SATELLITE SURVEYING TECHNIQUES

USED WITHIN

GEODETIC NETWORKS

Leopold J. Romeyn
Geodetic International Inc.
5635 Northwest Central Drive #100
Houston, Texas 77092

ABSTRACT

The utilization of Satellite Survey Techniques on control survey projects has steadily increased in the survey community. It's usage in remote areas domestic and foreign has shown exceptional results. Improved field techniques and processing procedures have contributed to it's present accuracies. There seems to be still a reluctance to make use of this technology in the private sector.

The use of this survey technique on small size construction, right-of-way and property surveys in urban areas is not economical, but to establish survey control for route surveys, mapping and to establish positions within a geodetic network of section corners, large property corners, oil and gas wells, offshore structures etc., the Satellite Survey Techniques used today can be more economical and accurate than conventional techniques.

The intent of this paper is to explain the utilization of this technique within Geodetic Networks, and to bridge the Geodetic gap of knowledge between the conventional survey and the Satellite Survey Techniques.

BASIC GEODESY

Introduction

Geodesy may be divided into areas of global geodesy, geodetic surveying, and plane surveying.

a. Global Geodesy

Is responsible for the determination of the figure of the earth including the complete external gravity field.

b. Geodetic Surveying

Defines the surface of a country by the coordinates of a sufficiently large number of control points. In this fundamental work, the overall curvature of the earth must be considered.

c. Plane Surveying

Is used for topographic, cadastral and engineering surveying and is usually confined to a limited area. The horizontal plane is in general sufficient as a reference system.

There is a close interaction between the different areas. Geodetic Surveying and Plane Surveying are the two areas where the surveyor is concerned about. The problems of Global Geodesy can only be solved with International cooperation of Governments agencies, Institutes and Universities.

REFERENCE SYSTEMS

Topography

The earth's surface as we know is anything but uniform. The oceans are reasonable uniform, but the surface of topography of the land masses show large vertical variations between mountains, valleys and plains, which make it impossible to approximate the shape over a large area with any reasonably simple mathematical model.

We can simplify matters by removing the earths topography above mean sea level and considering the resultant surface of the earth to be "level". Level in this context means that we can look a short distance from any point and find the surface to be at the same height in all directions. This will obviously not hold for long distances because this "Level" surface is actually curved and our level line of sight is a straight line.

When we set up a Theodolite and Level it by a spirit bubble the level line of sight is perpendicular to the direction of gravity at the Instrument Station.

Geoid

As the earth is a closed surface, the direction of the level line of sight will be different for each observation point on the earths level surface. If observations are taken at an infinite number of points, then level plains obtained by rotating the level lines around the local verticals will form a continuous "Level Surface" what runs parallel to the GEOID. This geoid is an equipotential surface corresponding with mean sea level (fig 1).

To compute coordinates and reduce measured distances to a common surface a mathematical model must be used, the most common model used is called a SPHEROID or ELLIPSOID and its definition is usually by semi-major axis (a) and flattening (f), Flattening (f) is depending on both the semi-major axis (a) and the Semi-minor axis (b).

