WUJNS
WUHAN UNIVERSITY JOURNAL OF NATURAL SCIENCES

Vol. 8 No.2B 2003 603-609

Article ID: 1007-1202(2003)02B-0603-07

PANDA Software and Its Preliminary Result of Positioning and Orbit Determination

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Abstract: PANDA (Position And Navigation Data Analyst) software is designed for data analysis of different satellite positioning and navigation systems, such as SLR, GPS and the future GALIEO. The software has being developed since 2000 at GPS Research Center of Wuhan University. A brief introduction of the software and its developing progress are given at first, and then the results of static positioning and GPS satellite orbit determination archived with PANDA are presented in this paper.

Key words: GPS; ambiguity; linear combination
CLC number: P 228.4

Received date: 2002-10-20
Foundation item: Supported by the National Natural Science Fundation of China (40174005)

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0 Introduction

The main purpose to develop a wide-oriented tool for analyzing data from satellite positioning and navigation system is to establish a basic platform for the scientific and application study in the related areas. As a basic part for the development of some Chinese applications satellite systems in the foreseeable future, PANDA (Position And Navigation Data Analyst) has gained the financial support from the National Foundation of Natural Science (NFNS) in China to aim at high precision real-time (including low earth orbit) satellite orbit determination and large scale positioning using data from multi satellite systems. GPS data processing is concentrated at the first stage, and SLR data and GALELIO data processing facilities will be implemented afterwards.

Based on the knowledge gained from some of the prestigious GPS software, such as BERNSE, EPOS, GAMIT and GIPSY, one-way satellite-receiver data as observation and filtering as estimator are taken in PANDA, which is much flexible for integrating static and kinematic as well as post-mission and real-time data processing capability. GPS observation model and satellite orbit model are similar to that in the softwares mentioned above.

As data editing is one of the critical issues in GPS data processing, especially for real-time applications, we made a lot of efforts on data editing and real-time quality control technology and developed a new quality control algorithm in the square root information filtering (SRIF).

Until now, the main part of the software has been finished and it is able to perform static and kinematic positioning and GPS satellite orbit determination. The result reaches a comparable accuracy to some widely used software. In the paper, the software structure is described firstly, and data flow and software developing progress are presented secondly. The results obtained now with the software using GPS data are displayed, finally.

1 Software Overview

The software starts from reading RINEX data and cleans them on the single station basis using the automatic editing strategy by Blewitt (1990)[1]. For data collected at static station without selective availability effect, with help of ionosphere-free phase fitting we successfully rescue data with high ionosphere effect or bad quality pseudo-range which is removed more or less in Ref. [1]. The clean module tries to find out and repair all cycle slips and remove bad observations. In the later parameter estimating module, a new ambiguity parameter is introduced for any unrepairable cycle slip, and undetected cycle slip and bad observations will be handled by the quality control part in estimating.

Satellite orbit is represented by its initial state vector and a set of force model parameters. The numeric orbit is derived by ADAMS/COWELL integrator. Perturbations of non-spheric earth gravity, earth tide and ocean tide, solar and planet point mass, relativity are modelled by IERS standard[2]. Geopotential force is calculated following the general gravity representation by Pines(1973)[3]. BERN solar radiation model with 6 parameters is used for GPS satellite. More general solar radiation and atmosphere drag model based on integration over all surface areas of the satellite are developed for low earth orbit satellite[4]. Special information for low earth orbit satellite are being prepared at this moment.

Observation equation is generated epoch by epoch within estimator for real-time or kinematic applications instead of creating observation equation and putting into a file in advance for estimator as most of the software does now.

The estimator includes a forward filter and a backward smoother, which can be used to determine parameters or parameters of stochastic process (white noise or random walk process). The square root information filter [5,6] is chosen for parameter estimation after experienced the divergence of Kalman-filter for orbit determination with one-way observation. A very efficient quality control algorithm is implemented into the SRIF based on the post-fit residuals instead of the predicted ones. In the algorithm, those problematic epochs are detected by using the orthogonal transformed residuals (post-fit residuals), which are independent to each other. Then the sensitive equation of the transformed residuals to the observation vector with help of the orthogonal transformation matrix is formed and saved in the lower part of the square root information matrix while performing transformation. Under the hypothesis test, a certain set of observations may be detected as outliers, and the sensitive equations will give the estimates of the bias and a new residual vector corresponding to the hypothesis will be formed. The new residual vector has the same feature as the former one, so that it can be used for making the decision whether to accept the hypothesis or not. If a set of bias is confirmed, with the same sensitive equations, the adaptation step is easy to apply in the filter[7].

