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Mobile Radio Interferometric Geodetic Systems

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SUMMARY

The mobile VLBI geodetic system called ARIES for Astronomical Radio Interferometric Earth Surveying is currently operating in a proof of concept mode that is adapted to also acquire geophysically significant data. These geophysical data are acquired by careful choice of the transportable antenna's location using the advice and counsel of the Caltech Seismological Laboratory. Figure I shows the fixed base stations at Goldstone and Owens Valley and portable antenna sites in southern California.

Initially, the ARIES 9m stations began S-band (2.3 GHz) experiments on a 307 m baseline near the Goldstone 64m MARS station (DSS 14) and demonstrated a 3 cm accuracy relative to a direct line of sight geodetic survey (Ong, et al 1976). That first experiment sequence demonstrated absolute three-dimensional accuracy (within 3 cm) in a limited case; that is, if the technique could not achieve the absolutely correct vector on 307 m, it certainly would fail on longer baselines where the initial goal was 10 cm. Such success was, of course, only a necessary condition since over such a short baseline the factors of troposphere and ionosphere were self-cancelling and the system was insensitive to radio source positional uncertainties, universal time and polar motion effects.

The next step was to operate on a longer baseline so the parameters that were previously self-cancelling or of low sensitivity could now be sensed, and the ability to calibrate for their effects could be demonstrated.

In August 1974, the ARIES station was moved to JPL in Pasadena, a location logistically favorable, accessible to conventional geodetic systems to check on claimed results and close to the San Gabriel fault.

The measurement accuracy for the 180 km JPL/Goldstone (DSS 14) baseline was estimated in June 1975 at approximately 8 cm. ARIES then made its measurements available to the National Geodetic Survey in advance of NGS geodetic connection of JPL to the TCT, Trans Continental Transverse, the most accurate large scale horizontal control network in the U.S. The results of the comparison of the ARIES derived baseline length with that of the NGS agreed within 13 cm, in good agreement with the 8 cm accuracy estimates of both techniques.

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While the ARIES accuracy results on 180 km were gratifying, the conventional geodesy accuracy estimates of 8 cm may have been overstated and a more conclusive test situation was desired. What was needed was as long a distance as could be found (hopefully also of geophysical interest) which a laser distance measuring device could make in a single direct line of sight. Such a pair of locations was found, Malibu (MAL), on the Santa Monica/Malibu fault and Palos Verdes (PV) Peninsula near the Inglewood/Newport fault. Both the MAL and PV sites are abandoned NIKE air defense bases with roads and their perimeter fences still intact. By observing on approximately 380 km baselines from ARIES 9m station to the 40m telescope of the Caltech Owens Valley Radio Observatory (OVRO), the three dimensional position of PV and MAL was derived relative to the OVRO telescope. By differencing the components of the positions of the two sites, the vector was obtained from Malibu to Palos Verdes, a 42 km path across Santa Monica Bay in southern California, with an estimated accuracy of better than 10 cm. In May 1977, the Santa Monica Bay experiment results were again provided in the blind to the National Geodetic Survey which then directly measured both the intersite distance and azimuth by conventional first-order horizontal geodetic control methods. The two techniques differ by 6 ± 10 cm in baseline length and 0.5 ± 1.2 arc sec in azimuth (corresponding to 10 ± 20 cm). The details of the Santa Monica Bay experiments are contained in (Niell, et al, 1979).

The ARIES Santa Monica Bay accuracy demonstrations were a prerequisite to the Sea Slope Experiment of the NGS to study the apparent differences between oceanographic and geodetic leveling determinations of the sea surface along the Pacific Coast. With joint NGS and NASA OSTA support, ARIES developed the relative geometric positions of tide gages at La Jolla and San Francisco, California where a 65 cm sea slope to the south was indicated by geodetic leveling. ARIES acquired data at San Francisco (SF) in June 1977 and La Jolla (LJ) in July 1977 spanning a total of 42 days. Using the 40m telescope at OVRO as the primary base station, 6 cm or better, three dimensional accuracies were obtained over these 380 to 500 km baselines. A secondary base station, the 26m Venus antenna at Goldstone, also participated. Based upon a triangle baseline vector closure criterion, individual baseline determinations indicated 6 cm accuracy with a one part in 10^7 closure. Simultaneous S-band (2.3 GHz) and X-band

(8.4 GHz) observations at SF to OVRO processed as separate experiments yielded identical baseline vector results within the 2 to 5 cm uncertainty estimates imposed by signal to noise limits. The San Francisco/La Jolla experiments also utilized dual channel water vapor radiometers at all stations and played an essential role in calibrations of local vertical relative positioning. Hydrogen maser frequency references were made available by the Goddard Space Flight Center for use at all stations. The final combination of ARIES geometric tide gage positional data with the geoid between La Jolla and San Francisco remains an analysis task for the NGS in order to directly compare with spirit leveling observations, to resolve the sea slope controversy.