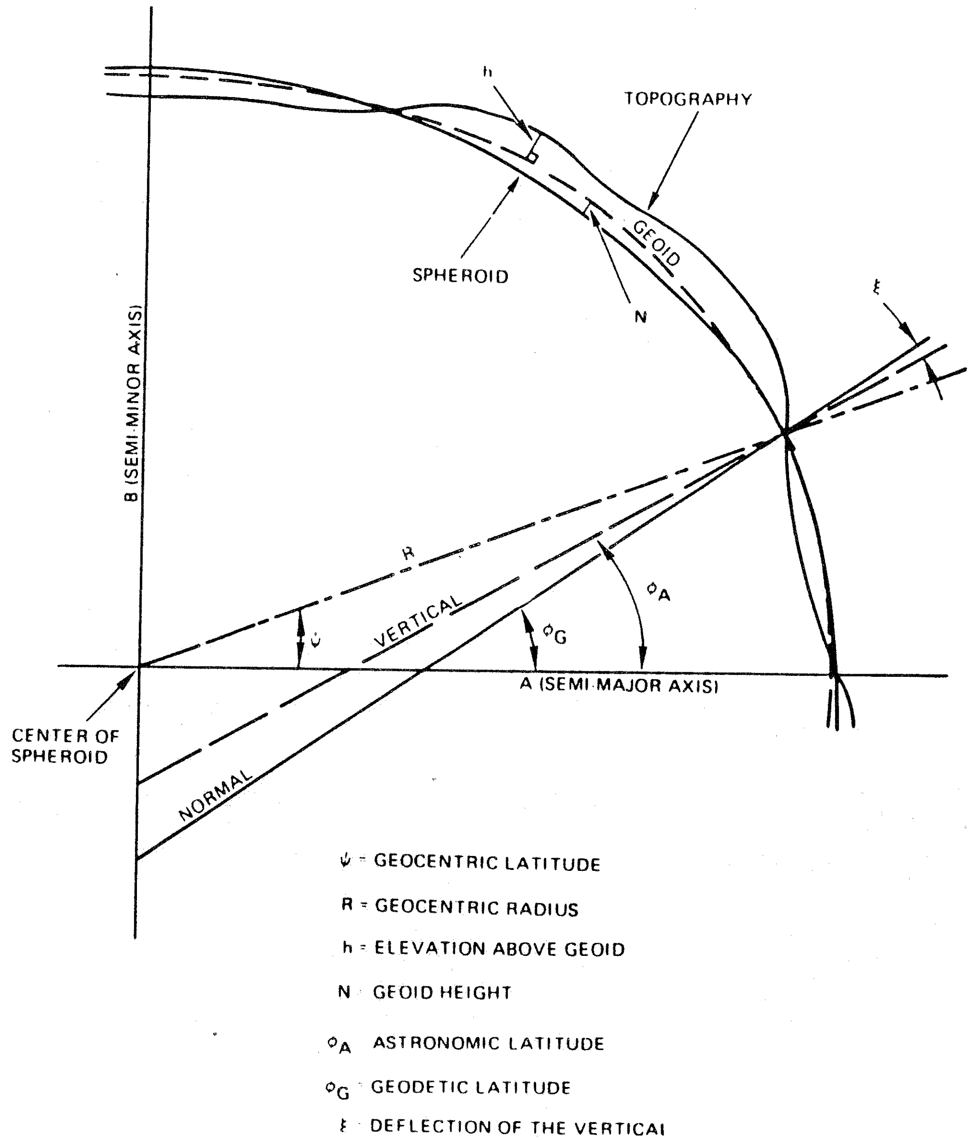


Fig - 1

Cartesian Coordinates

The Cartesian Coordinate System X,Y,Z is mainly used to compute observations to artificial Satellites and is also used for other purposes. This system will be discussed further in another section of this paper.

Astronomical Coordinates

Astronomical observations for Latitude and Longtitude are measured with reference to the direction of gravity at the point of observation, which in general is not parallel to the spheroidal normal at the corresponding point on the spheroid. (Normal is used for the line perpendicular to the Spheroid at any point.)

These observations are used to obtain control over the relationship Spheroid and Geoidal model. Astronomical Positions are also used as "Survey Datum Origin".

Plane Coordinates

It is sometimes convenient to record the position of points by rectangular coordinates (N) or (Y) and (E) or (X) on a plane projection of the spheroid. Plane coordinates are generally only used for Cadastral, military, engineering and mapping, but their derivation is commonly regarded as a geodetic problem.

SURVEY DATUMS AND ORIGINS

The origin of survey Datums is generally selected in a area in which the Geoidal Normal and Spheroidal Normal are parallel. A Geoidal Height (N) of "0" will be accepted and the Geodetic Network will be extended from this location. In the early years technology had not been advanced that rapidly and Gravitational data together with hardware constrain did not always supply reliable information. The old survey datums are still in use, although thru the years adjustments where applied, large distortions still exist, especially in areas presently under development. Fig 2 presents one area where several Survey Datums are used.

