τ) is taken at the ascending node of the orbit. (The ascending node is the point at which the satellite crosses the geographic Equator in a northward direction.) Both λ and τ are positive toward the west.

The orbital inclination ι is the angle between the suborbital track and the geographical equator. It is always considered to be 90° or less. If the inclination is given as an angle greater than 90° (as is often the case), the supplement of the given inclination should be used as the value for ι.

All equations assume a perfectly spherical Earth. The initial equations are for a nonrotating Earth. (Earth rotation is taken into account later.)

Two cases are shown; the variables for each are indicated respectively by subscripts 1 and 2. Case 1 is valid for $-90° \leq \tau \leq 90°$, which is the northbound half of the orbit. (λ will always be in the same quadrant as τ). Case 2 is valid for $90° \leq \tau \leq 270°$, which is the southbound half of the orbit. The variables τ' and λ' are internal angles of the triangles to be solved, and are related to τ and λ respectively in a different manner for the two cases.

For case 1, $\tau' = 90° - \tau$ (or $\tau' = 450° - \tau$, if it is desired to avoid negative angles). Thus $\sin \tau' = \cos \tau$, and $\cos \tau' = \sin \tau$. $\lambda' = \lambda + 90°$ (or $\lambda' = \lambda - 270°$), $\sin \lambda' = \cos \lambda$, and $\cos \lambda' = -\sin \lambda$. These equations also may be used when τ is needed in terms of τ', or λ in terms of λ'.

For case 2, $\tau' = \tau - 90°$, $\sin \tau' = -\cos \tau$, and $\cos \tau' = \sin \tau$. The corresponding relationships for λ and λ' are $\lambda' = 270° - \lambda$, $\sin \lambda' = -\cos\lambda$, and $\cos \lambda' = -\sin \lambda$.

Once the relationships between τ, τ', λ, and λ' have been established, the spherical triangle with apexes at the North Pole, the orbital pole, and the viewed point may be solved. If the position of the satellite in the orbit (τ) and the "orbital latitude" (ψ)[1] are known, and it is desired to find the latitude and longitude of the viewed point (ϕ and λ), the equations are:

$$\sin \phi = \cos \iota \sin \psi + \sin \iota \cos \psi \cos \tau' \quad (6)$$

$$\cos \lambda' = \frac{\sin \psi - \cos \iota \sin \phi}{\sin \iota \cos \phi} = \frac{\sin \iota \sin \psi - \cos \iota \cos \psi \cos \tau'}{\cos \phi} \quad (7)$$

$$\sin \lambda' = \frac{\cos \psi \sin \tau'}{\cos \phi} \quad (8)$$

If the viewed point latitude and longitude are known and the orbital position is required, the equations become:

---

[1]The orbital latitude is related to the more familiar satellite nadir and zenith angles through equations 4 and 5.

$$\sin \psi = \cos \iota \sin \phi + \sin \iota \cos \phi \cos \lambda' \quad (9)$$

$$\cos \tau' = \frac{\sin \phi - \cos \iota \sin \psi}{\sin \iota \cos \psi} = \frac{\sin \iota \sin \phi - \cos \iota \cos \phi \cos\lambda'}{\cos \psi} \quad (10)$$

$$\sin \tau' = \frac{\cos \phi \sin \lambda'}{\cos \psi} . \quad (11)$$

MOVING SATELLITE

On a nonrotating Earth, the suborbital track is a great circle. The relationship between the orbital longitude of the satellite (τ) and its geographical latitude (ϕ_s) and longitude (λ_s) may be derived by use of figure 3.

$$\sin \phi_s = \sin \iota \sin \tau \quad (12)$$

$$\sin \lambda_s = \frac{\cos \iota \sin \tau}{\cos \phi_s} \quad (13)$$

$$\cos \lambda_s = \frac{\cos \tau}{\cos \phi_s} \quad (14)$$

By determining both $\sin \lambda_s$ and $\cos \lambda_s$, the quadrant of λ_s is apparent. The first two equations may be combined to give a general equation relating latitude and longitude for any great circle:

$$\sin \lambda_s = \cot \iota \tan \phi_s \quad (15)$$

These equations also may be used to determine τ, from known values of ϕ_s and λ_s.

If the satellite orbit is considered circular, the position of the satellite is related to time by

$$\tau_s = \frac{360° \ t}{P} \quad (16)$$

where t is a time variable, and P is the orbital period of the satellite in the same units as t.

