Department of Geodetic Science

# BASIC RESEARCH AND DATA ANALYSIS FOR THE EARTH AND OCEAN PHYSICS APPLICATIONS PROGRAM AND FOR THE NATIONAL GEODETIC SATELLITE PROGRAM

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Columbus, Ohio 43212

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## PREFACE

These projects are under the supervision of Professor Ivan I. Mueller, Department of Geodetic Science, The Ohio State University, and are under the technical direction of Mr. James P. Murphy, Special Programs, Office of Applications, NASA Headquarters, Washington, D.C. 20546. The contracts are administered by the Office of University Affairs, NASA Headquarters, Washington, D.C. 20546.

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## 1. STATEMENT OF WORK

The statement of work includes data analysis and supporting research in connection with the following broad objectives:

(1) Provide a precise and accurate geometric description of the earth's surface.

(2) Provide a precise and accurate mathematical description of the earth's gravitational field.

(3) Determine time variations of the geometry of the ocean surface, the solid earth, the gravity field and other geophysical parameters.

## 2. ACTIVITIES RELATED TO THE NGSP
(Grant No. NGL 36-008-093)

### 2.1 Satellite Triangulation in Europe from WEST and ISAGEX Data

In 1974 the Department of Geodetic Science at The Ohio State University (OSU) obtained observational data that was acquired during the Western European Satellite Triangulation (WEST) program and the International Satellite Geodesy Experiment (ISAGEX) campaign.

The purpose of obtaining this data was twofold. Primarily, it was intended that a geometric solution be performed to improve the present values of coordinates of the European stations in the OSU WN14 solution. The secondary aim was to add some new stations and to assess the quality of the WN14 solution with the help of the additional data available.

#### 2.11 Data

The sets of data were thoroughly described in the Fifteenth and Sixteenth Semiannual Status Reports. No additional data has been acquired.

#### 2.12 Adjustments

A total of three solutions were performed. Solution WEST33 and WEST34 contain only observational data of the Western European Satellite Triangulation and WEST-ISAGEX36 (W.I.36) is a combination solution containing also the data of the ISAGEX campaign. In all cases only the single image data were processed. Preliminary computations with the seven image data (with assumed statistics about the observations) resulted in seemingly distorted station coordinates. In absence of any knowledge about the statistics of the observational data, it was felt very doubtful that the seven image data could improve the results of the single image data computation. Any further analysis with seven image data, therefore, must await knowledge about the statistics of the data.

The results of the WEST33 solution were submitted the the XVI General Assembly of the IUGG held in Grenoble, France from August 18 through September 6, 1975. The solutions WEST34 and W.I. 36 are documented in Reports of the Department of Geodetic Science No. 232, OSU.

The solutions WEST33 and WEST34 differ basically in the number of base lines which were constrained. It was recognized that the base line TROMSO-CATANIA was not sufficient to transfer scale to the whole net. The WEST satellite network is considered as consisting of two blocks: the central European block with a large number of observations and the northern block which is connected to the central block by relatively few observations (namely, between TROMSO and some stations of the central block). An overall scale factor of 10 ppm was computed between the ED50 coordinates and the adjusted values. Comparing individual chords in the two systems, it became clear that all chords originating from TROMSO yield a significantly smaller scale factor. Also the scale for the central area is partly inherent in the weighted positional constraints of the WN14 stations. It thus became necessary to include more chord constraints, especially in the central area. These were taken from [Ehrnsperger, 1974].

### 2.13 Results

(1) The ISAGEX data added three stations to the WEST34 system. Due to the small number of ISAGEX observations, only a minor improvement could be gained by the addition of the ISAGEX data.

(2) The coordinates of about seven stations still exhibit extraordinarily large standard deviations. This is an immediate result of the increased variances of the observational data (see Table 4 in [Ehrnsperger, 1974] for the standard errors stationwise, as obtained by the smoothing procedure), or it is due to lack of a sufficient number of observations or to unfavorable geometrical conditions.

(3a) Various transformations were carried out between the W.I. 36 solution and other systems. While the computed rotation angles between the W.I. 36 and the ED50 system are all below the one sigma level, the translation parameters agree well with those of solutions of other investigators.

(3b) Special effort was made to find the scale factor between the ED50 and the W.I. 36 system. The seven parameter transformation gives a scale factor of $\Delta(\text{ppm}) = 6.12 \pm 2.77$. However, there is evidence [Weightman, 1975] that current publications give revised coordinates for the terminal station of the European base lines which are based on traverse adjustment. Deleting these stations and the stations with extraordinarily large variances in the coordinates (see 2), the scale factor was computed to $\Delta(\text{ppm}) = 5.92 \pm 3.54$.

(4) The variances of the coordinates for the stations common to the WN14 system were all significantly reduced.

## 2.2 Similarity Transformation and Geodetic Network Distortions Based on Doppler Observations

The purpose of this investigation was twofold: (a) some theoretical contributions are given to the transformation models as used in geodesy, and (b) distortions in geodetic networks are investigated based on these transformation models.

This investigation which is laid down in Reports of the Department of Geodetic Science No. 235, OSU (with the same title as this section), presents a review of the commonly used transformation models and provides a geometrical interpretation for most of these models. It is shown that the translation components as computed from the so-called Molodenskii Model for seven transformation parameters should not be interpreted as the vector between the origins of the two coordinate systems involved. Only the Bursa Model permits such an interpretation. It is further shown that as for direct transformations, both the Bursa and Molodenskii Models give identical results, i.e., the same station coordinates and the same variance-covariance matrix. Also it is shown that the parameters as computed from both models, differ only in the translation components. An expression is given to exactly convert one set of translation vectors into the other.

Pitfalls in partial solutions are also discussed. It has been proposed in several publications [Bursa, 1967 and Kumar, 1972] that the orientation angles and the scale factor be computed separately from direction and chord comparisons by using them in all combinations between stations. Based on the method of eliminating parameters, it is shown that these proposed approaches are wrong as far as the "selection" of direction and chords is concerned. Although these approaches yield parameters which are close to those computed without eliminating some of the seven parameters, their standard deviations are much too optimistic. It is shown that only as many directions and chords can be used in the computation as are needed to completely determine the shape or size of the polyhedron implied in the set of Cartesian coordinates. Each additional element (direction or chord) causes the normal matrix to be singular.

In the closing section of this report a number of tables and maps indicating distortions in the North American Datum 1927, the Precise Traverse System M-R-72, the Australian Geodetic Datum and the South American Datum 1969 are given. The residuals of the coordinates are scanned for systematic patterns after transforming the geodetic system to the NWL9D system. Also, an attempt has been made to plot maps showing scale distortions on the NAD27.

Since the Reports of the Department of Geodetic Science No. 235, OSU does not include tables of coordinates, all the coordinates which were available for this investigation are given below. Some of these coordinates were already given in the Fifteenth Semiannual Status Report. The NWL-9D coordinates have been corrected in the meantime as explained in Attachment 1 of this report.

Table 1

NAD 1927 Coordinates for North American Stations



| | $\phi$ | $\lambda$ | h (m) |
|---|---|---|---|
| 10000 CHEYENNE,WY. | 41° 08′ 00″.069 | 255° 07′ 57″.202 | 1889.5 |
| 10003 GREENVILLE,MS | 33 28 42.470 | 268 59 51.486 | 44.2 |
| 10006 MEADES RANCH,KS | 39 13 26.686 | 261 27 29.494 | 599.4 |
| 10018 JONESTOWN,TX | 30 26 48.273 | 262 01 17.525 | 327.1 |
| 10019 FRANKTON,IN | 40 14 06.956 | 274 10 27.186 | 259.0 |
| 10020 MARYVILLE,IN | 38 35 20.787 | 274 21 07.740 | 212.6 |
| 10021 CASH,KY | 37 33 06.807 | 273 55 10.384 | 265.6 |
| 10022 IUKA,MS | 34 47 15.547 | 271 45 30.291 | 250.4 |
| 10023 WEBSTER,MS | 33 33 54.655 | 270 50 04.504 | 141.3 |
| 10031 GOLDSTONE,CA | 35 25 39.818 | 243 06 40.973 | 994.0 |
| 10055 PILLAR POINT,CA | 37 29 53.441 | 237 30 09.749 | 21.0 |
| 20003 WRIGHTWOOD.CA | 34 22 54.537 | 242 19 09.484 | 2258.8 |
| 20016 COLUMBIA,MS | 31 12 44.555 | 270 16 28.098 | 113.6 |
| 30025 BLOOMFIELD,OH | 40 05 11.583 | 278 15 39.706 | 360.6 |
| 30028 METAMORA.IL | 40 49 20.343 | 270 42 40.598 | 249.0 |
| 30029 MOSES LAKE,WA | 47 11 07.132 | 240 39 48.118 | 355.0 |
| 30098 ORLAND,CA | 39 44 44.602 | 237 50 57.839 | 42.6 |
| 30099 CHANCE 1967.MT | 47 47 07.507 | 251 22 07.573 | 1011.9 |
| 51008 BOLIVIA.NC | 34 02 10.298 | 281 50 39.478 | 6.8 |
| 51014 VALKARIA.FL | 27 57 25.330 | 279 26 31.977 | 13.3 |
| 51015 HIALEAH,FL | 25 53 24.868 | 279 41 34.285 | 16.3 |
| 51025 NEWTON,TX | 30 54 24.116 | 266 23 57.198 | 87.8 |
| 51030 KINGFISHER,OK | 35 47 01.393 | 262 01 13.051 | 363.0 |
| 51033 WOODBINE,IA | 41 42 12.717 | 264 21 21.183 | 425.5 |
| 51039 IRAAN,TX | 30 52 14.928 | 258 04 00.544 | 899.5 |
| 51041 ARTHUR,NB | 41 38 26.878 | 258 24 03.785 | 1184.0 |
| 51043 LOVELL.WY | 44 48 01.705 | 251 39 19.482 | 1220.4 |
| 51044 CRESTON,WY | 41 36 55.904 | 252 12 56.943 | 236.5 |
| 51048 ALBUQUERQUE.NM | 34 56 43.427 | 253 32 26.136 | 1830.1 |
| 51052 PICACHO,AZ | 32 43 24.838 | 248 29 08.192 | 472.8 |
| 51066 TERREBONNE,OR | 44 23 31.948 | 238 42 17.210 | 874.9 |
| 51067 MINERAL WELLS.TX | 32 57 44.684 | 261 54 37.082 | 357.6 |
| 51068 YULEE.FL | 30 41 45.583 | 278 15 59.260 | 21.4 |
| 51069 ASHEPOO,SC | 32 45 31.142 | 279 26 36.927 | 1.9 |
| 51074 MIDLAND,OR | 42 07 21.955 | 238 10 26.638 | 1229.9 |
| 51089 MAYHOOD 1971,CA | 38 08 32.163 | 238 16 38.179 | 21.1 |
| 51103 DONA ANA COUNTY,NM | 32 04 19.274 | 253 31 06.480 | 1268.1 |
| 51121 OPELOUSAS,LA | 30 37 54.669 | 267 50 03.650 | 22.6 |
| 51123 FORT DAVIS,TX | 30 40 16.006 | 255 58 38.812 | 2066.7 |
| 51124 EDEN,TX | 31 02 06.770 | 259 55 09.782 | 716.0 |
| 51125 MILTON,FL | 30 36 06.566 | 273 02 00.006 | 47.6 |
| 51126 MONTICELLO.FL | 30 31 36.400 | 276 12 31.929 | 55.8 |
| 52001 BELTSVILLE.MD | 39 01 39.492 | 283 10 26.756 | 40.1 |
| 52063 DOS PALOS,CA | 36 54 51.030 | 239 26 48.988 | 9.7 |
| 10008 GRAND FORKS.ND | 47 56 38.594 | 262 37 11.201 | 274.0 |
| 10056 SAN NICHOLS,CA | 33 14 48.875 | 240 28 50.994 | 248.3 |
| 10071 GALLUP,NM | 35 31 00.605 | 251 24 25.292 | 2030.6 |
| 20176 AJO,AZ | 32 26 54.473 | 247 08 54.990 | 422.9 |
| 20177 DOUGLAS,AZ | 31 22 36.699 | 250 27 35.724 | 1225.0 |
| 20208 KINGMAN,AZ | 35 11 48.275 | 245 57 35.557 | 1130.7 |
| 30030 GREEN RIVER,UT | 38 58 44.361 | 249 53 20.567 | 1311.1 |
| 51004 CHARLESTON,WV | 38 22 10.576 | 278 24 33.038 | 290.7 |
| 51005 CORBIN,KY | 36 57 21.573 | 275 53 09.046 | 394.5 |
| 51006 CLEVELAND,TN | 35 09 06.794 | 275 06 55.814 | 303.0 |

Table 1 (Continued)
NAD 1927 Coordinates for North American Stations

| | | | | |
|---|---|---|---|---|
| 51007 | LAURENS,SC | 34 35 08.088 | 277 56 35.685 | 224.2 |
| 51009 | SHELBY,AL | 33 07 03.028 | 273 30 01.505 | 222.7 |
| 51010 | SANDERSVILLE,GA | 33 03 38.048 | 277 05 30.233 | 154.1 |
| 51011 | FARMVILLE,VA | 37 18 51.596 | 281 33 38.410 | 142.5 |
| 51013 | CLEARWATER-ST.P.FL | 27 55 12.034 | 277 18 24.707 | 10.4 |
| 51017 | MIFFLINVILLE,PA | 41 00 57.554 | 283 39 41.596 | 295.8 |
| 51019 | HUDSON,NY | 42 14 37.446 | 286 13 23.691 | 112.1 |
| 51020 | ALBURG(GSC),VT | 44 54 29.145 | 286 42 29.965 | 66.8 |
| 51021 | ORLEANS,MA | 41 51 18.929 | 290 02 58.042 | 18.54 |
| 51022 | FAIRFIELD,ME | 44 35 59.357 | 290 24 45.325 | 45.8 |
| 51023 | BOUCHARD PN2,ME | 47 11 53.849 | 291 26 47.633 | 362.0 |
| 51024 | FREEPORT.TX | 29 02 30.776 | 264 39 51.252 | 5.7 |
| 51026 | CLARKSVILLE.TX | 33 38 22.616 | 264 58 57.010 | 153.1 |
| 51027 | SPRINGDALE,AR | 36 10 23.216 | 265 52 40.709 | 412.3 |
| 51028 | THAYER,MO | 36 34 36.984 | 268 22 24.460 | 296.8 |
| 51029 | PLATTE CITY.MO | 39 16 50.961 | 265 13 51.216 | 300.0 |
| 51031 | CLAY CITY,IL | 38 38 14.474 | 271 39 01.645 | 144.2 |
| 51032 | EL DARA,IL | 39 37 27.816 | 268 58 34.875 | 24 .2 |
| 51056 | KEARNS ,UT | 40 38 36.430 | 248 01 46.128 | 1592.1 |
| 51057 | DRY 1965,NV | 40 23 42.057 | 244 47 34.864 | 1847.6 |
| 51058 | DIATOM 1958.NV | 39 49 37.992 | 241 00 56.736 | 1290.9 |
| 51095 | AGAMENTICUS.ME | 43 13 24.048 | 289 18 27.146 | 211.4 |

a = 6378206.4 1/f = 294.9787

Table 2
NWL9D Coordinates for North American Stations

| | | $\phi$ | $\lambda$ | h(m) |
|---|---|---|---|---|
| 10000 | CHEYENNE,WY. | 41° 07′ 59″.949 | 255° 07′ 54″.486 | 1861.32 |
| 10003 | GREENVILLE.MISS. | 33 28 42.7900 | 268 59 50.314 | 7.09 |
| 10006 | MEADES RANCH,KAN. | 39 13 26.642 | 261 27 27.477 | 566.60 |
| 10018 | JONESTOWN,TEX | 30 26 48.888 | 262 01 15.657 | 293.46 |
| 10019 | FRANKTON,IND | 40 14 07.024 | 274 10 26.509 | 222.11 |
| 10020 | MARYVILLE.IND | 38 35 20.929 | 274 21 07.112 | 175.50 |
| 10021 | CASH,KY | 37 33 06.952 | 273 55 09.742 | 229.40 |
| 10022 | IUKA,MISS | 34 47 15.796 | 271 45 29.375 | 211.70 |
| 10023 | WEBSTER,MISS | 33 33 54.992 | 270 50 03.480 | 103.60 |
| 10031 | GOLDSTONE,CALIF. | 35 25 39.587 | 243 06 36.946 | 981.36 |
| 10055 | PILLAR POINT,CA | 37 29 53.123 | 237 30 04.985 | 13.51 |
| 20003 | WRIGHTWOOD,CAL | 34 22 54.416 | 242 19 05.403 | 2244.72 |
| 20016 | COLUMBIA,MISS | 31 12 45.084 | 270 16 27.027 | 76.91 |
| 30025 | BLOOMFIELD,OHIO | 40 05 11.758 | 278 15 39.452 | 321.94 |
| 30028 | METAMORA,ILL | 40 49 20.392 | 270 42 39.553 | 210.82 |
| 30029 | MOSES LAKE,WASH | 47 11 06.562 | 240 39 43.163 | 338.51 |
| 30098 | ORLAND,CALIFORNIA | 39 44 44.086 | 237 50 53.043 | 32.464 |
| 30099 | CHANCE1967.MONTANA | 47 47 07.425 | 251 22 04.173 | 984.20 |
| 51008 | BOLIVIA,NORTH CAR. | 34 02 10.816 | 281 50 39.664 | -34.318 |
| 51014 | VALKARIA.FLORIDA | 27 57 26.282 | 279 26 31.981 | -30.265 |
| 51015 | HIALEAH,FLORIDA | 25 53 26.196 | 279 41 34.325 | -28.143 |
| 51025 | NEWTON,TEXAS | 30 54 24.714 | 266 23 55.765 | 49.897 |

