MUELLER, I.I.
Department of Geodetic Science
The Ohio State University
Columbus Ohio 43210
United States of America

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EARTH PARAMETERS FROM GLOBAL SATELLITE TRIANGULATION AND TRILATERATION

Abstract

Results obtained from 159-station global satellite triangulation and trilateration (including Baker-Nunn, BC-4, PC-1000 camera observations, SECOR, C-Band radar and EDM distance measurements) indicate differences in the semidiameter and orientation of the Earth compared to results obtained from dynamic satellite solutions. Geoidal undulations obtained can be made consistent with dynamically determined ones at the expense of slight changes in the currently accepted parameters defining the gravity field of the level ellipsoid.

1. Introduction

The global triangulation and trilateration forming the basis of this paper was performed as part of the US National Geodetic Satellite Program. A summary of the networks involved in the adjustments reported here (solutions WN) is presented in table 1. The data for the MPS and BC networks was obtained through the National Space Science Center. The Defence Mapping Agency provided observations for the SECOR and the SA networks (Topographic Center and Aerospace Center respectively). The sources for the constraint information are listed in table 2. Figure 1 shows the combined network

Table 1
Basic Information on the OSU Solutions (Networks)

OSU Solution (Network)	No. of Stations	No. of Observations	No. of Constraints Used[8] Origin	Relative Position	Scale (Length)	Height	Directional	[6]σ_0	[7]Reference
[1]MPS	66	28,744	Inner	9	7	63	-	1.07	188
[2]BC	49	30,302	Inner	2	7	48	-	2.80	193
[3]SECOR	50	28,844	Inner	14	-	37	9	1.37	195
[4]SA	14	2,524	Inner	3	1	14	-	2.50	196
[5]WN	159	90,444	Inner	43	11	158	-	1.02	199

[1]MPS includes 14 PC-1000 stations, 15 MOTS-40 stations, 1 PTH-100 station, 7 C-Band stations, 6 European stations (8000 series), and 23 SAO stations (9000 series).

[2]BC includes all 49 stations of BC-4 Worldwide Geometric Satellite Network.

[3]SECOR includes 37 SECOR stations of the Equatorial Network and 13 collocated BC-4 Camera Stations.

[4]SA includes 9 PC-1000 stations of South American Densification Net and 5 BC-4 stations.

[5]WN includes all networks at [1], [2], [3], & [4], namely, MPS (less 1 C-Band Station 4742), BC, SECOR & SA.

[6]A posteriori standard deviation of unit weight.

[7]OSU Department of Geodetic Science Report No.

[8]No constraints imposed on station position.

Table 2

Summary of Constraint Types with the Source Information

Code	Constraint Type	Source (Agency)*
	Relative Position	
1	BC-4 - Baker-Nunn	SAO, NGS
2	BC-4 - SECOR	DMA/TC
3	BC-4 - BC-4	NGS
4	Others	OSU
	Height	
5	MSL (mean sea level heights)	CSC, NGS, NWL
6	Geoidal Undulations	OSU (RAPP 1973)
	Length (Chord)	
7	North America	NGS
8	Europe	NGS, DGFI
9	Africa	NGS
10	Australia	NGS, DNP
11	C-Band	NASA/Wallops Isl.

* CSC - Computer Sciences Corporation
DGFI - Deutsche Geodätisches Forschungsinstitut
DMA/TC - Defence Mapping Agency Topographic Center
DNP - Division of National Mapping, Australia
NGS - National Geodetic Survey
NWL - Naval Weapons Laboratory
SAO - Smithsonian Astrophysical Observatory

(WN). Different symbols indicate the various instruments utilized in the observations. Concentric symbols show collocated stations or nearby stations with relative positions from known geodetic surveys. The straight lines between some of the stations illustrate the location of the baselines.

2. Reference Ellipsoid, Origin and Orientation

The least squares adjustment of the observations was performed in terms of Cartesian co-ordinates of the tracking stations. The results are also converted into geodetic co-ordinates (latitude, longitude and height) referenced to a rotational ellipsoid of the following parameters:

$$a = 6\,378\,155.00 \text{ m} \quad ; \quad b = 6\,356\,769.70 \text{ m}.$$

The corresponding flattening is

$$f = 1/298.249\,498\,5 = 0.003\,352\,897\,507.$$

The origin of the co-ordinate system (or the centre of the above *reference ellipsoid*) is free as determined through "inner" constraints explained in (BLAHA 1971). The orientation of the system is inherent in the optical observations, through the star positions in the SAO catalogue (referenced to the FK4 system) updated to their apparent positions at the epoch of observation, and through UT1, x and y (co-ordinates of the true pole with respect to the CIO) as derived by BIH. Thus the positive

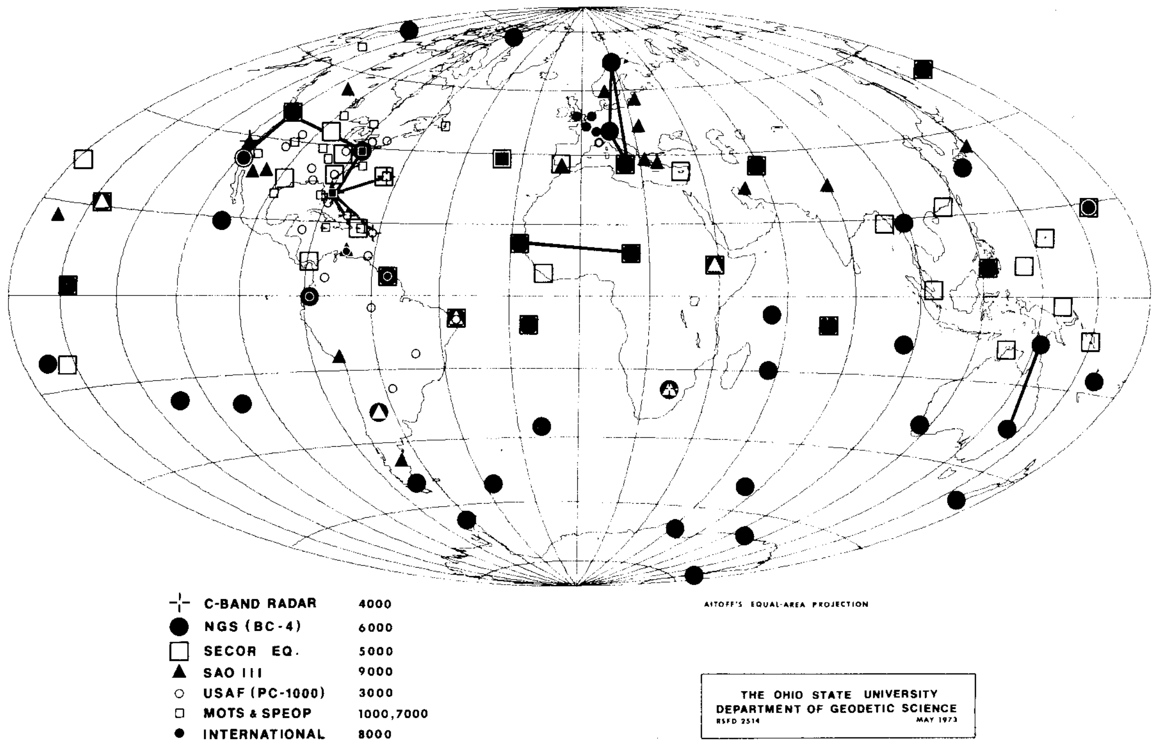

Figure 1. OSU Geometric Satellite Network (WN)

end of the axis u is in the direction of the Greenwich Mean Astronomical Meridian (and the zero geodetic meridian of the reference ellipsoid); the positive w axis passes through the Conventional International Origin (and coincides with the minor axis of the reference ellipsoid). The axis v completes the right handed co-ordinate system in the direction of the 90°(E) meridian, and with the u axis defines the plane of the average terrestrial (geodetic) equator.

3. Scale

The scale in the solution is defined through the dominating nearly 30,000 SECOR range observations, through the lengths of eight EDM (Geodimeter or Tellurometer) and three C-Band baselines, and also through a special procedure using constrained ellipsoidal heights.

3.1 SECOR Observations

The SECOR observations have an a posteriori standard deviation of ±4.1 m or approximately one part per million (MUELLER ET AL 1973b). The scale is propagated into the network through fifteen optical stations whose relative positions with respect to the nearby SECOR stations are maintained in the adjustment with their survey co-ordinate differences entered as weighted constraints.

3.2 Baselines

The available EDM and C-Band baselines are listed in table 3. The chord distances shown are entered in the adjustment as weighted constraints with weights computed from their estimated a priori

Table 3

Chord Constraints

Station-Station	Chord Distance (m)	σ×10[6] [1]	Source Code [2]
6002 - 6003	3 485 363.232	1.00	7
6003 - 6111	1 425 876.452	1.11	7
6006 - 6065	2 457 765.810	1.43	8
6016 - 6065	1 194 793.601	1.18	8
6063 - 6064	3 485 550.755	1.18	9
6023 - 6060	2 300 209.803	2.00	10
6032 - 6060*	3 163 623.866	2.00	10
6006 - 6016	3 545 871.454	1.00	8
3861 - 7043	1 531 562.9	1.33	7
4082 - 4050*	10 909 592	1.33	11
4082 - 4742*	7 362 142	2.00	11
4082 - 4740	1 593 106	2.00	11
4082 - 4081	1 230 691	2.00	11
4082 - 4061	2 288 026	2.00	11
4742 - 4280*	3 977 684	2.00	11

[1] Used in computing the weights

[2] Refer to table 2

* Rejected from the solution

standard deviations as listed in the table. The reasons for rejecting the east-west Australian tellurometer line (6032 - 6060) are explained below. Three C-Band lines were also rejected because of suspected errors in the survey co-ordinates of the terminal stations [Kauai (4742) in Hawaii and Pretoria (4040) in South Africa] needed to tie them to the nearest optical stations (9012 and 9002 respectively). Though these four lines were not constrained, at the end of the analysis, two of them (6032 - 6060 and 4082 - 4050) compared well with the lengths computed from the adjusted co-ordinates (see table 8). Thus the only station with survey co-ordinates in definite error is Kauai.

To get a feel for the quality of the EDM baselines listed in table 3, four preliminary adjustments of the BC network were performed in which the four longest scalars were individually constrained to their measured lengths, and their effect on the other (unconstrained) baselines investigated. The results are shown in table 4 in the form of the differences "adjusted - measured" lengths(Δd). Only independent lines longer than 2000 km are shown since the adjusted length of a short line, due to the geometry resulting from the high altitude of PAGEOS, the satellite used in the BC net, is not reliable. From the table it is clear that holding the east-west Australian line (3032 - 6060) to its measured value results in unreasonably larger differences of generally opposite signs than in any other case.