The azimuth angle α_s of the satellite at the viewed point, measured through 360° eastward from north, must be determined separately for positive and negative values of ψ. This is shown in figure 4. The symbols have the same meaning as given previously; the primes indicate variables when scanning in the negative ψ direction.

Case 1. $\psi > o.$

$$\cos \alpha_s = \frac{\sin \phi_s - \sin \phi \cos \psi}{\cos \phi \sin \psi} \tag{17}$$

$$\sin \alpha_s = \frac{- \cos \phi_s \sin (\lambda_s - \lambda)}{\sin \psi} \tag{18}$$

Case 2. $\psi < o.$

$$\cos \alpha'_s = \frac{\sin \phi_s - \sin \phi' \cos \psi}{- \cos \phi' \sin \psi} \tag{19}$$

$$\sin \alpha'_s = \frac{\cos \phi_s \sin (\lambda_s - \lambda')}{\sin \psi} \tag{20}$$

The quadrant of α_s and α'_s is clearly defined by the sine and cosine relationships for each case. It should be noted that although figure 4 illustrates the northbound orbit, the same relationships hold for the southbound case.

ROTATING EARTH

All the preceding was based on a nonrotating coordinate system (i.e., nonrotating Earth). The only effect of Earth rotation on a point in the fixed system is to increase the westward longitude at a fixed rate. The simplest way of considering Earth rotation is to work in the fixed system, and then adjust the calculated longitude as a final step. Thus, the true longitude (Λ) of a viewed point, relative to the ascending node, considering Earth rotation, may be obtained from the fixed longitude, λ, by

$$\Lambda = \lambda + \frac{360° \, t}{P_E} \tag{21}$$

where P_E is the rotation period of the Earth.

SOLUTION OF EQUATIONS

The problem of obtaining the satellite subpoint given a viewed point was solved in two different ways. The first was graphical and was obtained by solving eq. (6 thru 8), with the rotation of the Earth taken into account, and by specifying τ_s from eq. (16) for time increments of one minute and ψ for every 2° of great circle arc. The resulting graph is shown in figure 5 on a polar plot. It is for the NOAA-2 satellite with an inclination angle of 78.3° and a period of 115 min. Latitude goes from Equator to Pole and longitude is measured west of ascending node longitude for use in the Northern Hemisphere. The lines normal to the subsatellite track ($\psi=0$) are not scan lines but lines of constant time. However, since the radiometer revolves at 48 revolutions per minute, they are close approximations to scan lines. The graph is used by locating the viewed point in latitude and longitude relative to the ascending node. The geocentric arc distance (ψ) between the subsatellite point and the viewed point and the time of observation (t) relative to the ascending node are determined directly from the graph. The latitude and longitude of the satellite subpoint are determined at the intersection of the line of constant time and $\psi=0$. When using figure 5 for application to the Southern Hemisphere, the longitude is interpreted as degrees east of the next ascending node and time as minutes before the next ascending node.

The second method of solution is obtained by solving eq. (9-11) for τ of the satellite position. The procedure used is illustrated best by rewriting the equations without the primes and taking the Earth's rotation into account. For both case 1 and 2 the equations are:

$$\sin \psi = \cos \iota \sin \phi - \sin \iota \cos \phi \sin (\lambda_o - t/4) \qquad (9A)$$

$$\sin \tau = \sin \iota \sin \phi + \cos \iota \cos \phi \sin (\lambda_o - t/4) \qquad (10A)$$

$$\cos \tau = \frac{\cos \phi \cos (\lambda_o - t/4)}{\cos \psi} \qquad (11A)$$

where λ_o is the observed point longitude relative to ascending node longitude and t is the time of observation after ascending node. Thus, $\lambda_o - t/4 = \lambda$, the geographical longitude for a nonrotating Earth. Assuming a circular orbit, $\tau = 360\ t/P$ and

$$\cos \tau = \cos \frac{360\ t}{P} \quad . \qquad (12A)$$

Substituting for $\cos \psi$ in 11A from 9A gives

$$\cos \tau = \frac{\cos \phi \cos (\lambda_o - t/4)}{\sqrt{1 - (\cos \iota \sin \phi - \sin \iota \cos \phi \sin (\lambda_o - t/4))^2}} \qquad (13A)$$

Solving eq. (12A) and (13A) through an iterative procedure by incrementing t, leads to a value of τ and, thus, the satellite subpoint through applications of eq. (12 - 14).

The geocentric arc distance ψ between the viewed point (VP) and satellite subpoint (SSP) is obtained from eq. (9A) and the satellite nadir and zenith angles from eq. (3 - 5).