Table 2 (Continued)
NWL9D Coordinates for North American Stations

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 51030 | KINGFISHER,OKLAH | 35 | 47 | 01.478 | 262 | 01 | 11.075 | 327.349 |
| 51033 | WOODBINE,IOWA | 41 | 42 | 12.609 | 264 | 21 | 19.399 | 389.342 |
| 51039 | IRAAN,TX | 30 | 52 | 15.370 | 258 | 03 | 58.284 | 866.97 |
| 51041 | ARTHUR,NEB | 41 | 38 | 26.726 | 258 | 24 | 01.345 | 1151.98 |
| 51043 | LOVELL,WY | 44 | 48 | 01.457 | 251 | 39 | 16.310 | 1192.35 |
| 51044 | CRESTON,WY | 41 | 36 | 55.678 | 252 | 12 | 53.888 | 2208.73 |
| 51048 | ALBUQUERQUE,NM | 34 | 56 | 43.490 | 253 | 32 | 23.305 | 1801.95 |
| 51052 | PICACHO,AZ | 32 | 43 | 24.947 | 248 | 29 | 04.990 | 447.17 |
| 51066 | TERREBONNE,OREGON | 44 | 23 | 31.282 | 238 | 42 | 12.208 | 861.277 |
| 51067 | MINERAL WELLS.TEX | 32 | 57 | 44.997 | 261 | 54 | 35.104 | 323.845 |
| 51068 | YULEE,FLORIDA | 30 | 41 | 46.311 | 278 | 15 | 59.114 | -19.419 |
| 51069 | ASHEPOO,S.C. | 32 | 45 | 31.674 | 279 | 26 | 36.774 | -38.685 |
| 51074 | MIDLAND,OR | 42 | 07 | 21.398 | 238 | 10 | 21.891 | 1218.160 |
| 51089 | MAYWOOD 1971,CALIF | 38 | 08 | 31.754 | 238 | 16 | 33.529 | 10.232 |
| 51103 | DONA ANA COUTY.NM | 32 | 04 | 19.495 | 253 | 31 | 03.740 | 1239.35 |
| 51121 | OPELOUSAS,LA | 30 | 37 | 55.231 | 267 | 50 | 02.412 | -15.99 |
| 51123 | FORT DAVIS,TX | 30 | 40 | 16.420 | 255 | 58 | 36.396 | 2037.58 |
| 51124 | EDEN,TX | 31 | 02 | 07.231 | 259 | 55 | 07.739 | 682.73 |
| 51125 | MILTON.FL | 30 | 36 | 07.114 | 273 | 01 | 59.382 | 7.95 |
| 51126 | MONTICELLO,FL | 30 | 31 | 36.997 | 276 | 12 | 31.578 | 14.77 |
| 52001 | BELTSVILLE,MARYL | 39 | 01 | 39.775 | 283 | 10 | 27.054 | -0.485 |
| 52063 | DOS PALOS,CA | 36 | 54 | 50.765 | 239 | 26 | 44.563 | -1.310 |
| 10008 | GRAND FORKS,ND | 47 | 56 | 38.503 | 262 | 37 | 09.155 | 237.40 |
| 10056 | SAN NICHOLS,CA | 33 | 14 | 48.821 | 240 | 28 | 46.780 | 234.54 |
| 10071 | GALLUP,NEW MEXICO | 35 | 31 | 00.596 | 251 | 24 | 22.212 | 2006.397 |
| 20176 | AJO,ARIZONA | 32 | 26 | 54.600 | 247 | 08 | 51.637 | 399.77 |
| 20177 | DOUGLAS.ARIZONA | 31 | 22 | 36.952 | 250 | 27 | 32.654 | 1197.44 |
| 20208 | KINGMAN,ARIZONA | 35 | 11 | 48.172 | 245 | 57 | 31.854 | 1112.44 |
| 30030 | GREEN RIVER,UTAH | 38 | 58 | 44.214 | 249 | 53 | 17.276 | 1288.256 |
| 51004 | CHARLESTON,WV | 38 | 22 | 10.835 | 278 | 24 | 32.776 | 249.382 |
| 51005 | CORBIN.KENTUCKY | 36 | 57 | 21.781 | 275 | 53 | 08.520 | 354.976 |
| 51006 | CLEVELAND,TENNES. | 35 | 09 | 06.961 | 275 | 06 | 55.188 | 261.137 |
| 51007 | LAURENS,SOUTH CAR. | 34 | 35 | 08.446 | 277 | 56 | 35.479 | 182.541 |
| 51009 | SHELBY.ALABAMA | 33 | 07 | 03.355 | 273 | 30 | 00.801 | 181.752 |
| 51010 | SANDERSVILLE,G. | 33 | 03 | 38.462 | 277 | 05 | 29.905 | 112.977 |
| 51011 | FARMVILLE,VIRGINIA | 37 | 18 | 52.043 | 281 | 33 | 38.270 | 102.434 |
| 51013 | CLEARWATER-ST.P.FL | 27 | 55 | 13.006 | 277 | 18 | 24.529 | -32.083 |
| 51017 | MIFFLINVILLE,PA | 41 | 00 | 57.788 | 283 | 39 | 42.036 | 256.467 |
| 51019 | HUDSON,N.Y. | 42 | 14 | 37.676 | 286 | 13 | 24.447 | 72.477 |
| 51020 | ALBURG(GSC).VER. | 44 | 54 | 29.267 | 286 | 42 | 30.669 | 29.527 |
| 51021 | ORLEANS.MASS | 41 | 51 | 19.234 | 290 | 02 | 59.201 | -19.649 |
| 51022 | FAIRFIELD,ME | 44 | 35 | 59.522 | 290 | 24 | 46.393 | 7.587 |
| 51023 | BOUCHARD RM2,MAINE | 47 | 11 | 53.912 | 291 | 26 | 48.671 | 326.393 |
| 51024 | FREEPORT,TX | 29 | 02 | 31.525 | 264 | 39 | 49.664 | -31.911 |
| 51026 | CLARKSVILLE,TEXAS | 33 | 38 | 22.877 | 264 | 58 | 55.424 | 117.625 |
| 51027 | SPRINGDALE.ARK. | 36 | 10 | 23.417 | 265 | 52 | 39.252 | 374.242 |
| 51028 | THAYER,MISSOURI | 36 | 34 | 37.098 | 268 | 22 | 23.142 | 259.787 |
| 51029 | PLATTE CITY.MO | 39 | 16 | 50.854 | 265 | 13 | 49.562 | 261.807 |
| 51031 | CLAY CITY,ILL | 38 | 38 | 14.569 | 271 | 39 | 00.669 | 105.314 |
| 51032 | EL DARA,ILL | 39 | 37 | 27.900 | 268 | 58 | 33.650 | 201.181 |
| 51056 | KEARNS,UTAH | 40 | 38 | 36.160 | 248 | 01 | 42.569 | 1369.895 |
| 51057 | DRY 1965.NEVADA | 40 | 23 | 41.717 | 244 | 47 | 30.933 | 1828.559 |
| 51058 | DIATOM 1958,NEVADA | 39 | 49 | 37.575 | 241 | 00 | 52.340 | 1275.178 |
| 51095 | AGAMENTICUS.MAINE | 43 | 13 | 24.265 | 289 | 18 | 28.169 | 175.472 |

a = 6378145 m        1/f = 298.25

Table 3
Coordinates in the M R - 72 System (Precise Traverse)

| | | $\phi$ | $\lambda$ | h(m) |
|---|---|---|---|---|
| 10000 | CHEYENNE.WY. | 41° 08′ 00″.233 | 255° 07′ 57″.341 | 1889.5 |
| 10003 | GREENVILLE.MISS. | 33 28 42.387 | 268 59 51.400 | 44.2 |
| 10006 | MEADES RANCH,KAN. | 39 13 26.686 | 261 27 29.494 | 599.4 |
| 10018 | JONESTOWN,TEX | 30 26 48.204 | 262 01 17.452 | 327.1 |
| 10019 | FRANKTON,IND | 40 14 07.031 | 274 10 27.148 | 259.0 |
| 10020 | MARYVILLE,IND | 38 35 20.856 | 274 21 07.740 | 212.6 |
| 10021 | CASH,KY | 37 33 06.818 | 273 55 10.341 | 265.6 |
| 10022 | IUKA,MISS | 34 47 15.482 | 271 45 30.184 | 250.4 |
| 10023 | WEBSTER,MISS | 33 33 54.598 | 270 50 04.408 | 141.3 |
| 10028 | EGLIN AFB,FL | 30 34 04.242 | 273 47 01.109 | 40.9 |
| 10031 | GOLDSTONE,CALIF. | 35 25 39.774 | 243 06 40.716 | 994.0 |
| 10032 | EDWARS AFB.CA | 34 57 50.736 | 242 05 10.754 | 758.4 |
| 10055 | PILLAR POINT.CA | 37 29 53.688 | 237 30 09.319 | 21.0 |
| 10116 | EDWARDS AFB.CA | 34 49 59.147 | 242 22 13.248 | 939.7 |
| 10117 | EDWARDS AFB.CA | 34 45 48.361 | 241 52 23.015 | 678.3 |
| 20001 | BELTSVILLE,MD | 39 01 39.749 | 283 10 26.713 | 40.1 |
| 20003 | WRIGHTWOOD.CAL | 34 22 54.519 | 242 19 09.147 | 2258.8 |
| 20015 | WOODLINE.GA | 30 56 55.045 | 278 19 07.824 | 11.6 |
| 20016 | COLUMBIA,MISS | 31 12 44.481 | 270 16 27.995 | 113.6 |
| 30025 | BLOOMFIELD,OHIO | 40 05 11.744 | 278 15 39.648 | 360.6 |
| 30026 | COLUMBUS,OHIO | 40 00 27.772 | 276 57 30.130 | 240.2 |
| 30027 | GREENVILLE,OHIO | 40 09 51.434 | 275 23 26.755 | 313.5 |
| 30028 | METAMORA,ILL | 40 49 20.424 | 270 42 40.571 | 249.0 |
| 30029 | MOSES LAKE,WASH. | 47 11 07.389 | 240 39 48.048 | 355.0 |
| 30098 | ORLAND,CALIFORNIA | 39 44 44.800 | 237 50 57.547 | 42.6 |
| 30099 | CHANCE1967,MONTANA | 47 47 08.008 | 251 22 07.896 | 1011.9 |
| 51008 | BOLIVIA,NORTH CAR. | 34 02 10.438 | 281 50 39.492 | 6.8 |
| 51012 | BONIFAY,FLORIDA | 30 39 05.180 | 274 11 38.234 | 34.70 |
| 51014 | VALKARIA,FLORIDA | 27 57 25.291 | 279 26 32.023 | 13.258 |
| 51015 | HIALEAH,FLORIDA | 25 53 24.936 | 279 41 34.345 | 16.3 |
| 51025 | NEWTON,TEXAS | 30 54 24.080 | 266 23 57.134 | 87.8 |
| 51030 | KINGFISHER.OKLAH | 35 47 01.278 | 262 01 12.942 | 363.0 |
| 51033 | WOODBINE.IOWA | 41 42 12.708 | 264 21 21.168 | 425.5 |
| 51039 | IRAAN,TX | 30 52 14.847 | 258 04 00.426 | 899.5 |
| 51041 | ARTHUR,NEB | 41 38 27.013 | 258 24 03.844 | 1184.0 |
| 51043 | LOVELL,WY | 44 48 02.028 | 251 39 19.733 | 1220.35 |
| 51044 | CRESTON,WY | 41 36 56.136 | 252 12 57.024 | 2236.5 |
| 51048 | ALBUQUERQUE,NM | 34 56 43.351 | 253 32 25.929 | 1830.10 |
| 51052 | PICACHO,AZ | 32 43 24.722 | 248 29 08.032 | 472.8 |
| 51066 | TERREBONNE.OREGON | 44 23 32.167 | 238 42 17.070 | 874.9 |
| 51067 | MINERAL WELLS.TEX | 32 57 44.602 | 261 54 36.968 | 357.6 |
| 51068 | YULEE,FLORIDA | 30 41 45.626 | 278 15 59.246 | 21.4 |
| 51069 | ASHEPOO,S.C. | 32 45 31.194 | 279 26 36.789 | 1.9 |
| 51070 | WRIGHTWOOD,CALIF. | 34 22 44.426 | 242 19 08.972 | 2172.77 |
| 51074 | MIDLAND,OR | 42 07 22.217 | 238 10 26.461 | 1229.88 |
| 51089 | MAYHOOD 1971,CALIF | 38 08 32.353 | 238 16 37.829 | 21.10 |
| 51103 | DONA ANA COUNTY.NM | 32 04 19.097 | 253 31 06.299 | 1268.1 |

Table 3 (Continued)
Coordinates in the M R - 72 System (Precise Traverse)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 51121 | OPELOUSAS.LA | 30 | 37 | 54.595 | 267 | 50 | 03.628 | 22.6 |
| 51123 | FORT DAVIS,TX | 30 | 40 | 15.872 | 255 | 58 | 38.693 | 2066.7 |
| 51124 | EDEN,TX | 31 | 02 | 06.711 | 259 | 55 | 09.670 | 716.0 |
| 51125 | MILTON,FL | 30 | 36 | 06.465 | 273 | 02 | 00.036 | 47.6 |
| 51126 | MONTICELLO,FL | 30 | 31 | 36.314 | 276 | 12 | 31.932 | 55.8 |
| 51127 | MOSES LAKE,WA | 47 | 11 | 07.389 | 240 | 39 | 48.048 | 355.0 |
| 52001 | BELTSVILLE,MARYL | 39 | 01 | 39.749 | 283 | 10 | 26.713 | 40.1 |
| 52002 | BELTSVILLE,MARYL | 39 | 01 | 39.261 | 283 | 10 | 26.899 | 40.1 |
| 52063 | DOS PALOS.CA | 36 | 54 | 51.184 | 239 | 26 | 48.611 | 9.68 |
| 53002 | BELTSVILLE,MD | 39 | 01 | 29.261 | 283 | 10 | 26.899 | 40.1 |
| 53063 | DOS PALOS,CA | 36 | 54 | 51.182 | 239 | 26 | 48.611 | 9.68 |
| 60001 | BELTSVILLE,MD | 39 | 01 | 39.749 | 283 | 10 | 26.713 | 40.1 |
| 90008 | ???,ARIZONA | 32 | 39 | 10.738 | 245 | 24 | 32.567 | 61.3 |

a = 6378206.4 1/f = 294.9787

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Kumar, M., 1972. "Coordinate Transformation by Minimizing Correlations between Parameters," Reports of the Department of Geodetic Science No. 184, The Ohio State University, Columbus, OH.

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## 2.3 Data Acquisition and Processing

### 2.31 Geoceiver Data

Near simultaneous Geoceiver tracking data at station Nos. 51072 and 51024 for satellite 3140 (60), over the period January 25 to February 8, 1974, has been received from the National Geodetic Survey along with the Precise Ephemeris for the satellite (state vectors at minute intervals).

Short Arc Geodetic Adjustment (SAGA) Computer Program had already been acquired earlier from DBA Systems, Inc.

It is intended to investigate the possibility of obtaining station coordinates of geodetic accuracy with the help of on-board (and not precise) ephemeris. Operationally, there is generally a delay of several weeks in obtaining precise ephemeris, while suitable equipment (e.g., JMR-1 equipment) can acquire the on-board ephemeris along with Doppler data. Therefore, if a satisfactory procedure for obtaining station coordinates with on-board ephemeris is formulated, it may be possible to provide a coordinated control of geodetic accuracy more rapidly than at present.

The investigation is proposed to be carried out in the following steps:

(a) i) Assessment of the accuracy of station coordinates obtained with the available observational data and the precise ephemeris.

ii) Theoretical formulation which may help obtain results of comparable accuracy with on-board ephemeris.

(b) Recovery of station coordinates with the observational data and the on-board ephemeris, using the formulation indicated at (a) ii) above and comparing the results with results at (a) i).

The data is now available on tape E 13484 (SLOT NO F 112) in four files as follows:

| | | | |
|---|---|---|---|
| File # 1 | EPHEMERIS for Satellite | — | Station 51072 |
| File # 2 | GEOCEIVER DATA | — | Station 51072 |
| File # 3 | EPHEMERIS for Satellite | — | Station 51024 |
| File # 4 | GEOCEIVER DATA | — | Station 51024. |

Printout of the whole data is also available. As a result of the scrutiny of data, it is found that data for 30 passes is available. Preliminary runs with SAGA have revealed some problems in the adoption of the program. These problems are being looked into.

## 3. ACTIVITIES RELATED TO EOPAP
(Grant No. NGR 36-008-204)

### 3.1 Rotation of the Earth

The effect of crustal motions in the rotation vector of the earth may be studied as explained in the Fourth Semiannual Status Report, by solving the general Lagrange-Louiville equations under the assumption of quasi-rigidity.

The main problem then, is the obtention of $[\Delta I]_P$, that is, the contribution to $[I_0]$ (initial value of the earth's inertia tensor) due to plate mass displacements.

This value was expressed by

$$[\Delta I]_P = \sum_{i=1}^{n} [\Delta I]_{P_i} \tag{1}$$

where n is the number of tectonic plates constituting the earth's crust.