To verify the suspicion that something is wrong with the given measured value of line 6032 - 6060, a free adjustment was performed, in which both the origin and the scale constraints were "free" (BLAHA 1971). It is expected that the variances obtained from such an adjustment would primarily reflect the geometry of the situation. In other words, the variances of the various lengths would be due to the geometry of the network and free of the quality of the measured lengths. If the estimated variances of the measured lengths $(\sigma_d^{msrd})^2$ are added to those obtained from the free adjustment $(\sigma_d^{free})^2$, an estimate is obtained for the maximum expected variances of the length differences

Table 4

Adjusted - Given Lengths (m)

Solution	BC-8	BC-9	BC-10	BC-11
Line Fixed	6002 - 6003	6063 - 6064	6032 - 6060	6006 - 6016
6002 - 6003	0.0	-8.6	33.8	12.4
6006 - 6016	-13.3	-20.9	22.1	0.0
6063 - 6064	6.1	0.0	40.5	19.1
6023 - 6060	-9.5	-14.6	12.4	-0.7
6032 - 6060	-29.5	-36.6	0.0	-17.5
$\sum \Delta d$ (m)	-46.2	-83.6	108.8	13.3
$\sum \frac{\Delta d}{\text{length}} \times 10^6$	-2.89	-5.23	6.81	0.83

$(\sigma_d^{est})^2$. If an actual length difference is found to be 2 - 3 times greater than this estimated standard deviation, the measured length becomes suspect. The result of such analysis is shown in table 5.

From this table it is seen again that line 6032 - 6060 is out of bounds.

Another way of evaluating the effect of a scalar is through the semi-diameter of an ellipsoid best fitting the geoid resulting from a solution (see more of this in section 3.3). In this method, the undulations for each station are computed (ellipsoidal height - mean sea level height) and, after suitable transformations for shift of origin, are compared with some standard set of undulations, in this case with those in (RAPP 1973). The average difference N of these two sets of undulations is equivalent, with opposite sign, to the difference between the semi-diameter of the reference ellipsoid (a = 6 378 155 m) and that of the level ellipsoid of the same flattening to which the "standard" undulations refer.

Three sets of such comparisons were performed. One with the baselines constrained with weights corresponding to the standard deviations listed in table 3, one with all lines constrained to 1:3 M, and one with 1:30 M. Within each set, the adjustment was performed with all 6000 series EDM lines constrained and also without the line 6032-6060 (seven lines). The results are shown in table 6. In addition to the semi-diameter of the best-fitting level ellipsoid, the table also contains the

Table 5

Adjusted - Measured Lengths (Δd) from a Free Adjustment

Line	σ_d^{free} (m)	σ_d^{msrd} (m)*	$\sigma_{\Delta d}^{est}$ (m)	Δd (m)
6002 - 6003	4.2	3.5	5.5	-5.0
6006 - 6016	4.5	3.5	5.7	-17.2
6063 - 6064	4.4	4.1	6.0	2.4
6023 - 6060	4.4	4.6	6.4	-12.1
6032 - 6060	4.3	6.3	7.6	-33.1

* From table 3.

average standard deviations of a single co-ordinate ($\sigma^2 = \sigma_u^2 + \sigma_v^2 + \sigma_w^2$) as well as those of the heights (σ_H) and the ratios (adjusted - measured lengths)/lengths : $\sum(\Delta d/\text{length})$.

Table 6

Comparison of Seven- or Eight-Baseline Solutions

Solution	No. of Lines Constrained	Type of Constraint	$\sum \frac{\Delta d}{\text{length}} \times 10^6$	a (level ellipsoid) 6 378 000 + (m)	σ (m)	σ_H (m)
BC D12	8	As In table 3	0.81	124.1 ± 11.0	6.3	8.1
BC D 2	7		0.19	118.4 ± 11.2	6.2	8.3
BC D 7	8	1:3 M	0.08	128.0 ± 10.8	6.1	7.7
BC D 8	7		0.04	119.7 ± 11.2	6.2	7.9
BC D 9	8	1:30 M	0.02	127.0 ± 10.7	5.9	7.2
BC D10	7		0.01	118.0 ± 11.2	6.0	7.3

From the table it is evident that though the varying type and number of constraints do not change significantly, the quality of the co-ordinates in the seven baseline solutions (D2, D8, D10) is better, as the adjusted lengths agree better with their measured values, than in the eight-baseline solutions (D12, D7, D9). It is also seen that the inclusion of the single east-west Australian line increases the semi-diameter by the unreasonable amount of 6 - 9 m (1 - 1.5 parts per million) in all cases.

On the basis of the results in tables 4 to 6 and also based on other calculations not reported here, the measured value of the Australian line 6032 - 6060 was rejected as a useful constraint.

The high standard deviations attached to the semi-diameters of the level ellipsoids in table 6 also indicates the questionable value of only seven or eight baselines in scaling a global network regardless of their individual quality. The inclusion of height constraints in the solution is an attempt for a better scale.

3.3 Use of Constrained Ellipsoidal Heights as Scalars

The use of geodetic (ellipsoidal) heights as weighted constraints as a contribution to the scale requires a more detailed explanation (figure 2). The height H above a geocentric reference ellipsoid

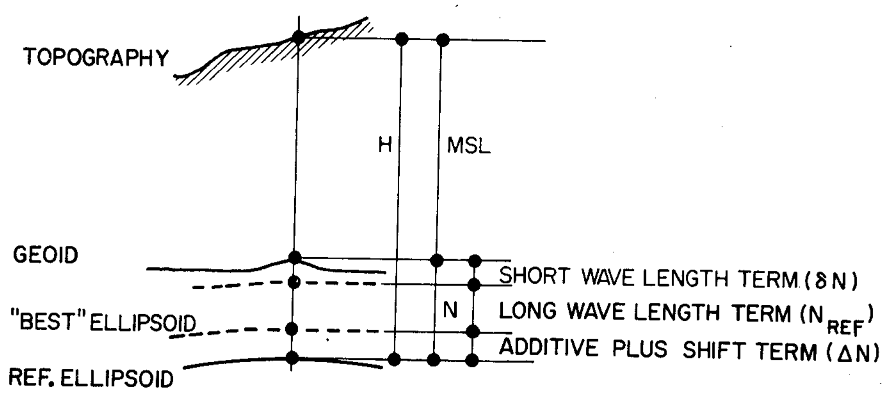

Figure 2. Height Components

has two main components:

- the orthometric (mean sea level) height (MSL); and
- the geoid undulation (N).

In this geocentric case, N consists of a long-wavelength component N_{REF}, a short-wavelength term δN, and an additive part Δa. The term N_{REF} generally corresponds to regional gravitational effects and can be computed for example from a truncated spherical harmonic series. The short-wavelength part δN corresponds to local gravity or mass disturbances and is generally not contained in the spherical harmonic representation. The additive part Δa is the so-called zero degree term which may exist due to the fact that the ellipsoid may not be of the same size (though it is of the same flattening) as the "best" (mean Earth) *level ellipsoid* to which the undulation N_{REF} is referenced. Since the N_{REF} undulations are, within reasonable limits, insensitive to the semi-diameter of the level ellipsoid, it is difficult to define a correct value for Δa. If the reference ellipsoid is *non-geocentric*, as is the case in this solution, an additional height term dH arises due to the "shift" of the origin (ellipsoidal centre) with respect to the geocentre. Thus the geodetic height may have the following components:

$$H = MSL + N \tag{1}$$

and

$$N = N_{REF} + \delta N + \Delta N \tag{2},$$

where (HEISKANEN & MORITZ 1967,p.207)

$$\Delta N = \Delta a + dH = \Delta a + u_o \cos\phi \cos\lambda + v_o \cos\phi \sin\lambda + w_o \sin\phi \tag{3},$$

Δa = a(level ellipsoid) - a(reference ellipsoid),

u_o, v_o, w_o are the co-ordinates of the geocentre with respect to the centre of the reference ellipsoid (origin); and

ϕ, λ are the geodetic co-ordinates of the station to which H refers.

In practice, at most satellite tracking stations, the quantity $MSL+N_{REF}$ is well known, and generally it constitutes the largest portion of the total height above the level ellipsoid. The additive plus shift term ΔN can be determined empirically through an iterative interpolation procedure as described later. Since $(MSL + N_{REF} + \Delta N)$ constitute the largest portion of the total height above the *reference ellipsoid* , it seems reasonable not to ignore this, admittedly partial, information on the height of the station and to include it in the adjustment as a constraint $(H_{CONSTR} = MSL + N_{REF} + \Delta N)$ with such a weight that the adjustment should be able to "pull out" the only remaining component, the short-wavelength term δN, together with possible errors in H_{CONSTR}. In this solution, the standard deviations used in computing the weights vary from ±2.5 m to ±8 m depending mostly on the location of the station, from the point of view of the extent of the available surface gravity observations in the area which was included in the spherical harmonic expansion for N_{REF} (RAPP 1973).

In trying to determine the "best" scale for the solution or, which is the same, the "best" additive term Δa, the first step is to establish the relationship between them. The problem differently stated is the determination of the relationship between the additive term and the semi-diameter of the "best" level ellipsoid to which the quantity N_{REF} refers. The meaning of the term "best" will be elaborated on later in this section. This is accomplished empirically from a set of solutions with height constraints containing different additive terms, from Δa = 0 to 30 m. The shift term dH initially is estimated from comparisons with various dynamic solutions, resulting in the co-ordinates u_o, v_o and w_o needed in equation 3. These solutions result in sets of geodetic heights (H_{WNi}) above the reference ellipsoid and also in sets of undulations after subtracting the MSL:

$$N_{WNi} = H_{WNi} - MSL.$$

These undulations thus refer to the reference ellipsoid of $a = 6\ 378\ 155$ m, whose origin is set by the inner constraint. Disregarding the short-wavelength term, the relationship between the undulations N_{WNi} and N_{REF} is given by equations 2 and 3, from where, for any station and for the solution WNi:

$$(N_{WNi} - N_{REF}) - (\Delta a_i + u_{oi}\cos\phi\cos\lambda + v_{oi}\cos\phi\sin\lambda + w_{oi}\sin\phi) = 0.$$

Since the quantity ($N_{WNi} - N_{REF}$) is known at all stations, the parameters Δa_i, u_{oi}, v_{oi}, w_{oi} can be calculated (iterated) from least squares adjustments for each set "i". This is the same as determining the size (scale) and the origin of the level ellipsoid which fits best the geoid defined for a given set by the undulations N_{WNi}. Its size is

$$a_i = 6\ 378\ 155 + \Delta a_i$$

and its origin with respect to the origin of the reference ellipsoid is defined by the co-ordinates u_{oi}, v_{oi} and w_{oi}. After some iterations, these co-ordinates hardly change from solution (set) to solution (set), regardless of the initial selection of Δa; thus the relationship between the input additive term and the resulting semi-diameter, $a = f(\Delta a)$, becomes straightforward and linear.

This empirically determined relationship is shown in figure 3, as the dashed line drawn from the lower left corner towards the upper right. The corresponding ordinate is on the right hand side of the diagram. The line now allows either to pick the correct initial additive term which when used in the height constraints, would result in an a priori defined semi-diameter (scale), or to determine which semi-diameter (scale) would correspond to an a priori defined additive term. As an example, if the semi-diameter of the level ellipsoid best fitting the geoid was to be 6 378 142 m, the WN solution would require height constraints computed with an additive term of -15 m.

