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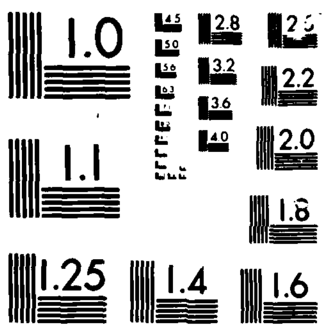

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The African Doppler Survey project (ADOS) is a multi-national effort to establish primary control (via Doppler satellite observations) on the African continent. There are four Computing Centers under the ADOS project which use three different point positioning programs. These programs are: DOPL79, GEODOP V, and ORB-SPP. The differences observed in the computations using the various softwares were recently investigated. This paper presents preliminary results of this study.

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A COMPARISON OF ADOS POINT POSITIONING RESULTS FROM VARIOUS SOFTWARES

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SUMMARY

The African Doppler Survey project (ADOS) is a multi-national effort to establish primary control (via Doppler satellite observations) on the African continent. There are four Computing Centers under the ADOS project which use three different point positioning programs. These programs are DOPL79, GEODOP V, and ORB-SPP. The differences observed in the computations using the various softwares were recently investigated. This paper presents preliminary results of this study.

1.0 INTRODUCTION

The ADOS project was initiated in 1981 to, among other things, establish zeroeth order control over the African continent [1]. To date over 270 stations have been observed by survey teams from various countries. These data sets have been (or will be) distributed to the four Computing Centers as designated under ADOS [2]. The Computing Centers and their respective point positioning softwares involved under the ADOS project are as follows:

ADOS COMPUTING CENTER	SOFTWARE USED
Computing Center No. 1 Nairobi, Kenya	GEODOP V
Computing Center No. 2 Brussels, Belgium	ORB-SPP
Computing Center No. 3 Washington, DC, USA	DOPL79
Computing Center No. 4 Alger, Algeria	GEODOP V

Motivation for this study arose from the fact that the Computing Centers use different softwares to obtain point position solutions, even if these softwares utilize the same data sets. This would be of little concern if the softwares involved were all versions of the same original program. This is certainly not the case. Three of the four Computing

Centers use totally different software, not to mention the different computer system configurations.

It was determined that it would be useful to the ADOS project to embark on some limited analysis of results obtained from these differing softwares. The environment would be controlled and every effort would be made to insure compatibility and comparability between the different solutions. These constraints are reflected in the current testing procedure. It should be noted that the solutions obtained under this study are strictly for test purposes and are in no way to be construed as official Defense Mapping Agency (DMA) solutions. Also, all solutions under this study were obtained using the precise ephemerides of the Navy Navigation Satellite System (NNSS) as computed by DMA.

2.0 PROCEDURES

The major steps of this study are summarized below:

- Softwares were obtained and modified for use on the Sperry Univac 1100/61 computer at DMA.
- Stations were selected.
- Options were selected to standardize specific test cases.
- Data sets of the selected stations were de-archived from DMA's database and solutions obtained with the author's version of DOPL79.
- Comparison solutions were generated utilizing the imported softwares.
- Results of these comparisons were then compiled and summarized for presentation.

2.1 SOFTWARE ACQUISITION

2.1.1 DOPL79

The software DOPPLR was written in 1976 at DMA [3]. The program was subsequently revised [4] and resides on DMA's Sperry Univac 1100/61 computer as DOPL79. (Note that this software has also been referred to in literature as DOPPLR 79). A copy of this software was obtained by the author.

2.1.2 GEODOP V

The software GEODOP was originally written for a CDC 6400 computer in 1976 by J. Kouba and J. Boal of the Geodetic Survey of Canada [5]. The preprocessing sections of this program system were written in the same time frame by J. Lawnikanis [6,7]. A set of utility programs was also written by Lawnikanis [8]. An updated version of GEODOP (GEODOP V) was acquired by B. Archinal of The Ohio State University [9] and re-coded for use on an IBM computer system. This version was obtained by the National Geodetic Survey (NGS) and subsequently adapted for use on a Sperry Univac system. It was this version that has been acquired by DMA. The program has been maintained by updates as they have been forthcoming from the original author (Dr. Jan Kouba) [10]. Other modifications have been applied to ease operation.

