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Beginning in 1992 June and continuing indefinitely as part of our contribution to FLINN (Fiducial Laboratories for an International Natural Science Network), DOSE (NASA's Dynamics of the Solid Earth Program), and the International GPS Geodynamics Service (IGS), analysts at the Jet Propulsion Laboratory (JPL) have routinely reduced data from a globally-distributed network of Rogue Global Positioning System (GPS) receivers,

Three products are produced and distributed weekly: (i) precise GPS ephemerides, providing satellite positions with one to two orders of magnitude improvement over the broadcast ephemerides, (ii) estimates of polar motion and length-of-day, and (iii) a descriptive narrative of the analysis for the week, These are typically made available to the public approximately two weeks following the data recording.

Based on comparisons of our earth orientation parameters with independent techniques, we estimate pole positions accuracies (1 σ) of ±0.6 milliarcseconds, and length-of-day accuracies of *0,13 msec.

Based on separate estimates of GPS ephemerides using nearly-independent data sets, we estimate their accuracy to be approximately ±40 cm (3-dimensional root-sum-squared) in an earth-fixed reference frame, A comparisen of JPL-produced ephemerides with those from other iGS Analysis centers shows similar agreement,

Ongoing work at JPL is aimed at continuing the trend of producing more and higher-quality results at lower cost,

INTRODUCTION

The first GPS experiment for the IERS and Geodynamics (GIG '91), a two-week campaign in early 1991, saw the first globally-distributed deployment of precise Global Positioning System receivers, and demonstrated few-parts-per-billion precision [1] in estimates of terrestrial site locations. Largely as a result of the success of GIG '91, the International GPS Geodynamics Service (IGS) began informally in 1992 June. JPL has contributed to the IGS since it began and, in conjunction with its ongoing support of NASA's Dynamics of the Solid Earth (DOSE) program, will continue to contribute.

Shown in Figure 1 is the distribution of terrestrial GPS P-code receivers as of 1993 February. Global coverage is currently very good, with only a few noticeable "holes". Within the next two years it is anticipated that these holes will be plugged with new receivers at strategic locations.

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Figure 2 summarizes the steadily increasing number of stations and satellites beginning in early 1992 and continuing to the present, One can speculate on whether the trend will continue, but currently the data volume, as measured by stations x satellites, doubles in just over a year!

Described in this paper are the analysis procedures used at JPL, the resulting products, and their estimated accuracies, We conclude with a brief look at JPL's plans for improving the efficiency and quality of its analyses,

PROCEDURE AND PRODUCTS

Figure 3 gives a simplified overview of the routine procedure. JPL's GPS Networks Operations (GNO) Group retrieves data from the global network, organizes them by time and site, converts them to the Rinex format, and makes them available for analysts,

Once it is determined that sufficient data are available for a given day, a file like that shown in Figure 4 is created. Such a file specifies what data are to be used in the day's analysis, as well as specific sites or GPS satellites from which data should be deleted or deweighted, due to known problems.

Based on input from this file, a daily script that runs several programs is launched, requiring a total of approximately 19 hours of cpu time on a 17-Mflop Unix workstation when data from 30 stations and 20 satellites are included, When completed, the daily analysis results in estimates for earth orientation, GPS satellite ephemerides, and location of terrestrial sites.

Each day is processed separately using the 24 hours of the UTC day plus the last 3 hours of the previous day and first 3 hours of the following day. Normal points are formed every 10 minutes, The data types are the undifferenced ionosphere-free phase and pseudorange, with assumed noise of 5 mm and 50 cm, respectively.

The GPS satellite motion is modeled as a 9-parameter epoch state vector which includes three-dimensional position, velocity, and solar radiation pressure. Additional parameters allow the solar radiation pressure to vary in a stochastic way about its average value. The noise model for this variation is Gauss-Markov with a 4-hour time constant and 10% standard deviation, Especially during periods when a satellite is in the Earth's shadow, the extra variation allows significantly better modeling of its motion.