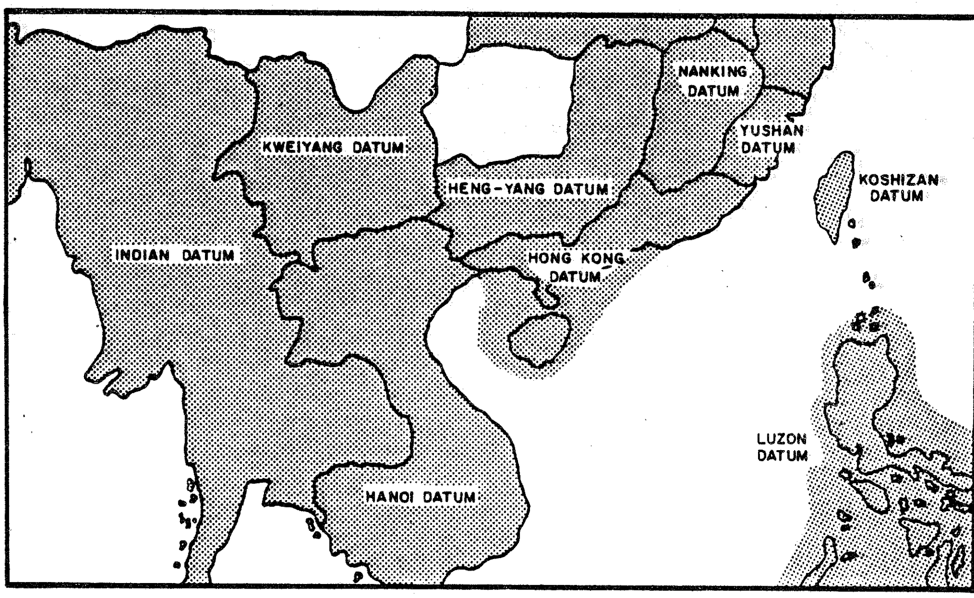


Fig - 2 AN EXAMPLE OF THE MANY DATUMS IN THE S.E. ASIA AREA

Astronomical observations have been utilized in the past to define local distortions in networks, since the introduction of the Satellite System "TRANSIT" operated by the U.S. Department of Defense, presently there are no restrictions in private use of this system, spheroidal positions Latitude, Longitude and Ellipsoidal Heights based on the NWL-10D or W.G.S. 72 are obtained on the following Spheroidal Parameters W.G.S. -72:

$$a = 6\ 378\ 135$$
$$1/f = 298.26$$

Distortions in Local Survey control are defined by placing one or more Satellite Receivers on excisting survey control thru out the area, a minimum of Fifty (50) Satellite passes with one (1) Satellite Receiver will be collected or Thirty Five (35) Common Satellite Passes will be collected with more receivers. With the utilization of the Cartesian Coordinate System, Datum shift values are obtained. Local Geoidal Height values are obtained from available data. W.G.S. 72 Geoidal Height Values are obtained thru data reduction or a Gravity Model like the GEM-10C is used.

Offshore surveys for Miniral resources have seen large positioning problems in areas there where Two (2) Survey Datums meet. Some positioning errors do to the unknown local distortions have cost the Construction and Oil industry millions of dollars, due to wrongly positioning offshore surveys or structures. Although the majority of Government Agencies are publishing their Geodetic info into three (3) to five (5) Decimal places of units, care must be given to the PHYSICAL distortions, therefore verification of the excisting survey control, especially in remote areas, should be a mandatory requirement prior to any major project. Even a simple Astronomical Azimuth can check the orientation in a network.

DISTORTIONS IN LOCAL GEODETIC NETWORKS

Due to the irregular shape of the earth, many different spheroids are presently in use (fig. 3) thru out the world, some are specially designed for the use with Satellite Systems and others are selected to closely fit the Local Geoid for the Continent, Country or Island. A reference Spheroid will be selected by a individual Nation or a group of Nations to closely fit the Geoid in the area of concern. For this reason different Spheroids are used thru out the world. Fig 4 is showing the relationship between the North American Datum of 1927 (N.A.D. -27) and the European Datum of 1950 (ED-50). In some cases a bad fitting spheroid was selected for a continent such as South America (Fisher, 3). The Provisional South American Datum of 1956 (PSAD 56) with the datum point in La Ganoa Venezuela and based on the Hayford International Spheroid with a semi-major axis of 6 378 388 and a flattening of 1/297. With an Geoidal Height (N) (Distance from spheroid surface to Geoid surface of zero (0) on the origin at La Ganoa and at Latitude 41° South an Geoidal Height of Minus (-) 327 meters or 1070 feet is present.

To appreciate the significance of this fact, one must recall the standard procedure of survey data reduction Angles and Distances are measured on the physical surface of the earth and then routinely reduced to sea level (the Geoid). Then they are adjusted by means of some adopted ellipsoid, because an ellipsoidal surface is mathematically easier to manage than the quite irregular sea-level surface.