2.1.3 ORB-SPP

The software ORB-SPP was obtained from Dr. Paul Paquet of the Observatoire Royal De Belgique (Royal Observatory of Belgium - ORB). Since the software resides on a Sperry Univac 1100/81 computer, installation onto DMA's own Univac 1100/61 was essentially tranparent. One note should be made concerning data preprocessing: the data received at ORB for input into ORB-SPP are in the Standard Exchange Format (SEF) [11] as preprocessed by the Institut Geographique National (IGN) of France. Efforts to reformat DMA preprocessed data into this format were not wholly satisfactory. This issue is discussed further in Sections 2.6.2 and 4.2.

2.2 SOFTWARE ADAPTATION

The software adaptations and actual writing of new code necessary for successful completion of this project are outlined below:

2.2.1 DOPL79

Only minor changes were made to decrease paper output and allow processing with the "new" satellite 30500.

2.2.2 GEODOP V

Changes were made to compute and output the solution to the ground mark (if antenna height given). FORTRAN routines were written to a) convert the Alpha-Coded Hexidecimal (ACH) format of the archived DMA Magnavox data to binary format as expected by the preprocessor and b) determine the best satellite frequency offsets to use for that particular date. Code was modified as dictated by Table 1 to match ADOS options.

2.2.3 ORB-SPP

Changes were made to allow for more complete searching for the proper ephemerides, computation and output of the solved position to the ground mark (if antenna height given), and to allow processing with satellite 30500. FORTRAN routines were written to reformat DMA preprocessed data into the SEF and also to sort the precise ephemerides into chronological order. Code was modified as dictated by Table 1 to match ADOS options.

Software was also written to generate the necessary computer operating system commands to a) retrieve the precise ephemerides corresponding to the date of occupation and the location of the station and b) to obtain precise point position solutions with the three softwares.

2.3 TEST STATION SELECTION

Two criteria for station selection were established a) a balanced distribution on the African continent was desired, and b) all softwares involved must be able to process the types of data selected. The significance of the last point is that the program which preprocesses Geoceiver data for GEODOP V (PREPAR) as recoded by NGS had never been tested. Some effort was expended toward testing this version of the program but the testing was not completed. As a result, no Geoceiver data were included in this study. The Doppler satellite receiver types employed in this study were JMR (various models), Magnavox 1502 and Magnavox 1502-DS. A total of 27 stations were selected for investigation. Sixteen stations (59%) were observed with JMR receivers; eleven stations (41%) were observed with Magnavox receivers.

2.4 SELECTION OF TEST PROCEDURES

There are many different program parameters one could alter for study. After much deliberation, it was decided to use the parameters as outlined in Table 1. It was also decided that the solutions obtained with the software DOPL79 were to be held fixed as the control set, i.e., differences in solutions would be relative to the corresponding DOPL79 solution. Two sets of solutions were generated with the remaining softwares (GEODOP V and ORB-SPP). The first set of solutions was obtained with the options currently in use at the particular Computing Center (as is the case with ORB-SPP). If the software is not presently in use at a Computing Center (as is the case with GEODOP V), reasonable options were then selected by the author. A second set of solutions was obtained with options as recommended by Dr. Claude Boucher of the IGN [12]. If an option was not specified by Boucher, then the option was set as per the DOPL79 default options.