CONCLUDING REMARKS

It should be stressed that the preceding results are based on the assumptions of a circular orbit and a spherical Earth. Since the Earth most nearly approximates an ellipsoid, and since satellite orbits usually depart from circular, the results are not free from error. However, most meteorological satellites have been placed in orbits that are very close to circular. NOAA-3, for example, had an eccentricity of .00057 (a variation in radius vector of 9 km in 7880 km). Calculations were made of satellite positions using the orbital elements of NOAA-3, and compared with the positions assuming a circular orbit. The maximum displacement was only 0.1° of geocentric arc. The positions determined by using the elliptical orbit were then located on an ellipsoidal Earth (International Ellipsoid of Reference). The latitude on the ellipsoid is defined as the angle made with the equatorial plane by a line passing through the satellite normal to the surface of the ellipsoid. When these positions are compared with those obtained by using a circular orbit and a spherical Earth, the maximum deviation is slightly less than 0.3° of geocentric arc.

The validity of these computations can be checked by calculating the subsatellite positions assuming a circular orbit and spherical Earth, and comparing them to the positions obtained from the ephemeris. Two such computations, one for a NOAA-2 orbit and one for a NOAA-3 orbit, are shown in figure 6. For most of the orbit the absolute difference in latitude and longitude between the calculated and observed subsatellite point is 0.2° or less. This is approximately the location accuracy of the satellite (Conlan 1973). There were a few occasions, however, when the absolute differences exceeded 0.2° - reaching a maximum absolute value of 0.6° for NOAA-3 and 0.4° for NOAA-2. The time and magnitude of these differences may vary from orbit to orbit. Since the ephemeris location is accurate only to within 0.2°, these data seem to agree with the first comparisons. The seriousness of the error depends in part on the accuracy required. For some applications, the errors may be more than offset by the computational ease gained by the assumption of a circular orbit and a spherical Earth. Note that the error caused by the assumption of a spherical Earth, which is larger of the two effects with satellite orbits of small eccentricities, may be taken into account rather easily. To obtain the tangent of the latitude on the ellipsoid requires only that the tangent of the latitude on the sphere be multiplied by the constant a^2/b^2, where a and b are the semimajor and the semiminor axes of the ellipsoidal Earth.

ACKNOWLEDGEMENTS

We would like to thank Ms. G. Lucas for typing the manuscript, Ms. M. Varnadore for her programming efforts, and Mr. L. Hatton for his drafting work.

REFERENCES

Conlan, E.F., "Operational Products from ITOS Scanning Radiometer Data," NOAA Technical Memorandum NESS 52, U. S. Department of Commerce, Washington, D. C., 1973, 55 pp.

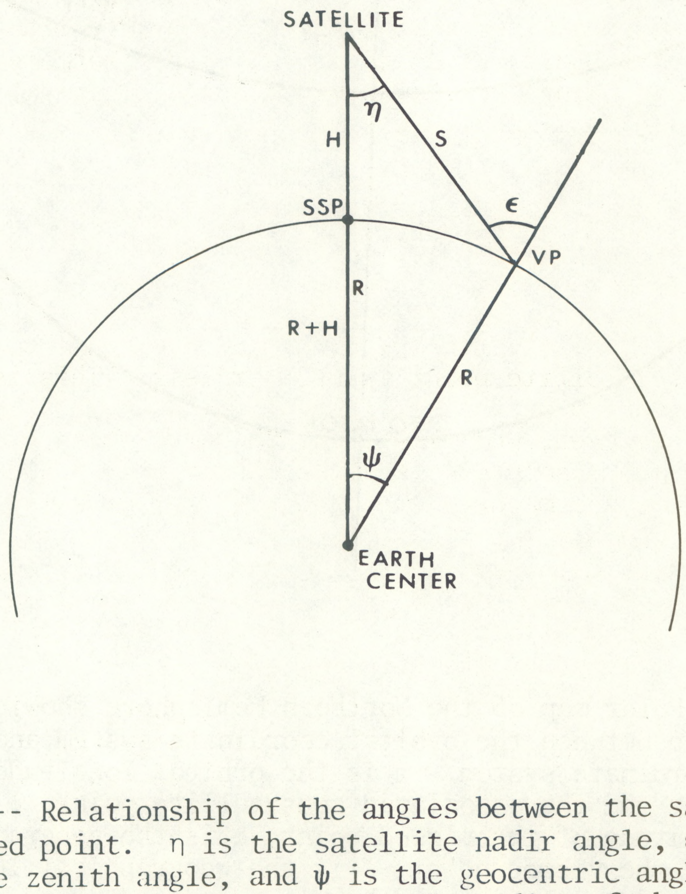

Figure 1. -- Relationship of the angles between the satellite and the viewed point. η is the satellite nadir angle, ε is the satellite zenith angle, and ψ is the geocentric angle between the satellite and viewed point. R is the radius of the Earth and H is the altitude of the satellite. SSP is the satellite subpoint and VP is the viewed point.