The next question, of course, is just how big should this desired semi-diameter be. Putting it differently, what criterion should be used to select the "best" scale ? If the scale was to be determined only from the EDM and C-Band baselines and/or the SECOR observations, these questions would not arise since the scale would be inherently defined. The use of weighted height constraints, as explained above, provides a unique tool to select the scale to fit some criterion. There could be several non-inclusive criteria, e.g.,

(1) The lengths of the EDM baselines as computed from the adjusted co-ordinates of the terminal stations should be
  - (a) exactly the same as the given lengths in table 3, or
  - (b) their differences should be within the limit of one (average) standard deviation,
  - or (c) within a certain limit, e.g., 1:1,000,000, etc.

(2) Same as (1) but for the C-Band baselines.

(3) The scale difference as determined from the station co-ordinates of the WN solution and from the same co-ordinates of *some* dynamic solution should be
  - (a) exactly zero,
  - (b) within the limit of one standard deviation of the scale difference factor,
  - (c) within 1:1,000,000, etc.

(4) The scale difference as determined in (3) should be within a certain limit with respect to *all* the dynamic solutions.

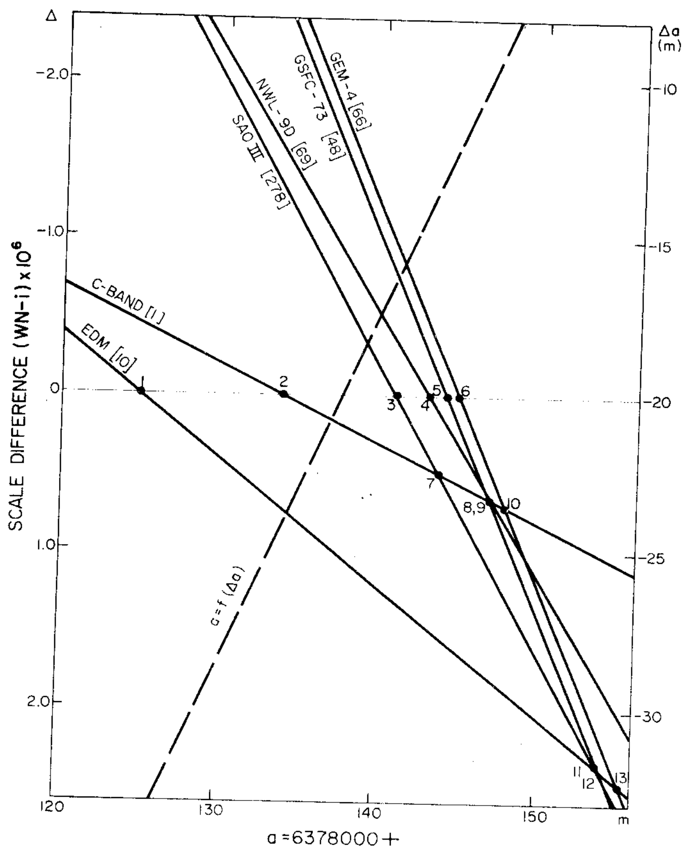

Figure 3. Determination of Scale

(5) The scale difference should be within a certain limit with respect to all the dynamic solutions *and* the EDM and C-Band baselines.

In order to be able to enforce any of the above criteria, first the relationship between the scale difference factor and the semi-diameter has to be established. This is accomplished again empirically by determining the scale differences between the different WNi solutions (used to determine the function a = f(Δa)) and the EDM and C-Band baselines and the dynamic solutions NWL-9D (ANDERLE 1973), SAO III (GAPOSCHKIN ET AL 1973), GEM 4(LERCH ET AL 1972), GSFC 73 (MARSH ET AL 1973). The method of calculating the scale difference factor is described in (KUMAR 1972), and the results are shown in figure 3 where, with the ordinate on the left hand side, the scale differences are plotted against the semi-diameters corresponding to the various Δa's used in the height constraints. The numbers on the lines indicate relative weights based on the uncertainties of the scale-difference determinations. It can be seen that the lines representing the geometric (EDM and C-Band) scale differences are much less well determined than the dynamic ones. As an example, the scale-difference factor between the WNi solution computed with Δa = -15 m (a = 6 378 142 m), and the solutions NWL-9D is -0.18×10^{-6}; the GEM 4 is -0.68×10^{-6} (the dynamic scales are larger). Also, the lengths of the EDM baselines from the adjustment differ from their directly measured values by 1.38×10^{-6} (the measured values are smaller).

The diagram is used by recognizing the importance of the various intersection points, marked by numbers. For example, point 1 illustrates the fact that if the semi-diameter of the level ellipsoid was 6 378 125 m, the difference between the adjusted chord lengths and their given values would be zero; point 4 shows that with an a = 6 378 143 m, there would be no scale difference between WNi and NWL-9D. Fourteen similar intersection points are listed in table 7 with weights and interpretation.

From the table it is immediately clear that taking the weighted mean of the intersection points from the "geometric" scalars (points 1 and 2), the "best" semi-diameter is 6 378 125.8 m, while from the "dynamic" lines (points 3 - 6) it is 6 378 142.0 m. The difference of some 16 m, or about 2.5 parts in a million, seems to be real but unexplained at this time. The combined weighted mean from points 1 - 6 is 6 378 141.7 m; while from all the points (1 - 14), it is 6 378 142.7 m.

For the solution reported here (WN14), the criterion for the scale is (5) above; i.e., that the scale should correspond well to all geometric and dynamic information available at present. Based on the above numbers and on previously published parameters, a = 6 378 142 m was *selected*. This then requires an adjustment in which the scale is defined, in addition to the SECOR, EDM and C-Band observations, through height constraints with the initial additive constant $\Delta a = -15$ m. As can be seen from figure 3, at this semi-diameter, the maximum scale difference expected between WN14 and any of the dynamic solutions is about 0.8×10^{-6}, and with respect to the EDM about 1.4×10^{-6} or 1:700,000 which is about the average standard deviation of the EDM baselines. Using this scale, the resulting geoid undulations

$$N = H_{WN14} - MSL - \Delta N \qquad (4),$$

with

$$\Delta N(\text{metres}) = -13 - 23.2 \cos\phi \cos\lambda - 2.9 \cos\phi \sin\lambda + 2.7 \sin\phi$$

Table 7

Determination of Scale

Point	Interpretation	Weight	a (m)	Weighted Mean a (m)
1	WN = EDM	10	6 378 125.0	6 378 125.8 (from points 1 & 2)
2	WN = C-Band	1	6 378 133.7	
3	WN = SAO III	278	6 378 140.8	6 378 141.7 (from points 1 - 6)
4	WN = NWL 9D	69	6 378 143.0	
5	WN = GSFC 73	66	6 378 144.9	6 378 142.0 (from points 3 - 6)
6	WN = GEM 4	48	6 378 144.1	
7	C-Band = SAO III	1	6 378 143.6	6 378 142.7 (from points 1 - 14)
8	C-Band = GSFC 73	1	6 378 146.8	
9	C-Band = NWL 9D	1	6 378 147.1	
10	C-Band = GEM 4	1	6 378 147.8	
11	EDM = SAO III	10	6 378 153.7	
12	EDM = GSFC 73	8	6 378 154.0	
13	EDM = GEM 4	9	6 378 155.2	
14	EDM = NWL 9D	9	6 378 160.5	

are consistent with dynamically computed ones when the following set of constants defining the gravity of the level ellipsoid are used (HEISKANEN & MORITZ 1967,p.64):

$f = 1/298.25$ (flattening) ; $\omega = 0.729\ 211\ 514\ 67 \times 10^{-4}\ \mathrm{sec}^{-1}$ (rotational velocity);

$a = 6\ 378\ 142$ m ; and

$W_o = 6\ 263\ 688.00$ kgal m (geopotential on the geoid).

Derived from these are the following parameters:

$k^2M = 3.986\ 009\ 22 \times 10^{14}\ \mathrm{m^3 sec^{-1}}$ (gravitational constant × Earth mass);

$\gamma_e = 978.032\ 26\ \mathrm{cm\ sec^{-2}}$ (equatorial normal gravity); and

$J_2 = 1\ 082.6863 \times 10^{-6}$ (second degree harmonic).

All the above constants are in good agreement with their current best estimates. The parameters in equation 4 ($\Delta a = -13 \pm 0.7$ m, $u_o = -23.2 \pm 0.9$ m, $v_o = -2.9 \pm 0.8$ m, $w_o = 2.7 \pm 1.2$ m) are the result of fitting an ellipsoid to the WN14 geoid as explained earlier in this section, and they represent the size and position of the best fitting level ellipsoid with respect to the reference ellipsoid (of the same flattening). In the case of a good global station distribution, the centre of this level ellipsoid is the "geometric" centre of the geoid. If this point is assumed to be identical with the centre of mass, then the above co-ordinates may be viewed as its co-ordinates with respect to the origin of the reference ellipsoid, and with opposite signs they can be used to shift the WN14 co-ordinates to the geocentre:

$$\begin{aligned} u(\text{geocentric}) &= u_{WN14} + 23.2\ \mathrm{m} \\ v(\text{geocentric}) &= v_{WN14} + 2.9\ \mathrm{m} \\ w(\text{geocentric}) &= w_{WN14} - 2.7\ \mathrm{m} \end{aligned} \qquad (5).$$

It should be pointed out again that the selection of the semi-diameter 6 378 142 m was arbitrary. Had the lowest extremity in table 7 been chosen (6 378 125 m), the gravitational parameters (keeping f, ω and the geoidal undulations the same) still would not become completely unreasonable:

$W_o = 6\ 263\ 705.35$ kgal m ; $k^2M = 3.986\ 009\ 68 \times 10^{14}\ \mathrm{m^3 sec^{-1}}$

$\gamma_e = 978.037\ 62\ \mathrm{cm\ sec^{-2}}$; $J_2 = 1\ 082.695\ 6 \times 10^{-6}$.

Thus the question of what is the "best" semi-diameter still needs to be answered.

4. Comparison of the Results

4.1 Comparisons with Geometric Information

In addition to solution WN14, two other adjustments were also performed with the same data. The only differences were that in one of them (WN12), the weighted height constraints were not applied; thus the scale is defined through the SECOR, EDM and C-Band data. In the other (WN16), the EDM and C-Band lengths were not entered as weighted constraints; thus the scale is through the SECOR and the weighted height constraints.