The nominal value of the Earth's pole position is that of the IERS Bulletin B predicts, and its deviation from that nominal is modeled as a linear function of time. The deviation of UT1R–UTC from the nominal (again, IERS Bulletin B predicts) is also assumed to be linear with time, but in this case only the rate is estimated. This rate is the negative of length of day (LODR).

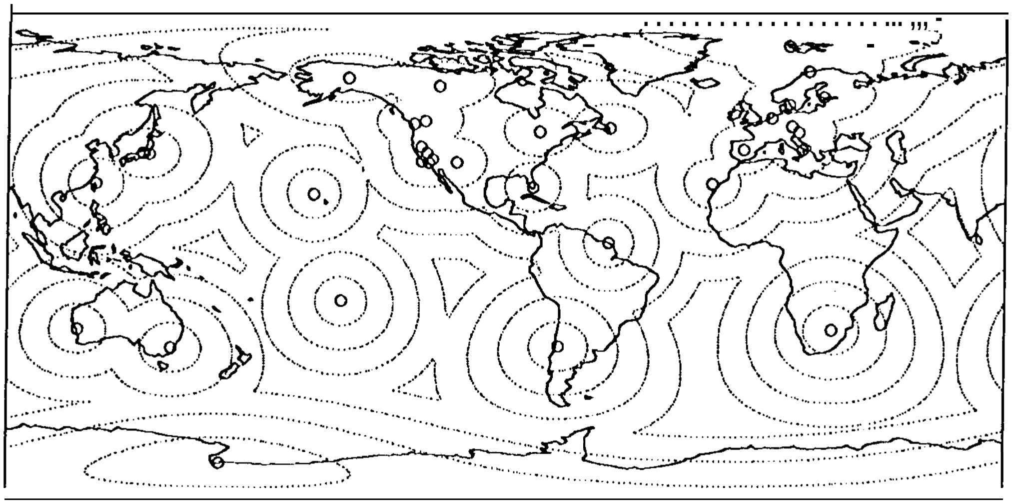

Figure 1 Distribution of terrestrial GPS receivers used in the daily analyses. The dotted lines represent contours of the distance-to-nearest-site function. The contour interval is 1000 km.

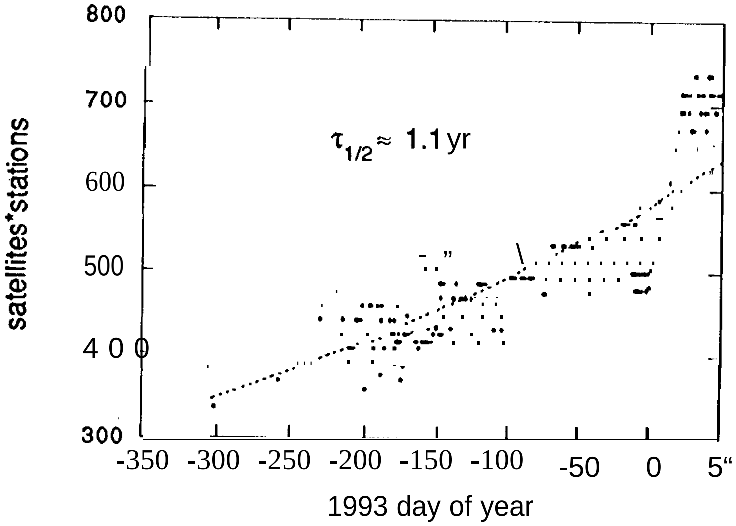

Figure 2 The number of satellites times the number of stations used in daily analyses beginning early 1992. At the current rate, the data volume doubles in a little over 1 year.