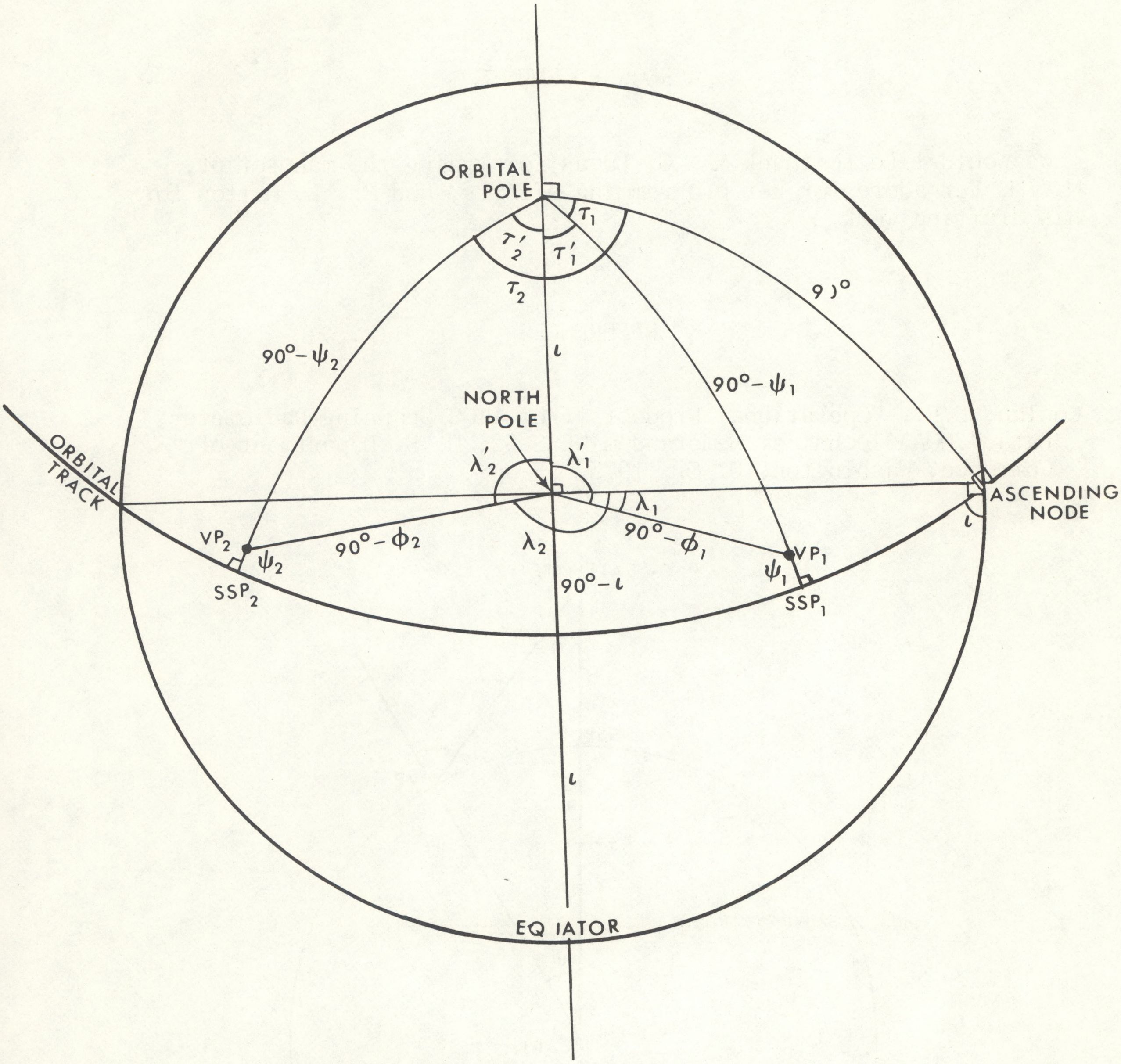

Figure 2. -- Polar map of the Northern Hemisphere showing the relationship between the orbital coordinate system and the geographic coordinate system. τ is the orbital longitude of the viewed point and the associated subsatellite point, ψ is the orbital latitude of the viewed point, ϕ is the geographical latitude of the viewed point, λ is the geographical longitude of the the viewed point relative to the ascending node, and ι is the satellite inclination angle. SSP is the satellite subpoint and VP is the viewed point.