SPHEROID PARAMETERS

SPHEROID NAME	UNITS	a	$\frac{1}{f} = \frac{a}{a-b}$	AREA OF USE
Everest 1830	Indian Foot	20 922 931.80	300.801726..	(Original Definition)
Everest 1830	Indian Chain	317 014.1182..	300.801726..	Malaysia (see also below)
Everest	Int. metre	6 377 301.243..	300.801726..	Pakistan
Everest	Int. metre	6 377 276.345..	300.8017	India Thailand
Everest Modified	Int. metre	6 377 304.063..	300.8017	West Malaysia
Everest 1967	Int. metre	6 377 298.556..	300.8017	East Malaysia
Airy 1830	Imp foot	20 923 713	299.324 965..	(Original Defination)
Airy	Int. metre	6 377 563.396..	299.324 965..	GB Onshore, UK and Eire Scientific
Airy Modified 1849	Int. metre	6 377 340.189..	299.324 965..	Ireland Onshore
Bessel 1841	Int. metre	6 377 397.155..	299.152 813..	Japan, Indonesia (see below) N. Europe
Bessel Modified	Int. metre	6 377 492.018..	299.152 813..	Norway
Clarke 1858	Imp. foot	20 926 348	294.260 676..	(Original Definition)
Clarke 1858	Int. metre	6 378 293.645..	294.260 676..	Australia (Obsolete)
Clarke 1866	Imp. foot	20 926 062	294.978 390..	(Original Definition)
Clarke 1866	Int. metre	6 378 206.4	294.978 698..	North America (NAD 27), Philippines
Clarke 1880	Imp. foot	20 926 202	293.466 308..	(Original Definition)
Clarke Modified 1880	Int. metre	6 378 249.145	293.465	Africa, Arabia
Clarke 1880 (IGN)	Int. metre	6 378 249.2	293.466 021..	Africa by IGN Paris (e.g. Tunisia)
Helmert 1906	Int. metre	6 378 200	298.3	Egypt (obsolete)
Hayford 1910	Int. metre	6 378 388	296.959.263..	(Not in use: see International 1924)
International 1924 (Madrid) ("Hayford Int.")	Int. metre	6 378 388	297	Northern and Western Europe, European Waters (ED50) South America (PSAD 56)
International 1967 (Lucerne) ("GRS 67")	Int. metre	6 378 160	298.247	Australia, Indonesia (IND 74) South America (SAD 69)
International 1979 (Canberra)	Int. metre	6 378 137	298.257	
Krassowsky 1940	Int. metre	6 378 245	298.3	China, Russia
NWL 9D	Int. metre	6 378 145	298.25	Transit Precise Ephemeris
NWL 10D ("WGS72")	Int. metre	6 378 135	298.26	Transit Broadcast Ephemeris

Fig - 3 SPHEROIDS IN USE

As a consequence, we trace the following distortions: the Length of the arc along 70° West Longitude from La Ganoa, Venezuela to 41° South Latitude along the Geoid is about 140 meters or 459 feet to short. The Geodetic position of this point will have an error in latitude of about 4.5" seconds of Arc. To adjust for this error all the bases in the triangulation should have been lengthened in proportion to their Geoidal Heights. This would make the deflections of the vertical more positive and would change the preliminary geoid heights to correct ones.