The tectonic model described in [Solomon, et al., 1975] is used in this work. It consists of eleven plates, of which the relative angular velocities with respect to a reference plate (Pacific) are given. The absolute angular velocity of the reference plate with respect to the underlying mantle is also given. Therefore, the absolute angular velocity of any plate $P_i$ may be computed using the following column matrix notation

$$\{\omega_a\}_{P_i} = \{\omega_r\}_{P_i} + \{\omega_a\}_{RP} \tag{2}$$

where

$\{\omega_r\}_{P_i}$ ≡ relative angular velocity vector of any plate $P_i$ with respect to an arbitrary reference plate (Pacific);

$\{\omega_a\}_{RP}$ ≡ absolute angular velocity vector of the reference plate (Pacific) with respect to the underlying mantle;

$\{\omega_a\}_{P_i}$ ≡ absolute angular velocity vector of any plate $P_i$ with respect to the underlying mantle.

Several velocity models for $\{\omega_a\}_{RP}$ are described in [Solomon, et al., 1975]. In the present study their model B4 (continents have 3 times more drag than oceans) was considered, primarily because of the fact that their final values agree closely to the recent ones given by [Kaula, 1974] using a completely different approach.

Once the absolute angular velocities $\{\omega_a\}_{P_i}$ for each plate are known, the differential changes $\delta\theta$ and $\delta\lambda$ in colatitude and longitude for each $1^\circ \times 1^\circ$ block may be computed.

Following the theory in [Soler, 1976], this can be expressed in the case of a spherical curvilinear system as:

$$\begin{Bmatrix} \delta\theta \\ \delta\lambda \\ \delta r \end{Bmatrix} = H^{-1} R \, [\underline{\delta\omega}]^T_{P_i} \begin{Bmatrix} r \sin\theta \cos\lambda \\ r \sin\theta \sin\lambda \\ r \cos\theta \end{Bmatrix} \tag{3}$$

where

$H$ ≡ "matric matrix" of the transformation between spherical and Cartesian coordinates;

$R$ ≡ rotation matrix of the transformation between the geocentric and moving frames;

$[\underline{\delta\omega}]_{P_i}$ ≡ skew-symmetric matrix of the absolute angular velocity vector.

Observe that $\{\delta\omega\}_{P_i} \equiv \{\omega_a\}_{P_i}$.

After the proper values are substituted in (3), it is seen that one immediately obtains

$$\delta\theta = \delta\omega_1 \sin\lambda - \delta\omega_2 \cos\lambda \tag{4a}$$

$$\delta\lambda = \delta\omega_1 \cos\lambda \cot\theta + \delta\omega_2 \sin\lambda \cot\theta - \delta\omega_3 \tag{4b}$$

where the values of $\{\delta\omega\}$ correspond to the absolute angular velocity components for the specific plate containing the block $(\theta, \lambda)$.

Finally the elements in the summation of the right-hand side of equation

(1) will be given by

$$[\Delta I]_{P_i} = \sum_{k=1}^{m} \left( \delta\theta_k [\Delta I_\theta]_k + \delta\lambda_k [\Delta I_\lambda]_k \right) \tag{5}$$

where m is the total number of $1^\circ \times 1^\circ$ blocks on the plate $P_i$ and

$[\Delta I_\theta]_k \equiv$ differential changes in the earth's tensor of inertia due to a differential motion $\delta\theta_k$ of the block k;

$[\Delta I_\lambda]_k \equiv$ differential changes in the earth's tensor of inertia due to a differential motion $\delta\lambda_k$ of the block k.

The computation of $[\Delta I_\theta]_k$ and $[\Delta I_\lambda]_k$ involves the integration over the volume of every block k, taking into consideration the theory of isostasy according to Heiskanen.

## REFERENCES


Soler, Tomas, 1976. "On the Differential Transformations between Cartesian and Curvilinear Geodetic Coordinates," Reports of the Department of Geodetic Science No. 236, The Ohio State University, Columbus, OH.

Solomon, S.C., N.H. Sleep and R.M. Richardson, 1975. "Forces Driving Plate Tectonics: Inferences from Absolute Plate Velocities and Interplate Stress," Geophysical Journal of the Royal Astronomical Society, Vol. 42, No. 2, p. 769.

## 3.2 Close Grid Geodynamic Satellite (CLOGEOS) System

The preliminary investigation with a grid network of 9 stations at 5 minute spacing in both latitude and longitude in the San Andreas fault zone for the Close Grid Geodynamic Satellite (CLOGEOS) system was completed during the period under report. The results were published under Reports of the Department of Geodetic Science No. 230, OSU.

A more detailed simulated study with 75 stations along the three major faults (viz., San Andreas, Hayward and Calaveras) in central California has been started. In addition to the experiments conducted in the preliminary investigation, the present effort will include the following:

(i) Simulation of weather effect and actual crustal motion;

(ii) Study of the effect of observation pattern or station grouping in geometric and short arc modes;

(iii) Study of the effect of significant digits in computing a solution in near critical station configuration;

(iv) Geodetic monitoring of crustal motion.

The results are expected to be included in the next status report.

## 3.3 Modeling of VLBI Observations

Let two stations denoted i and j be engaged in a VLBI observation of a radio source p at some epoch $t_k$. The observed time delay $t_{ijpk}$ of arrival of a certain wavefront at the two stations provides a distance $d_{ijpk} = c \cdot t_{ijpk}$ which is the projection of the station-to-station vector $\vec{B}_{ij}$ on the instantaneous unit vector of the radio source direction $\vec{e}_p^*(t_k)$. Both $\vec{B}_{ij}$ and $\vec{e}_p^*(t_k)$ refer to a reference frame fixed to a network of stations in a certain way. Obviously

$$d_{ijpk} = B_{ij}^T \ e_p^*(t_k).$$

If $e_p$ is the unit vector in the direction of the radio source with respect to an inertial (source-fixed) frame, then one has

$$e_p^*(t_k) = M_{(t_k)} e_p.$$

The transformation matrix M can be parameterized in terms of Eulerian angles as

$$M = R_3(\varphi) R_1(\theta) R_3(\psi).$$

If a deterministic model for the time variation of $\varphi$, $\theta$, $\psi$ were available in the form

$$\frac{d^2E}{dt^2} = f(E,t) \qquad E = [\varphi, \theta, \psi]^T$$

then solving this equation, one should have $E(t_k) = F[E(t_0), \dot{E}(t_0)]$, or

$$M(t_k) = M(\varphi_0, \theta_0, \psi_0, \dot{\varphi}_0, \dot{\theta}_0; \dot{\psi}_0, t_k)$$

with a total number of six parameters. However, such an approach is not possible because of the uncertainties surrounding current knowledge of the earth's rotation. Alternatively, one may set

$$M = R_3(\varphi^\circ + \delta\varphi) R_1(\theta^\circ + \delta\theta) R_3(\psi^\circ + \delta\psi)$$

where $\varphi^\circ$, $\theta^\circ$, $\psi^\circ$ are approximate values provided from the analysis of classical astronomical observations and $\delta\varphi$, $\delta\theta$, $\delta\psi$ are small corrections which are assumed to be constant over a short interval of time (e.g., one day).

The number of parameters in M is now only 3, as compared to the previous 6. However, the direction and magnitude of the instantaneous vector of rotation $\vec{\omega}$ is one of the objectives of this analysis, and since

$$\vec{\omega} = \vec{\omega}(\varphi, \theta, \psi, \dot{\varphi}, \dot{\theta}, \dot{\psi})$$

one has to interpolate between values of $\varphi = \varphi^\circ + \delta\varphi$, $\theta = \theta^\circ + \delta\theta$, $\psi = \psi^\circ + \delta\psi$ to obtain $\dot{\varphi}$, $\dot{\theta}$, $\dot{\psi}$. This additional approximation destroys the optimality in estimates of $\vec{\omega}$.

For this reason, and despite the fact that 3 parameters are sufficient for the description of the relative rotation of the two reference frames, a 6 parameter model is used which explicitly contains the $\vec{\omega}$ vector,

$$M(t_k) = R_1(-\eta)\, R_2(-\xi)\, R_3[\Omega(t_k - t_0) + \theta_0]\, R_2(\Xi)\, R_1(H)$$

where $\Omega$ is the angular velocity of the earth's rotation and the geometric meaning of the rest of the parameters is depicted in Figures 1, 2 and 3. Also, $\xi$ and $\eta$ are the usual coordinates of polar motion; $\Xi$ and H are two similar parameters describing precession-nutation and $\theta_0 + \Omega(t_k - t_0)$ is an analog of GAST (Greenwich Apparent Sidereal Time). A priori approximate knowledge of the $\vec{\omega}$ direction with respect to both inertial and network frames, can lead to selection of coordinate systems so that $\Xi$, H, $\xi$, $\eta$ are small quantities with zero approximate values. Then one can write to a high degree of approximation

$$R_1(-\eta)R_2(-\xi) \approx \begin{pmatrix} 1 & 0 & \xi \\ 0 & 1 & -\eta \\ -\xi & \eta & 1 \end{pmatrix}, \quad R_2(\Xi)R_1(H) \approx \begin{pmatrix} 1 & 0 & -\Xi \\ 0 & 1 & H \\ \Xi & -H & 1 \end{pmatrix}$$

Setting $B_{ij} = (x_j - x_i,\ y_j - y_i,\ z_i - z_j)^T$, $t_k = t_k - t_0$ and $e_p = (\cos\delta_p \cos\alpha_p,\ \cos\delta_p \sin\alpha_p,\ \sin\delta_p)$, the model becomes

$$d_{ijpk} = \begin{pmatrix} x_j - x_i \\ y_j - y_i \\ z_j - z_i \end{pmatrix}^T \begin{pmatrix} 1 & 0 & \xi \\ 0 & 1 & -\eta \\ -\xi & \eta & 1 \end{pmatrix} R_3(\Omega\tau_k + \theta_0) \begin{pmatrix} 1 & 0 & -\Xi \\ 0 & 1 & H \\ \Xi & -H & 1 \end{pmatrix} \begin{pmatrix} \cos\delta_p \cos\alpha_p \\ \cos\delta_p \sin\alpha_p \\ \sin\delta_p \end{pmatrix}$$

The partials with respect to parameters evaluated at approximate values ($\Xi = H = \xi = \eta = \theta$) become after setting $\Psi_k = \theta_0 + \Omega\tau_k$, $\chi_{kp} = \Psi_k - \alpha_p$, $x_{ij} = x_j - x_i$, $y_{ij} = y_j - y_i$ and $z_{ij} = z_j - z_i$:

$$\frac{\partial d}{\partial \xi} = -z_{ij}\cos\delta_p \cos\chi_{kp} + x_{ij}\sin\delta_p$$

$$\frac{\partial d}{\partial \eta} = -z_{ij}\cos\delta_p \sin\chi_{kp} - y_{ij}\sin\delta_p$$

$$\frac{\partial d}{\partial \Xi} = (-x_{ij}\cos\psi_k + y_{ij}\sin\psi_k)\sin\delta_p + z_{ij}\cos\delta_p\cos\alpha_p$$

$$\frac{\partial d}{\partial H} = (x_{ij}\sin\psi_k + y_{ij}\cos\psi_k)\sin\delta_p - z_{ij}\cos\delta_p\sin\alpha_p$$

$$\frac{\partial d}{\partial \theta_0} = -(x_{ij}\sin\chi_{kp} + y_{ij}\cos\chi_{kp})\cos\delta_p$$

$$\frac{\partial d}{\partial \Omega} = \tau_k \frac{\partial d}{\partial \theta_0}$$

$$\frac{\partial d}{\partial x_j} = -\frac{\partial d}{\partial x_i} = \cos\delta_p \cos\chi_{kp}$$

$$\frac{\partial d}{\partial y_j} = -\frac{\partial d}{\partial y_i} = -\cos\delta_p \sin\chi_{kp}$$

$$\frac{\partial d}{\partial z_j} = -\frac{\partial d}{\partial z_i} = \sin\delta_p$$

$$\frac{\partial d}{\partial \alpha_p} = (-x_{ij}\sin\chi_{kp} + y_{ij}\cos\chi_{kp})\cos\delta_p$$

$$\frac{\partial d}{\partial \delta_p} = (-x_{ij}\cos\chi_{kp} + y_{ij}\sin\chi_{kp})\sin\delta_p + z_{ij}\cos\delta_p$$

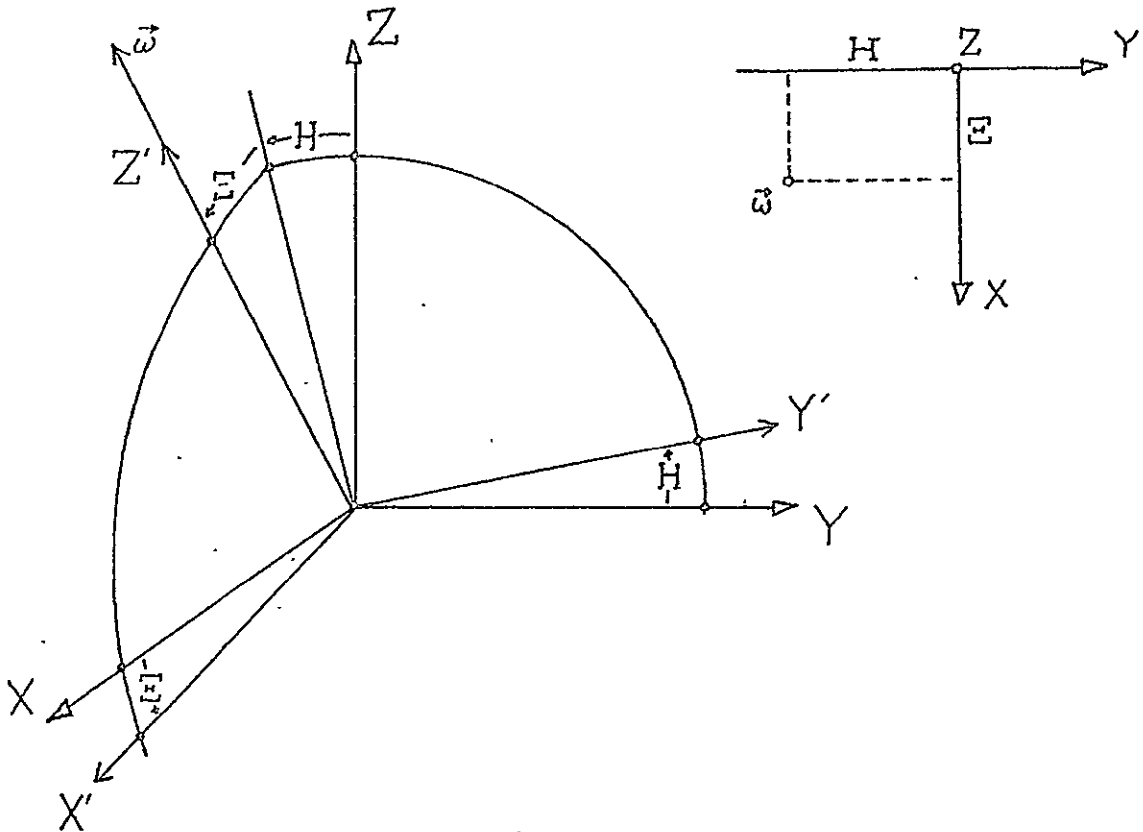



Fig. 1

XYZ ~ Inertial Frame

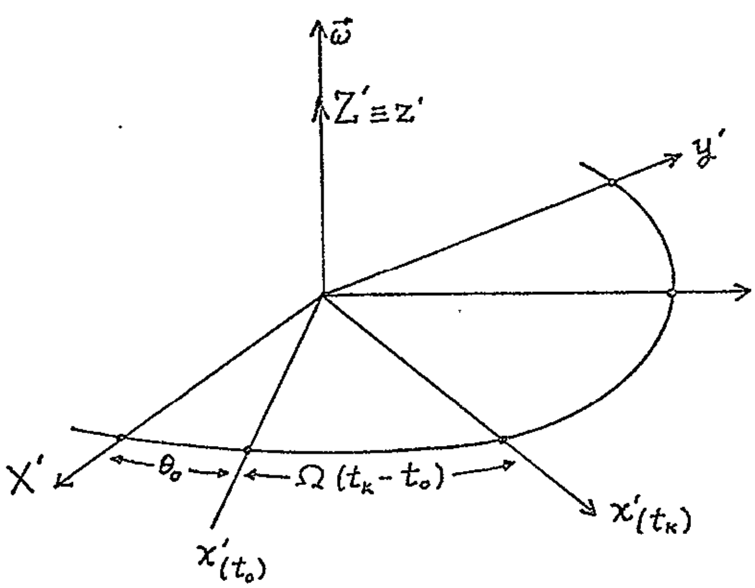
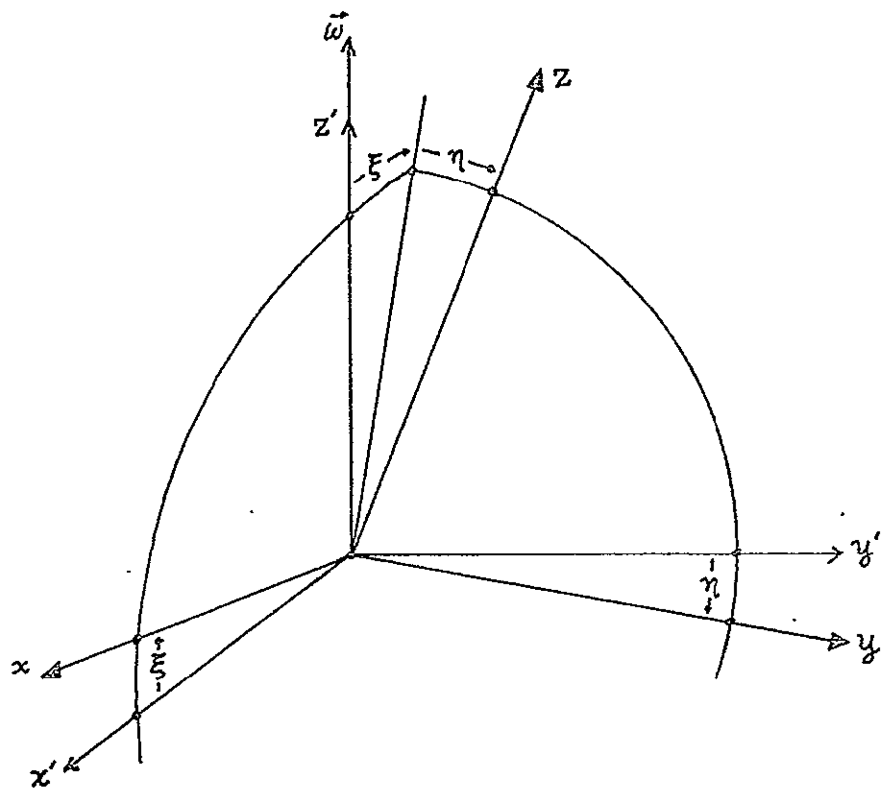



Fig. 2



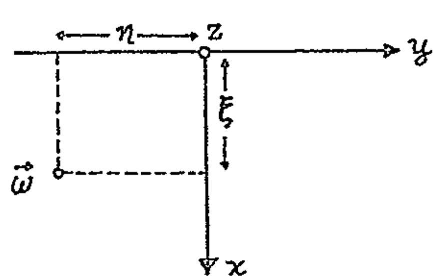




Fig. 3

xyz ~ Earth-fixed Frame

### 3.31 Definition of Coordinate Systems, Inner Constraints

Linearization of the observations leads to the equations

$$L = AX + V$$

where L contains differences between observed and computed distances; A contains the partials already derived; X contains corrections to parameters and V is the vector of random residuals. Setting the weight matrix to $P = I$ for simplicity, the normal equations become

$$(A^T A)X = A^T L \qquad \text{or} \quad NX = U.$$

But because of a lack of system definition, one has $\text{rank}(A) = \eta - 9$, where $\eta$ is the number of parameters and consequently N is singular. The rank deficiency 9 of A is due to the 9 degrees of freedom of the undefined coordinate systems: 3 for the orientation of the inertial system, 3 for the orientation and 3 for the origin position of the earth-fixed system.