2.5 DOPL79 SOLUTIONS

The data sets of the selected stations (see Section 2.3 above) were de-archived from DMA's Doppler Geodetic Point Position (DGPP) data base. Then, the DMA satellite - observed summary cards for the selected stations were obtained. These cards represent DMA's official ADOS point position solution for these stations. Solutions were obtained with the author's version of DOPL79 to validate the data sets selected. If any differences were noted (solved position, passes used in the solution, points used, etc.) between DMA's solution and those from the author's version of the software, effort was made to resolve it. Nearly all of the solutions agreed exactly. Differences were noted because, in some instances, a subset of the data had been used to obtain DMA's ADOS solution. In such cases effort was made to match the DMA solution . If it was not possible to match the DMA solution, then the solution obtained with the author's version of DOPL79 was used as the basis for comparison. It should be noted that when the same set of data (and, of course, the same program options) was used in these two versions of DOPL79, the results were in complete agreement. The set of solutions from the author's version of the software DOPL79 henceforth will be referred to as 'D1' solutions. There are 27 D1 solutions.

2.6 COMPARISON SOLUTIONS

Solutions with the imported softwares GEODOP V and ORB-SPP were then attempted using the stations of Section 2.3 and options of Table 1.

2.6.1 GEODOP V Solutions

Solutions were first obtained with the 'standard' options as selected for GEODOP V (see Table 1). Solutions were then obtained with GEODOP V using the so called ADOS options as also outlined in Table 1. No undo difficulties were encountered in completing these station solution runs. The solutions obtained under standard options will be referred to as 'G' solutions and those using ADOS options will be referred to as 'G1' solutions . Solutions were possible for the entire set of selected stations; there are a total of 27 G station solutions and a total of 27 G1 station solutions.

2.6.2 ORB-SPP Solutions

Solutions with the software ORB-SPP were somewhat more difficult to obtain. In several cases (and all involving DMA Magnavox data) no 'acceptable' passes were found. Effort was expended to resolve this difficulty but time constraints necessitated abandonment of the investigation before meaningful progress could be made. Previous validation of the DMA's version of ORB-SPP showed exact agreement with results from the original version, when the same data set and program options were used. One can only infer that the preprocessors used at IGN and DMA obtain differing results which affect computational results. These difficulties with the DMA data reformatted into SEF decreased the number of solutions from ORB-SPP available for comparison. Solutions with ORB-SPP using options currently in use by ORB will be referred to as 'O' solutions. Solutions obtained using the ADOS options (and zero weather parameters) will be referred to as the 'O1' solution set. There are a total of 13 O solutions and a total of 12 O1 solutions (note: these sets are comprised of only JMR data).

Dr. Paquet sent all of his SEF data to the author. Eighteen sets of the data received from Paquet correspond to sets studied under this research. This provides a good opportunity to compare solutions obtained with ORB SEF data to those obtained with the DMA reformatted data. Solutions were obtained with these sets using the usual ORB options and also using the ADOS options. Solutions with the ORB data using the usual ORB options are referred to as 'O2' solutions. Solutions with the ORB data with zeroed weather parameters under ADOS program options will be referred to as 'O3' solutions. There are a total of 17 O2 solutions and a total of 16 O3 solutions.

Another set of solutions utilizing Paquet's data was attempted. These solutions were generated using the program ORB-SPP with ADOS options, but using the ORB SEF data with the weather parameters as inserted during preprocessing. These solutions will henceforth be referred to as 'O4' solutions. There are a total of 16 O4 solutions.

In review: The G and G1 solutions were generated using the de-archived DMA data sets. The G solutions were obtained with standard program options; the G1 solutions were generated using ADOS program options. The O and O1 solutions were obtained using DMA data reformatted into SEF. The O solutions were obtained with standard options used in the software and selected weather parameters in the data. O1 solutions were obtained using ADOS program options and (zeroed) weather data. The O2, O3 and O4 sets were generated using ORB SEF data. The O2 solutions were generated with standard program options and with default weather parameters if real weather data were not available. The O3 solutions were obtained with ADOS software options and the data having zero weather parameters inserted in place of real or default weather. The O4 set was obtained with the ORB SEF data used with ADOS program options (i.e., O2 data under O3 program options).

3.0 RESULTS

Several factors helped insure meaningful results from this study: the softwares were under the control of one individual, the solutions were obtained from softwares established on one computer system and a unique set of data for each station was used to obtain the individual station solutions.