Five measurement sessions have now been conducted between the JPL Pasadena site and Goldstone since August 1974 for a total of eight measurements to Goldstone and five to OVRO. The precision in the east-west coordinate appears to be approximately 3 cm when measurements are taken closely in time as in the Sea Slope experiment previously discussed. For the JPL/Goldstone baseline, a 12-15 cm westward movement of JPL site relative to Goldstone has occurred with most of the displacement taking place in the last half of 1975. For 1976 to 1978 relative stability is indicated using both OVRO and Goldstone base stations. For all baselines, no vertical displacements appear significant in the presence of the 6 to 10 cm system noise imposed mainly because water vapor radiometer tropospheric calibrations are not yet consistently available.

A 4m high mobility ARIES station has now begun initial field demonstrations. Early experiment results indicate an inadequate signal to noise margin which limited the quasar catalog resulting in a biased solution. Telecommunications upgrades to the 4m antenna are dual Mark II recording (8 Mb/sec) and a traveling wave maser first stage receiver amplifier. With these improvements, the 4m station will probably out perform the 9m station while providing a two site per week site measurement yield compared to the one site per month yield of the 9m system. At present the 4m antenna is undergoing side-by-side tests with the 9m antenna at the JPL site. Following successful side-by-side tests, the 4m station will demonstrate its high mobility and accuracy by repeating the Malibu/Palos Verdes experiment but this time to acquire the data at both sites in one week.

The satellites of the NAVSTAR Global Positioning System (GPS) offer an important new geodetic resource making possible a highly accurate portable radio geodetic system. A concept called SERIES (Satellite Emission Radio Interferometric Earth Surveying) makes use of GPS radio transmissions without any satellite modifications. By employing the technique of VLBI and its calibration methods, 0.5 to 4 cm three dimensional baseline accuracy can be achieved over distances of 3 to 300 km respectively, with only 2 hours of on-site data acquisition. The use of quasar referenced ARIES Mobile VLBI to establish a sparse fundamental control grid will provide a basis for making SERIES GPS measurements traceable to the time-invariant quasar directions. Using four SERIES stations deployed at previously established ARIES sites, will allow the GPS satellite apparent positions to be determined. These apparent positions then serve as calibrations for other SERIES stations at unknown locations to determine their positions in a manner traceable to the quasars. Because this proposed radio interferometric configuration accomplishes its signal detection by cross-correlation, there is no dependence upon knowledge of the GPS transmitted waveform which might be encrypted. Since GPS radio signal strengths are 10^5 stronger than quasar signals, a great reduction in telecommunications sophistication is possible which will result in an order of magnitude less cost for a SERIES GPS station-compared to a quasar based mobile VLBI system. The virtually all-weather capability of SERIES offers cost-effective geodetic monitoring at less than $1,000 per site.

Details of the SERIES-GPS system will be published in the Bulletin Géodésique in early 1979.

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2. Niell, A. E., K. M. Ong, P. F. MacDoran, G. M. Resch, D. W. Fite, L. J. Skjerve, D. J. Spitzmesser, D. D. Morabito, L. Tanida, E. S. Claflin, B. B. Johnson, M. G. Newsted, A. Banisch and J. F. Dracup, Comparison of a Radio Interferometric Differential Baseline Measurement with Conventional Geodesy, Tectonophysics, 52 (1979), 532.