Coordinate systems can be defined by means of 9 minimal constraints on the station coordinates ($dx_i$, $dy_i$, $dz_i$) and the radio sources coordinates ($d\alpha_p$, $d\delta_p$). The number of constraints can be reduced if use is made of naturally defined observable directions— in the present case— the direction of the earth's vector of rotation $\vec{\omega}$. One may then assume that the Z axis of the inertial system coincides in direction with $\vec{\omega}$, (but not with the z axis of the earth-fixed system), and thus avoid or limit the variation of station coordinates with time. This leads to elimination of the columns of the design matrix A corresponding to the parameters $\Xi$, H, so that only 7 constraints are now necessary. One has $\text{rank}(A) = \text{rank}(N) = \eta - 7$.

Among the solutions to the normal equation, the unique one given by $X = N^+U$ has the properties $X^T X = \min$ and trace $N^+ = \min$. In view of the interpretation of $N^+$ as the variance-covariance matrix of parameters, the second property makes the solution optimal. To avoid the use of a pseudoinverse computation algorithm, one may construct a set of inner constraints giving the same solution as the pseudoinverse. The inner constraints can be constructed with the help of the geometry of the operator represented by the matrix N.

The domain $\mathcal{D}$ of this operator is the space of all $n \times 1$ column vectors and can be turned into a complete inner product space introducing the inner product $\langle f, g \rangle = g^T f$. Then $\mathcal{D}$ has the orthogonal decomposition

$$\mathcal{D} = \mathcal{N} \oplus \mathcal{N}^{\perp}$$

where $\mathcal{N}$ is the null space of the operator, i.e., the set

$$\{ y \in \mathcal{D};\quad Ny = 0 \}.$$

It is well known that $X = N^{+} U \in \mathcal{N}^{\perp}$, and therefore the condition $X \perp \mathcal{N}$ uniquely defines X. If $\{ C_i \}$ is a basis for $\mathcal{N}$ ($i = 1, 2, \cdots 7$, since $\mathcal{N}$ is of dimension 7), then the condition $X \perp \mathcal{N}$ can be written

$$X \perp C_i \qquad \langle X, C_i \rangle = C_i^T X = 0 \qquad i = 1, 2, .., 7 .$$

In matrix notation:

$$\begin{pmatrix} C_1^T \\ C_2^T \\ C_7^T \end{pmatrix} X = \left( C_1 \; C_2 \ldots C_7 \right)^T X = C^T X = 0 .$$

The problem thus reduces to finding a basis in $\mathcal{N}$, i.e., in finding 7 linearly independent $n \times 1$ vectors $C_i$ satisfying

$$NC_i = 0, \qquad \text{or since } N = A^T A, \qquad AC_i = 0.$$

If $A_j$ is the jth row of A, one must find 7 linearly independent solutions $y = C_i$, $i = 1, 2, \cdots 7$ to the set of equations

$$A_j y = 0 \qquad j = 1, 2, \cdots s \quad (s = \text{number of observations}).$$

Setting $y^T = [\omega_1\, \omega_2\, \omega_3\, \omega_4\, \alpha_1 \beta_1 \gamma_1 \ldots \alpha_m \beta_m \gamma_m\, f_1\, g_1 \ldots f_k\, g_k]$

where m = number of stations and k = number of radio sources.

For the row of A corresponding to an observation $d_{ijpk}$ (stations i and j observing radio source p at epoch $t_k$), one obtains

$$\omega_1 \frac{\partial d}{\partial \eta} + \omega_2 \frac{\partial d}{\partial \xi} + \omega_3 \frac{\partial d}{\partial \theta_o} + \omega_4 \frac{\partial d}{\partial \Omega} + \alpha_i \frac{\partial d}{\partial x_i} + \beta_i \frac{\partial d}{\partial y_i} + \gamma_i \frac{\partial d}{\partial z_i} + \alpha_j \frac{\partial d}{\partial x_j} + \beta_j \frac{\partial d}{\partial y_j} + \gamma_j \frac{\partial d}{\partial z_j} +$$

$$+ f_p \frac{\partial d}{\partial \alpha_p} + g_p \frac{\partial d}{\partial \delta_p} = 0 .$$

Making use of the analytical expressions for the partials and after a considerable computational effort, one arrives at a set of solution vectors $\{C_i\}$, which gives rise to the inner constraints $C^T X = 0$ with the $C^T$ matrix being

$$X^T = \left[ d\eta \;\; d\xi \;\; d\theta_o \;\; d\Omega \;\; dx_1 \;\; dy_1 \;\; dz_1 \;\; dx_2 \;\; dy_2 \;\; dz_2 \cdots dx_m \;\; dy_m \;\; dz_m \;\vdots\; d\alpha_1 \;\; d\delta_1 \;\; d\alpha_2 \;\; d\delta_2 \cdots\cdots d\alpha_k \;\; d\delta_k \right]$$

$$C^T = \left[ \begin{array}{cccccccccccccc:ccccccc}
0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & \cdots & 1 & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & \cdots & 0 & 1 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & \cdots & 0 & 0 & 1 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & -z_1 & y_1 & 0 & -z_2 & y_2 & \cdots & 0 & -z_m & y_m & 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\
0 & 1 & 0 & 0 & z_1 & 0 & -x_1 & z_2 & 0 & -x_2 & \cdots & z_m & 0 & -x_m & 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\
0 & 0 & -1 & 0 & -y_1 & x_1 & 0 & -y_2 & x_2 & 0 & \cdots & -y_m & x_m & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 \\
0 & 0 & 0 & 0 & -y_1 & -x_1 & 0 & -y_2 & -x_2 & 0 & \cdots & -y_m & -x_m & 0 & 1 & 0 & 1 & 0 & \cdots & 1 & 0
\end{array} \right]$$

More explicitly, there are 3 sets of inner constraints. The first defines the origin of the earth-fixed system

$$\sum_{i=1}^{m} \begin{bmatrix} dx_i \\ dy_i \\ dz_i \end{bmatrix} = 0 .$$

The second set defines the orientation of the earth-fixed system

$$\begin{bmatrix} -d\eta \\ -d\xi \\ d\theta_o \end{bmatrix} = \sum_{i=1}^{m} \begin{bmatrix} 0 & -z_i & y_i \\ z_i & 0 & -x_i \\ -y_i & x_i & 0 \end{bmatrix} \begin{bmatrix} dx_i \\ dy_i \\ dz_i \end{bmatrix} .$$

Finally, the third set defines the direction of the X axis of the inertial frame

$$\sum_{p=1}^{k} d\alpha_p = \sum_{i=1}^{m} (y_i \, dx_i + x_i \, dy_i) .$$

### 3.32 The Role of Minimal Constraints in System Definition for a Non-rigid Network of Stations

The solution for station coordinates using minimal constraints depends on the set of used approximate values. The motions of stations with respect to each other can be modeled as follows: Consider a sequence of time intervals $\Delta t_i = [t_{i-1}, t_i]$ $i = 1, 2, \cdots$, and assume that within each interval that station coordinates remain unchanged. At the epochs $t_i$ the coordinate values "jump" to a new set of values, i.e., the variation of coordinates with time is modeled by simple "step functions." Now observations within each interval $\Delta t_i$ can be treated separately in a sequential fashion. If for the $\Delta t_i$ interval one uses as approximate values of the coordinates, their estimates provided from the analysis of observations in the interval $\Delta t_{i-1}$, then the minimal constraints provide a means of system definition for a deformable network of points.

The coordinate axes thus defined are "geographical axes," i.e., they are prescribed to the station in a specified way. From this point of view inner constraints may be inappropriate because they involve the direction of the rotation axis of the earth. Some more appropriate and intuitively appealing sets of minimal constraints are discussed next.

For the position of the origin of the system, the constraints

$$\sum_i \begin{bmatrix} dx_i \\ dy_i \\ dz_i \end{bmatrix} = 0$$

already contained in the inner constraints assures that the coordinates of the center of mass of the stations (considered of unit mass) will remain the same. For the definition of the direction of the system axes, two choices appear to be dynamically meaningful.

One is to consider the axes of zero relative angular momentum for the stations unit mass points in a fashion similar to the definition of the Tisserand axes for the whole earth. If $\vec{r}_i$ denotes position vector of the ith station, then the total relative angular momentum vector of the network is

$$\vec{h} = \sum_i \vec{r}_i \times \frac{d\vec{r}}{dt} = 0 \quad \text{or} \quad \sum_i \vec{r}_i \times d\vec{r}_i = 0$$

In matrix form one has

$$\sum_{i=1}^{m} \begin{bmatrix} 0 & -z_i & y_i \\ z_i & 0 & -x_i \\ -y_i & x_i & 0 \end{bmatrix} \begin{bmatrix} dx_i \\ dy_i \\ dz_i \end{bmatrix} = 0$$

A second choice is the principal axes of the network, i.e., the choice of axes that makes products of inertia of the stations vanish. To retain the zero (or some other constant) value of these products one must set their variation equal to zero. The products of inertia are

$$D = \sum_i y_i z_i , \quad E = \sum_i x_i z_i , \quad F = \sum_i x_i y_i ,$$

$$dD = \sum_i (dy_i z_i + y_i dz_i) = 0, \quad dE = \sum_i (dx_i z_i + x_i dz_i) = 0, \quad dF = \sum_i (dx_i y_i + x_i dy_i) = 0 .$$

or, in matrix form

$$\sum_{i=1}^{m} \begin{bmatrix} 0 & z_i & y_i \\ z_i & 0 & x_i \\ y_i & x_i & 0 \end{bmatrix} \begin{bmatrix} dx_i \\ dy_i \\ dz_i \end{bmatrix} = 0 .$$

## 4. PERSONNEL

Ivan I. Mueller, Project Supervisor, part time

Manohar G. Arur, Graduate Research Associate, part time

Athanasios Dermanis, Graduate Research Associate, part time from 10/1/75

Michael Gildengorin, Graduate Research Associate, part time

Muneendra Kumar, Graduate Research Associate, part time from 10/1/75

Alfred Leick, Graduate Research Associate, part time

Michelle A. Neff, Administrative Assistant, full time from 10/1/75

Tomas Soler, Graduate Research Associate, part time

Irene B. Tesfai, Research Assistant, part time from 10/1/75

Boudewijn H.W. van Gelder, Graduate Research Associate, part time from 10/1/75

## 5. TRAVEL

Mueller, Ivan I.
Washington, D.C. — July 29-30, 1975
To attend meeting at NASA Headquarters

Mueller, Ivan I.
Grenoble, France — August 16-31, 1975
To attend the I.U.G.G. XVI General Assembly

Mueller, Ivan I.
Leningrad, USSR — November 24-30, 1975
To attend symposium on "New Methods of Space Geodesy"

Dermanis, Athanasios
Washington, D.C. — December 1-4, 1975
To attend Precise Time and Time Interval Planning Meeting

[Note: Please refer to Attachment Nos. 2 and 3 for further information concerning the Grenoble and Leningrad meetings.]

## 6. REPORTS PUBLISHED TO DATE

OSU Department of Geodetic Science Reports published under Grant No. NSR 36-008-003:

70 The Determination and Distribution of Precise Time
by Hans D. Preuss
April, 1966

71 Proposed Optical Network for the National Geodetic Satellite Program
by Ivan I. Mueller
May, 1966

82 Preprocessing Optical Satellite Observations
by Frank D. Hotter
April, 1967

86 Least Squares Adjustment of Satellite Observations for Simultaneous Directions or Ranges, Part 1 of 3: Formulation of Equations
by Edward J. Krakiwsky and Allen J. Pope
September, 1967

87 Least Squares Adjustment of Satellite Observations for Simultaneous Directions or Ranges, Part 2 of 3: Computer Programs
by Edward J. Krakiwsky, George Blaha, Jack M. Ferrier
August, 1968

88 Least Squares Adjustment of Satellite Observations for Simultaneous Directions or Ranges, Part 3 of 3: Subroutines
by Edward J. Krakiwsky, Jack Ferrier, James P. Reilly
December, 1967

93 Data Analysis in Connection with the National Geodetic Satellite Program
by Ivan I. Mueller
November, 1967

OSU Department of Geodetic Science Reports published under Grant No. NGR 36-008-093:

100 Preprocessing Electronic Satellite Observations
by Joseph Gross
March, 1968

106 Comparison of Astrometric and Photogrammetric Plate Reduction Techniques for a Wild BC-4 Camera
by Daniel H. Hornbarger
March, 1968

110 Investigations into the Utilization of Passive Satellite Observational Data
by James P. Veach
June, 1968

114 Sequential Least Squares Adjustment of Satellite Triangulation and Trilateration in Combination with Terrestrial Data
by Edward J. Krakiwsky
October, 1968

118 The Use of Short Arc Orbital Constraints in the Adjustment of Geodetic Satellite Data
by Charles R. Schwarz
December, 1968

125 The North American Datum in View of GEOS I Observations
by Ivan I. Mueller, James P. Reilly, Charles R. Schwarz
June, 1969

139 Analysis of Latitude Observations for Crustal Movements
by M. G. Arur
June, 1970

140 SECOR Observations in the Pacific
by Ivan I. Mueller, James P. Reilly, Charles R. Schwarz, George Blaha
August, 1970

147 Gravity Field Refinement by Satellite to Satellite Doppler Tracking
by Charles R. Schwarz
December, 1970

148 Inner Adjustment Constraints with Emphasis on Range Observations
by Georges Blaha
January, 1971

150 Investigations of Critical Configurations for Fundamental Range Networks
by Georges Blaha
March, 1971

177 Improvements of a Geodetic Triangulation through Control-Points Established by Means of Satellite or Precision Traversing
by Narendra K. Saxena
June, 1972

184 Coordinate Transformation by Minimizing Correlations Between Parameters
by Muneendra Kumar
July, 1972

185 On the Geometric Analysis and Adjustment of Optical Satellite Observations
by Emmanuel Tsimis
August, 1972

187 Geodetic Satellite Observations in North America (Solution NA-9)
by Ivan I. Mueller, J. P. Reilly and Tomas Soler
September, 1972

188 Free Adjustment of a Geometric Global Satellite Network (Solution MPS-7)
by Ivan I. Mueller and M. C. Whiting
October, 1972

190 The Ohio State University Geometric and Orbital (Adjustment) Program (OSUGOP) for Satellite Observations
by James P. Reilly, Charles R. Schwarz and M. C. Whiting
December, 1972

191 Critical Configurations (Determinantal Loci) for Range and Range-Difference Satellite Networks
by E. Tsimis
January, 1973

193 Free Geometric Adjustment of the DOC/DOD Cooperative Worldwide Geodetic Satellite (BC-4) Network
by Ivan I. Mueller, M. Kumar, J. Reilly and N. Saxena
February, 1973

195 Free Geometric Adjustment of the Secor Equatorial Network (Solution SECOR-27)
by Ivan I. Mueller, M. Kumar and Tomas Soler
February, 1973

196 Geometric Adjustment of the South American Satellite Densification (PC-1000) Network
by Ivan I. Mueller and M. Kumar
February, 1973

199 Global Satellite Triangulation and Trilateration for the National Geodetic Satellite Program (Solutions WN 12, 14 and 16)
by Ivan I. Mueller and M. Kumar, J. P. Reilly, N. Saxena, T. Soler
May, 1973

216 Marine Geodesy, A Multipurpose Approach to Solve Oceanic Problems
by Narendra K. Saxena
October, 1974

228 The OSU 275 System of Satellite Tracking Station Coordinates
by Ivan I. Mueller and Muneendra Kumar
August, 1975

232 Satellite Triangulation in Europe from WEST and ISAGEX Data
by Alfred Leick and Manohar G. Arur
November, 1975

OSU Department of Geodetic Science Reports published under Grant NGR 36-008-204:

235 Similarity Transformations and Geodetic Network Distortions Based on Doppler Observations
by Alfred Leick and Boudewijn H.W. van Gelder
November, 1975

236 On the Differential Transformations between Cartesian and Curvilinear Geodetic Coordinates
by Tomas Soler
(in press)

The following papers were presented at various professional meetings:

"Report on OSU participation in the NGSP"
47th Annual meeting of the AGU, Washington, D. C., April 1966

"Preprocessing Optical Satellite Observational Data"
3rd Meeting of the Western European Satellite Subcommission, IAG, Venice, Italy, May 1967.