Table 8 contains differences between the adjusted and given chord lengths (table 3) from the three solutions. The lines originating from Station 4742 (Kauai) are not listed for reasons explained earlier. Comparing solutions WN14 and WN12, the effect of including the heights is not very significant. The average length discrepancy decreases 0.48×10^{-6} in the case of EDM, and 0.60×10^{-6} in the C-Band case, both numbers being within the noise level. At first glance, the difference between WN14 and WN16 seems to be significant since the average length discrepancy increases by about

Table 8

Chord Length Comparisons (Solutions WN12, 14 and 16)

Type	Line	Adjusted - Given Length					
		WN12		WN14		WN16	
		m	ppm	m	ppm	m	ppm
EDM	6002 - 6003	8.3 ± 2.5	2.38	2.7 ± 2.3	0.78	5.9 ± 3.0	1.70
	6003 - 6111	2.7 ± 1.4	1.90	2.3 ± 1.4	1.60	11.4 ± 3.1	8.00
	6006 - 6065	7.7 ± 2.1	3.13	6.1 ± 2.0	2.47	19.9 ± 3.5	8.13
	6016 - 6065	-2.8 ± 1.3	2.30	-2.9 ± 1.3	2.47	-18.9 ± 3.4	15.87
	6006 - 6016	2.7 ± 2.2	0.77	1.3 ± 2.1	0.37	1.6 ± 3.3	0.46
	6063 - 6064	13.7 ± 2.4	3.94	10.6 ± 2.3	3.03	15.2 ± 2.8	4.37
	6023 - 6060	7.9 ± 3.1	3.42	5.9 ± 3.0	2.55	9.6 ± 3.8	4.16
	6032 - 6060*	-2.4 ± 3.9	0.76	-4.5 ± 3.6	1.42	-2.9 ± 3.7	0.92
	3861 - 7043	2.2 ± 1.8	1.44	1.5 ± 1.8	0.99	7.6 ± 3.7	5.00
C-Band	4082 - 4050*	26.5 ± 6.9	2.42	-5.2 ± 3.9	0.48	-4.2 ± 4.0	0.39
	4082 - 4740	2.0 ± 2.7	1.25	1.3 ± 2.7	1.90	6.6 ± 5.0	4.13
	4082 - 4081	3.0 ± 2.3	2.40	2.3 ± 2.3	0.79	17.9 ± 6.2	14.49
	4082 - 4061	-0.4 ± 3.6	0.19	-1.5 ± 3.6	0.65	2.1 ± 6.1	0.93
Average	EDM		2.22		1.74		5.40
	C-Band		1.56		0.96		4.98
	All		2.02		1.50		5.27

4×10^{-6} or 1:250,000 for both types of observations. Close inspection, however, reveals that though the inclusion of the EDM and C-Band chords in the solution improves the positions of stations 6111 (Wrightwood), 6065 (H.Peissenberg) and 4081 (Grand Turk), it does not otherwise contribute to the overall scale determination significantly. If the above mentioned stations are left out of the comparison, the average length discrepancies in the WN16 solution decrease to 2.76×10^{-6} for the EDM and 1.81×10^{-6} for the C-Band, both within the noise level from WN14 (about 1×10^{-6}).

The above conclusion is also strengthened by the content of table 9 where the average standard deviations of the co-ordinates and the heights are compared from the three solutions. It is seen that while the inclusion of the weighted heights decreases standard deviations significantly, the exclusion of the geometric scalars hardly changes the results.

Table 9

Standard Deviation Comparisons
(Solutions WN12, 14 and 16)

Solution	Constituent Networks								WN_i	
	BC		SECOR		MPS		SA			
	σ	σ_H	σ	σ_H	σ	σ_H	σ	σ_H	σ	σ_H
WN12	4.4	5.0	4.2	4.8	6.9	7.6	5.2	5.9	5.5	6.2
WN14	3.5	3.2	2.8	2.4	4.8	2.9	4.1	3.0	3.9	2.9
WN16	3.5	3.2	2.8	2.4	4.9	2.9	4.1	3.0	4.0	2.9

All units in metres

4.2 Comparisons with Dynamic Solutions

Table 10 is a compilation of transformation parameters between the WN co-ordinates and those from the dynamic solutions NWL-9D, SAO III, GEM-4 and GSFC-73. The method of computing the parameters is described in (KUMAR 1972). In the table the positive angles ω, ψ and ε are counter-clockwise rotations about the w, v and u axes respectively, as viewed from the end of the positive axis. The scale difference factor Δ is in units of ppM. In the transformations the variances of both sets of the co-ordinates are taken into account. Taking the variances of the WN solutions as standard, those of the dynamic solutions are scaled by the weight factors indicated. These numbers are also indicative of the over-optimism over the quality of some of the published solutions. For example, a weight factor of 25 would indicate that the published standard deviations of a given solution need to be multiplied by $\sqrt{25} = 5$.

Table 10

Relationships Between Various Dynamic and the WN Systems

(Dynamic - WN14)

Solution	NWL-9D			SAO III			GEM-4	GSFC-73
Sta.Considered	5000	6000	all	6000	9000	all	all	all
No. Stations	12	22	32	47	22	73	30	26
Weight Factor*	1.5	7.75	4	2	2	2	50	22
Δu(m)	15.6 ±1.6	16.8 ±1.1	15.9 ±1.0	16.8 ±1.5	10.7 ±2.1	13.9 ±1.3	14.5 ±1.6	13.7 ±1.5
Δv(m)	13.1 ±1.5	9.6 ±1.1	10.3 ±1.0	12.8 ±1.5	13.6 ±2.2	13.6 ±1.3	11.6 ±1.6	12.9 ±1.4
Δw(m)	-7.8 ±2.0	-3.2 ±1.1	-3.4 ±1.1	-5.2 ±1.5	-15.7 ±2.3	-10.4 ±1.3	1.9 ±1.7	-1.7 ±1.9
Δ (10^{-6})	0.74±0.15	0.26±0.05	0.29±0.04	-0.50±0.05	0.74±0.15	-0.17±0.04	0.93±0.11	0.96±0.11
ω (")	0.73±0.03	0.70±0.01	0.71±0.01	0.51±0.02	0.26±0.03	0.37±0.01	-0.02±0.02	-0.38±0.02
ψ (")	-0.11±0.04	-0.15±0.01	-0.15±0.01	0.15±0.02	0.08±0.04	0.15±0.01	0.12±0.03	0.19±0.03
ε (")	0.23±0.07	-0.17±0.01	-0.14±0.01	-0.18±0.02	0.07±0.03	-0.03±0.01	0.17±0.02	0.24±0.03
σ_o^2	0.65	0.91	0.87	0.83	1.20	1.14	1.11	1.09

* Weight Factor = $\sigma^2_{o,i} / \sigma^2_{o,WN14}$

As it is seen there is good agreement between the translational elements Δu-s and Δv-s of the main (all stations inclusive) dynamic solutions and a discrepancy of about 8.5 ± 1.7 m with respect to the geometric values (see equation 5). The largest discrepancy occurs in the Δw components, where there seems to be a 12.3 ± 2.1 m difference between the SAO III and the GEM-4 solutions. Eliminating the SAO III value, all Δw's, including the geometric one, are within the noise level.

The weighted mean shifts from the main dynamic solutions (excluding Δw from SAO III), or the co-ordinates of the geocentre with respect to the WN14 origin, are listed in table 11. The quantity $r_o = \sqrt{u_o^2 + v_o^2}$ is the distance of the WN14 origin from the rotation axis of the Earth. Calculating the same number from the JPL-LS 37 co-ordinates of the Deep Space Network (stations DSN1 = 4711, DSN2 = 4712, DSN4 = 4714, DSN6 = 4742 and DSN7 = 4751) as published in (GAPOSCHKIN ET AL 1973), one gets r_o = 25.9 ± 2.5 m, which value is nearest to the one calculated from the geometric fit.

The differences in scale between dynamic solutions are significant (see figure 3 for comparison). The largest discrepancy is between the SAOIII and GSFC-73 with Δ = (1.13 ± 0.12) × 10^{-6}, which is

Table 11

Shifts to the Geocentre (Solution WN14)

Source	u_o (m)	v_o (m)	w_o (m)	r_o (m)
1. Dynamic Comparison	14.8 ± 1.4	11.8 ± 1.3	-1.8 ± 1.6	18.9 ± 1.9
2. Geometric Fit (eqn.5)	23.2 ± 0.9	2.9 ± 0.8	-2.7 ± 1.2	23.4 ± 1.2
3. Weighted Mean of 1 & 2	20.7 ± 1.2	5.3 ± 1.1	-2.4 ± 1.4	21.4 ± 1.6
4. JPL/DSN				25.9 ± 2.5

larger than what one would expect from the noise. The other dynamic scales are within near noise level and, on the average, differ from the scale of the WN14 solution by

$$\Delta = (0.12 \pm 0.08) \times 10^{-6}$$

or about one part in 8.3 million. The largest discrepancies occur in the orientation of the various dynamic systems with respect to each other and to WN14. In the rotation about the w axis (ω), the largest difference occurs between the NWL-9D and the GSFC-73 solutions, where $\omega = 1''.1$, or about 34 m on the equator (figure 4). The other differences are smaller but significant. These rotations may be partly due to the definition of the zero meridian in the case of purely electronic systems (e.g., Doppler), partly to the various definitions of vernal equinox in the star catalogues used, and also to its motion with respect to inertial space, in the case of optical observations. The latter alone requires a correction to the FK4 right ascensions amounting to $+0''.65$ at 1960.0, changing with a rate of $+1''.36$ per century (MARTIN & VAN FLANDERN 1970).

The rotations about the axes u and v are even more confusing. Figure 5 illustrates the situation at the pole. The weighted means of the dynamic solutions are $\psi = 0''.02 \pm 0''.02$ and $\varepsilon = -0''.04 \pm 0''.02$. The discrepancy between the poles as determined separately from the SAO III 6000 stations and then from the 9000 stations is unexplained at this time. It is interesting to note that the weighted mean pole and zero meridian positions computed from the dynamic solutions hardly differ from those of the WN14 solution.

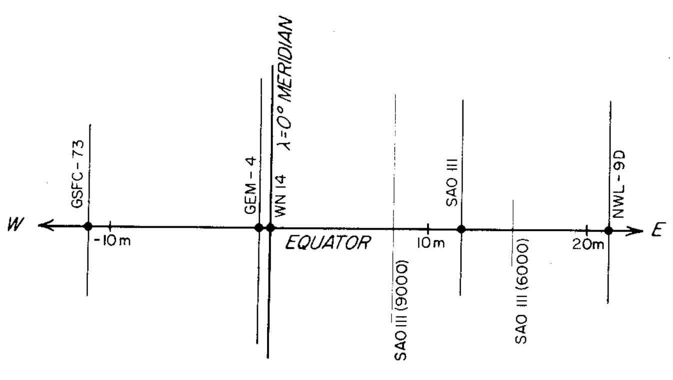

Figure 4. Dynamic Zero Meridians Relative to the WN14 Zero Meridian

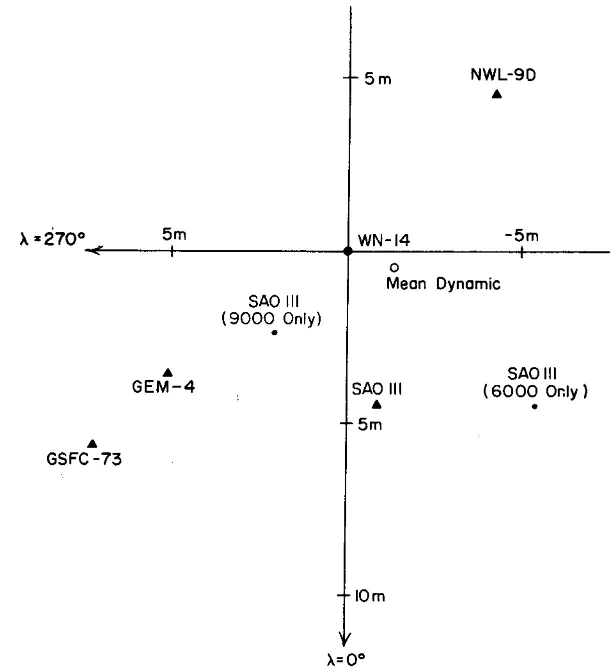

Figure 5. Dynamic Pole Positions Relative to the WN14 Pole

The only general conclusion that one can draw from the rotation parameters is that the co-ordinate systems used in the dynamic solutions need to be more carefully defined and conditions enforcing these definitions more strongly applied than evidenced from the solutions discussed.