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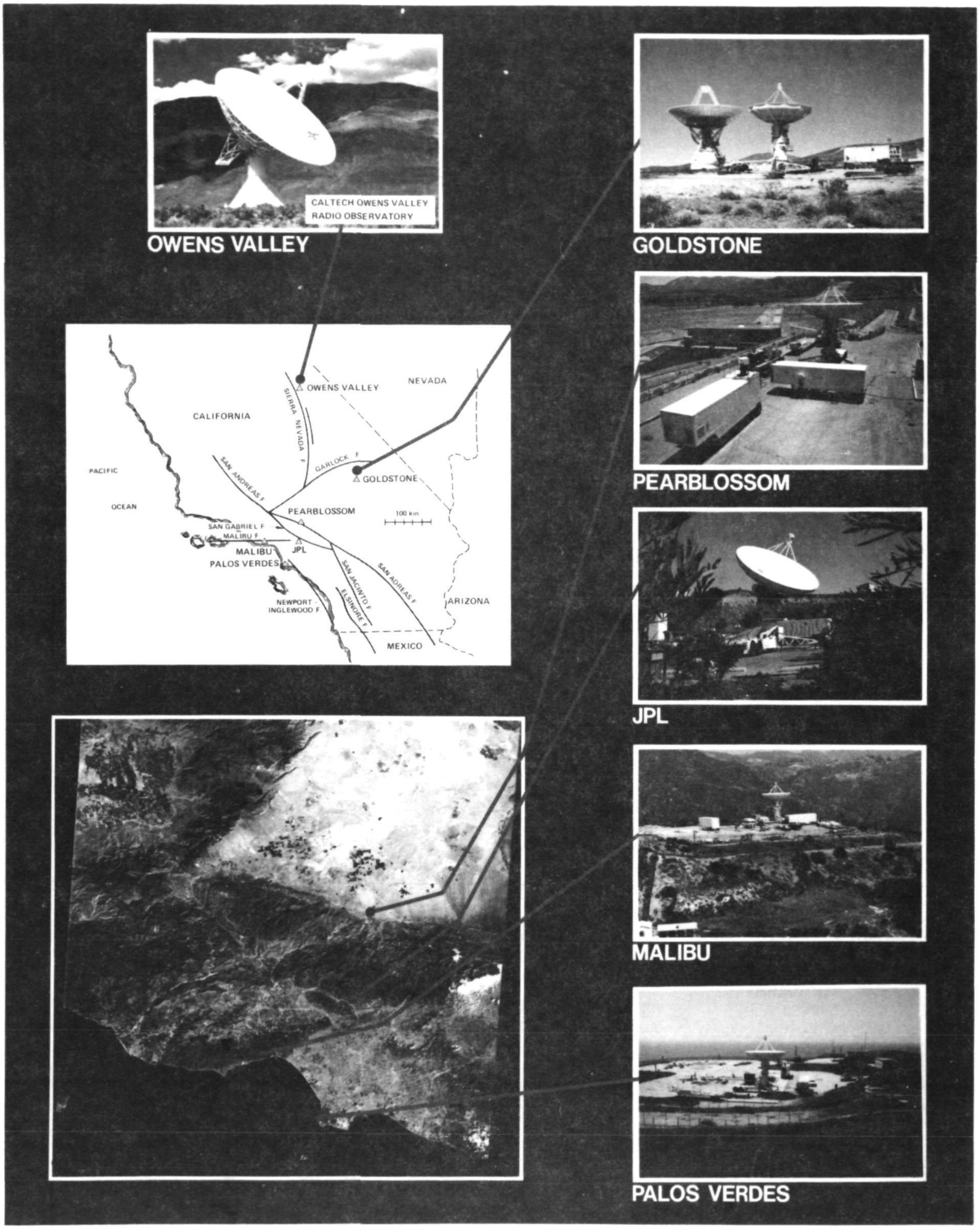
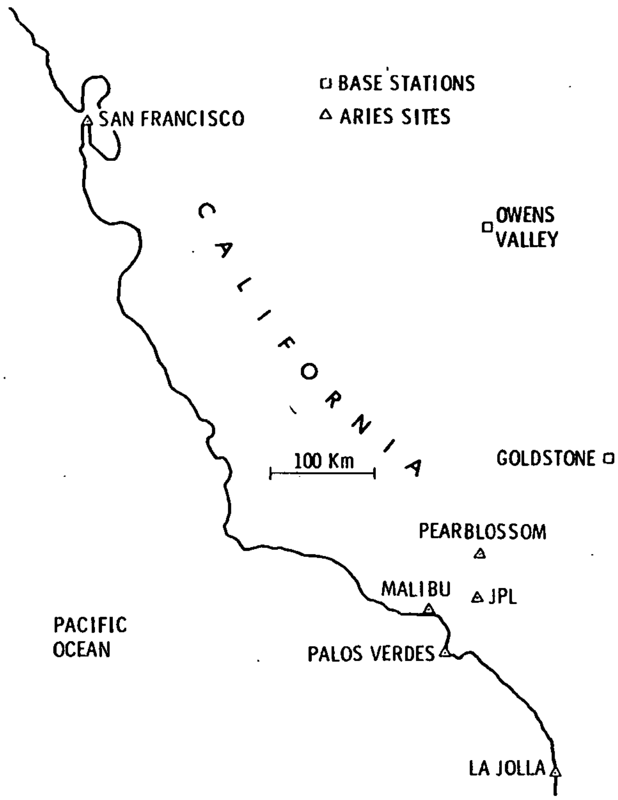
PROJECT ARIES NETWORK