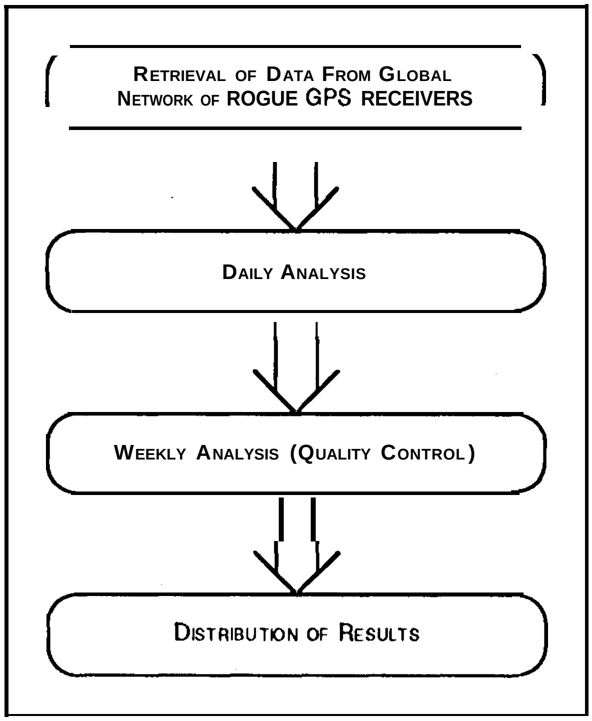

Figure 3 Simplified Flow **Chart** of FLINN Analysis

```
setenv RUNDIR       /usr3/djeff                          # run directory
setenv TEMPLATES    ~jfz/Flinn                           # template directory
set    SRCE   =     ( /net/logos/rinex /net/apu/usr1/djeff/xrinex )
setenv DEST         /net/apu/usr3/jfz/hold               # output files
setenv YYMMMDD      93feb14                              # day of analysis
setenv YYMMMDDa     13-FEB-1993                          # for tp_nml start
set.env YYMMMDDb    15-FEB-1993                          # for tp_nml end
setenv YES          044_                                 # yesterday
setenv DOY          045_                                 # today
setenv 10M          046_                                 # tomorrow
setenv 01_START     '13-FEB-1993 11:00:00'               # oi file start
setenv OI_END       '15-FEB-1993 13:00:00'               # oi file end
setenv DT_START     '13-FEB-1993 21:00:00'               # .rnx file start
setenv DT_END       '15-FEB-1993 03:00:00'               # .rnx file end
setenv INTERVAL     600                                  # IO-minute data interval
set    DELQMs =     ( )                                  # delete transmitters
set.   DELQMg =     ( JPL1 JPLL MCMU WEST )              # delete receivers
set    DEWGTs =     ( GPS08 )                            # deweight transmitters
set    DEWGTg =     ( CASA)                              # deweight receivers
set    SCLNOs =     100.0                                # dwgt xmtr scale factor
setenv MAP_ START   '13-FEB-1993 11:59:52.0000'          # mapping interval, start
setenv MAP_END      '15-FEB-1993 11:44:52.0000'          # mapping interval, end
setenv RATEPOCH     '14-FEB-1993 11:59:52.0000'          #epoch for rate estimate
setenv SITEPOCH     '1993 02'                            #epoch for site locations
```

Figure 4 Example of file used to control analysis of a given day, The terrestrial sites include eight which are assumed to be at known locations, These are Algonquin Park, Ontario, Canada; Fairbanks, Alaska, U. S.; Hartebeesthoek, South Africa; Kokee Park, Hawaii, U. S.; Madrid, Spain; Santiago, Chile; Tromso, Norway, and Yaragadee, Australia, The fixed values are updated at the beginning of each month to allow site velocities from ITRF91 (IGS mail message 90).

Location of other terrestrial sites are solved for every day,

The operational cycle is one week, during which seven daily analyses are completed, Together with the result from Saturday of the previous week and Sunday of the following week, these are used in quality control,

The three dimensional root-sum square orbit overlap Q for a given satellite and day is defined as

$$Q^2 \equiv \sum_t |\mathbf{X}(t) - \mathbf{X}_-(t)|^2 + \sum_t |\mathbf{X}(t) - \mathbf{X}_+(t)|^2 , \qquad [1]$$

where X(t), $X_-(t)$, and $X_+(t)$ are, respectively, the vector estimates of the satellite's position at time t using data from the current, previous, and subsequent days, In the first sum, t covers the first three hours of the current day, while in the second sum it covers the last three hours, for a six-hour total overlap with adjacent days,