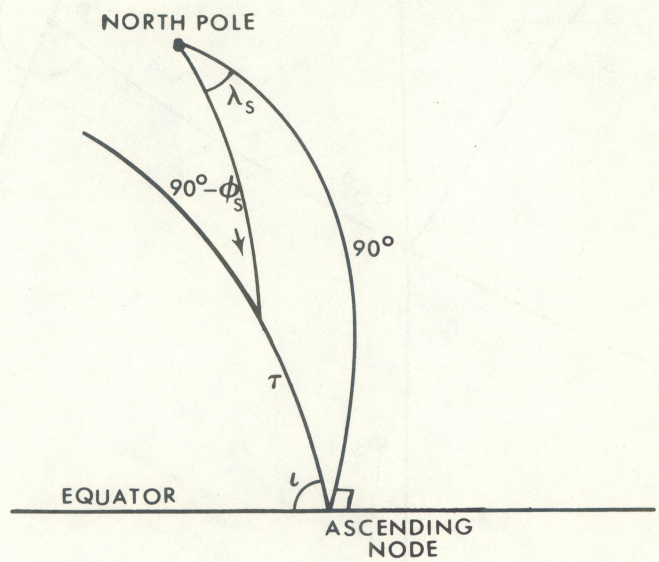

Figure 3. -- The relationship between the orbital longitude (τ) of the satellite and its geographical latitude (ϕ_S) and longitude (λ_S). ι is the satellite inclination angle.