Table 2 contains statistics derived from the station solution differences obtained under this study. The average differences and the standard deviations are given for each solution set and also for differences partitioned between JMR and Magnavox receiver types.

3.1 TOTAL SOLUTION STATISTICS

The O4 set displayed the best agreement with the D1 set on the basis of the smallest average radial difference. The next best agreement was achieved with the O2 solutions, which had slightly better standard deviations. The set showing the poorest agreement with the D1 solutions was the O3 set, with average radial differences of nearly 2 meters. The standard deviations were also large (> 1.5 m in all components). All sets (except for one) had an average height difference that was negative - that is to say, the computed height was greater than the height as computed by DOPL79. The O solutions were the lone exception. This solution set had a somewhat high standard deviation of 1.6 m, so this average could be somewhat misleading.

3.2 JMR AND MAGNAVOX SOLUTIONS

The inability to obtain any O and O1 solutions with Magnavox data leaves direct comparison between JMR and Magnavox possible with O2, O3, O4, G and G1 solutions only. In all cases the standard deviations of the average differences obtained from Magnavox data were smaller than those obtained from JMR receivers even considering, that for all solution sets there were more JMR data sets involved than Magnavox.data. Of particular note is the large bias (2 meters) in the longitude for the JMR portion of O3 solutions.

4.0 ANALYSIS

The results will be examined on a software - by - software basis and then from a more general standpoint. The desire at this point is not to determine if any results are more valid, but to uncover trends which may ultimately lead to more consistent results with the softwares involved under the ADOS project.

4.1 GEODOP V

Both sets of solutions obtained with the software GEODOP V exhibited good agreement with the corresponding solutions obtained with software DOPL79. Of particular note is that the use of ADOS program options decreased the average differences in the latitude and longitude components, but the average height difference increased.

4.1.1 G SOLUTIONS

The G solutions had biases of -0.24, 0.26 and -0.56 m in latitude, longitude and height. The numerous differences in software options (Table 1) can certainly be expected to account for much of the difference between these solutions. The standard deviations are of interest here. The latitude component had the largest standard deviation of 1.5 m, the longitude component had the smallest standard deviation of 0.7 m and the height component fell between the two with a standard deviation of 1.2 m.

4.1.2 G1 SOLUTIONS

The G1 solutions were significant in that ADOS program options decreased the average differences in the latitude and longitude components with no significant change in their standard deviations. The average height difference increased to -0.82 m but had a standard deviation that was equal to that of the G solution set. Moreover, nearly all of the individual solutions obtained with ADOS options had a smaller standard deviation of unit weight than the corresponding standard option solutions obtained, indicating improved modeling.

4.2 ORB-SPP

Difficulties in obtaining useful solutions arose from reformatting problems with DMA Magnavox 1502 data. These SEF data, as provided to ORB from IGN, have a slightly different 'look' from the SEF data simulated under this research. The data as processed and formatted by IGN are compressed into 30 second counts by summing 6 consecutive

Doppler intervals. Consequently, the time interval for each 30 second Doppler count could be (approximately) 27.6 seconds or 27.9 seconds [13]. The preprocessor at DMA, however, sums the Doppler data in a slightly different fashion. The Doppler counts are compressed into 30 second counts by summing 7 Doppler intervals, then 6 intervals, then 7 intervals, and so on. Three time intervals of the compressed counts are then possible: (approximately) 27.6 seconds, 27.9 seconds and 32.2 seconds. The conversion of these 7/6/7/6 data into SEF data was unsuccessful for Magnavox data; the total number of Doppler counts agreed for a pass but the timing intervals seemed to be incorrect. Efforts to rectify this problem were unsuccessful and ultimately had to be abandoned. Hence, no Magnavox solutions were available from DMA data reformatted into SEF (i.e. the O and O1 sets contain no solutions with Magnavox data). Because of this, we have no basis for comparison of data containing real weather parameters vs. data containing default weather parameters. However this reformatting process seemed to work reasonably well for JMR data .