Four files are produced and distributed weekly, with naming convention `jpl0www7`, where www is the GPS week and 7 indicates the results are for the entire week. The files are distinguished by their extension, `.sum` for a narrative summary, `.sp1` or `.sp3` for GPS ephemerides [2,3], and `.erp` for Earth orientation,

RESULTS

Earth Orientation

Shown in Figure 5 are the Earth orientation results, A discontinuity at 1992 days 200-201 (July 18-1 9) is a consequence of the change in fiducial strategy which went from three (Fairbanks, Algonquin, and Madrid) fixed sites to the eight described earlier. From July 19 through the end of 1992, excluding some days during which anti-spoofing was in effect, the average difference between JPL's pole position measurements and those from the IERS Bulletin B Final values is about 0.8 mas for X and 1.2 mas for Y, with standard deviations of about 0.6 mas for both X and Y.

Although GPS measurements are almost completely insensitive to UT1R–UTC, they are sensitive to its time derivative, essentially the Earth's spin rate. With T ≡ 1 day, the quantity

$$\mathrm{LODR} \equiv -T \frac{d}{dt} (\mathrm{UT1R-UTC}) , \qquad [2]$$

is the conventional measure of this spin rate. We began including daily estimates of LODR beginning with GPS week 660 (1992 August 30). Shown at the bottom of Figure 5 are our daily estimates of LODR and a smooth curve which represents the negative derivative of the IERS Bulletin B Final values of UT1 R-UTC. Excluding a few 3σ outliers, the agreement is approximately 0.13 msec, 1σ, with a negligible bias, Because the daily estimates of LODR are independent, an integration of them to recover UT1 R–UTC (given some initial starting value) would exhibit random-walk behavior, so some method is required to prevent the walk from wandering too far away. We are currently investigating the forward-running filter

$$UT1\ R\text{-}UTC(t+T) = \alpha\ A + (1 - a)\ [UT1\ R\text{-}UTC(t) + LODR(t+T/2)], \quad [3]$$

where A is a separate estimate of UT 1 R–UTC(t+T) and α is a free parameter, (We continue to use $T \equiv 1$ day.) The parameter α should be small enough so that the resulting UT1 R-UTC series will exhibit a time variation consistent with the daily GPS-measured LODR values, and only just large enough to suppress large random-walk excursions, A reasonable choice for A is the most-recent IERS Bulletin B *Final* value of UT 1R–UTC (typically 30- to 60-days old), incremented to the present by the daily GPS measurements of LODR. In the near future we intend to include the results of such a procedure in our **. erp** files. We expect the resulting series to be consistent with the IERS Bulletin B Final values to within a few msec or better, and will be available several weeks earlier,

GPS Satellite Ephemerides

Shown in Figure 6 is a histogram of the quantity Q defined in [1] above, for all satellites and days from GPS week 666 through 684 (1992 Ott 11 – 1993 Feb 20; we began 30-hour daily arcs with stochastic solar radiation pressure on Ott 11). The median value is 40 cm, Using this as a measure of orbit accuracy, the precise ephemerides are more than an order or magnitude better than the broadcast ones,

Another indication of orbit quality is shown in Figure 7. Based on "Orbit Comparison" results published in IGS Reports and covering GPS weeks 660 through 682 (1992 August 30 – 1993 Feb 06), we show the comparison between JPL-produced ephemerides and those produced by the Center for Orbit Determination in Europe (CODE). Histograms for the rotation, translation, and scale indicate how much these need to be adjusted to bring into alignment the JPL and CODE coordinate systems. Once this is done, the satellite position estimates differ by amounts indicated in the 3drss histogram. The median value is 39 cm, remarkably consistent with the distribution of Q.

EPOCH '92

The Epoch '92 period, 1992 July 26 – August 8, occurred when our estimation strategy had not matured to its current state. These days were reprocessed in early 1993 with the current estimation strategy. The results are on JPL's `bodhi` distribution computer, and will be available also on the Crystal Dynamics Data information System at Goddard Space Flight Center.