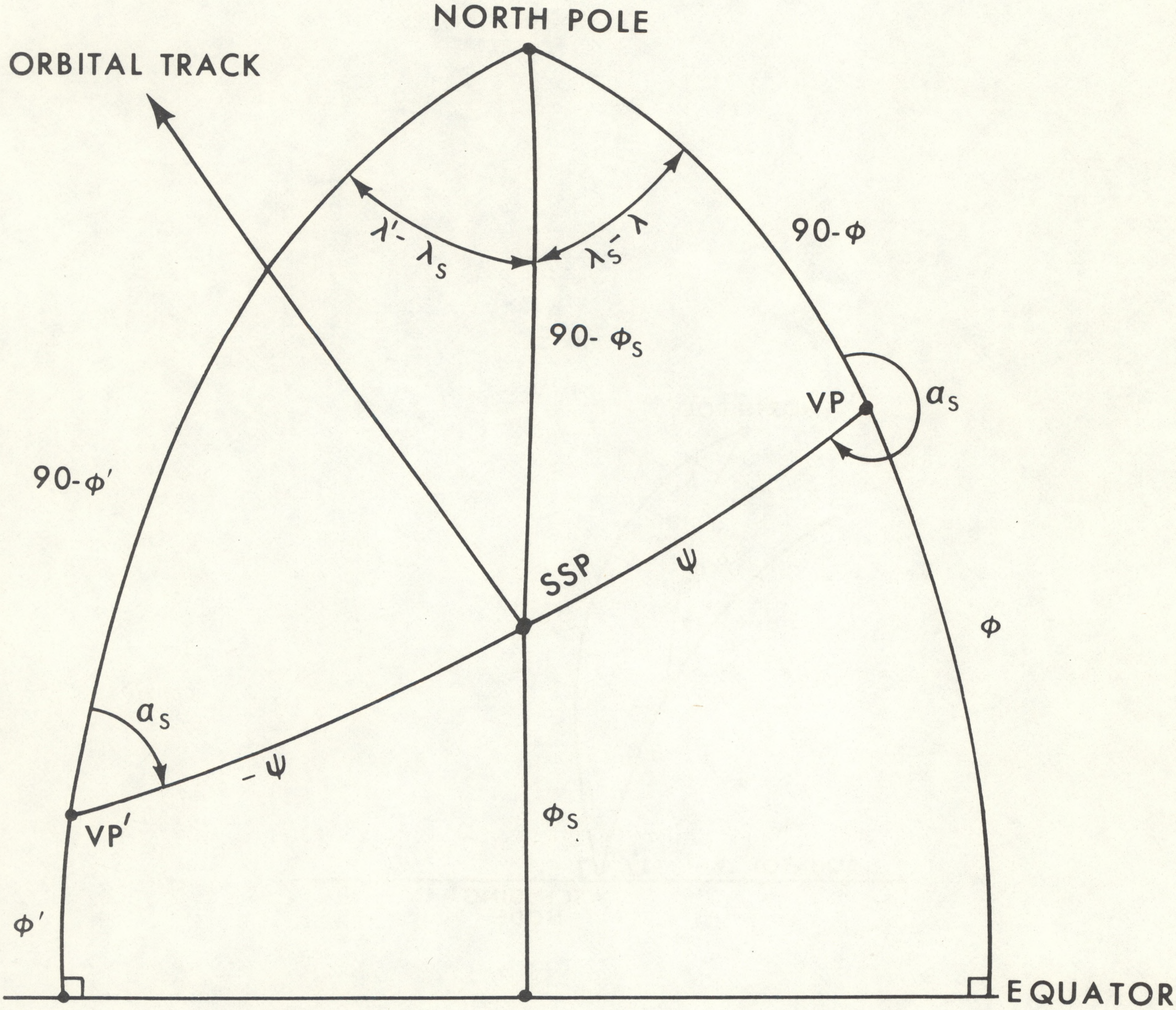

Figure 4. -- The relationship between the azimuth angle of the satellite (α_S), the satellite subpoint latitude (ϕ_S) and longitude (λ_S), and the viewed point latitude (ϕ) and longitude (λ). Primes indicate variables when scanning in the negative ψ direction. The azimuth angle is measured through 360° eastward from north.