4.2.1 O SOLUTIONS

The O solutions yielded the unexpected results of close agreement in latitude and height with the D1 solutions, but poor agreement (-0.67 m) in the longitude component. This large bias in the longitude (also visible in other ORB-SPP solutions) could be attributable to timing problems discussed in Section 4.2 or to modeling differences. Also of note is the large (4.3 m) standard deviation associated with the average difference in the longitude component.

4.2.2 O1 SOLUTIONS

The O1 solutions demonstrated the problems one can encounter in ORB-SPP solutions when "zeroed" meteorological parameters are employed in the data. This likely accounts for the large (1.8 m) difference between the average heights of the O and O1 sets. There is also a 1.3 m shift apparent in the longitude component.

4.2.3 O2 SOLUTIONS

The O2 set differences, using ORB SEF data and standard ORB options, yielded statistically strong results - small biases with small standard deviations. Also noteworthy is that the standard deviations are uniform between the three geodetic components. While these differences are not as small as those mentioned in previous testing [14], the larger differences could be attributed to inclusion of a number of stations with noticeably different (and statistically weaker) solutions, i.e. the DOPL79 solution of some stations exhibited an uncommonly large rms when compared to the other solutions. This fact was also noted on the satellite - observed summary card.

4.2.4 O3 SOLUTIONS

The O3 set, as did others using ADOS program options, showed a lessening of the average latitude bias but also experienced a doubling of the standard deviation. The longitude displayed a positive shift, as did the other ORB-SPP ADOS solution sets, of nearly a meter. The associated standard deviation showed some weakness in the average longitudinal difference, however. The height lessened by a meter and its standard deviation was in the 1.6 m range.

4.2.5 O4 SOLUTIONS

The O4 set which used the data of the O2 set and program options of the O3 set gives us some valuable insight on the effect of not considering weather parameters. The average difference in the latitude component decreased relative to the O2 solution set. The associated standard deviation was slightly smaller as well. The bias of the longitude coordinate was somewhat greater, but with a slightly smaller standard deviation. The average height difference was slightly smaller while its standard deviation was slightly larger. Hence one can conclude that the change in just the program options (with ORB SEF data) caused the latitude and height components to improve while the longitude component bias deteriorated slightly. This could again point to timing difficulties but the bias in the longitude is not really so large to be of much consequence to this study.

The differences between the O3 and O4 sets readily give direct comparison between the use of no weather versus the use of some default weather . What immediately stands out is the dramatic decrease of the average height difference. The shift from O3 to O4 is nearly 1.3 m (toward closer agreement with the D1 solutions).

4.3 GEODOP V / ORB-SPP COMPARISON

It would be useful at this point to briefly look at the agreement between the ORB-SPP solutions and GEODOP V solution sets. The O2 set is directly comparable to the G set with differences as obtained from the common D solutions. The O2 - G differences in latitude, longitude and height are 0.45, -0.18, and 0.10 m. Likewise, the O4 and the G1 solution sets are comparable. The O4 - G1 differences in the same coordinates are 0.24, 0.42 and 0.62 m.

5.0 DISCUSSION

From the results obtained under this study, it is apparent that some weather data should always be utilized; real weather when available or some default weather parameters should be used in the data processing. This is especially important for ORB-SPP, - as evidenced by the O1 and O3 solution sets. These sets having zero weather parameters in the data gave noticeably weaker solutions, not to mention very poor agreement with the other solution sets which used some sort of weather parameters. Another matter evident from this testing is the possibility of data preprocessing differences. Previous tests have shown good agreement between DOPL79 and GEODOP V [15] and between DOPL79 and ORB-SPP [14], but these tests were carried out with data sets processed elsewhere. To the author's knowledge, this study is the first instance where the same raw data have been used and preprocessed at one site. The results obtained with GEODOP V were good but those obtained with the raw data reformatted into SEF (for ORB-SPP) were mixed. Results obtained from IGN SEF data (for ORB-SPP) were also good.