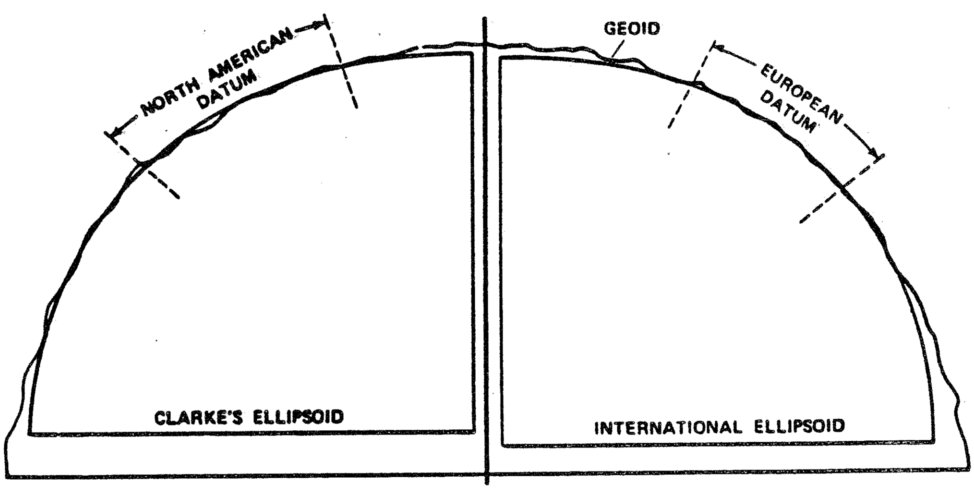
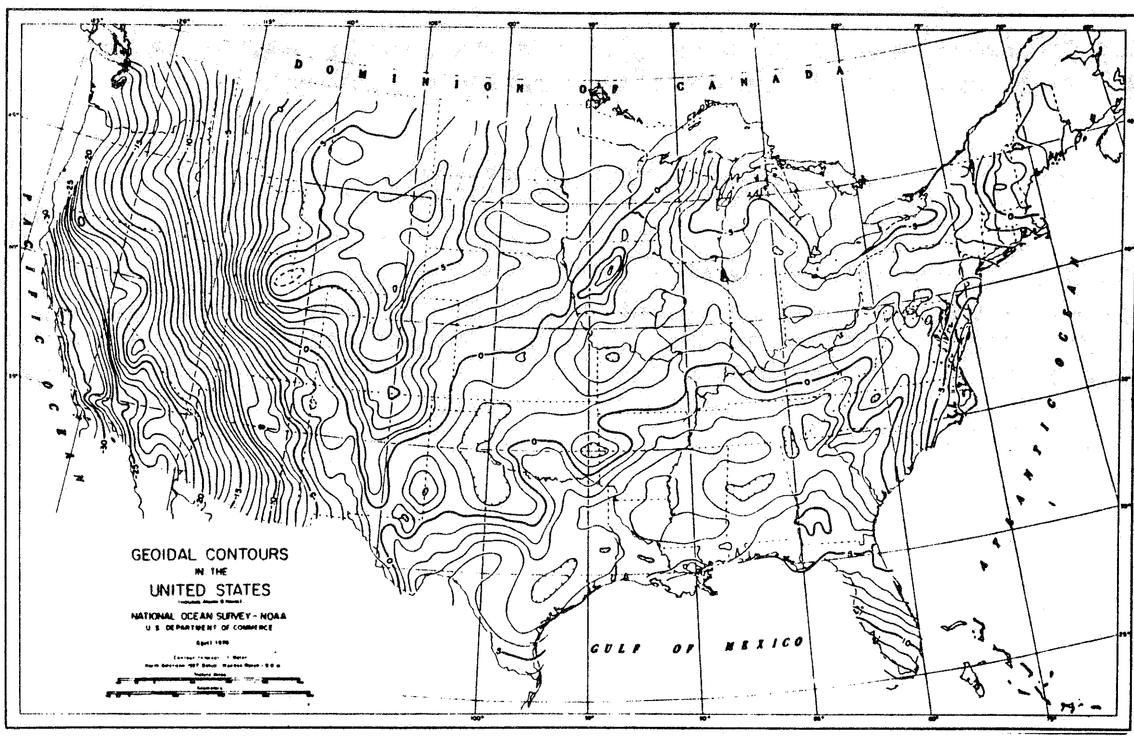


Fig - 4 THE PREFERRED DATUMS ARE RELATIVE DATUMS

Distortions in base lines combined with orientation errors due to irregular Geoids and rough topographic terrain are quite common in Geodetic Networks thru out the world. A similar problem exist in the North American Datum 1927 (N.A.D. 27) based on the Clarke 1866 spheroid. Due to the irregular shape of the Geoid thru out the Rocky mountain range, west coast (fig 5) and thru British Columbia into Alaska, position errors within the Geodetic Network, in Alaska, in relation to the NAD-27 origin "Meades Ranch" of up to 48 meters or 157 feet have been found (D.M.A., 1975). The majority of this error will disappear after the acceptance of the N.A.D. -83 adjustment. The National Geodetic Survey (N.G.S.) will list together with the newly adjusted coordinates based on the following spheroidal parameters:
Geodetic Reference System 1980 (G.R.S. -'80)

$$a = 6\ 378\ 137$$
$$1/f = 298.257$$

the Geoidal Height at the station denoted by the symbol (N). This new value will assist the surveyor to reduce his surveys to the spheroidal surface and reduction down to "Sea Level" can be avoided.