4.3 Comparison with Geodetic Datums

Table 12 is a summary of datums. Table 13 summarizes the relationships between the various geodetic datums and the WN14 system for those datums where stations were located.

5. Cartesian Co-ordinates From Solutions WN12 and WN14

Table 14 is a summary of the Cartesian co-ordinates of solutions WN12 and WN14. As mentioned earlier the former differs from the latter only in that in it, the heights are not constrained. The resulting scale in WN12 is such that when the co-ordinates are transformed to a geocentric rotational ellipsoid of $a = 6\ 378\ 154$ m and $1/f = 298.2495$, they produce geoid undulations consistent with dynamically determined ones with $k^2M = 3.986\ 008\ 91 \times 10^{14} m^3 sec^{-2}$ and $\gamma_e = 978.028\ 47$ cm sec^{-2}. Derived from these constants are the values $W_o = 6\ 263\ 675.76$ kgal m and $J_2 = 1\ 082.6797 \times 10^{-6}$. These values together with those mentioned at the end of section 3.3 seem to be the extreme limits within which the truce must lie, provided that the dynamically determined undulations are correct.

Comparisons with geoid undulations from satellite and surface gravimetric solutions in case of the WN14 solution show an rms residual of ±6.1 m, with an average of only -0.3m. Similar comparison with the WN12 solution, where the heights are not constrained, shows that the rms of the residuals is ±16.1 m, and the average -0.2 m.

Table 12

Geodetic Datums

Code	Datum	Ellipsoid	Origin	Latitude	Longitude
1	Adindan (Ethiopia)	Clarke 1880	STATION Z5 ADINDAN	22°10'07".110	31°29'21".608
2	American Samoa 1962	Clarke 1866	BETTY 13 ECC	-14 20 08.341	189 17 07.750
3	Arc-Cape (South Africa)	Clarke 1880	Buffelsfontein	-33 59 32.000	25 30 44.622
4	Argentine	International	Campo Inchauspe	-35 58 17	297 49 48
5	Ascension Island 1958	International	Mean of three stations	-07 57	345 37
6	Australian Geodetic	Australian National	Johnston Memorial Cairn	-25 56 54.55	133 12 30.08
7	Bermuda 1957	Clarke 1866	FT. GEORGE B 1937	32 22 44.360	295 19 01.890
8	Berne 1898	Bessel	Berne Observatory	46 57 08.660	07 26 22.335
9	Betio Island, 1966	International	1966 SECOR ASTRO	01 21 42.03	172 55 47.90
10	Camp Area Astro 1961-62 USGS	International	CAMP AREA ASTRO	-77 50 52.521	166 40 13.753
11	Canton Astro 1966	International	1966 CANTON SECOR ASTRO	-02 46 28.99	188 16 43.47
12	Christmas Island Astro 1967	International	SAT.TRI.STA. 059 RM3	02 00 35.91	202 35 21.82
13	Chua Astro (Brazil-Geodetic)	International	CHUA	-19 45 41.16	311 53 52.44
14	Corrego Alegre (Brazil-Mapping)	International	CORREGO ALEGRE	-19 50 15.140	311 02 17.250
15	Easter Island 1967 Astro	International	SATRIG RM No. 1	-27 10 39.95	250 34 16.81
16	European	International	Helmert Tower	52 22 51.45	13 03 58.74
17	Graciosa Island (Azores)	International	SW BASE	39 03 54.934	331 57 36.118
18	Gizo, Provisional DOS	International	GUX 1	-09 27 05.272	159 58 31.752
19	Guam	Clarke 1866	TOGCHA LEE NO. 7	13 22 38.49	144 45 51.56
20	Heard Astro 1969	International	INTSATRIG 0044 ASTRO	-53 01 11.68	73 23 22.64
21	Iben Astro, Navy 1947 (Truk)	Clarke 1866	IBEN ASTRO	07 29 13.05	151 49 44.42
22	Indian	Everest	Kalianpur	24 07 11.26	77 39 17.57
23	Isla Socorro Astro	Clarke 1866	Station 038	18 43 44.93	249 02 39.28
24	Johnston Island 1961	International	JOHNSTON ISLAND 1961	16 44 49,729	190 29 04,781
25	Kusaie, Astro 1962, 1965	International	ALLEN SODANO LIGHT	05 21 48,80	162 58 03.28
26	Luzon 1911 (Philippines)	Clarke 1866	BALANCAN	13 33 41.000	121 52 03,000
27	Midway Astro 1961	International	MIDWAY ASTRO 1961	28 11 34.50	182 36 24.28
28	New Zealand 1949	International	PAPATAHI	-41 19 08.900	175 02 51.000
29	North American 1927	Clarke 1866	MEADES RANCH	39 13 26.686	261 27 29.494
30	*NAD 1927 (Cape Canaveral)	Clarke 1866	CENTRAL	28 29 32.364	279 25 21.230
31	*NAD 1927 (White Sands)	Clarke 1866	KENT 1909	32 30 27.079	253 31 01.306
32	Old Bavarian	Bessel	Munich	48 08 20.000	11 34 26.483
33	Old Hawaiian	Clarke 1866	OAHU WEST BASE	21 18 13.89	202 09 04.20
34	Ordnance Survey G.B. 1936	Airy	Herstmonceux	50 51 55.271	00 20 45.882
35	Pico de las Nieves (Canaries)	International	PICO DE LAS NIEVES	27 57 41.273	344 25 49.476
36	Pitcairn Island Astro	International	PITCAIRN ASTRO 1967	-25 04 06.97	229 53 12.17
37	Potsdam	Bessel	Helmert Tower	52 22 53.954	13 04 01.153
38	Provisional S.American 1956	International	LA CANOA	08 34 17.17	296 08 25.12
39	Provisional S. Chile 1963	International	HITO XVIII	-53 57 07.76	291 23 28.76
40	Pulkovo 1942	Krassovski	Pulkovo Observatory	59 46 18.55	30 19 42.09
41	South American 1969	South American 1969	CHUA	-19 45 41.653	311 53 55.936
42	Southeast Island (Mahe)	Clarke 1880		-04 40 39.460	55 32 00.166
43	South Georgia Astro	International	ISTS 061 ASTRO POINT 1968	-54 16 38.93	323 30 43.97
44	Swallow Islands (Solomons)	International	1966 SECOR ASTRO	-10 18 21.42	166 17 56.79
45	Tananarive	International	Tananarive Observatory	-18 55 02.10	47 33 06.75
46	Tokyo	Bessel	Tokyo Observatory (old)	35 39 17.51	139 44 40.50
47	Tristan Astro 1968	International	INTSATRIG 069 RM No. 2	-37 03 26.79	347 40 53.21
48	Viti Levu 1916 (Fiji)	Clarke 1880	MONAVATU (latitude only) SUVA (longitude only)	-17 53 28.285	 178 25 35.835
49	Wake Island, Astronomic 1952	International	ASTRO 1952	19 17 19.991	166 38 46.294
50	Yof Astro 1967 (Dakar)	Clarke 1880	YOF ASTRO 1967	14 44 41.62	342 30 52.98
51	Palmer Astro 1969	International	ISTS 050	-64 46 35.71	295 56 39.53
52	Eftate	International	Belle Vue IGN	-17 44 17.400	168 20 33.250

*Local datums of special purpose, based on NAD 1927 values for the origin stations.

Table 13

Relationship Between Various Geodetic Datums and the WN System (Datum - WN14)

Datum No.	Datum Name[1]	No. of stations	Δu (m)*	Δv (m)*	Δw (m)*	ω (″)**	ψ (″)**	ϵ (″)**	Δ ($\times 10^6$)
1	Adindan (Ethiopia)	2	184 ±19	21 ±11	-200 ± 6				
2	American Samoa 1962	1	119 ± 8	-105 ± 8	-413 ±10				
3	Arc Cape (South Africa)	1	152 ± 7	126 ± 7	298 ±10				
5	Ascension Island 1958	1	227 ± 7	- 93 ± 7	- 58 ± 8				
6	Australian Geodetic	3	118.2± 5.0	41.1± 6.2	-121.0± 6.9	1.03±0.18	0.99±0.18	-0.25±0.22	-1.20±0.71
10	Camp Area Astro 1961/62(USGS)	1	111 ±10	148 ± 9	-238 ±10				
12	Christmas Island Astro 1967	1	-115 ± 9	-224 ±12	529 ± 8				
15	Easter Island Astro 1967	1	-182 ±10	-138 ±10	-128 ±11				
16	European-50 (W)[2]	11	133.3± 9.5	114.2±15.9	152.2± 9.2	-1.76±0.38	0.01±0.31	-0.38±0.44	-7.30±1.14
	European-50 (All stations)[3]	16	134.3± 9.1	152.7± 8.0	144.6± 8.8	-0.41±0.20	0.27±0.30	-0.51±0.22	-7.24±0.88
17	Graciosa Island (Azores)	1	123 ±17	-147 ± 9	37 ±17				
20	Heard Astro 1969	1	182 ±12	56 ±12	-114 ±14				
22	Indian[4]	1	-165 ±17	-711 ±10	-228 ±11				
23	Isla Socoro Astro	1	-134 ±12	-206 ± 7	-503 ± 9				
24	Johnston Island 1961	1	-161 ±13	51 ±25	211 ±13				
26	Luzon 1911 (Philippines)	1	151 ±10	51 ± 7	111 ± 8				
27	Midway Astro 1961	1	-377 ± 7	84 ± 7	-279 ± 9				

*If (Datum - Geocenter) is sought add to the tabulated values of Δu, Δv, Δw the respective quantities -21m, -5 m, 2 m see Table 11

**ω, ψ, ϵ when positive, represent counterclockwise rotations about the respective w, v, u axes, as viewed from the end of the positive axis.