"Global Satellite Triangulation and Trilateration"
XIVth General Assembly of the IUGG, Lucerne, Switzerland, September 1967, (Bulletin Geodesique, March 1968).

"Investigations in Connection with the Geometric Analysis of Geodetic Satellite Data"
GEOS Program Review Meeting, Washington, D. C., Dec. 1967.

"Comparison of Photogrammetric and Astrometric Data Reduction Results for the Wild BC-4 Camera"
Conference on Photographic Astrometric Technique, Tampa, Fla., March 1968.

"Geodetic Utilization of Satellite Photography"
7th National Fall Meeting, AGU, San Francisco, Cal., Dec. 1968.

"Analyzing Passive-Satellite Photography for Geodetic Applications"
4th Meeting of the Western European Satellite Subcommission, IAG, Paris, Feb. 1969.

"Sequential Least Squares Adjustment of Satellite Trilateration"
50th Annual Meeting of the AGU, Washington, D. C., April 1969.

"The North American Datum in View of GEOS-I Observations"
8th National Fall Meeting of the AGU, San Francisco, Cal., Dec. 1969 and GEOS-2 Review Meeting, Greenbelt, Md., June 1970 (Bulletin Geodesique, June 1970).

"Experiments with SECOR Observations on GEOS-I"
GEOS-2 Review Meeting, Greenbelt, Md., June 1970.

"Experiments with Wild BC-4 Photographic Plates"
GEOS-2 Review Meeting, Greenbelt, Md., June 1970.

"Experiments with the Use of Orbital Constraints in the Case of Satellite Trails on Wild BC-4 Photographic Plates"
GEOS-2 Review Meeting, Greenbelt, Md., June 1970.

# Land use planning progresses

By DICK REBBECK
Journal Outdoor Editor

STURGIS — By no means unique in its problems of subdivision sprawl, Meade County is well into a comprehensive land use planning demonstration that promises to develop ideas other counties might well apply to their situations.

Describing the problem for the project, Arnold Bateman, rural development specialist for South Dakota State University, has specified "uncoordinated growth occuring adjacent to the I-90 corridor and contiguous to the city of Sturgis."

Kirk Carlsten, Meade County planning and zoning coordinator, points out that most of the county is agricultural, with little prospect of residential or industrial impact: "99 per cent of the problem is along I-90, from the (Black Hills National) Cemetery to Black Hawk."

"Much of the development (there) is within steeply sloping, forested areas, which increases erosion potentials, creating the possibility of stream siltation and pollution or water source contamination," Bateman reports.

"Such development presents problems of sewage disposal and adequate water supply for all demands, including firefighting requirements, congestion which may exceed the carrying capacity of the land, increased demands for police and fire protection and other public services, such as adequate roads," he explained.

Similar land use questions have arisen adjacent to Ellsworth Air Force Base and near Bear Butte State Park.

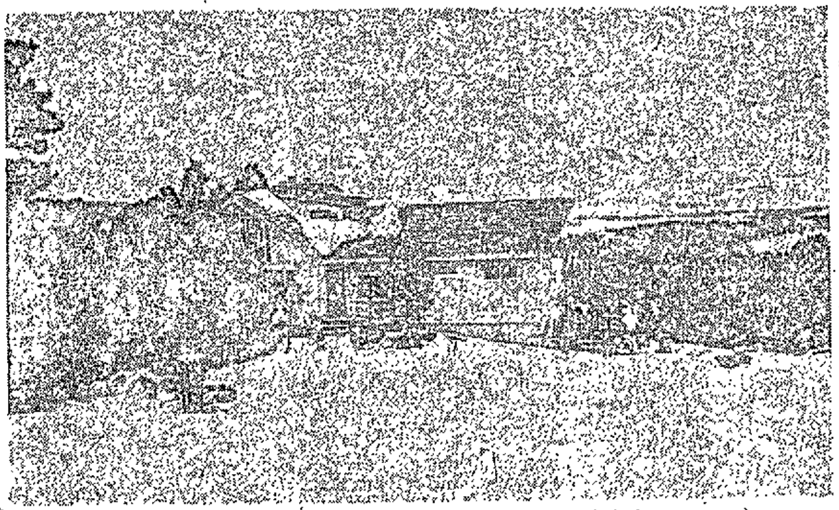
At Bear Butte, Carlsten notes, present 20-acre ownerships are not within the scope of a newly adopted subdivision ordinance. "If someone wants to subdivide a 20-acre site, it might come under it," he says.

Several subdivisions have been well laid out, from a land use planning aspect. Evidence of this, cited by Carlsten, includes community water systems, which avoid sanitation problems from septic tanks, provisions for safe waste disposal, provisions for drainage and flood protection, access for emergency vehicles, water supply for firefighting and grouping of like-value houses.

"In residential zoning, we should aim for more than one type of residential zone, and in each area define the size of lot, square footage of buildings and some other covenants," Carlsten comments. "If people put good money into a place . . . the value of their property goes down if someone else puts a lower value house in with the higher ones."

All gradations of building can be provided for through zoning without jeopardizing investment, he believes.

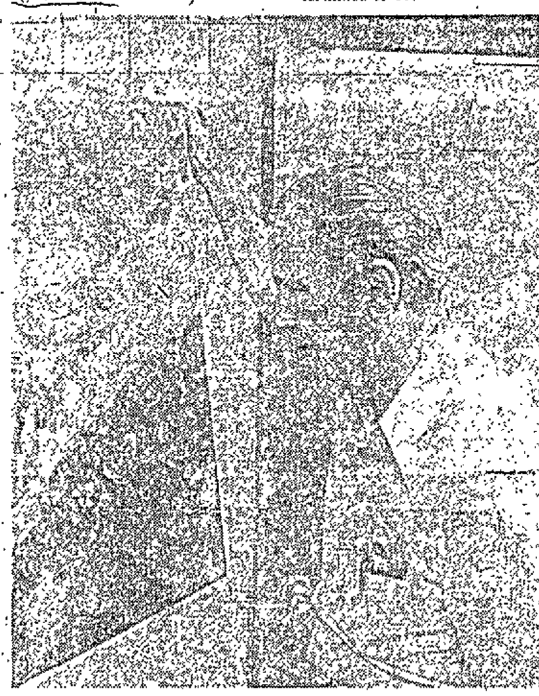
Mobile homes and modular homes present a special case in this context. Phil Cerveny, physical planner with the Sixth District Council of Local Governments, says mobile homes historically have been confined to commercial zones because lots were rented for profit. But it's actually a residential type of use, and one that's growing as economic factors dictate greater use of this type of housing. Zoning should provide for it as a type of residential zone, he indicates.



Spectacular views make Sturgis area subdivisions popular (Journal photos)

Observing one mobile home area where residents buy their one-acre lots, Cerveny suggests ownership motivates people to take better care of their property.

While acknowledging good land use judgments in some developments, planning specialists and county officials have detected problems along the I-90 strip, not the least of which was the loss of prime agricultural land.



Carlsten finds remote sensing map valuable tool

"The inevitable deterioration of the . . . natural environment, quality of living and the increasing demand for public services became apparent and the Meade County commissioners began looking for solutions," Bateman reported in an Agricultural Experiment Station article soon to be published.

Out of such concern came the countywide comprehensive land use planning pilot project, one grounded in local public involvement.

"Since the general objective of the whole planning operation is to provide in every respect a better environment for the people," Bateman reasoned, "the citizens of the county must be given the opportunity to take part in the planning process."

Bateman further emphasizes that goals and objectives must be the primary responsibility of citizens and their local officials "and not the responsibility of the technical planner." The planner implements within guidelines laid down by the people.

In Meade County, the principal goals and objectives have been determined to be:

- Protect the land base supporting agriculture, forests, natural resources, and minerals; with orderly land use change to meet people's needs and protect key sites for future development.
- Preserve a high quality environment through pollution abatement, soil erosion control, wildlife protection, maintaining recreation and other special-value areas and avoiding particular hazards, such as flood plains.
- Encourage development of pleasant, efficient and safe communities.

In response to 1974 state legislation, the county set out to set up a comprehensive land use plan by the July 1, 1976, deadline. Elements in this plan are to include a zoning ordinance, a planning ordinance and a land use map.

A county subdivision ordinance that went into effect Jan. 1 essentially provides for "harmonious development" through coordination of different developments so that, in Cerveny's words, an undue "financial burden won't fall back on the county" for such public services as road maintenance, schools and fire and police protection.

Weather and high interest rates have "pretty well brought construction starts to zero," so Carlsten doesn't have a measure of how the subdivision ordinance will function. "We won't have a good evaluation until spring and summer."

Meade County is now working on its county zoning ordinance. Carlsten believes Meade County is as far along toward the 1976 deadline as any West River county. The zoning ordinance is expected to be ready for the county commissioners to act upon "in four or five months." "I don't see building codes for some time to come, in the county," he adds. "That will take quite an enforcing arm. The city is into this, but the county is not."

Work is also proceeding on a soils map using aerial photographs obtained in cooperation with the Remote Sensing Institute at Brookings. This will be especially helpful in identifying better agricultural land, something people of the county have indicated they want protected from urban sprawl.

"If we zone an area strictly agricultural, we'll protect it totally," Carlsten says. "If it gets zoned residential and it's in agricultural use, it'll stay restricted for agricultural (and taxed agricultural). But if it is subdivided, it will be considered residential in all senses."

A landowner still has the right to subdivide, in a residential zone, and the county doesn't have to go through rezoning it from agricultural use. At the same time, though, it is hoped that this will encourage retention of some agricultural and open space land within the I-90 strip.

The land use map will also help identify flood hazard, high water table, soil slippage and other problem areas to be accounted for in any future development.

"I'm sure we'll have the tools with which we can do a better job," Carlsten summarizes. "If we don't do a better job, it'll be our own fault."

"GEOS-I SECOR Observations in the Pacific (Solution SP-7)"
National Fall Meeting of the American Geophysical Union, San Francisco, California, December 7-10, 1970.

"Investigations of Critical Configurations for Fundamental Range Networks"
Symposium on the Use of Artificial Satellites for Geodesy, Washington, D. C., April 15-17, 1971.

"Gravity Field Refinement by Satellite to Satellite Doppler Tracking"
Symposium on the Use of Artificial Satellites for Geodesy, Washington, D. C., April 15-17, 1971.

"GEOS-I SECOR Observations in the Pacific (Solution SP-7)"
Symposium on the Use of Artificial Satellites for Geodesy, Washington, D. C., April 15-17, 1971.

"Separating the Secular Motion of the Pole from Continental Drift - Where and What to Observe?"
IAU Symposium No. 48, "Rotation of the Earth," Morioka, Japan, May 9-15, 1971.

"Geodetic Satellite Observations in North America (Solution NA-8)"
Annual Fall Meeting of the American Geophysical Union, San Francisco, California, December 6-9, 1971.

"Scaling the SAO-69 Geometric Solution with C-Band Radar Data (Solution SC 11)"
Annual Fall Meeting of the American Geophysical Union, San Francisco, California, December 6-9, 1971.

"The Impact of Computers on Surveying and Mapping"
Annual Meeting of the Permanent Committee, International Federation of Surveyors, Tel Aviv, Israel, May 1972.

"Investigations on a Possible Improvement of Terrestrial Triangulation by Means of Super-Control Points"
IAG International Symposium - Satellite and Terrestrial Triangulation, Graz, Austria, June, 1972.

"Free Adjustment of a Geometric Global Satellite Network (Solution MPS7)"
IAG International Symposium - Satellite and Terrestrial Triangulation, Graz, Austria, June, 1972.

"Conjugate Gradient Method (Cg-Method) for Geodetic Adjustments"
Annual Fall Meeting of the American Geophysical Union, San Francisco, California, December 3-6, 1972.

"Preliminary Results of the Global Satellite Triangulation Related to the NGSP"
Journees Luxembourgeoises de Geodynamique, Luxembourg, February 19-21, 1973.

"Present Status of Global Geometric Satellite Triangulation and Trilateration"
54th Annual Spring Meeting of the American Geophysical Union, Washington, D.C., April 16-20, 1973.

"Free Geometric Adjustment of the OSU/NGSP Global Network (Solution WN4)"
First International Symposium on the Use of Artificial Satellites for Geodesy and Geodynamics, Athens, Greece, May 14-21, 1973.

"Earth Parameters from Global Satellite Triangulation and Trilateration"
International Symposium on Earth's Gravitational Field and Secular Variations in Position, Sydney, Australia, November 26-30, 1973.

"Review of Problems Associated with Geodetic Datums"
International Symposium on Problems related to the Redefinition of North American Geodetic Networks, Fredericton, N.B., Canada, May 20-25, 1974.

"Marine Geodesy - Problem Areas and Solution Concepts"
International Symposium on Application of Marine Geodesy, Battelle Auditorium, Columbus, Ohio, June 3-5, 1974.

"Station Coordinates and Geodetic Datum Positions from the National Geodetic Satellite Program"
First Pan American Congress and the
Third National Congress of Photogrammetry, Photointerpretation and Geodesy, Mexico City, Mexico, July 7-12, 1974.

"Review of Classical Methods for the Determination of Geodetic Datums"
International Colloquium on Reference Coordinate Systems for Earth Dynamics.
(IAU Colloquium No. 26)
Torun, Poland, August 26-31, 1974.

"Global Satellite Triangulation and Trilateration Results"
Intercosmos Symposium on Results of Satellite Observations
Budapest, Hungary, October 21-24, 1974.

"Crustal Motion Monitoring with the Proposed Close Grid Geodynamics Satellite Measurement System"
IUGG XVI General Assembly
Grenoble, France, August 16-31, 1975.

"Western European Satellite Triangulation (WEST) Station Coordinates in the OSU WN14 System"
IUGG XVI General Assembly
Grenoble, France, August 16-31, 1975.

"Aspects of Positioning Using Satellite Borne Laser or RF Systems"
Symposium on New Methods of Space Geodesy
Leningrad, USSR, November 24-30, 1975.

Attachment 1

**U.S. DEPARTMENT OF COMMERCE**
**National Oceanic and Atmospheric Administration**
NATIONAL OCEAN SURVEY
Rockville, Md. 20852

C13/BKM

September 16, 1975

Dr. Ivan I. Mueller
Department of Geodetic Science
The Ohio State University
1958 Neil Avenue
Columbus, Ohio 43210

Dear Dr. Mueller:

In accordance with our telephone conversation about two months ago, data for 55 stations along the transcontinental traverse network are enclosed. These data include NA 1927 Datum positions, elevations and geoid heights; M-R '72 Datum positions (see comments attached); and Doppler results for each station.

The data sheets are arranged in numerical order by station number. A sketch of the transcontinental traverse net, attached to the data, shows the approximate location of each station. Please note that Doppler positions were redetermined at the following four stations.

1 - 20001-52001-60001

2 - 52002-53002

3 - 52063-53063

4 - 30029-51127

The M-R '72 Datum positions and geoid heights are considered as preliminary. A simultaneous adjustment of the T.T. net will be performed after the field surveys are completed. The expected completion date is July or August 1976.

Sincerely,

B. K. Meade

B. K. Meade
National Geodetic Survey (Retired)

Enclosures (2)

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

## Comments on M-R '72 Datum Geographic Positions

'he geographic positions of stations given on the Doppler lata sheets, identified as the M-R '72 Datum, were obtained 'rom adjustments as follows.

1 - Western loop adjustment of the transcontinental traverse. This loop involves stations 10006-10018-51103-30098-30099-10006. The NA 1927 Datum position of MEADES RANCH was used for position control.

2 - Eastern loop adjustment of the transcontinental traverse. This loop involves stations 10006-10019-20001-51068-20016-10018-10006. Also the loop involving station 10003 and section from 20016 to junction near 10019. The NA 1927 Datum position of MEADES RANCH was used as position control.

3 - Northeastern section of the western loop from junctior north of MEADES RANCH to 51044 to 30099. The junction point north of MEADES RANCH and station 30099, as determined in the western loop adjustment, were used as position control.

4 - Positions of stations 51014-51015; 51048; 10031; and 10055 were determined from spur adjustments with control from the main traverse loops.

5 - Stations 10018, 51067, and 51030 are common to the eastern and western loops. The positions given for these stations are the mean values of results from the eastern and western loop adjustments.