After the adjustment of the Geodetic Network from NAD-27 to NAD-83 Satellite Surveying technology should have even a greater acceptance in the Survey community due to its close relationship with the W.G.S. -72 spheroid. Final position accuracies should increase due to the adjustment. Presently the major source of position errors in Satellite Doppler derived positions are the unknown distortions in the Local Geodetic Network especially the Geoidal Height.

SATELLITE SURVEY CONTROL

Internal accuracies within the Satellite frame work have increased in the last several years due to improved processing capabilities and error recovery. The multi station adjustment programs like, GEODOP and MAGNET have produced internal accuracies of less than Thirty (30) centimeters or about a foot. With the proper utilization of the Satellite Survey techniques and the knowledge of the distortions within the Triangulation Network where the project will take place, Geodetic Positions within a Horizontal accuracy of Sixty (60) centimeters or Two (2) feet can be obtained. Due to the unknown Geoidal undulations and the limitation of the Broadcast Ephemeris, accuracies in sea level elevations are of lower order. In areas where sufficient vertical control is available and Geoidal profiles can be observed. Sub-meter accuracies can be expected, and in areas where no vertical control is available the GEM-10C gravity model is used and accuracies within Two (2) meters, within coastal zones, and Three (3) meters inland, can be expected.

FIELD PROCEDURES

The following is a description of guide lines to be used to obtain reliable results using the Satellite Survey Technology.

SATELLITE DOPPLER STATIONS

The U.S. Government has established a large number of Geodetic Satellite Doppler Stations in Domestic U.S. and foreign, with the use of portable tracking equipment. With the post processing of the Doppler Data collected during these surveys, the Precise Ephemeris was utilized. These stations can be used as base stations to obtain good results. Within the U.S. the majority of these stations will have the Local Datum shift values available to be used for final data reduction. NWL 9D Spheroidal coordinates are transferred into Broadcast Emphemeris coordinates and then used for data collection and Data reduction.

When the base station is established Satellite Receivers can be placed on pre selected locations. Manufactures of Satellite Tracking Equipment such as J.M.R. Magnavox, Motorola etc. will give the user sufficient information on site selection.

Thirty Five (35) common Satellite Passes must be included in the Final solution to obtain reliable results. When optimum results are required Two (2) or more Bases can be utilized during the project.

All Final Doppler Data will be post processed using a Multi Station adjustment program. Several Satellite Receivers have the capability to produce results in the field. The micro processor built in the receiver is utilized in the offline mode to process Translocation Data with acceptable results. During Satellite Survey Projects in the U.S. and Foreign the Author has been involved in, Horizontal accuracies within Sixty (60) centimeters or Two (2) foot where obtained, using the in-box Translocation results.

Geoidal Profiles

Surveys requiring reliable vertical control in addition to Geodetic Horizontal Positions will require Geoid Height information when the Satellite Survey technique is used to obtain Geodetic positions. In domestic U.S.A. sufficient level nets are available to define the local geoidal model. Satellite Receivers are placed at regular intervals on Bench Marks (B.M.) surrounding the working area. After Thirty Five (35) common satellite passes have been accepted in the final solutions of the stations occupied, the data can be post processed using a multi station adjustment program. The published sea level elevation of the B.M. will be subtracted from the Final Spheroidal Height of the marker, producing the Geoidal Height at the station. A final contour map will be developed to be utilized for the production survey.

DATUM SHIFT PROCEDURES

Satellite derived locations are expressed in spheroidal parameters based on the Broadcast Ephemeris and Coordinates need to be transferred into the W.G.S. 72 system prior to any Datum shift computations can take place.

Based upon the findings described in Jenkins "Broadcast" versus "Precise" Jenkins and Leroy, 1979 together with Seppelin (Seppelin, 1974) formulas a satellite derived position can be transformed to the W.G.S. 72 system using the following provisional transformation parameters: (Eg. 1)

$$\begin{aligned} \Delta z &= -2.6 \text{ meters (z-axis shift)} \\ \Theta z &= +0.260 \text{ seconds (z-axis rotation)} \\ \varepsilon &= -6.1 \times 10^{-7} \text{ (scale)} \end{aligned} \qquad (1)$$

Submeter parameters have been ignored in the above selection. Significant transformation parameters between "broadcast" and WGS-72 affect Latitude and height by the z-axis translation, correct for a longitude rotation, and correct for a scale bias affecting height by -3.87 meters.