ARIES NETWORK



ARIES/CONVENTIONAL GEODESY INTERCOMPARISON

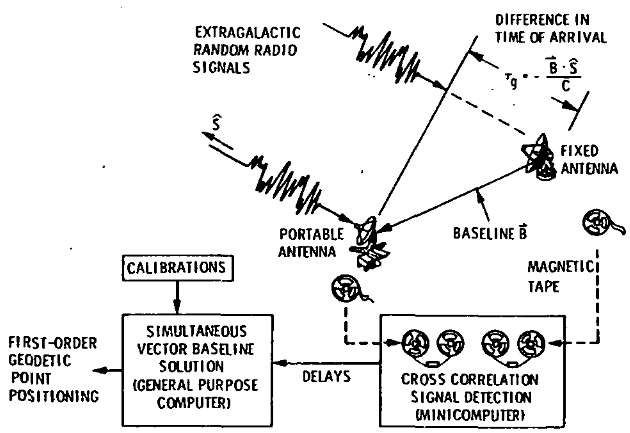
ARIES $|\overrightarrow{(OVRO\text{-}PV)} - \overrightarrow{(OVRO\text{-}MAL)}|$ = 41 573.902 ± 0.086 M

NGS* (PV-MAL) = 41 573.844 ± 0.06 M

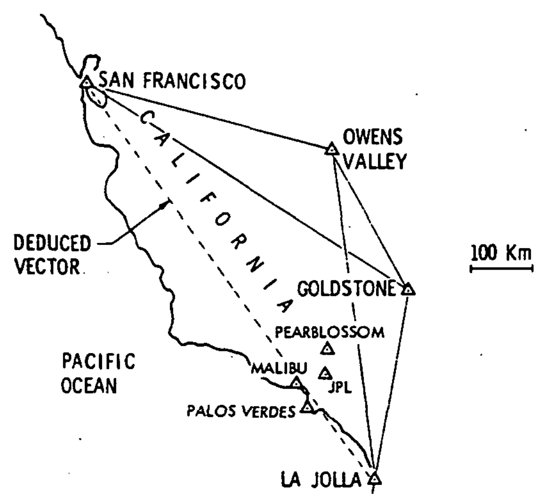
ARIES - NGS = 0.058 ± 0.105 M AND AGREEMENT WITHIN 0.5 ARC SEC RELATIVE TO GEODETIC NETWORK LOCATIONS IMPLYING ~ 6 CM THREE DIMENSIONAL ACCURACY IS BEING ACHIEVED BY ARIES ON ~ 400 KM BASELINES.

*RESULTS AS OF 9/16/77 FROM J. DRACUP, CHIEF
HORIZONTAL CONTROL BRANCH
NATIONAL GEODETIC SURVEY

ARIES GEODETIC SYSTEM



ARIES SEA SLOPE I NETWORK



ARIES SEA SLOPE I RESULTS

OVRO, PRIME BASE STATION

	X, m	Y, m	Z, m
OVRO-SF	298 106.79 ± 0.03	-220 735.63 ± 0.04	-49 774.66 ± 0.05
LJ-OVRO	-45 849.77 ± 0.03	-289 087.63 ± 0.04	-397 130.42 ± 0.06
SF-LJ	-252 257.02 ± 0.05	509 823.26 ± 0.06	446 905.08 ± 0.08

LENGTH SF-LJ = 723 379.23 ± 0.03 m

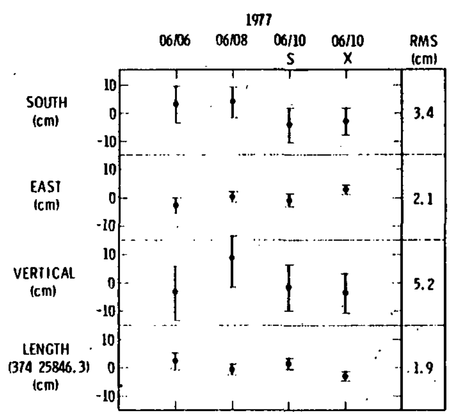
GOLDSTONE (DSS 13) SECONDARY BASE STATION

SF-LJ	-252 257.12 ± 0.04	509 823.07 ± 0.06	446 905.17 ± 0.09

LENGTH = 723 379.19 ± 0.05m

$$\overrightarrow{(SF\text{-}LJ)}_{ov} - \overrightarrow{(SF\text{-}LJ)}_{13} = \begin{pmatrix} 10\text{cm} \\ 19 \\ -9 \end{pmatrix}_{geocentric} \Longrightarrow \begin{pmatrix} -6\text{ cm} \\ -1 \\ -22 \end{pmatrix}_{local}$$

OVRO/ARIES (SAN FRANCISCO) BASELINE VECTOR
RELATIVE LOCAL COORDINATES AT S.F.; OVRO ASSUMED FIXED



GOLDSTONE (DSS-14)/ARIES (JPL) BASELINE VECTOR
RELATIVE LOCAL COORDINATES AT JPL; DSS-14 ASSUMED FIXED