## Comments on Doppler Data

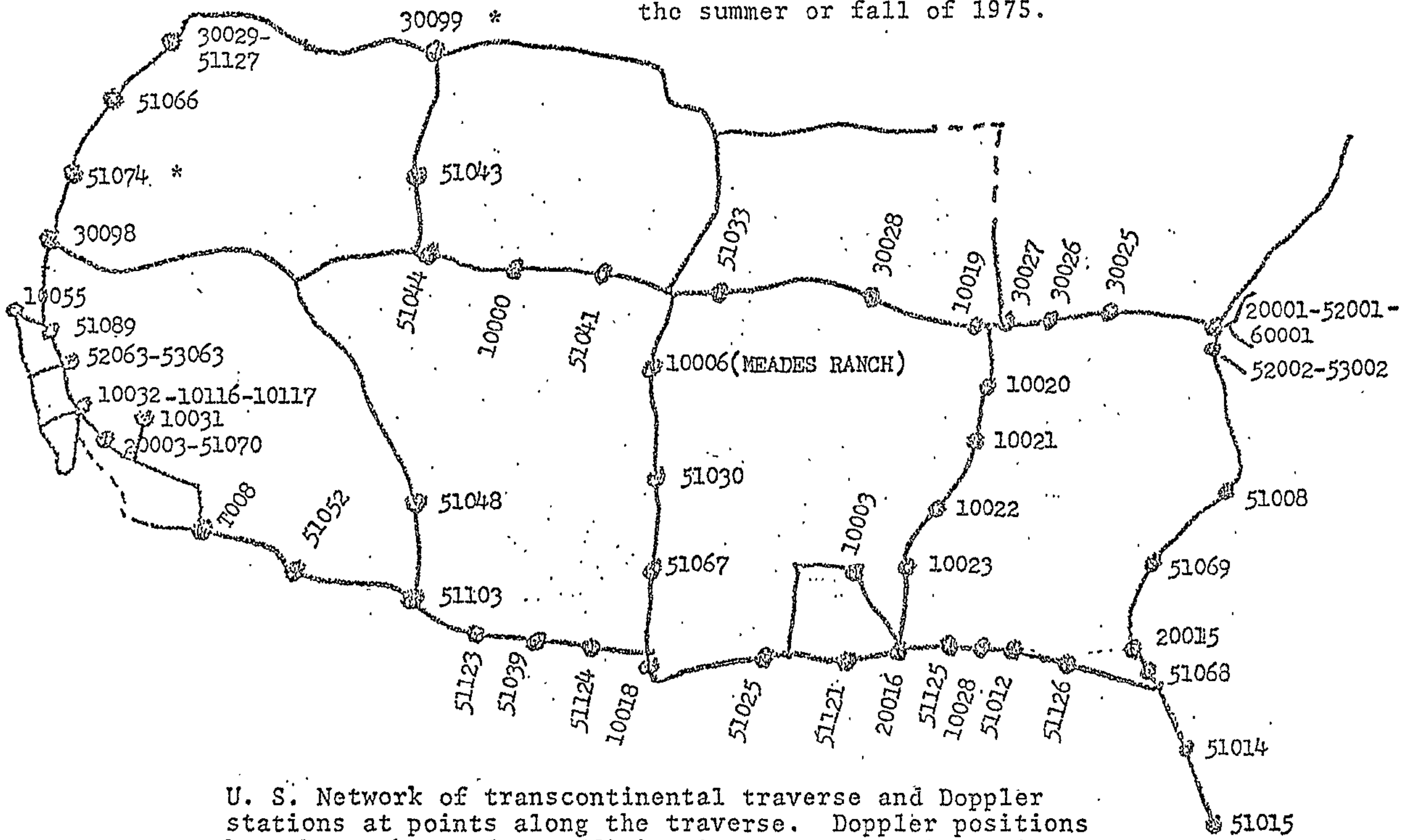
The original version of NOAA Form 76-178 gives the Doppler X-Y-Z coordinates and height above the ellipsoid referred to the tracking equipment reference point. The height of the reference point above the mark is given with the data.

The Doppler positions and ellipsoid heights furnished by DMATC, Form 115-84, have been corrected to agree with results computed by DMAAC, dated October 7, 1974.

All Doppler data to be used in the new adjustment of the NA 1927 Datum, determined from computer programs of other organizations, will be recomputed using the NGS program.

B. K. Meade
National Geodetic Survey (Retired)
September 16, 1975

* Doppler positions to be reobserved during the summer or fall of 1975.




U. S. Network of transcontinental traverse and Doppler stations at points along the traverse. Doppler positions have been observed at additional traverse stations along the interior sections of the western loop, however, adjusted positions based on the M-R '72 Datum are not available on this date, ~~June 27~~ 9/16, 1975.

UNION GEODESIQUE ET GEOPHYSIQUE INTERNATIONALE

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ASSOCIATION INTERNATIONALE DE GEODESIE

| Communications présentées à la XVI Assemblée Générale de l'A.I.G. | | Section 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| The Nottingham multipillar base line<br>V. Ashkenazi and A.H. Dodson - U.K. | 001 | x | | | | |
| Proposed System for high accuracy geodetic measurements over long distances<br>J. Levine - U.S.A. | 002 | x | | | | |
| Velocity of light in vacuo<br>A.V. Kondrashkov - U.S.S.R. | 003 | x | | | | x |
| The influence of molecular resonances on groups velocity of light in E.D.M.<br>Y.S. Galkin - A.A. Genike - U.S.S.R. | 004 | x | | | | |
| Interferometer for measurements of geodetic refraction<br>M.T. Prilepin - U.S.S.R. | 005 | x | | | | |
| The topographic atmospheric reduction of mean refractive index<br>M. Schadlich - D.D.R. | 006 | x | | | | |
| Experimental researches concerning turbulence behaviour of ground near air stratum<br>Lang H. - D.D.R. | 007 | x | | | | |
| On levelling refraction<br>J. Stefanovič - Yougoslavia | 008 | x | | | | |
| Higher accuracy of 1st order heights and vertical crustal movements by motorized levelling<br>H. Peschel - D.D.R. | 009 | x | | | | |
| Recent results of precise geodetic survey in Japan<br>H. Suzuki - T. Harada | 010 | x | | | | |

| | | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Status of the new adjustments of the North American horizontal datum II<br>J.D. Bossler - U.S.A. | 011 | ⊗ | | | * |
| The geodetic data base at NGS<br>Charles R. Schwarz - U.S.A. | 012 | x | | | |
| NGS Computer programs for the adjustment of horizontal networks<br>J. Gergen - Ch. Schwarz - U.S.A. | 013 | ⊗ | | | * |
| Computation of precision of distances in two and three dimenisional figures<br>G. Bruins and L.G. Bisselink - Netherlands | 014 | ⊗ | x | | |
| Comparing the stellar triangulation to the terrestrial 1st order triangulation<br>J. Kakkuri - Finland | 015 | ⊗ | * | | |
| Numerical filtering of trilateration networks<br>H. Kahmen - D.B.R. | 016 | x | | | ⊗ |
| Relation between fundamental astronomical constants and the major geodetic constants<br>S. Henriksen - U.S.A. | 017 | x | x | x | x |
| Strenght of long lines in terrestrial geodetic control networks<br>V. Ashkenazi - P.A. Cross - U.K. | 018 | x | | | |
| Smoothing of Laplace Azimuths<br>D. Ehlert - D.B.R. | 019 | ⊗ | | | * |
| On the accuracy of Longitude observation with the VUGTK-CSSR<br>G. Soltau - D.B.R. | 020 | x | | | |
| On the temperature influence upon the transit observations in the meridian<br>J. Dittrich - D.D.R. | 021 | x | | | |
| Latitude and Longitude determinations with a transportable zenith camera<br>J. GESSLER and G. SEEBER - D.B.R. | 022 | x | | | |

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|---|---|---|---|---|---|---|
| The establisment of a net of vertical deflection points in Italy by means of a photo-astronomic procedure<br>G. BIRARDI - Italie | 023 | ⊗ | | | | x |
| Use of Doppler positions to control classical geodetic networks<br>J.F. DRACUP - U.S.A. | 024 | ⊗ | x | | | |
| Comparison between the results of astronomical and Doppler satellite observations<br>S. TAKAGI - Japon | 025 | x | ⊗ | | | |
| Semi dynamical Doppler satellite positoning<br>WELLS D.E. - U.S.A. | 026 | | x | | | |
| Results of the Doppler campaign of Summer 1974 in Italy<br>L. CIRAOLO, L. MEZZANI - Italy | 027 | x | ⊗ | | | |
| Variation of latitude and longitude of station of CERGA from Doppler satellite tracking and precise satellite ephemeris<br>N. CAPITAINE - L. SAINT-CRIT - France | 028 | | ⊗ | | | * |
| Semi-dynamical Doppler satellite positioning<br>D.E. WELLS - J. KOUBA - Canada | 029 | | x | | | |
| Position determination using Doppler observations of the Navy navigation Satellites<br>P. WILSON - D.B.R. | 030 | | x | | | |
| Determination of the Earth's Rotation by Lunar Laser ranging<br>P. BENDER - D. CURRIE - J. MULHOLLAND - J. WILLIAMS - U.S.A. | 031 | | ⊗ | | | x |
| Results of aerotriangulation with Apollo Lunar photography<br>J.R. LUCAS - U.S.A. | 032 | | x | | | |
| Fitting of Laser range measurements of one station by means of orbital method<br>H. MONTAG - D.D.R. | 033 | | x | | | |
| On the derivation of short term variations in polar motion from laser ranging to artificial satellites<br>L. STANGE - D.D.R. | 034 | | x | | | x |

| | | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Experiments obtained by the Potsdam Laser ranging Equipment<br>H. FISCHER - R. NEUBERT - CH. SELKE - R. STECHER - D.D.R. | 035 | | x | | |
| An Investigation of the calibration error of the laser ranger Wettzell<br>K. NOTTARP - H. SEEGER - P. WILSON - D.B.R. | 036 | | x | | |
| The measurement of latitude time and height variations at a single laser station<br>P.J. DUNN - D.E. SMITH - R. KOLENKIEWICZ - U.S.A. | 037 | | x | | |
| Long base line geodesy using a mobile lunar laser station<br>E. SILVERBERG - U.S.A. | 038 | | x | | |
| Geometric adjustment of W. European satellite triangulation<br>W. EHRNSPERGER - D.B.R. | 039 | x | ⊗ | | |
| Determination of a simple layer density on the earth's surface from changes of satellite motion parameters<br>V.F. EREMEIEV - M.I. YURKINA - U.R.S.S. | 040 | | ⊗ | x | x |
| The analysis of the accuracy of the distance determination between two stations on the Earth surface when the distance between two artificial satellites has been measured<br>M. SOLARIČ - Yougoslavie | 041 | ⊗ | x | | |
| Methods for analysis of long periodic orbit variations<br>B.C. DOUGLAS - C.G. GOAD - J.G. MARSH - U.S.A. | 042 | | x | | |
| The work perdormed to date at the satellite observation station Wettzell<br>K. NOTTARP - M. SCHNEIDER - H. SEEGER - R. SIGL - P. WILSON - E. WOLF - D.B.R. | 043 | | x | | |
| Crustal motion monitoring with the proposed close geodynamics satellite measurements systems<br>I. MUELLER - B.H.V. VAN GELDER - M. KUMAR - U.S.A. | 044 | | ⊗ | | |
| The national geodetic satellite program (NGSP) the earth and ocean physics application program (EOPAP)<br>J. SIRY - U.S.A. | 045 | | ⊗ | | |

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| Le satellite et le programme GEOLE<br>G. BRACHET - M. LEFEVRE - FRANCE | 046 | | ⊗ | | | x |
| Final report of the SSG 3.37<br>special techniques of gravity measurements<br>T. HONKASALO - Finland | 047 | | | x | | |
| Gravimetric network and new gravity values in Japan<br>H. SUZUKI - Japon | 048 | | | x | | |
| Gravity tie between Japan and Europe<br>T. SETO - M. TAZIMA - Japon | 049 | | | x | | |
| High precision gravity measurements in northern Iceland<br>W. Torge - D.B.R. | 050 | | | x | | |
| Establishment of a high precision gravity network in the Eastern Mediterranean (D.B.R. - GREECE)<br>W. TORGE - L. MAVRIDIS - H. DREWES - D. ARABELOS | 051 | | | x | | |
| On precise gravity measurements at stations of small gravity difference<br>J. NAKAGAWA - M. SATOMURA - Japan | 052 | | | x | | |
| On characteristics of Lacoste Romberg gravimeters G<br>I. Nakagawa - Japan | 053 | | | x | | |
| Stability of temperature in a transformed Askania gravimeter<br>H.G. Wenzel - D.B.R. | 054 | | | x | | |
| Tidal change of gravity by means of an Askania gravimeter at Kyoto Japan<br>I. NAKAGAWA - M. SATOMURA - M. OZEKI - H. TSUKAMOTO | 055 | | | x | | ⊗ |
| Comparison of earth tide observations with seven different gravimeters at Hannover<br>W. TORGE - H. WENZEL - D.B.R. | 056 | | | | | ⊗ |
| Interpolation of calibration values for earth tide observations with prediction filtering<br>H.G. WENZEL - D.B.R. | 057 | | | x | | ⊗ |

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| Carte gravimétrique de la France<br>A. GERARD - C. WEBER - France | 058 | | | x | |
| The terrain subdivision for the computation of the topographic gravity correction by the method of weight factors<br>K. COLIC - Yugoslavia | 059 | | | ⊗ | |
| An attempt to physical interputation of total conceptual system of geodetic information<br>F. HALMOS - I. KADAR - Hongrie | 060 | | | | x |
| A representation of the standard gravity field<br>E. GRAFAREND - E. HEIDENREICH - B. SCHAFFRIN - D.B.R. | 061 | | | x | ⊗ |
| A plane restangular model for the strength analysis of geodetic networks<br>P. CROSS - V. ASHKENAZI - U.K. | 062 | ⊗ | | | x |
| Représentation d'une fonction par une somme de fonctions translatées<br>H.M. DUFOUR - France | 063 | | | | x |
| A rigourous non linear least square adjustment of extensive geodetic networks<br>L. GRUNDIG - K. LINKWITZ - D.B.R. | 064 | ⊗ | | | x |
| Investigations on the accuracy of transforming the European datum 1950 into a global reference system by means of the minimax error method<br>R. SIGL - E. REINHART - D.B.R. | 065 | ⊗ | | | x |
| Adjustment by the principle of minimal maximum error<br>G. HEINDI - E. REINHART - D.B.R. | 066 | x | | | ⊗ |
| A contribution to land surveying<br>E. Ecker - D.B.R. | 067 | | | | x |
| About the method of the weight factors with one treatment of the near zone<br>K. COLIC - Yugoslavia | 068 | | | ⊗ | x |
| The prediction of point and mean gravity anomalies using local bivariate covariance function<br>K. PAUL - Canada | 069 | | | x | ⊗ |

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| On the estimation of the degree of best fitting polynomials<br>J. ARNOLD - D.B.R. | 070 | | | | x | |
| Some consideration using interval analysis in adjustment computations<br>G. SCHMITT - D.B.R. | 071 | | | | x | |
| The statistics of residuals and the detection of outliers<br>A.J. POPE - U.S.A. | 072 | | | | x | |
| Evaluation de la précision des observations géodésiques à la base de l'analyse de la répartition d'un ensemble empirique<br>M.K. SZACHERSKA - Pologne | 073 | x | | | x | |
| Theoretical analysis of rounding error propagation during the direct solution of geodetic normal equations of the leveling type<br>P. MEISSL and N. BARTELME - Austria | 074 | x | | | x | |
| The determination of fundamental constants<br>J.W. SIRY - U.S.A. | 075 | | x | | | x |
| On the state of the astro gravimetric geoid determination in the Federal Republic of Germany<br>D. LELGEMANN | 076 | | | | | x |
| A method of direct gravimetrical determination of differences of geoid undulations<br>H. DREWES - D.B.R. | 077 | | | x | | x |
| Astrogeodetic geoid determination in the western Harz<br>W. TORGE - D.B.R. | 078 | | | | | x |
| Astrogravimetric levelling with direct regard to topography<br>G. BOEDECKER - D.B.R. | 079 | | | | | x |
| Gravimetric orientation of the Adindan (African) Geodetic datum<br>G. OBENSON - Nigeria | 080 | | | | | x |
| Goddard space flight center global detailed gravimetric geoid 1975<br>S. VINCENT - J. MARSH - U.S.A. | 081 | | x | | | x |
| Construction du Géoïde par utilisation du gradient de la pesanteur<br>J.J. LEVALLOIS - France | 082 | | | | x | x |

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| Le géoïde Européen version 1975<br>J.J. LEVALLOIS et H. MONGE - France 083 | | | | |
| Prediction of deviations of the vertical using heterogenous data<br>G. LACHAPELLE - Canada 084 | | | | x |
| Complex studies in planetary dynamics of the earth<br>H. KAUTZLEBEN - C. ELSTNER - G. HEMMLEB - H. MONTAG - D.D.R. 085 | | | | |
| The estimation of amplitude and phase caracteristics for the Earthtide Equipment Potsdam<br>H. WIRTH - H. DITTFELD - D.D.R. 086 | | | | |
| One year tide registrations with the gravimeter GS 15 nº222 in Potsdam. Preliminary experimental results<br>H.J. DITTFELD - D.D.R. 087 | | | | |
| The influence of the annual period of air pressure variations on polar motion<br>H. JOCHMANN - D.D.R. 088 | | | | |
| Application of the spectral analysis to individual latitude observations<br>J. HÖPFNER - D.D.R. 089 | | | | |
| Un pendule horizontal VM équipé d'un capteur de déplacement à capacité variable<br>M. VAN RUYMBEKE - Belgium 090 | | | | |
| The ratio l/h : a simple method for the prospection of tidal deformations<br>P. MELCHIOR et B. DUCARME - Belgium 091 | | | | |
| The computation methods used at the International center for earth tides<br>B. DUCARME - Belgium 092 | | | | |
| Etude de la structure du spectre diurne<br>J.C. USANDIVARAS - B. DUCARME - Rep. Argent. Belgium 093 | | | | |
| Global and local values of Earth Tides<br>R. VINCENTE - Portugal 094 | | | | |