The distances between base station and remote station will play an important role in the final data reduction. Datum shift values obtained from Satellite Doppler Data collected on excisting Triangulation Stations will be the most accurate procedure to assure that reliable Datum shift values are used. The Geoidal Height information on the Local Datum MUST be available to the user. In the U.S. the Local Geoidal Height can be obtained in N.A.D. 27 from a contour map such as Fig. 5. After the NAD-83 adjustment this information should be widely available. Local Geoidal Heights in Foreign Countries are not always available, but thru local government agencies and the U.S. Defense Mapping Agency, Geoidal Heights based on Local Survey Datums can be obtained.

The transformation of Satellite derived coordinates to coordinates within a local Network are obtained using the following process:

Satellite Derived Coordinates Latitude, Longtitude, height and adjusted for shift, rotation and scale are transferred to Cartesian coordinates based on the W.G.S. -72 spheroid using the following formula; (Eg. 2)

$$x = (\nu + N + h) \cos\phi \cos\lambda$$
$$y = (\nu + N + h) \cos\phi \sin\lambda \qquad (2)$$
$$z = ((1-e^2)\nu + N + h) \sin\phi$$

After the cartesian coordinates are obtained the Datum shift values Δx, Δy, Δz will be added and the following process will be used to compute back into the Local System using constants of the spheroid where the Local System is based on: (Eg. 3)

$$^*\tan\phi = \frac{z + e^2 \nu \sin\phi}{(x^2 + y^2)^{\frac{1}{2}}}$$

$$\tan\lambda = y/x \qquad (3)$$

$$(N + h) = (x^2 + y^2)^{\frac{1}{2}} \sec\phi - \nu$$

*Note: use a approximate ϕ for $\sin\phi$ and ν, and re-iterating as necessary. Convergence will be rapid.

For Sea Level elevations it's advisable to remain on the W.G.S. -72 system and use values for Geoidal Heights as obtained and described earlier.

Final Local coordinates can be transferred into any Local Grid system as applicable, using the Standard transformation procedures for the projection(s) in use.

PUBLISHED DATUM SHIFT VALUES.

Governments, Local survey agencies and manufactures of Satellite Tracking equipment are publishing datum shift values. Care must be taken that most of these values are an average of the Specific Survey Datum and should only be used as a guide or if sub-meter accuracy is not required.

For domestic U.S. Contour maps are available and can be used to transfer coordinates if no other data is available.

Notations:

ν = Radius of curvature in Prime vertical
ε = Eccentricity of spheroid
ϕ = Latitude (+north)
λ = Longitude (+east)
H = Spheroidal Height
h = Sea Level Elevation
N = Geoidal Height above spheroid

REFERENCES

1. Bomford, B.: 1980 Geodesy, Fourth Edition. Clarendon Press Oxford

2. Ferrari, Dorival: 1979 A look at Brasilian Geodesy using Satellite Doppler as a tool, Brasilian Institute of Geography and Statistics Superintendence of Geodesy, Rio de Janeiro - Brasil.

3. Fischer, Irene: The Geoid in South America Referred to various Reference Systems, U.S. Army Topographic Command, Washington, D.C. 20315

4. Hoar, Gregory J.: 1982 Satellite Surveying, Magnavox Torrance, California 90503.

5. Jenkins, R.E. and Leroy, C.F.: 1979 "Broadcast" versus "Precise" Proceedings of the Second International Geodetic Symposium on Satellite Doppler Positioning, Austin, Texas.

6. Magnavox,: 1980 Network Adjustment Computer program Magnet, Magnavox, Torrance, Ca. 90503.

7. Sepplin, T.O.: 1974 The Department of Defense World Geodetic System, DMA, May.

8. Walker, James W.: 1977 Derivation and application of Datum transformations relating Doppler positions to Local and National Datums in Latin America, Defense Mapping Agency Topographic Center, Washington D.C. 20315.

9. Geoid Heights and coordinate shifts in Alaska from Doppler Satellite Data, 1975 Geodetic Survey S.Q. D.M.A.A.C.