Table 13 (cont'd)

Datum No.	Datum Name[1]	No. of stations	Δu (m)*	Δv (m)*	Δw (m)*	ω (″)**	ψ (″)**	ϵ (″)	Δ (×10⁶)
28	New Zealand 1949	1	- 61 ± 8	41 ± 9	-192 ± 9				
29	North American 1927 (W)[5]	8	30.6± 7.3	-170.3± 4.5	-134.9± 6.8	0.21±0.20	0.59±0.21	-0.45±0.23	-7.91±0.45
	North American 1927 (E)[6]	13	56.4± 6.9	-144.6± 4.4	-196.4± 4.3	1.01±0.19	-0.01±0.16	0.54±0.14	2.15±0.62
	North American (All Stations)[7]	21	57.1± 2.2	-147.9± 2.6	-187.5± 2.9	0.86±0.06	0.23±0.06	0.33±0.11	0.80±0.27
36	Pitcairn Island Astro	1	-167 ±12	-168 ±11	- 60 ±11				
39	Provisional South Chile 1963	1	0 ± 8	-196 ± 8	- 93 ± 9				
41	South American 1969[9]	10	54.4± 5.5	30.0± 4.8	42.9± 4.9	-0.63±0.17	0.17±0.12	-0.12±0.13	6.67±0.59
42	Southeast Island (Mahe)	1	54 ± 8	186 ± 8	272 ± 9				
43	South Georgia Astro	1	820 ± 8	-101 ±11	291 ±11				
46	Tokyo	1	183 ±10	-506 ± 9	-686 ± 9				
47	Tristan Astro 1968	1	654 ±14	-420 ±11	622 ±13				
49	Wake Island Astronomic 1952	1	-260 ± 7	67 ±12	-140 ± 8				
50	Yof Astro 1967 (Dakar)	1	55 ± 6	-143 ± 7	- 95 ± 7				
51	Palmer Astro 1969	1	-218 ± 9	- 8 ±12	-226 ±12				

*If (Datum - Geocenter) is sought add to the tabulated values of Δu, Δv, Δw the respective quantities -21m, -5 m, 2 m see Table 11.

**ω, ψ, ϵ when positive, represent counterclockwise rotations about the respective w, v, u axes, as viewed from the end of the positive axis.

Table 13 (cont'd)

[1] See Table 12 for datum description and other related information.

[2] Stations included are Tromso (6006), Catania (6016), Hohenpeissenberg (6065), Wippolder (8009), Zimmerwald (8010), Haute Provence (8015), Nice (8019), Meudon (8030), San Fernando (9004), Dionysos (9091) and Harestua (9426).

[3] Stations included are as in #2 and Mashhad (6015), Malvern (8011), Naini Tal (9006), Shiraz (9008) and Riga (9431).

[4] Based on p. 70, Bulletin Geodesique, 107, 1973.

[5] Stations included are Goldstone (1030), Colorado Springs (3400), Vandenberg AFB (4280), Wrightwood II (6134), Moses Lake (6003), Edinburg (7036), Denver (7045) and Organ Pass (9001).

[6] Stations included are Blossom Point (1021), Fort Myers (1022), E. Grand Forks (1034), Rosman (1042), Bedford (3401), Semmes (3402), Hunter AFB (3648), Aberdeen (3657), Homestead (3861), Beltsville (6002), Greenbelt (7043), Jupiter (7072) and Sudbury (7075).

[7] Stations included are as in #4 and #5 above.

[8] Stations included are Brasilia (3414), Asunction (3431), Bogota (3477), Paramaribo (6008), Quito (6009), Villa Dolores (6019), Natal (6067), Arequipa (9007), Curacao (9009) and Comodoro Rivadavia (9031).

Table 14

Summary of Cartesian Coordinates (Solutions WN12 and WN14)

STATION		SOLUTION WN-12						SOLUTION WN-14					
NO	NAME	U	V	W	σ_u	σ_v	σ_w	U	V	W	σ_u	σ_v	σ_w
1021	BLOSSOM POINT	1118021.8	-4876331.7	3942970.9	3.1	4.0	4.2	1118023.1	-4876323.4	3942963.9	2.8	2.6	2.8
1022	FORT MYERS	807850.8	-5652004.0	2833509.0	2.6	3.3	3.3	807851.9	-5651989.6	2833500.2	2.2	1.9	2.3
1030	GOLDSTONE	-2357249.2	-4646346.4	3668312.5	6.1	4.4	4.7	-2357242.9	-4646338.5	3668306.8	5.6	3.3	3.2
1032	ST. JOHN'S	2602704.3	-3419179.7	4697621.1	49.1	89.5	29.9	2602688.6	-3419228.9	4697637.3	39.3	46.7	13.8
1033	FAIRBANKS	-2299292.3	-1445690.5	5751823.3	7.5	10.0	10.5	-2299282.6	-1445693.7	5751811.6	6.9	9.7	5.7
1034	E. GRAND FORKS	-521708.3	-4242074.9	4718726.5	3.5	4.0	4.4	-521704.5	-4242064.3	4718716.8	3.1	3.0	2.7
1042	ROSMAN	647495.9	-5177948.0	3656714.4	3.1	3.6	4.0	647497.5	-5177935.6	3656705.9	2.8	2.4	2.8
3106	ANTIGUA	2881840.5	-5372180.7	1868548.5	4.1	4.6	4.9	2881838.3	-5372164.6	1868538.6	3.7	3.3	4.3
3334	STONEVILLE	-84969.1	-5327986.3	3493434.3	15.6	14.0	10.8	-84963.8	-5327974.9	3493428.3	13.6	6.8	9.0
3400	COLORADO SPRINGS	-1275239.4	-4798062.9	3994229.5	16.3	12.4	8.6	-1275207.2	-4798029.3	3994208.3	9.1	5.1	5.7
3401	BEDFORD	1513134.8	-4463580.1	4283061.2	3.5	5.3	4.6	1513136.1	-4463576.8	4283055.8	3.2	3.4	3.0
3402	SEMMES	167256.1	-5481980.4	3245042.6	4.2	4.3	4.6	167259.7	-5481971.0	3245037.0	3.9	2.8	3.5
3404	SWAN ISLAND	642485.7	-6053942.4	1895690.5	5.0	5.3	5.5	642491.4	-6053940.3	1895688.6	4.7	3.7	4.9
3405	GRAND TURK	1919482.1	-5621096.5	2315780.1	3.6	5.6	4.9	1919482.9	-5621088.1	2315775.3	3.3	3.5	4.0
3406	CURACAO	2251802.9	-5816929.0	1327197.4	2.8	3.5	3.8	2251800.2	-5816912.9	1327191.1	2.4	2.1	3.4
3407	TRINIDAD	2979892.9	-5513532.6	1181126.8	5.2	5.1	5.9	2979891.1	-5513530.9	1181129.3	4.7	3.4	5.3
3413	NATAL	5186366.4	-3654225.1	-653022.7	3.4	2.9	3.2	5186348.4	-3654222.4	-653018.9	2.1	2.2	2.7
3414	BRASILIA	4114987.8	-4554148.5	-1732166.1	9.9	8.4	7.9	4114977.8	-4554142.5	-1732154.0	7.7	6.1	7.2
3431	ASUNCION	3093056.1	-4870100.4	-2710845.8	8.5	9.3	12.5	3093045.4	-4870081.7	-2710823.0	7.6	6.5	10.8
3476	PARAMARIBO	3623293.6	-5214213.7	601514.0	3.4	3.3	3.6	3623277.3	-5214210.7	601515.3	2.2	2.0	3.0
3477	BOGOTA	1744649.6	-6114305.6	532205.2	10.4	13.7	9.8	1744650.2	-6114296.7	532208.6	10.2	6.6	9.6
3478	MANAUS	3185705.4	-5514574.5	-347713.2	19.3	35.4	35.8	3185777.0	-5514585.9	-347703.2	18.7	14.5	35.1
3499	QUITO	1280834.0	-6250966.2	-10605.5	3.8	5.9	4.5	1280834.2	-6250955.9	-10000.6	3.6	3.4	4.1
3648	HUNTER AFB	832562.6	-5349553.4	3360596.4	4.1	5.0	5.4	832566.2	-5349540.7	3360585.3	3.6	2.5	3.6
3657	ABERDEEN	1186786.1	-4785205.1	4032892.3	3.4	5.0	4.5	1186787.1	-4785193.1	4032882.3	3.1	3.0	3.0
3861	HOMESTEAD	961766.7	-5679170.6	2729893.8	3.3	3.8	3.7	961767.9	-5679156.6	2729883.5	3.0	2.3	2.6
3902	CHEYENNE	-1234689.4	-4651235.9	4174763.4	28.6	32.1	11.3	-1234700.7	-4651242.8	4174758.6	8.6	6.3	6.3
3903	HERNDON	1088960.0	-4842973.2	3991763.9	12.3	15.5	11.4	1088989.7	-4843005.4	3991776.6	12.1	8.5	8.9
4050	PRETORIA	5051614.8	2726608.6	-2774181.0	4.4	3.8	5.5	5051608.1	2726603.3	-2774166.8	3.2	3.2	4.4
4061	ANTIGUA	2881594.5	-5372540.2	1868034.3	4.2	4.7	5.0	2881592.3	-5372523.9	1868024.4	3.8	3.5	4.3
4081	GRAND TURK	1920409.9	-5619426.1	2319133.4	3.7	5.7	5.0	1920410.9	-5619417.8	2319128.5	3.3	3.6	4.0
4082	MERRITT ISLAND	910567.9	-5539130.2	3017974.8	2.9	3.8	3.7	910567.2	-5539113.2	3017965.3	2.6	2.4	2.8
4280	VANDENBERG AFB	-2671883.7	-4521217.3	3607495.0	4.3	4.4	4.8	-2671873.8	-4521210.5	3607490.4	3.8	3.3	3.6
4740	BERMUDA	2308808.6	-4874314.8	3393092.0	3.8	5.4	5.1	2308807.3	-4874298.2	3393082.1	3.3	3.1	3.8
5001	HERNDON	1088874.4	-4842954.9	3991857.8	4.9	10.2	7.9	1088849.4	-4842948.7	3991840.2	3.6	3.0	3.7
5201	MOSES LAKE	-2127810.4	-3785912.3	4656011.9	2.7	2.8	3.7	-2127802.2	-3785911.5	4656012.1	2.3	2.2	2.4
5410	MIDWAY ISLANDS	-5618764.5	-258231.5	2997243.8	2.9	3.2	4.1	-5618754.1	-258237.5	2997250.2	2.3	2.8	3.6
5648	FORT STEWART	794687.3	-5360063.7	3353093.5	4.2	5.0	5.5	794691.0	-5360051.1	3353082.4	3.6	2.5	3.6
5712	PARAMARIBO	3623307.1	-5214190.5	601672.3	3.4	3.3	3.6	3623289.8	-5214188.0	601673.2	2.1	2.0	2.9
5713	TERCEIRA	4433654.4	-2268159.2	3971673.1	2.7	2.8	3.8	4433637.8	-2268153.2	3971656.8	2.0	2.2	2.5

Table 14 (cont'd)