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| An experiment to determine radial deformation of earth tides in Australia by ocean tides<br>R. MATHER - K. BRETREGER - Australia | 095 | | | | | x |
| Tidal loading in the Western Italy<br>C. CHIARUTTINI - G. PORETTI - Italy | 096 | | | | | x |
| Observation of Earth tides in Finland<br>T. HONKASALO - Finland | 097 | | | | | x |
| Atmospheric effects in Physical Geodesy<br>E.G. ANDERSON - C. RIZOS - R. MATHER - Australia | 098 | | | | | x |
| Model II analysis of variance of astronomic latitude and longitude<br>CARROLL D.C. | 099 | x | | | | |
| Inertial surveying experiments in Canada<br>GREGERSON L.F. and CARRIERE R.C. | 100 | x | | | | |
| Recent results of precise geodesie survey in japan<br>SUZUKI H. and HARADA T. | 101 | x | | | | |
| A high precision traverse for scale determination of stellar triangulation and for controlling the first order triangulation<br>PARM T. | 102 | x | x | | | |
| Extraneous influences on the levelling invar rods<br>VYSKOCIL P. and BENES F. | 103 | x | | | | |
| Investigation of distorsions in triangulation due to the absence of geoidal reductions in the greek area<br>BALORDIMOS A.M. | 104 | x | | | | |
| The use of laser pulses in measuring the distance between Greece and Italy<br>BILLIRIS H. and VEIS G. | 105 | x | | | | |
| The accuracy of microwave distance measurement<br>BANDELLAS A. | 106 | x | | | | |

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| Analysis of ISAGEX Data<br>GAPOSHLIN and LATIMER | 108 | | x | | |
| Review and Revision of geodetic parameters<br>GAPOSHKIN & WILLIAMSON & VEIS & KOZAI | 109 | | x | | |
| The geodésy & geophysics program at SAO<br>GAPOSHKIN & PEARLMAN & WEIFFENBACH | 110 | | x | | |
| Capability of the Sao satellite tracking system<br>PEARLMAN | 111 | | x | | |
| On long-range gravity measurements with Lacoste-Romberg gravimeters in the international gravity net (IGSN 1971)<br>GERSTENECKER & GROTEN E. Darmstadt | 112 | | | x | |
| Reobservations over the U.S. gravity base network<br>STRANGE W.E. - U.S.A. | 113 | | | x | |
| Analysis of a Local Gravity Field by locally orthogonal surface spherical harmonics<br>S.METE NAKIBOGLU - Turkey | 114 | | | x | x |
| The gravitational potential of earth to degree 36 from terrestrial gravity data<br>RAPP R.H. - U.S.A. | 115 | | | | |
| The Greek geoid and connections with neighbouring countries and continents<br>BALODIMOS - Greece | 116 | | | | |
| Geocentric gravitational constant determined from space graft radiometric data<br>ESPOSITO - U.S.A. | 117 | | x | | |
| The satellite doppler station network in the U.S.A.<br>STRANGE & HOTHERN & WHITE | 118 | | x | | |

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| Evaluation of precision and error sources associated with satellite Doppler positioning<br>HOTHERN | 119 | | x | | | |
| The Lageos satellite and complementary systems<br>LUNDQUIST | 120 | | x | | | |
| On solving the main problem of the satellite theory<br>KUTUZOV | 121 | | x | | x | |
| Report on the short arc campaign<br>TENGSTRÖM | 122 | | x | | | |
| On the determination and application of gravity gradients in geodetic systems<br>E. GROTEN | 123 | | | | x | x |
| Implications of contemporary research involving the geodetic boundary value problem, collocation, gravity gradiometry and inertial navigation<br>H. BAUSSUS VON LUETZOW | 124 | | | | x | |
| Earth tide phase lag and elasticity of the mantle<br>B. BODRI | 125 | | | | | x |
| Meteorological excitation of earth wobble<br>WILSON | 126 | | | | | x |
| An astrogeodetic geoid for the united states<br>D.G. CARROLL and C.W. WESSELS | 127 | | | | | x |
| Earth model parameters and coordinate systems<br>W.E. STRANGE | 128 | x | x | x | x | x |
| On the interaction of satellite geodesy and classical geodesy (with particular reference to European datum and the European geoid)<br>J.A. WEIGHTMAN | 129 | | | | | |

# Western European Satellite Triangulation (WEST) Station Coordinates in the OSU WN14 System

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1. Introduction — The Ohio State University acquired the data collected during the WEST program to improve the values of some station coordinates on the European continent which are presently included in the OSU WN14 solution [3]. The secondary aim of the solution was to add some new stations and to assess the quality of the WN14 solution with the help of the additional data available.

The WEST optical data was available in two forms. In the first form the data comprised the direction cosines of a single fictitious image per plate and the corresponding standard deviations derived from polynomial fitting. The second form contained the direction cosines of seven fictitious images without statistics.

Solutions with the single image data have been completed and the results are summarized here in a brief form. More detail may be found in [6].

2. Method of Computation and Results — A modified version of OSUGOP [5] was utilized to obtain the normal equations and to perform the adjustment.

Table 1 gives a list of all the stations for which observational data was available. The stations had to be renumbered in order to avoid confusion with the WN14 numbering system.

Stations which already appeared in the original WN14 solution were constrained in the new adjustment to their WN14 coordinates (see [3]) with weights compatible to their a posteriori variances. These stations are indicated with an asterisk in Table 1.

For appropriate scaling the chord 6006 TROMSO - 6016 CATANIA was constrained to 3,545,871.454 m with a weight corresponding to 1: $10^6$.

Relative constraints were also applied to maintain the relative positions of nearby stations. These relative constraints are based on survey information available in [1], [2] and [4] (Table 4.)

Ellipsoidal height constraints were also applied after transforming the European Datum height information available in [2] to the WN14 system (Table 3.)

The final coordinates as a result of the solution with the single image data are presented in Table 1.

The transformation parameters between this solution and other recent solutions which give the coordinates of common stations are presented in Table 2.

3. Conclusions — In all cases the variances of the ex-stations in the WN14 solution have improved by utilization of the WEST single image data. The coordinates of the stations 8705 (BRDUX), 8712 (OPICI), 8713 (ORIAA) and 8714 (SRDIN) still exhibit extraordinarily large standard deviations. This is an immediate result of increased variances in the observational data. See [2], Table 4, which gives the standard errors stationwise as obtained by the smoothing procedure. The adjusted coordinates of 8711 (CATAN) were also expected to exhibit a large standard deviation according to [2], Table 4, but this station has been connected to the nearby WN14 station 6016

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(CATANIA) by relative constraints, and therefore does not exhibit a large variance. The large standard deviations at station 8722 (REKVK) are due to unfavorable geometric conditions and insufficient numbers of observations.

The transformation parameters in Table 2 show that the origin of the present WEST solution coincide with the WN14 origin, as was intended. The parameters for the ED 50 datum can be regarded as reliable, while shifts with respect to the solutions NGS, SE3 and GEM6 should not be overemphasized due to the lack of adequate numbers of common stations.

References —

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| OSU No. | X | $\sigma_X$ | Y | $\sigma_Y$ | Z | $\sigma_Z$ | Name | WEST No. |
|---|---|---|---|---|---|---|---|---|
| *6006 | 2102927.8 | 2.2 | 721665.6 | 2.6 | 5958181.8 | 2.3 | TROMSO | 14002 |
| 6016 | 4896388.4 | 1.5 | 1316170.7 | 2.2 | 3856668.1 | 1.8 | CATANIA | |
| 6065 | 4213564.2 | 1.8 | 820829.8 | 2.2 | 4702781.9 | 1.9 | PEISEN | |
| *8009 | 3923390.0 | 4.1 | 299875.7 | 5.4 | 5002971.9 | 3.6 | DELFTH | 9001 |
| *8010 | 4331299.2 | 3.5 | 567500.4 | 5.1 | 4633113.7 | 3.6 | ZIMLD | 12001 |
| *8011 | 3920161.1 | 3.5 | -134766.6 | 5.3 | 5012730.2 | 3.7 | MALVRN | 13002 |
| *8019 | 4579462.5 | 3.5 | 586585.7 | 6.7 | 4386418.8 | 3.7 | NICEFR | 5004 |
| *8030 | 4205628.3 | 4.5 | 163697.3 | 7.8 | 4776540.2 | 4.0 | MUDONI | 5001 |
| 8701 | 4194420.8 | 4.0 | 1162689.6 | 7.4 | 4647203.4 | 4.8 | GRAZA | 1001 |
| 8702 | 4027911.8 | 4.8 | 306993.8 | 7.8 | 4919441.0 | 5.3 | BRXOR | 2001 |
| 8703 | 3513620.8 | 7.8 | 778932.6 | 6.9 | 5248202.4 | 5.3 | COPHN | 8703 |
| 8704 | 4188643.3 | 3.5 | 571413.8 | 4.7 | 4760145.9 | 4.0 | STRBG | 5002 |
| 8705 | 4530509.7 | 16.9 | -41750.8 | 32.3 | 4474376.3 | 17.5 | BRDUX | 5003 |
| 8706 | 4587888.7 | 7.2 | 419515.6 | 5.2 | 4396444.7 | 7.8 | GOULT | 5005 |
| 8707 | 3818496.3 | 5.3 | 708046.0 | 5.7 | 5042645.9 | 4.5 | BRNSG | 6004 |
| 8708 | 4041858.2 | 4.8 | 620627.3 | 6.4 | 4878632.9 | 4.6 | FRNFT | 6005 |
| 8709 | 4213543.4 | 1.8 | 820776.4 | 2.3 | 4702807.0 | 1.9 | HOPBG | 6010,6110 |
| 8710 | 3818494.5 | 5.3 | 708047.3 | 5.7 | 5042646.1 | 4.5 | WSNDF | 6012 |
| 8711 | 4896386.8 | 1.5 | 1316170.3 | 2.2 | 3856670.3 | 1.8 | CATAN | 8004 |
| 8712 | 4335515.2 | 17.0 | 1063080.2 | 29.1 | 4540934.2 | 18.8 | OPICI | 8005 |
| 8713 | 4628609.4 | 18.9 | 1471957.0 | 37.9 | 4120465.3 | 26.4 | ORIAA | 8006 |
| 8714 | 4885405.7 | 22.8 | 784057.4 | 28.6 | 4011522.4 | 31.3 | SRDIN | 8007 |
| 8715 | 4896390.8 | 1.5 | 1316178.5 | 2.2 | 3856662.4 | 1.8 | TANIA | 8008 |
| 8716 | 4850679.1 | 8.3 | -315920.2 | 8.7 | 4116616.4 | 10.1 | MADRD | 10002 |
| 8717 | 4850679.1 | 8.3 | -315932.9 | 8.7 | 4116616.1 | 10.1 | MADRI | 10003 |
| 8718 | 4146528.6 | 6.1 | 613106.3 | 6.7 | 4791490.5 | 5.6 | KLSRH | 6006 |
| 8719 | 4883056.8 | 1.5 | 1306097.6 | 2.2 | 3879629.2 | 1.8 | CATNA | 8009 |
| 8720 | 3104184.0 | 12.2 | 998354.1 | 9.7 | 5463291.9 | 6.3 | LOVOA | 11002 |
| 8721 | 3593850.3 | 9.3 | -202776.1 | 7.5 | 5248065.1 | 6.9 | EDNBG | 13001 |
| 8722 | 2592004.7 | 10.0 | -1078487.6 | 17.7 | 5707860.5 | 5.7 | REKVK | 15001 |
| 8723 | 3919681.0 | 4.1 | 298822.2 | 5.4 | 5005897.7 | 3.6 | DELFY | 9002 |

Table 1. WEST (33). Coordinates in the WN14 System
(all units in meters)

| Solution | NGS (comb.) | SE3 | WN14 | GEM6 | ED50 |
|---|---|---|---|---|---|
| No. of Stations | 3 | 5 | 8 | 3 | 29 |
| $\Delta X$(m) | -11.4± 1.8 | -11.9± 3.5 | -0.4± 1.2 | -22.5±2.3 | -96.6±3.3 |
| $\Delta Y$(m) | -10.6± 2.2 | -20.4± 4.1 | 0.6± 1.6 | -30.1±2.9 | -122.1±3.4 |
| $\Delta Z$(m) | 11.6± 2.0 | 9.2± 3.5 | -0.6± 1.4 | 6.1±2.5 | -126.3±3.2 |

Table 2. Transformation Parameters (WEST(33) - Other System)

Table 3. Height Constraints*

| Station | Ellipsoidal Height (m) | $\sigma$(m) | Station | Ellipsoidal Height (m) | $\sigma$(m) |
|---|---|---|---|---|---|
| 6006 | 113.2 | 4.0 | 8708 | 186.7 | 3.0 |
| 6016 | 16.3 | 4.0 | 8709 | 949.3 | 3.0 |
| 6065 | 960.1 | 2.5 | 8710 | 80.4 | 3.0 |
| 8009 | 41.1 | 4.0 | 8711 | 15.4 | 3.0 |
| 8010 | 920.6 | 2.5 | 8712 | 393.4 | 3.0 |
| 8011 | 135.0 | 4.0 | 8713 | 194.4 | 3.0 |
| 8019 | 394.7 | 4.0 | 8714 | 144.4 | 3.0 |
| 8030 | 183.2 | 2.5 | 8715 | 15.4 | 3.0 |
| 8701 | 490.8 | 3.0 | 8716 | 686.8 | 3.0 |
| 8702 | 114.1 | 3.0 | 8717 | 686.8 | 3.0 |
| | | | 8718 | 143.7 | 3.0 |
| 8703 | 51.4 | 3.0 | 8719 | 1740.9 | 3.0 |
| 8704 | 164.5 | 3.0 | 8720 | 40.8 | 3.0 |
| 8705 | 107.3 | 3.0 | 8721 | 300.6 | 3.0 |
| 8706 | 224.2 | 3.0 | 8722 | 0.6 | 3.0 |
| 8707 | 81.1 | 3.0 | 8723 | 13.5 | 3.0 |

*with respect to the WN14 system and a = 6378155.0 m, b = 6,356,769.7 m.

Table 4. Relative Position Constraints

| From Station | To Station | $\Delta X_{(m)}$ | $\Delta Y_{(m)}$ | $\Delta Z_{(m)}$ |
|---|---|---|---|---|
| 8711 | 8719 | 13329.91 | 10072.67 | -22958.92 |
| 8711 | 8715 | -4.04 | -8.24 | 7.88 |
| 8715 | 8719 | 13333.95 | 10080.89 | -22966.80 |
| 8707 | 8710 | 1.78 | -1.33 | -0.16 |
| 8716 | 8717 | -0.06 | 2.70 | 0.28 |
| 8009 | 8723 | 3709.06 | 1053.54 | -2925.82 |
| 8711 | 6016 | -1.61 | -0.43 | 2.17 |
| 6065 | 8709 | 20.79 | 53.37 | -25.09 |

# Crustal Motion Monitoring with the Proposed Close Grid Geodynamics Satellite Measurement System

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## Abstract

The Close Grid Geodynamics Satellite Measurement System consists of a satellite-borne laser or microwave system and closely spaced inexpensive reflectors or transponders on the ground. The feasibility of the system is investigated and the expected accuracies, based on extensive simulations, are presented. Various possible applications, including crustal motion monitoring, are discussed.

* * * *

1. Introduction. -- Originally, CLOGEOS was conceived as an orbiting ranging device with ground base reflectors. A grid of these reflectors (spacing 0.5 - 50 km) which are projected to be low cost (passive, maintenance free and unattended) will permit the saturation of a local area to obtain data useful for geodynamic and geodetic (oceans included) purposes. In this investigation a first attempt was made to get an insight on how maximum accuracy of relative station positions can be achieved in a short time span (3-5 days).

2. Instrumental Concepts. -- Measurement systems as laser radar, RF radar or a combination of both operating in continuous wave or pulse mode are able to provide ranges, range rates (Doppler) or range differences (integrated Doppler).

In this study only ranges were considered with the already feasible laser precision of 10 cm. The ranges are observed in two modes, simultaneous and non-simultaneous.

Two types of vehicles carrying the transmitter have been considered: A. Satellites at various altitudes: 392, 657, and 1007 km. The satellite orbits (passes) were generated with the Goddard Trajectory Determining System (GTDS), developed at NASA's Goddard Space Flight Center [1,2]. B. Airplane flying at an altitude of 9 km.

3. Ground Stations. Two types of stations were considered (Fig. 1): A. Nine grid stations with a spacing of 5' were chosen in the vicinity of the San Andreas Fault area in California ( $\Delta\varphi$ = 9.3 km and $\Delta\lambda$ = 7.3 km). The ellipsoidal height differences between the stations were varied between 0 and 1000m. B. Three distant reference stations were selected outside the grid area near San Diego, and Quincy in California, and near Bear Lake, Utah.

4. Recovery of Relative Positions of Grid Stations. -- Having simultaneous

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and non-simultaneous ranges two different algorithms can be used to compute the relative positions of grid stations: A. Geometric adjustment which takes advantage of the simultaneity of the observations. The software used was the Ohio State University Geometric and Orbital (Adjustment) Program for Satellite Observations (OSUGOP) [3]. B. Short arc adjustment (dynamic mode) which does not have the requirement of simultaneous observations. The software used was the Short Arc Geodetic Adjustment Program (SAGA) [4, 5].