The O2 set gave the the best agreement with DOPL79 solution, closely followed by the O4 set. This further points out the importance of preprocessor compatability inasmuch as these two solution sets exhibited the best agreement in terms of their means and their associated standard deviations. The results of these two sets would also support the assertion that the use of ADOS options (vs. some other set of reasonable options) is not significant. Certainly at the 1.5 m accuracy level [16], a difference between average biases of 40 cm between standard option solutions and ADOS option solutions is not significant. This sort of reasoning holds true for the G and G1 solutions which had a maximum coordinate difference between the two sets of 25 cm.

6.0 CONCLUSIONS

Even after hosting the three main softwares used under the ADOS project on one computer system, adapting these softwares to make them as compatible as possible and using unique data sets, differences in the solved coordinates exist. These average differences range from -0.24 to 0.21 m in latitude, from -0.67 to 1.23 m in longitude and -1.68 to 0.15 m in height. These differences can be attributable to differences in data preprocessing, weather parameters used, program modeling and other factors.

7.0 ACKNOWLEDGEMENTS

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TABLE 1

SOFTWARE OPTIONS

Parameters	GEODOP V (standard)	ORB-SPP (standard)	"ADOS" (test)
Data / Pass cutoff angle	5 / 10 degrees	5 / 10 degrees	10 / 10 degrees
Minimum points @ pass	6	10	6
Rms multiplier for datapoint rejection	3.0	2.3	3.0
speed of light	299792500 m/s	299792458 m/s	299792500 m/s
Hopfield * hd (km) = hw (km) =	40.136 + .14872tcel 11.0	40.082 + .14898tcel 12.0	40.082 + .149tcel 11.0
Weather used : JMR : MAG :	default real	default default	default real
Points used for ephemeris fit	10	8	10

* Values for Hopfield model actually used in DOPL79 are :

hd (km) = 40.1 + .149tcel
hw (km) = 12.0

TABLE 2

SOLUTION SET STATISTICS

DIFFERENCES RELATIVE TO DOPL79 (m)

		G	G1	O	O1	O2	O3	O4
(# of solutions)		27	27	13	12	17	16	16
$\overline{\Delta\phi}$	TOTAL	–.24	-.20	0.10	0.02	0.21	–0.02	0.04
	JMR	–.49	-.35	0.10	0.02	0.18	0.14	0.11
	MAG	0.07	0.00	0.00	0.00	0.29	–.36	–.10
$\overline{\Delta\lambda}$	TOTAL	0.26	0.17	–.67	0.63	0.37	1.23	0.59
	JMR	0.22	0.12	–.67	0.63	0.10	1.96	0.54
	MAG	0.32	0.24	0.00	0.00	1.01	–.93	–.97
$\overline{\Delta H}$	TOTAL	–.56	-.82	0.15	–1.68	–.46	–1.46	–.20
	JMR	–.90	-1.05	0.15	–1.68	–.45	–1.70	0.16
	MAG	–.14	-.53	0.00	0.00	–.49	–.93	–.97
$\sigma\ \overline{\Delta\phi}$	TOTAL	1.50	1.51	0.63	1.27	0.76	1.56	0.68
	JMR	1.97	2.04	0.63	1.27	0.85	1.78	0.80
	MAG	0.45	0.18	0.00	0.00	0.57	0.90	0.32
$\sigma\ \overline{\Delta\lambda}$	TOTAL	0.73	0.68	4.26	2.39	0.79	3.23	0.74
	JMR	0.80	0.84	4.26	2.39	0.67	3.51	0.87
	MAG	0.68	0.45	0.00	0.00	0.71	1.87	0.37
$\sigma\ \overline{\Delta H}$	TOTAL	1.19	1.19	1.56	2.40	0.81	1.58	1.19
	JMR	1.39	1.40	1.56	2.40	0.95	1.88	1.24
	MAG	0.71	0.83	0.00	0.00	0.30	0.10	0.57

JMR : Statistics derived from JMR solutions sets

MAG : Statistics derived from Magnavox solution sets

END
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