Figure 8 shows histograms similar to Figure 6. The dotted line is the original result for the Epoch '92 period, while the solid line is a histogram of the same quantity after reprocessing. The improvement is clear.

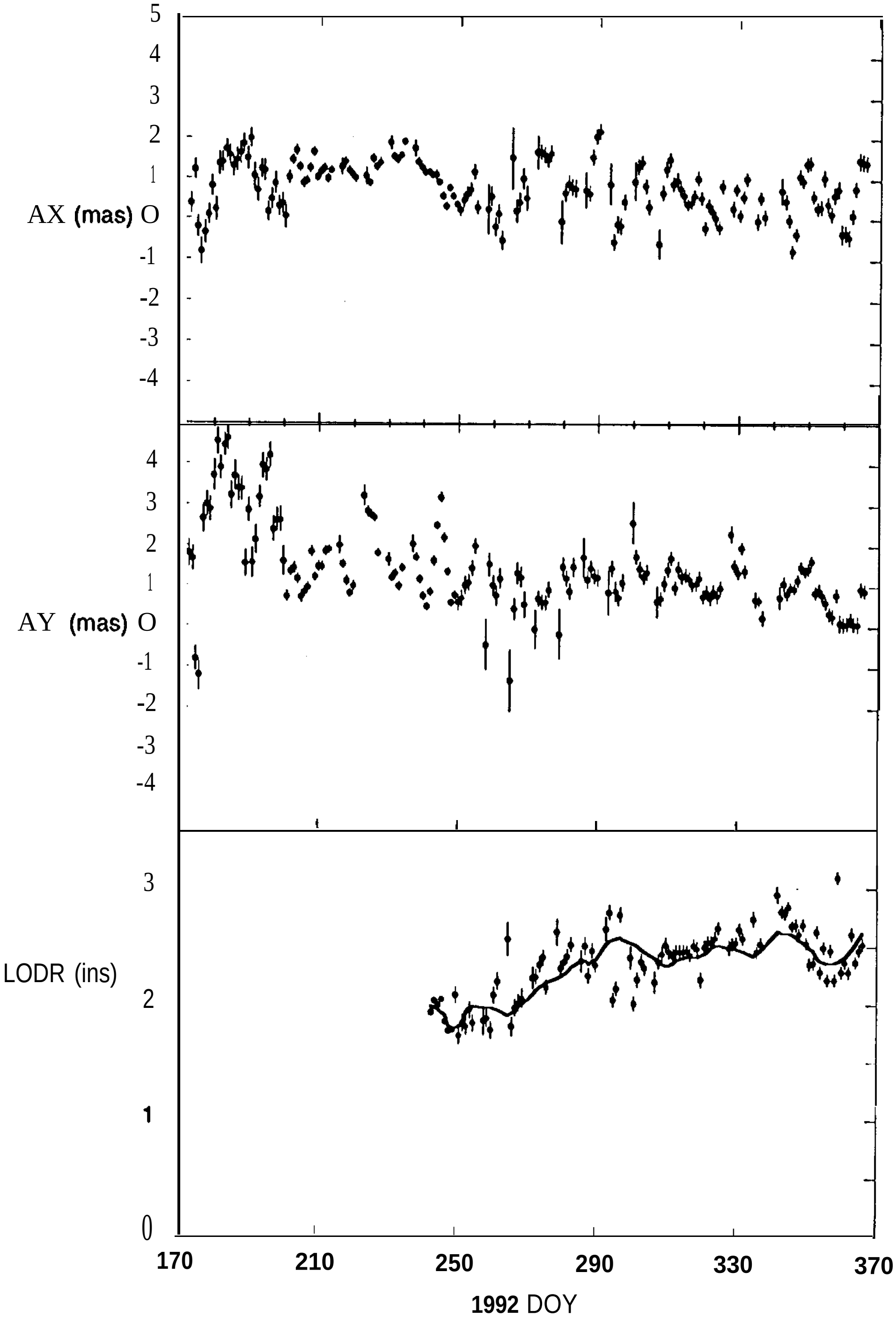

Figure 5 GPS estimates of Earth orientation parameters compared with IERS Bulletin B Final Values, For pole position, the values shown (AX and AY) arc the GPS measurements minus the IERS values, and the error bars reflect the formal uncertainty in the GPS measurements. For LODR, the solid line indicates the negative time derivative of the IERS value of UT 1R-UTC, and the points indicate the GPS measurements and formal uncertainties.