Since a range measurement system lacks any coordinate system definition, especially in the geometric mode, the recovery of the relative positions was expressed in terms of the estimable quantities, the lengths of the chords between the grid stations (Fig. 1) and the angles between the chords[6,7].

5. Geometric Mode Results. -- The geometric mode leads to a very simple mathematical model. However, local satellite ranging networks often degenerate into critical configurations (see Table 1, line 1) as opposed to global satellite ranging networks[8]. To avoid these critical configurations two possibilities are mentioned:
1. Separate stations in height either by giving the grid stations some height difference $\Delta H$ (Table 1, line 2), a possibility only in the case of accomodating topography, or by including into the observation campaign the three reference stations outside the area (Table 1, line 4). This possibility has the stringent requirement of having favourable weather conditions at 4 different sites (grid area and 3 reference stations).
2. Separate the ranging devices in height. The best (and most realistic) solution, to avoid the effects of critical configurations within the limited area of the grid is the combination of an airplane and a satellite (Table 1, line 5. Note that no distant [reference] stations are needed). The only disadvantage of geometric mode is the instrumental problem related to the realization of the simultaneous observations. These at least for the lasers may be overwhelming.

6. Short Arc Mode Results. -- The absence of the requirement of having simultaneous observations and the absence of the bothersome critical configurations are the main advantage of the short arc mode. However, in order to get stability in the solutions the 3 distant (reference) stations must be observed during each pass (Table 1, line 6). A pass of 4 to 10 minutes lengths for satellites at altitudes between 400 and 1000 km, is so short in duration of time that favourable weather conditions almost simultaneously at all the sites might be just as a stringent requirement as in the case of the geometric mode. (Short arc mode using RF radar may alleviate the weather dependency but is negatively compensated by more serious refractional problems and more complex active grid stations).

7. Conclusions and Applications. -- Ranging with $\sigma_R = 10$ cm and 500 observations per station can recover relative positions well ($\sigma_{r_{ij}} = 4$ cm and $|v_{r_{ij}}| < 3$ cm). Unit efficiency $\sigma_R/\sigma_{r_{ij}}$ can be achieved with fewer observations (50-100). Expected improvements in the ranging accuracy ( to 1-2 cm) and in the corresponding precision makes the proposed system an excellent candidate for geodetic and geodynamic applications. As far as the mode of operation is concerned in case of a laser system the following trade-offs need to be considered:

- The likeliness of having more or less favourable weather conditions at 4 distant sites in case of the short arc mode (possibly with a single satellite and non simultaneous ranging) vs. the feasibility to overcome instrumental problems in the geometric mode (airplane and satellite with simultaneous ranging).

In case of an RF system neither of these problems are critical, and the decisive factor is whether systematic errors effecting the RF systems can be reduced to the level of those effecting the laser systems.

Possible candidates as users of a Close Grid Geodynamic Measurement System (CLOGEOS) are: Solid Earth - motions near plate boundaries, subsidence and uplift, regional strain measurements, horizontal motions and dilatancy near faults, post earthquake resurvey, regional tidal loading, volcanism associated motions, surface motions on unstable slopes, geodetic surveys. Cold Regions - dynamics of pack ice and ice islands, snow/ice motions in major ice sheets, profile and flow of glaciers, surface motions in permafrost. Marine Geodesy - positioning of ocean bottom geodetic reference frame, positioning or tracking of surface bouys.

Acknowledgement

This work was supported through Contract No. NAS8-31195 from the George C. Marshall Space Flight Center, NASA, Huntsville, Ala.

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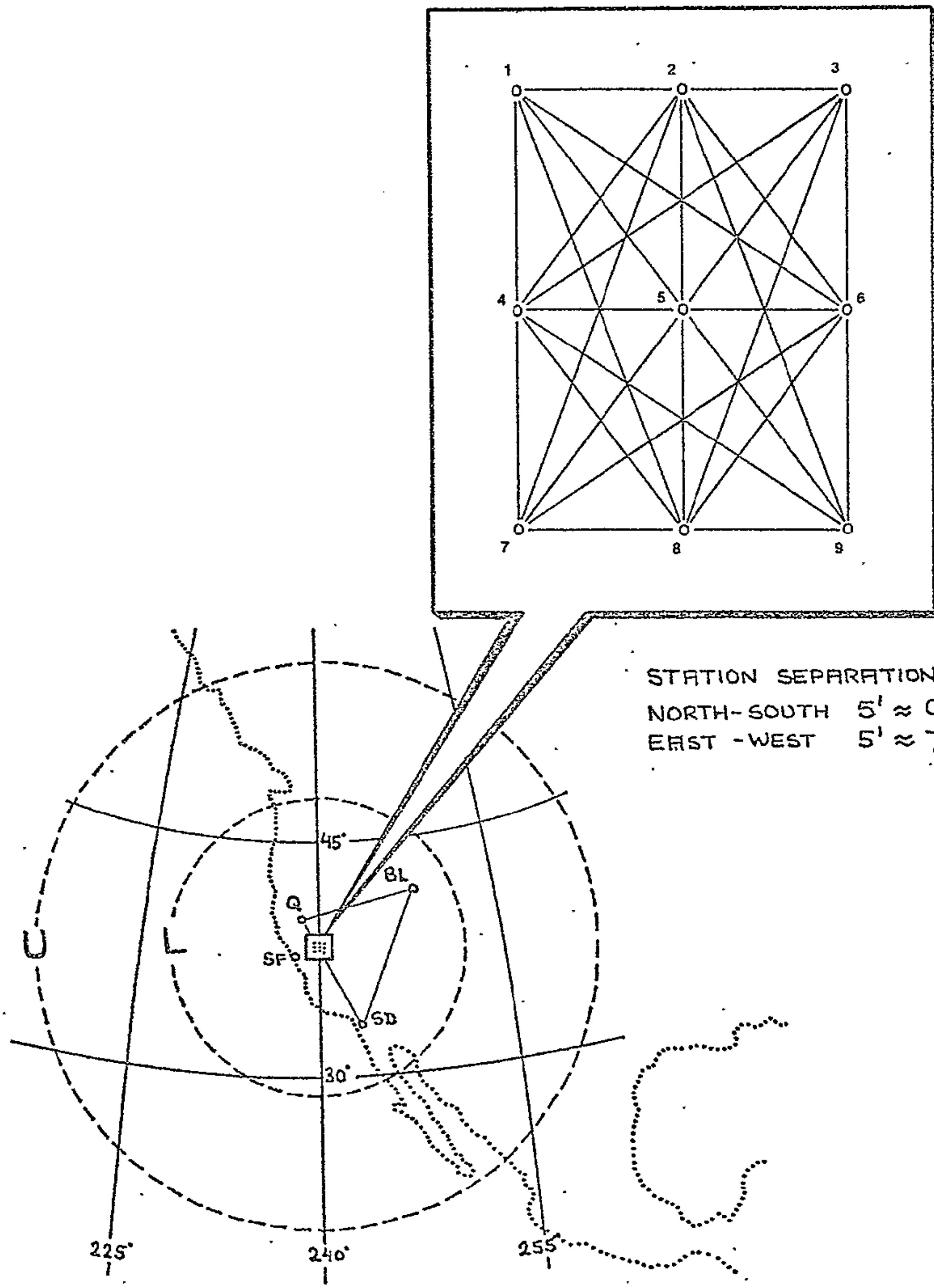
FIGURE 1 LOCATION OF GRID AND REFERENCE STATIONS




STATION SEPARATION
NORTH-SOUTH 5' ≈ 9.3 KM
EAST-WEST 5' ≈ 7.3 KM

TABLE 1

## RECOVERY OF STATION-TO-STATION DISTANCES

36 DISTANCES BETWEEN 9 GRID STATIONS 500 OBS./STAT.
ACCURACY OF RANGE MEASUREMENTS. $\sigma_R = 10$ cm.

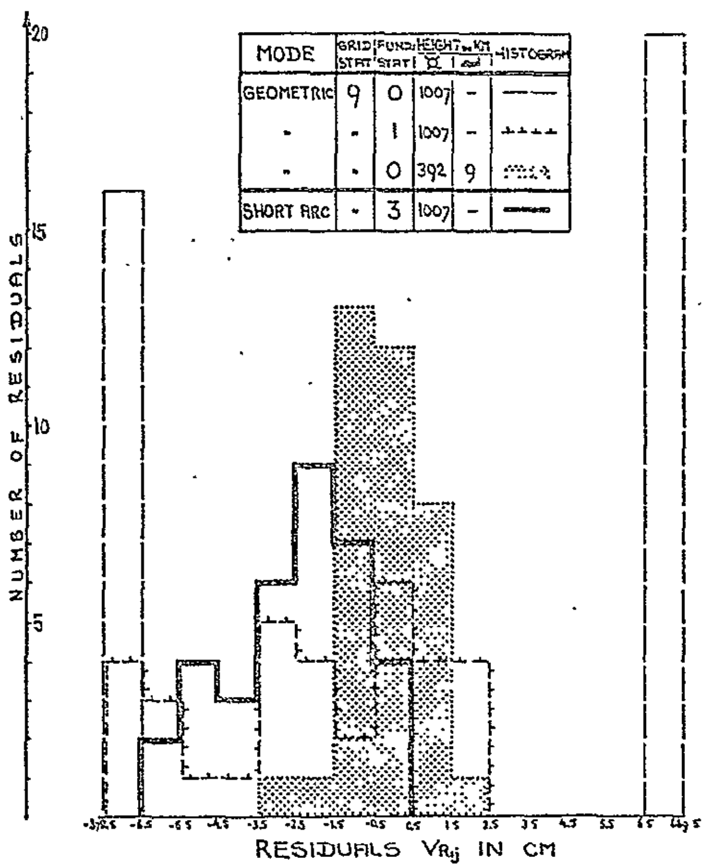
| | | MODE | $\Delta H_m$ | NUMBER OF STATIONS | | HEIGHT IN KM | | PERCENTAGES OF RESIDUALS (ABSOLUTE) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | GRID | FUND. | ⌑ | ⌓ | 0-1 cm | 1-2 cm | 2-3 cm | 3-4 cm | >4 cm | MAX RES. IN CM | MAX $\sigma$ IN CM |
| 1 | | GEOM. | 0 | 9 | 0 | 1007 | - | | | | | 100 | 669 | 569 |
| 2 | ALTERNATIVES | " | 1000 | " | 0 | 1007 | - | 14 | 11 | 11 | 11 | 53 | 25 | 14 |
| 3 | | " | 0 | " | 1 | 1007 | - | 28 | 16 | 14 | 14 | 28 | 11 | 11 |
| 4 | | " | 0 | " | 3 | 1007 | - | 72 | 22 | 6 | | | 3 | 2 |
| 5 | | " | 0 | " | 0 | 392 | 9 | 69 | 28 | 3 | | | 3 | 4 |
| 6 | | SHORT ARC | 0 | " | 3 | 1007 | - | 22 | 28 | 14 | 14 | 22 | 7 | 7 |

FOR A GRAPHICAL REPRESENTATION SEE FIGURE 2.

FIGURE 2

## RECOVERY OF STATION-TO-STATION DISTANCES

36 DISTANCES BETWEEN 9 GRID STATIONS 500 OBS./STAT.
ACCURACY OF RANGE MEASUREMENTS: $\sigma_R = 10$ cm.



USSR Academy of Sciences

Astronomical Council

International Seminar "New Methods of Space Geodesy"

Leningrad, 24 - 30 November, 1975

## PRELIMINARY PROGRAM

25 November

Morning Session (10 am - 2 pm)

The Opening Ceremony - Bakratov - Greetings

A.H. MASEVICH, N.P. ERPYLYOV, S.K. TATEVYAN (USSR) - Review of Space Geodesy Programs as Realized by the Astronomical Council of the USSR Academy of Sciences in 1970-1975.

J. KOVALEVSKY (France) - Installation du Centre d'Etudes et de Recherches Geodynamiques et Astronomiques (CERGA).

T.J. KUKKAMAKI (Finland) - Utilization of the 890km Long Geodimeter Traverse in Space Geodesy.

E.P. FYODOROV (USSR) - On the Observational Methods used for the Earth Rotation Studies.

EITSCHBERGER (FRG) - On Problems of Accuracy of World Geodetic Data from Satellites.

W. PACHELSKI (Poland) - Results of the Analysis of Laser Ranging Measurements and Synchronous Photographic Observations of GEOS-B (1968) by the Successive Adjustments Method.

Afternoon Session (4 pm - 6 pm)

Y. KOZAI (Japan) - Orbital Elements of GEOS-A and -B by Use of Laser Observations.

A. DINESCU, N.RADULESCU (Rumania) - Sur la Determination preliminaire de la station de Bucarest dans le systeme "The Standard Earth."

KISSILEV and BIKOV (USSR) - Orbital Elements from Direct Observations.

M. BURSA (CSSR) - The Satellite Altimetry and the Scale Factor of the Geopotential.

F.NOUEL (France) - Traitement des mesures et resultats de Geodesie Spatiale par recepteur Doppler.

26 November

Morning Session (10 am - 2 pm)

YU.L. KOKURIN, V.K. ABALAKIN (USSR) - On Potentialities and Some Results of the Laser Ranging to the Moon.

I.I. MUELLER (USA) - Aspects of Positioning using Satellite Borne Lasers.

V.V. ZLOTIN (USSR) - On Necessary and Practicable Accuracy of Accounting for the Light Velocity Variation in the Atmosphere in Laser Ranging to AES and to the Moon.

G. KARSKY (CSSR) - On the Problem of Reduction of Heterogeneous Satellite Observations in a Local Network.

J. KOSTELECKY (CSSR) - Problems of Accurate Reduction of Observations to Synchronous Time Moments.

J. KAKKURI (Finland) - The Finnish Stellar Triangulation Net as a Geodetic Control for the First Order Terrestrial Triangulation.

J. KABELAC (CSSR) - First Realizations of the Triangulation Project using High-altitude Targets in the CSSR.

M.V. PAUNONEN, A.B. SHARMA (Finland) - Satellite Laser Transmitter and Receiver, Technical Solution and Test Results.

Afternoon Session (4 pm - 6 pm)

H. KAUTZLEBEN, CL. ELSTNER, G. HEMMLEB, H. MONTAG (GDR) - Complex Studies in the Planetary Dynamics of the Earth.

N. CAPITAINE, L. SAINT CRIT (France) - Variations de la latitude et longitude de la station Doppler du CERGA.

N.L. MAKARENKO (USSR) - On the Accuracy of Geometrical Satellite Method as Applied to Constructing a Regional Geodetic Network.

## 27 November

Morning Session (10 am - 2 pm)

L.P. PELLINEN, O.M. OSTACH, G.V. DEMYANOV (USSR) - On Prospects of using the combined Satellite, Gravimetric and Astrogeodetic Data for Determination of the Figure and the Gravity Field of the Earth and their Time Variations

L.R. KOGAN, V.I. KOSTENKO, L.I. MATVEYENKO (USSR) - On Potentialities of the Radio-interferometric Facility of the Institute for Space Research as Applied to Geodesy and Astronomy.

W.H. CANNON, R.B. LANGLEY, W.T. PETRACHENKO, N.W. BROTEN, D.L. FORT, T.H. LEGGE (Canada), P.A. BARBER, M.J. QUIGLEY (England) - Geodetic and Astronometric Measurements using the Algonquin-Chilbolton Long Baseline Interferometer.

P.E. ELIASBERG (USSR) - On Interfering Parameters Affecting the Solution of the Problem of Combined Determination of the Earth Figure and Gravity Field.

V.S. GUBANOV, YU.S. STRELETSKY, N.D. UMARBAYEV, B.A. FIGARO (USSR) - On Prospects of Solution of Astrometric Fundamental Problems by use of the VLBI and Special Space Experiments.

M.L. LIDOV, YU.F. GORDEYEVA (USSR) - On the Mascons' Influence on Determination of the Moon's Gravitation Coefficients.

HALMOS, F., ADAM, J., ALMAR, I., FEJES, I. (Hungary) - An Application of Radiotechnic Methods (Doppler Measurements) to AES Observations for Solution of the Geometrical and Dynamical Problems of Space Geodesy.

G. BALMINO, B. MOYNOT (France), CH. REIGBER (FRG) - Modele de potentiel terrestre GRIM 1.

## 28 November

Morning Session (10 am - 2 pm)

M.S. PETROVSKAYA (USSR) - On Construction of the Everywhere Convergent Geopotential Expansion.

V.V. BROVAR (USSR) - Coordination of the Satellite and Gravimetric Observations in Calculations of Harmonic Coefficients of the Potential of the Ellipsoidal Earth.

GH. VASS (Rumania) - On the AFU-75 Network Adjustment.

N. GEORGIEV, B. SHUSTOV (USSR) - On Mechanical Approximation of AES Orbits by Means of Power Series.

M. SOLARIC (Yugoslavia) - On Determining the Distance between Two Terrestrial Surface Points by Use of Two AES.

A. CAZENAVE (France) - Determination des Coefficients des marees oceaniques a partir d'observation des satellites.

L.K. LAUCENIEKS (USSR) - The General Theory of the One-parameter Mobile Barrier.

IVANOVA (USSR) - Improvement of Orbit using Photographic Observations of Planets.

## Closing of Seminar

Proceedings of the seminars will be published by the Astronomical Council, as Vol. XV of the Observations of Artificial Satellites.