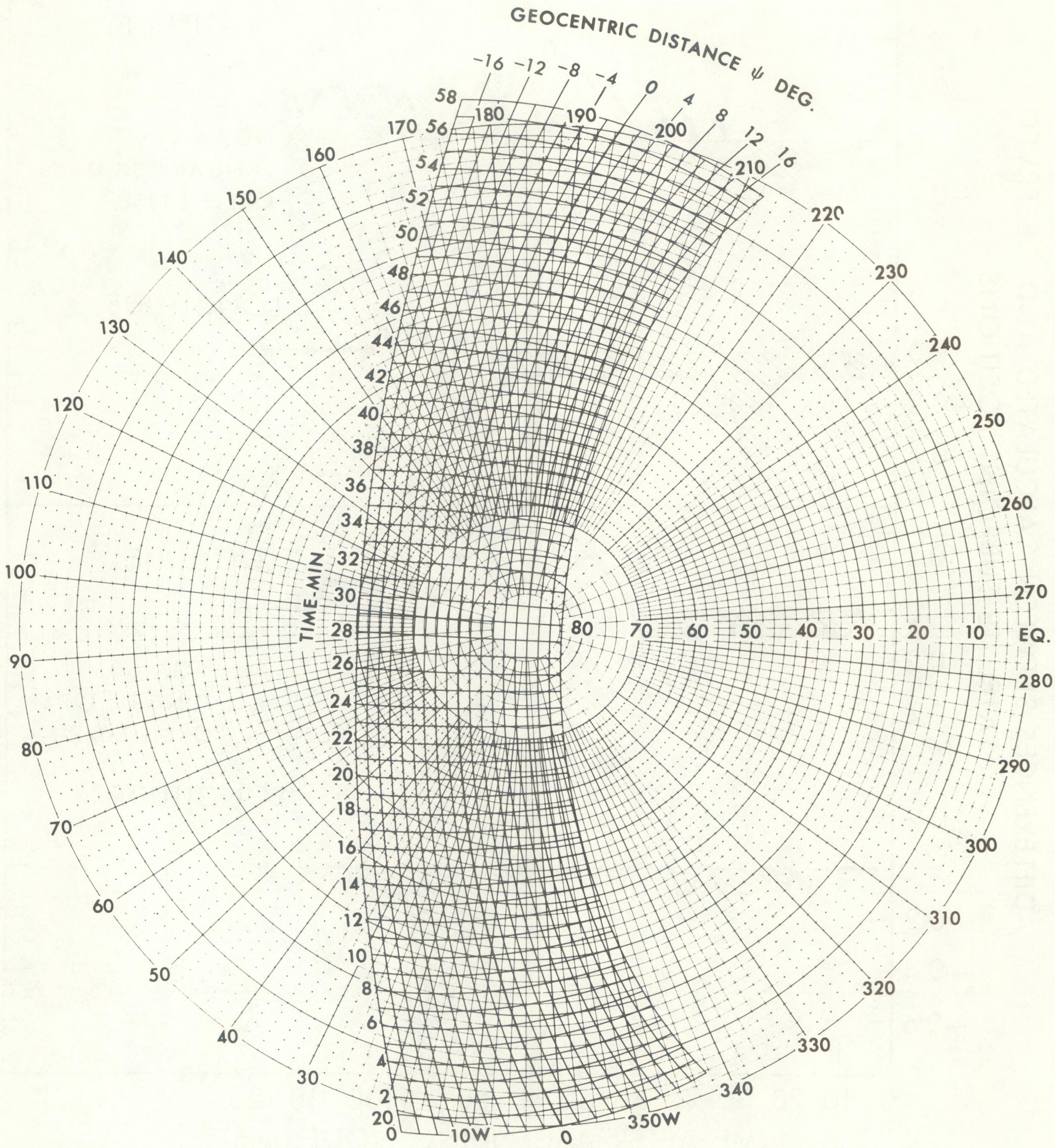

Figure 5. -- An illustration of the graphical solution to eq. (6 thru 8). For use in the Northern Hemisphere, time is interpreted as minutes after ascending node and longitude as degrees west of ascending node. For the Southern Hemisphere, time is interpreted as minutes before next ascending node and longitude as east of the next ascending node.