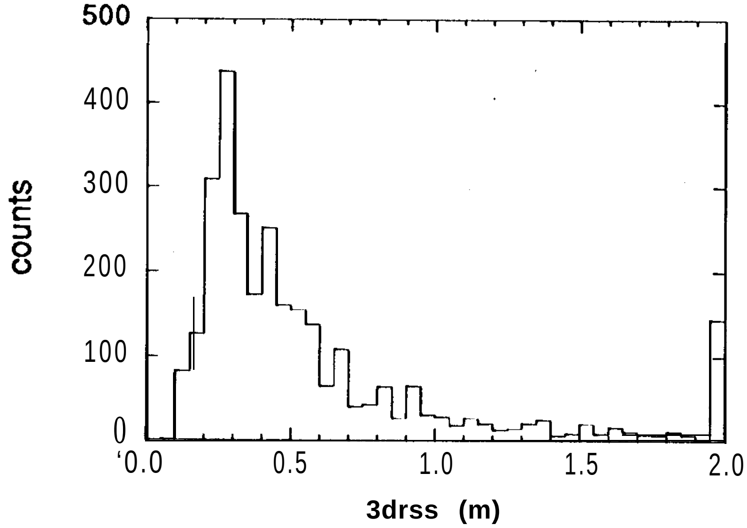

Figure 6 Quality of GPS ephemerides based on the degree to which ephemerides from adjacent days agree near midnight. The median value is 40 cm.