STATION		SOLUTION WN-12						SOLUTION WN-14					
NO	NAME	U	V	W	σ_u	σ_v	σ_w	U	V	W	σ_u	σ_v	σ_w
5715	DAKAR	5884479.9	-1853580.1	1612763.8	2.3	2.5	3.1	5884468.8	-1853580.1	1612760.1	1.6	2.0	2.3
5717	FORT LAMY	6023416.1	1617949.5	1331651.2	2.7	2.8	3.3	6023410.7	1617946.5	1331655.8	2.0	2.0	2.7
5720	ADDIS ABABA	4900750.1	3968255.1	966348.3	2.7	2.9	3.4	4900749.1	3968253.0	966354.7	2.0	2.1	2.9
5721	MASHHAD	2604406.6	4444124.9	3750345.7	2.6	2.8	3.5	2604404.8	4444122.3	3750344.3	2.1	2.1	2.7
5722	DIEGO GARCIA	1905122.3	6032294.5	-810776.4	4.2	5.5	4.8	1905127.0	6032287.5	-810716.2	3.5	4.1	4.3
5723	CHIANG MAI	-941713.7	5967448.6	2039317.5	3.1	3.3	4.1	-941709.4	5967445.0	2039322.9	2.5	2.3	3.5
5726	ZAMBOANGA	-3361953.2	5365845.5	763623.6	3.0	3.3	3.8	-3361946.8	5365837.0	763627.8	2.3	2.2	3.2
5730	WAKE ISLAND	-5858583.8	1394474.9	2093844.7	2.8	3.1	3.8	-5858574.6	1394467.2	2093847.4	2.1	2.5	3.1
5732	PAGO PAGO	-6099984.0	-997345.6	-1568577.0	5.7	4.4	4.9	-6099970.5	-997355.3	-1568570.9	3.6	3.5	4.1
5733	CHRISTMAS ISLAND	-5885350.8	-2448375.3	221663.1	4.4	3.5	4.6	-5885333.9	-2448380.4	221670.7	2.7	2.9	3.9
5734	SHEMYA	-3851808.1	396416.1	5051343.3	3.2	3.7	4.9	-3851799.0	396409.3	5051342.0	2.7	3.3	3.9
5735	NATAL	5186368.5	-3654226.0	-653022.6	3.3	2.8	3.1	5186350.6	-3654223.7	-653018.9	2.0	2.1	2.5
5736	ASCENSION ISLAND	6118355.5	-1571763.1	-878558.4	3.3	2.9	3.3	6118340.3	-1571761.9	-878553.6	2.3	2.2	2.7
5739	TERCEIRA	4433646.0	-2268192.2	3971663.3	2.7	2.8	3.8	4433629.3	-2268186.2	3971647.0	2.0	2.2	2.5
5744	CATANIA	4896444.1	1316129.4	3856628.4	2.4	2.8	3.2	4896437.7	1316125.0	3856626.2	1.8	2.2	2.3
5907	WORTHINGTON	-449391.6	-4600910.6	4380315.4	5.8	13.8	13.5	-449417.5	-4600905.5	4380288.1	4.2	3.2	4.5
5911	BERMUDA	2308010.4	-4873778.3	3394476.1	3.6	4.9	5.2	2307991.2	-4873773.2	3394463.4	2.6	2.3	3.0
5912	PANAMA	1142664.4	-6196104.1	988340.8	4.8	9.1	7.0	1142644.5	-6196109.1	988336.6	3.1	3.4	4.1
5914	PUERTO RICO	2349423.9	-5576023.2	2010340.5	13.5	21.1	9.7	2349456.9	-5576027.1	2010342.6	10.5	7.0	6.4
5915	AUSTIN	-744066.7	-5465234.3	3192485.8	5.6	15.3	12.8	-744091.1	-5465238.7	3192467.4	3.8	3.8	4.7
5923	CYPRUS	4363335.9	2862258.8	3655380.7	2.5	2.7	3.3	4363332.2	2862254.9	3655380.7	1.9	2.1	2.4
5924	ROTA	5093565.8	-565319.1	3784273.1	2.4	3.1	3.8	5093556.2	-565322.3	3784268.3	1.9	2.6	2.9
5925	ROBERTS FIELD	6237376.8	-1140241.8	687740.0	3.0	3.1	3.6	6237366.3	-1140241.5	687740.2	2.3	2.6	3.0
5930	SINGAPORE	-1542556.4	6186964.6	151827.8	3.3	3.9	4.0	-1542549.4	6186956.7	151833.8	2.6	2.7	3.4
5931	HONG KONG	-2423919.1	5388254.8	2394863.9	3.1	3.5	4.3	-2423914.9	5388250.3	2394869.2	2.5	2.5	3.6
5933	DARWIN	-4071578.3	4714267.0	-1366533.3	4.3	4.4	4.3	-4071568.4	4714253.3	-1366528.3	3.2	3.2	3.7
5934	MANUS	-5367671.7	3437861.4	-225419.4	3.6	3.5	3.8	-5367663.1	3437869.9	-225416.0	2.5	2.5	3.3
5935	GUAM	-5059832.6	3591194.2	1472759.4	2.9	3.0	3.4	-5059825.7	3591186.0	1472762.5	2.1	2.2	2.8
5937	PALAU	-4433470.5	4512939.3	809955.3	3.1	3.2	3.7	-4433463.6	4512930.3	809958.7	2.2	2.2	3.2
5938	GUADALCANAL	-5915106.0	2146873.2	-1037912.8	4.4	3.9	4.0	-5915096.5	2146860.8	-1037909.5	3.0	3.0	3.5
5941	MAUI	-5467771.9	-2381242.7	2254024.0	3.5	3.2	4.4	-5467757.3	-2381246.7	2254033.8	2.5	2.8	3.8
6001	THULE	546566.4	-1389993.6	6180242.4	2.7	2.7	4.4	546560.7	-1389993.7	6180236.7	2.6	2.4	3.4
6002	BELTSVILLE	1130762.7	-4830837.6	3994709.9	2.2	2.7	3.1	1130764.9	-4830831.9	3994704.0	2.0	1.7	1.9
6003	MOSES LAKE	-2127839.9	-3705864.2	4656037.4	2.5	2.7	3.5	-2127832.1	-3705863.0	4656037.2	2.1	2.0	2.3
6004	SHEMYA	-3851806.8	396416.1	5051341.7	3.2	3.7	5.0	-3851797.5	396409.4	5051340.5	2.7	3.3	3.9
6006	TROMSO	2102930.3	721674.1	5958181.7	2.7	3.3	4.4	2102927.4	721660.5	5958180.8	2.4	2.9	2.9
6007	TERCEIRA	4433653.3	-2268156.9	3971671.0	2.7	2.7	3.8	4433637.3	-2268151.4	3971655.0	2.0	2.2	2.5
6008	PARAMARIBO	3623257.3	-5214236.7	601534.8	3.4	3.3	3.6	3623241.0	-5214233.7	601536.1	2.1	2.0	2.9
6009	QUITO	1280834.0	-6250966.2	-10805.5	3.8	5.9	4.5	1280834.2	-6250955.9	-10800.6	3.6	3.4	4.1
6011	MAUI	-5466039.2	-2404429.3	2242224.6	4.4	3.4	3.9	-5466018.6	-2404431.5	2242224.4	3.0	2.9	3.3

Table 14 (cont'd)

STATION		SOLUTION WN-12						SOLUTION WN-14					
NO	NAME	U	V	W	σ_u	σ_v	σ_w	U	V	W	σ_u	σ_v	σ_w
6012	WAKE ISLAND I	-5858578.8	1394516.4	2093817.4	2.9	3.2	3.8	-5858569.3	1394508.7	2093820.3	2.1	2.6	3.2
6013	KANOYA	-3565901.4	4120723.2	3303426.9	4.0	5.2	5.9	-3565892.8	4120713.6	3303428.3	3.3	4.4	4.9
6015	MASHHAD	2604355.4	4444169.2	3750321.7	2.6	2.9	3.5	2604353.3	4444166.0	3750320.5	2.1	2.2	2.6
6016	CATANIA	4896394.6	1316176.2	3856670.7	2.4	2.8	3.2	4896380.3	1316172.1	3856660.2	1.8	2.2	2.2
6019	VILLA DOLORES	2280630.7	-4914547.7	-3355417.9	2.7	3.6	5.2	2280627.1	-4914543.2	-3355402.8	2.4	2.7	3.7
6020	EASTER ISLAND	-1888621.5	-5354898.4	-2895762.3	6.0	6.1	6.9	-1888614.3	-5354894.4	-2895749.0	5.4	4.5	5.5
6022	TUTUILA	-6099975.9	-997357.7	-1568593.6	4.8	3.9	5.2	-6099961.7	-997362.2	-1568585.5	3.4	3.6	4.7
6023	THURSDAY ISLAND	-4955391.2	3842255.7	-1163855.5	4.5	3.9	4.7	-4955386.8	3842247.8	-1163847.4	3.2	3.0	4.0
6031	INVERCARGILL	-4313830.4	891340.6	-4597277.7	4.4	4.2	5.3	-4313825.3	891333.9	-4597265.8	3.4	3.9	3.8
6032	CAVERSHAM	-2375426.0	4875557.6	-3345424.5	3.7	4.3	5.0	-2375420.6	4875546.7	-3345411.1	3.3	3.2	3.9
6038	SOCORRO ISLAND	-2160989.6	-5642717.9	2035360.0	2.9	3.8	4.4	-2160980.9	-5642710.5	2035367.8	2.5	2.8	3.8
6039	PITCAIRN ISLAND	-3724775.0	-4421234.4	-2686094.4	7.9	7.2	7.3	-3724765.9	-4421237.6	-2686084.7	6.2	5.4	5.5
6040	COCOS ISLAND	-741986.1	6190803.6	-1338557.1	4.7	4.8	4.7	-741981.7	6190792.9	-1338546.3	4.5	3.7	4.2
6042	ADDIS ABABA	4900752.0	3968255.1	966318.9	2.7	2.9	3.4	4900750.7	3968252.7	966325.3	2.0	2.1	2.9
6043	CERRO SOMBRERO	1371376.5	-3614750.6	-5055947.1	3.5	4.2	7.0	1371375.9	-3614750.3	-5055927.8	3.3	3.8	4.8
6044	HEARD ISLAND	1098898.5	3684617.0	-5071900.1	6.9	6.7	11.1	1098897.9	3684606.6	-5071873.1	6.8	6.2	7.8
6045	MAURITIUS	3223434.7	5045343.6	-2191818.0	3.6	4.0	4.6	3223432.0	5045336.3	-2191805.7	3.2	3.1	3.9
6047	ZAMBOANGA	-3361983.5	5365820.6	763620.5	3.1	3.4	3.8	-3361976.9	5365811.9	763624.7	2.4	2.3	3.2
6050	PALMER STATION	1192679.3	-2451013.2	-5747052.4	5.0	6.3	9.8	1192678.8	-2451015.6	-5747034.2	4.9	6.1	6.1
6051	MAWSON STATION	1111337.1	2169270.2	-5874355.2	5.0	4.2	7.3	1111336.1	2169262.7	-5874334.1	4.9	3.7	4.4
6052	WILKES STATION	-902611.4	2409530.0	-5816569.9	4.6	4.4	7.4	-902608.8	2409522.1	-5816551.8	4.4	4.0	5.4
6053	MCMURDO STATION	-1310854.8	311262.9	-6213294.3	4.8	4.8	7.4	-1310852.3	311257.5	-6213276.5	4.6	4.5	4.3
6055	ASCENSION ISLAND	6118349.3	-1571749.2	-878601.3	3.3	2.9	3.4	6118334.2	-1571748.3	-878596.5	2.3	2.3	2.8
6059	CHRISTMAS ISLAND	-5885350.2	-2448374.4	221663.6	4.3	3.4	4.5	-5885333.5	-2448379.0	221671.1	2.7	2.9	3.8
6060	CULGOORA	-4751655.0	2792065.7	-3200174.2	4.5	4.0	4.7	-4751650.0	2792058.1	-3200164.0	3.3	3.3	3.7
6061	SOUTH GEORGIA IS.	2999921.2	-2219366.3	-5155267.1	3.9	5.9	7.8	2999915.6	-2219369.3	-5155246.0	3.7	5.7	5.3
6063	DAKAR	5884479.3	-1853496.4	1612858.7	2.4	2.6	3.2	5884467.4	-1853495.8	1612855.1	1.7	2.1	2.5
6064	FORT LAMY	6023394.4	1617934.2	1331731.7	3.3	3.1	3.7	6023386.7	1617931.9	1331733.2	2.7	2.6	3.2
6065	HOHENPEISSENBERG	4213570.2	820833.7	4702786.5	2.6	3.0	3.6	4213564.6	820830.0	4702784.4	2.0	2.4	2.3
6066	WAKE ISLAND II	-5858580.7	1394474.0	2093843.0	2.9	3.2	3.8	-5858571.2	1394466.4	2093846.0	2.1	2.6	3.2
6067	NATAL	5186415.0	-3653935.9	-654280.7	3.3	2.8	3.1	5186397.1	-3653933.3	-654276.9	2.1	2.2	2.6
6068	JOHANNESBURG	5084837.1	2670346.5	-2768109.3	4.2	3.5	5.3	5084830.4	2670341.2	-2768095.2	3.0	2.9	4.2
6069	TRISTAN DA CUNHA	4978430.9	-1086871.1	-3823187.7	8.3	6.6	10.4	4978421.7	-1086874.0	-3823167.8	6.5	6.4	8.1
6072	CHIANG MAI	-941707.8	5967462.5	2039307.4	5.9	5.1	4.9	-941702.1	5967455.1	2039311.6	5.7	4.0	4.3
6073	DIEGO GARCIA	1905134.3	6032292.0	-810742.3	3.7	4.8	4.7	1905134.1	6032282.4	-810732.7	3.4	3.7	4.2
6075	MAHE	3602824.5	5238248.2	-515957.7	4.2	4.6	4.5	3602820.6	5238240.7	-515948.3	3.8	3.6	4.0
6078	PORT VILA	-5952307.7	1231910.5	-1925983.7	19.9	9.4	16.6	-5952303.4	1231904.9	-1925972.5	9.7	8.0	12.4
6111	WRIGHTWOOD I	-2448862.8	-4667992.3	3582759.4	3.0	3.2	3.8	-2448853.3	-4667985.8	3582754.9	2.6	2.1	2.4
6123	POINT BARROW	-1881807.4	-812435.3	6019599.3	4.9	4.6	7.1	-1881799.4	-812439.0	6019590.7	4.6	4.4	4.5
6134	WRIGHTWOOD II	-2448916.5	-4668082.4	3582454.1	3.0	3.2	3.8	-2448907.0	-4668075.9	3582449.6	2.6	2.1	2.4