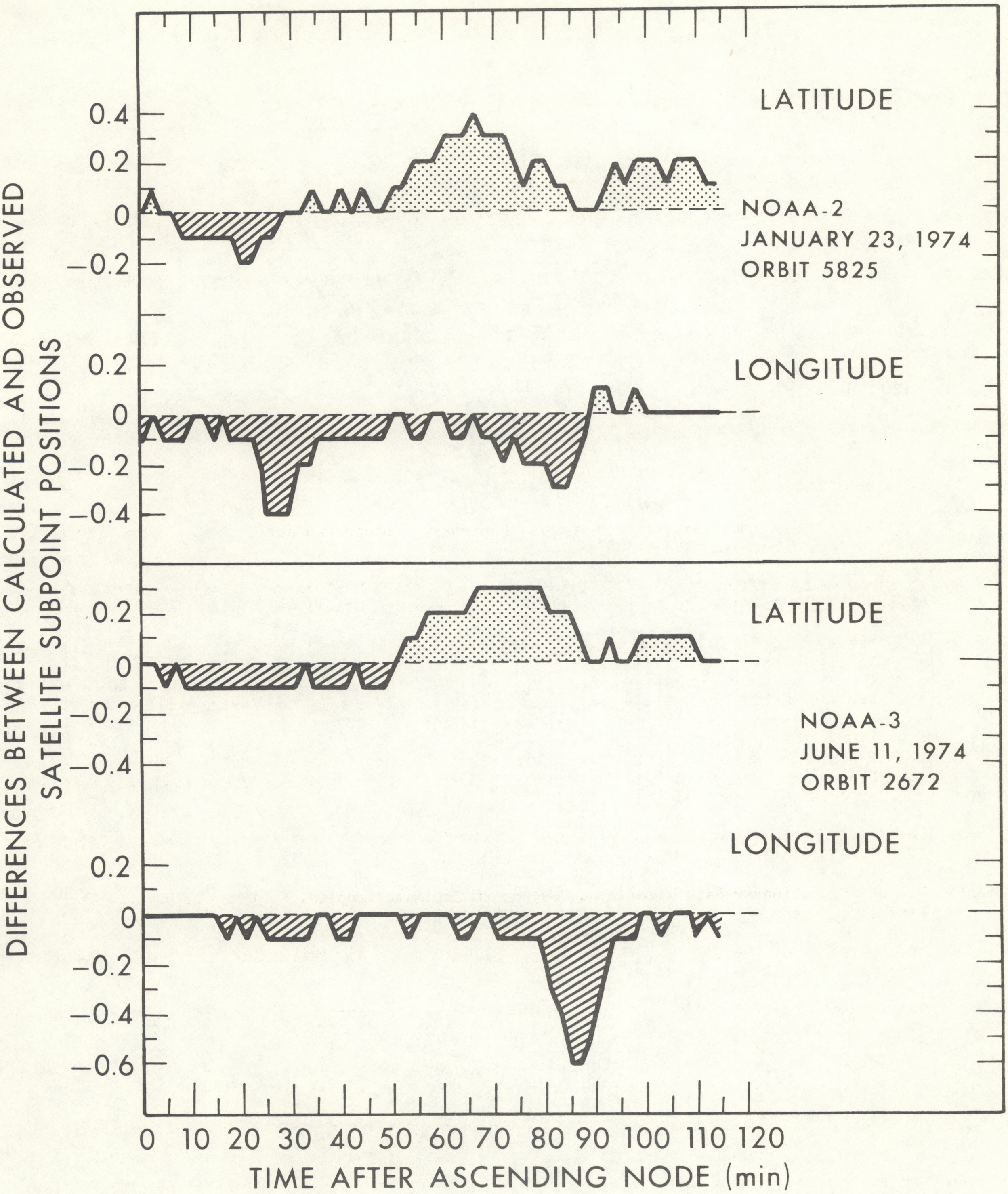

Figure 6. -- A comparison of the latitude and longitude of the sub-satellite positions calculated by assuming circular orbits and spherical Earth, with the positions obtained from the emphemeris. Two orbits are illustrated, one from NOAA-2 and one from NOAA-3.

(Continued from inside front cover)

NESS 47 Stratospheric Photochemistry of Ozone and SST Pollution: An Introduction and Survey of Selected Developments Since 1965. Martin S. Longmire, March 1973, 29 pp. (COM-73-10786)

NESS 48 Review of Satellite Measurements of Albedo and Outgoing Long-Wave Radiation. Arnold Gruber, July 1973, 12 pp. (COM-73-11443)

NESS 49 Operational Processing of Solar Proton Monitor Data. Louis Rubin, Henry L. Phillips, and Stanley R. Brown, August 1973, 17 pp. (COM-73-11647/AS)

NESS 50 An Examination of Tropical Cloud Clusters Using Simultaneously Observed Brightness and High Resolution Infrared Data From Satellites. Arnold Gruber, September 1973, 22 pp. (COM-73-11941/4AS)

NESS 51 SKYLAB Earth Resources Experiment Package Experiments in Oceanography and Marine Science. A. L. Grabham and John W. Sherman, III, September 1973, 72 pp. (COM 74-11740/AS)

NESS 52 Operational Products From ITOS Scanning Radiometer Data. Edward F. Conlan, October 1973, 57 pp. (COM-74-10040)

NESS 53 Catalog of Operational Satellite Products. Eugene R. Hoppe and Abraham L. Ruiz (Editors), March 1974, 91 pp. (COM-74-11339/AS)

NESS 54 A Method of Converting the SMS/GOES WEFAX Frequency (1691 MHz) to the Existing APT/WEFAX Frequency (137 MHz). John J. Nagle, April 1974, 18 pp. (COM-74-11294/AS)

NESS 55 Publications and Final Reports on Contracts and Grants, 1973. NESS, April 1974, 8 pp. (COM-74-11108/AS)

NESS 56 What Are You Looking at When You Say This Area Is a Suspect Area for Severe Weather? Arthur H. Smith, Jr., February 1974, 15 pp. (COM-74-11333/AS)

NESS 57 Nimbus-5 Sounder Data Processing System, Part I: Measurement Characteristics and Data Reduction Procedures. W.L. Smith, H. M. Woolf, P. G. Abel, C. M. Hayden, M. Chalfant, and N. Grody, June 1974, 99 pp. (COM-74-11436/AS)

NESS 58 The Role of Satellites in Snow and Ice Measurements. Donald R. Wiesnet, August 1974, 12 pp. (COM-74-11747/AS)

NESS 59 Use of Geostationary-Satellite Cloud Vectors to Estimate Tropical Cyclone Intensity. Carl. O. Erickson, September 1974, 37 pp. (COM-74-11762/AS)

NESS 60 The Operation of the NOAA Polar Satellite System. Joseph J. Fortuna and Larry N. Hambrick, November 1974, 127 pp. (COM-75-10390/AS)

NESS 61 Potential Value of Earth Satellite Measurements to Oceanographic Research in the Southern Ocean. E. Paul McClain, January 1975, 18 pp.

NESS 62 A Comparison of Infrared Imagery and Video Pictures in the Estimation of Daily Rainfall From Satellite Data. Walton A. Follansbee and Vincent J. Oliver, January 1975, 14 pp.

NESS 63 Snow Depth and Snow Extent Using VHRR Data From the NOAA-2 Satellite. David F. McGinnis, Jr., John A. Pritchard, and Donald R. Wiesnet, February 1975, 10 pp.

NESS 64 Central Processing and Analysis of Geostationary Satellite Data. Charles F. Bristor (Editor), in press, 1975.

AMERICAN REVOLUTION BICENTENNIAL 1776-1976