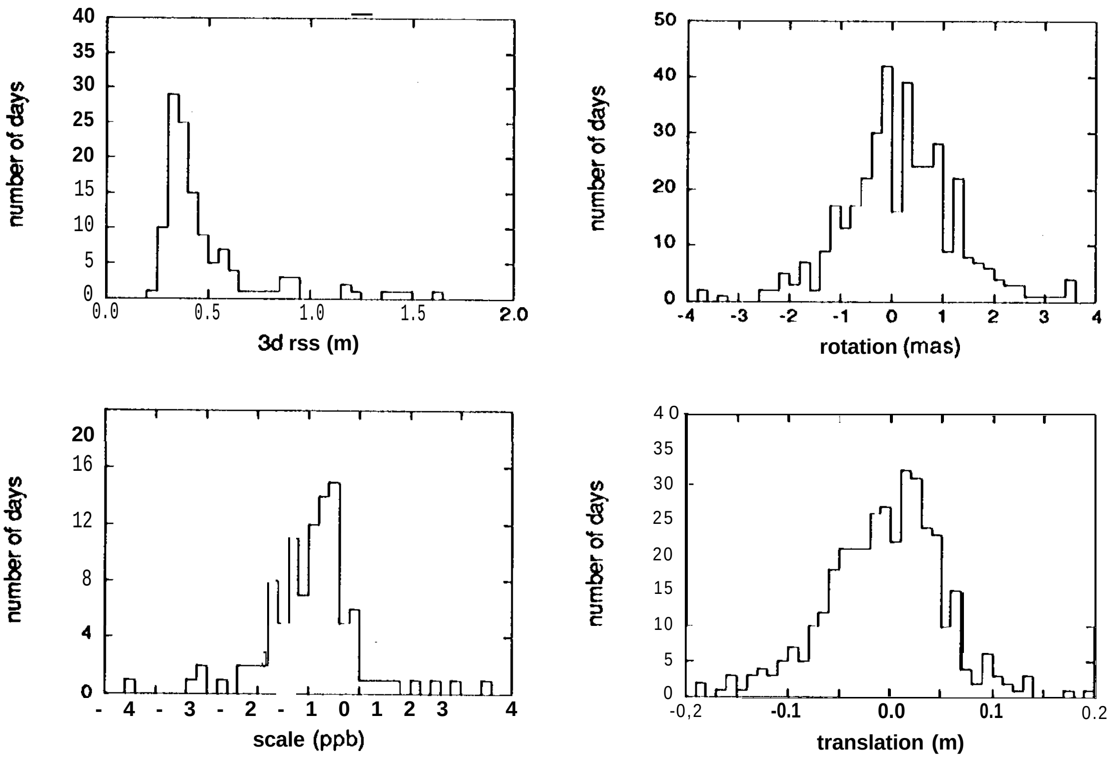

Figure 7 Comparison of JPL-produced GPS ephemerides with those from the Center for Orbit Determination in Europe.

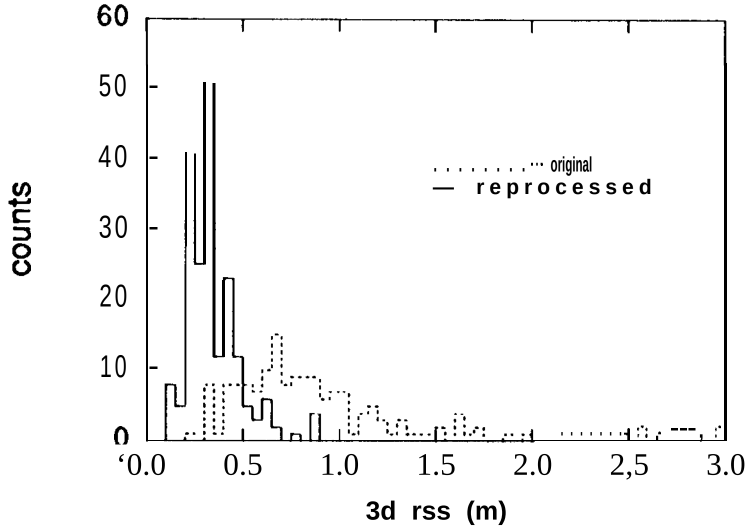

Figure **8** Improvement in orbit repeatability for the Epoch '92 period (1992 July 26 – **August** 8). The dotted line indicates the original result, and the solid line indicates the result after rc-processing with the current estimation strategy.

CONCLUSIONS AND FUTURE PROSPECTS

Since the first half of 1992, JPL has made regular contributions to the IGS, consisting of precise GPS orbits and Earth orientation results. We expect to continue these contributions.

Accuracies are currently estimated to be a few tens of cm for GPS orbits, about half a milliarcsec for pole position, and a bit over 0.1 msec for LODR.

Accuracies of all quantities may improve significantly once we start resolving carrier phase bias ambiguities [4], which should begin sometime this calendar year (the current limit is computing resources). Quality control will be enhanced by daily monitoring of several regional baselines,

A number of weekends during 1992 saw implementation of Anti-spoofing (AS). Only recently has the Rogue receiver software been upgraded to handle AS data, Since the upgrade, AS has been processed successfully, although with somewhat degraded accuracies, Analysts at JPL will be investigating modifications of the nominal strategy to better accommodate AS data,

As was shown earlier in Figure 2, the quantity of data has steadily increased, and will probably continue to increase in the near future, because of both more satellites and more receivers. So that the computational burden remains tractable, we may need to process a select number of stations to fix orbits, and then use fixed orbits for the remaining stations, In addition to the current offerings, new products to be distributed soon will be satellite and station clock solutions. If a demand exists, troposphere estimates and stochastic solar radiation pressure estimates could also be made available.

Finally, additional automation in the routine processing may reduce the manpower required to keep up to date with the analyses. The current turnaround of approximately two weeks could conceivable be reduced to a few days, or even less,

ACKNOWLEDGMENT

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REFERENCES

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[3] Remondi, B. W., NGS *Second Generation ASCII and Binary Orbit Formats and Associated Interpolation Studies,* presented at the Twentieth General Assembly of the International Union of Geodesy and Geophysics, Vienna, Austria, Aug 11-24, 1991.

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