Table 14 (cont'd)

STATION		SOLUTION WN-12						SOLUTION WN-14					
NO	NAME	U	V	W	σ_u	σ_v	σ_w	U	V	W	σ_u	σ_v	σ_w
7036	EDINBURG	-828491.0	-5657486.5	2816825.5	3.8	3.9	4.0	-828487.0	-5657471.3	2816816.0	3.5	2.4	2.9
7037	COLUMBIA	-191294.8	-4967308.3	3983264.5	3.2	3.5	3.9	-191291.0	-4967293.9	3983252.6	2.9	2.2	2.4
7039	BERMUDA	2308214.8	-4873614.8	3394568.4	3.7	5.3	5.0	2308213.4	-4873598.3	3394558.5	3.3	3.1	3.6
7040	SAN JUAN	2465050.9	-5534945.5	1985522.2	4.0	4.4	4.7	2465049.5	-5534930.0	1985513.1	3.7	3.2	4.0
7043	GREENBELT	1130706.5	-4831337.2	3994141.4	2.2	2.7	3.1	1130708.6	-4831331.3	3994135.5	2.0	1.7	1.9
7045	DENVER	-1240475.1	-4760256.0	4048997.8	4.6	4.2	4.7	-1240470.2	-4760242.1	4048985.3	4.2	2.8	2.9
7072	JUPITER	976261.3	-5601416.4	2880251.4	2.5	3.3	3.3	976261.3	-5601399.9	2880241.9	2.2	1.8	2.3
7075	SUDBURY	692618.7	-4347090.4	4600487.7	4.0	5.7	5.4	692620.7	-4347076.5	4600475.4	3.7	3.8	3.4
7076	KINGSTON	1384159.2	-5905680.0	1966554.4	4.3	5.8	5.9	1384158.7	-5905662.0	1966545.7	4.1	4.4	5.3
8009	WIPPOLDER	3923429.9	299866.1	5003013.3	13.3	13.1	15.2	3923397.4	299869.4	5002975.5	8.5	10.1	6.9
8010	ZIMMERWALD	4331312.7	567499.7	4633118.9	7.9	10.9	11.5	4331307.0	567490.8	4633108.3	5.7	8.3	5.4
8011	MALVERN	3920186.9	-134806.7	5012776.2	12.8	16.5	15.5	3920153.5	-134804.5	5012734.8	8.9	14.3	6.9
8015	HAUTE PROVENCE	4578328.1	457945.6	4403204.8	6.4	10.7	10.2	4578322.1	457936.5	4403195.3	4.2	8.0	4.4
8019	NICE	4579469.1	586582.7	4386428.4	6.3	10.6	10.1	4579463.2	586573.5	4386419.2	4.1	7.9	4.3
8030	MEUDON	4205629.1	163695.4	4776550.9	9.0	12.3	11.8	4205626.9	163683.4	4776540.6	6.5	9.7	5.8
9001	ORGAN PASS	-1535755.1	-5167026.6	3401047.1	4.6	3.9	3.8	-1535750.7	-5167014.4	3401039.4	4.2	2.8	2.7
9002	OLIFANTSFONTEIN	5056115.1	2716514.0	-2775782.9	4.2	3.6	5.3	5056108.4	2716508.7	-2775768.8	3.0	3.0	4.2
9004	SAN FERNANDO	5105589.8	-555269.7	3769680.6	6.3	12.9	8.5	5105581.5	-555271.5	3769676.0	3.4	10.0	4.0
9005	TOKYO	-3946751.4	3366303.2	3698830.3	11.2	10.3	9.8	-3946730.5	3366286.1	3698822.9	9.2	9.0	7.5
9006	NAINI TAL	1018153.3	5471119.3	3109622.2	14.2	10.9	9.6	1018164.5	5471108.7	3109625.6	12.4	5.5	6.0
9007	AREQUIPA	1942762.4	-5804101.6	-1796905.8	2.8	4.0	5.3	1942760.9	-5804098.2	-1796900.9	2.5	2.9	4.4
9008	SHIRAZ	3376872.6	4403990.0	3136250.1	8.1	10.3	9.5	3376875.2	4403976.2	3136257.3	6.8	6.1	6.1
9009	CURACAO	2251813.5	-5816933.6	1327169.7	2.8	3.5	3.8	2251810.7	-5816917.6	1327163.4	2.4	2.1	3.4
9010	JUPITER	976276.2	-5601418.8	2880244.0	2.5	3.3	3.3	976276.2	-5601402.2	2880234.5	2.1	1.8	2.3
9011	VILLA DOLORES	2280578.9	-4914584.8	-3355398.8	2.7	3.6	5.3	2280575.3	-4914580.2	-3355383.7	2.4	2.7	3.7
9012	MAUI	-5466088.5	-2404310.5	2242188.7	4.5	3.4	3.9	-5466067.8	-2404312.7	2242180.4	3.0	2.9	3.3
9021	MOUNT HOPKINS	-1936799.1	-5077719.4	3331926.1	7.3	6.8	6.4	-1936789.3	-5077714.7	3331922.7	7.1	5.3	5.3
9028	ADDIS ABABA	4903727.7	3965208.6	963853.2	2.8	2.9	3.4	4903726.6	3965206.3	963859.6	2.1	2.1	2.9
9029	NATAL	5186459.3	-3653874.6	-654317.9	3.4	2.9	3.2	5186441.4	-3653871.9	-654314.1	2.1	2.2	2.7
9031	COMODORO R'DAVIA	1693795.5	-4112354.3	-4556644.1	8.4	9.4	14.3	1693797.3	-4112353.1	-4556622.0	8.3	8.8	11.2
9051	ATHENS	4606866.7	2029708.0	3903567.4	6.0	12.6	8.9	4606861.5	2029692.2	3903562.2	4.2	10.3	4.4
9091	DIONYSOS	4595164.1	2039433.4	3912675.8	6.0	12.6	8.9	4595158.9	2039417.6	3912670.6	4.2	10.3	4.4
9424	COLD LAKE	-1264834.5	-3466912.6	5185449.2	5.2	6.5	7.7	-1264831.9	-3466915.4	5185450.9	4.7	5.5	4.3
9425	EDWARDS AFB	-2450022.2	-4624438.2	3635041.1	3.1	3.2	3.8	-2450012.7	-4624431.6	3635036.6	2.6	2.2	2.4
9426	HARESTUA	3121262.6	592607.0	5512720.9	9.6	11.4	15.5	3121261.3	592605.7	5512723.0	8.6	9.4	5.8
9427	JOHNSTON ISLAND	-6007458.1	-1111834.2	1825730.0	10.9	20.6	8.8	-6007428.7	-1111852.5	1825733.9	8.9	19.8	8.6
9431	RIGA	3183691.2	1421439.3	5322819.8	13.1	11.7	14.7	3183897.6	1421426.7	5322814.7	12.3	9.4	7.0
9432	UZHGOROD	3907423.8	1602394.2	4763932.7	10.2	12.6	13.7	3907419.2	1602378.6	4763922.1	7.9	10.4	5.9

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8. Discussion

MELCHIOR: Can you tell me where the BIH zero meridian is, and where CIO is?

MUELLER: Theoretically, the BIH zero meridian and CIO should be exactly those of WN14, for they were enforced in this solution.

MELCHIOR: The NWL solution has also been adjusted to that.

MUELLER: These numbers (transformation parameters) are based on the published co-ordinates and there is no agreement. We have done a lot of thinking since this thing was noticed last June and there is no easy explanation. In the dynamic solution, due to the fact that some of the harmonic coefficients are enforced to be zero, some biasing can happen to the co-ordinate systems. I hope that next summer we can have a conference on the topic to resolve this problem.

BOMFORD: A variety of co-ordinates are being produced for stations on the world network. In Europe, no co-ordinate system has yet been adopted because every four years at the IAG more information is produced which people think should be included. I ask our colleagues from the United States if WN14, which I think is an excellent solution, is likely to be adopted in any formal way? Do we wait tili we go to Grenoble in 1975, by which time there is likely to be some more information? What is likely to happen?

MUELLER: I think this is a political question. I really cannot answer this at all. We have to keep producing improved solutions and let someone else decide on which of the systems should be used. A scientist always *uses* the best current solution and not an earlier *adopted* one. My suggestion is : Don't wait for an international body to adopt a solution. A user should decide on which set suits his needs and then determine the relations between this system and all other available systems.