The square root information smoother (SRIS) is being developed, since it is essential for getting the estimates of process parameter, such as clock correction, troposphere delay etc.

A least square estimator is also designed mainly for post-mission and near real-time applications as well as for validating the result estimated from filter and smoother.

From the experience of using EPOS software at GFZ, further data cleaning based on post-fit residuals can lead to a better result. The method will also be used in PANDA software and run into the filter iteratively for high precision post-mission applications.

At all IGS data processing centers, solution combination on the normal equation level is the final step for providing high quality result. A GPS network adjustment software named PowerAdj, developed at Wuhan University, is being modified for this purpose at this moment.

Fig.1 shows system structure and data flow of PANDA. Green indicates modules we already finished and yellow is for that we are working on and red for what will be started soon.

2 Data Processing Test

For testing PANDA software, 2 weeks data of 25 IGS stations collected from day 125 to 138 in 2002 are chosen as test data set. The station list and the data availability are listed in Table 1. Fig.2 shows the station distribution.

2.1 Positioning

The 2 weeks data are processed to estimate station position by fixing satellite orbit to IGS final result. The model and parameters used in the processing are listed in Table 2.

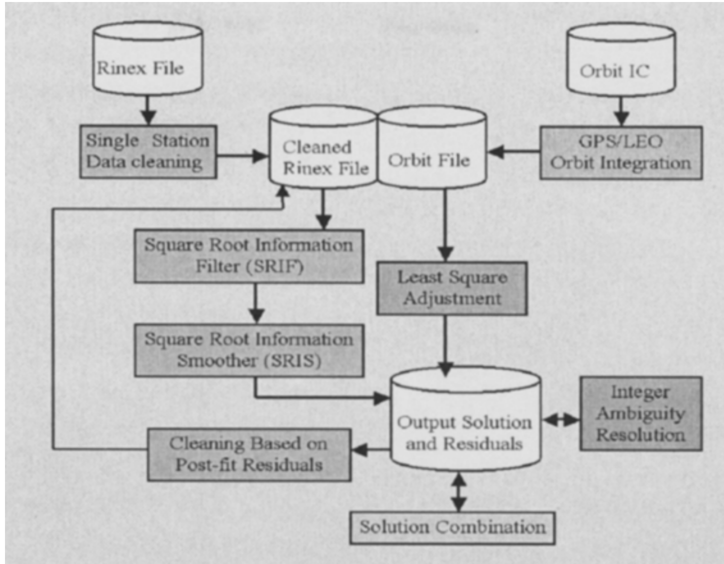

Fig. 1 PANDA System Structure and Data Flow. Green for modules we have already developed and yellow for modules we are working on and red is for modules will be started soon

Table 1 Station List and Data Availability

		day of year (2002)													
ID	SiteName	125	126	127	128	129	130	131	132	133	134	135	136	137	138
ALGO	Algonquin	x	x	x	x	x	x	x	x	x	x	x	x	x	x
AOML	Key Biscayne	x	x	x	x	x	x	x		x	x	x	x	x	x
AUCK	Auckland	x	x	x	x	x	x	x	x	x	x	x	x	x	x
COCO	Cocos	x	x	x	x	x	x	x	x	x	x	x	x	x	x
EISL	Easterisl	x	x	x	x	x	x	x	x	x	x	x	x	x	x
FAIR	Fairbanks	x	x	x	x	x	x	x	x	x	x	x	x	x	x
FORT	Fortaleza	x	x	x	x	x	x	x	x	x	x	x	x	x	x
GOL2	Goldstone	x	x	x	x	x	x	x	x	x	x	x	x	x	x
KOKB	Lokee park	x	x	x	x	x	x	x	x	x	x	x	x	x	x
KOUR	Kourou	x	x	x	x	x	x	x	x	x	x	x	x	x	x
LHAS	Lhasa	x	x	x	x	x	x	x	x	x	x	x	x	x	x
MALI	Malindi	x	x	x	x	x	x	x	x	x	x	x	x	x	x
MAS1	Maspalomas	x	x	x	x	x	x	x	x	x	x	x	x	x	x
NYA1	Ny Alesund	x	x	x	x	x	x	x	x	x	x	x	x	x	x
PIMO	Manila	x	x	x		x	x	x	x	x		x	x	x	
POTS	Potsdam	x	x	x	x	x	x	x	x	x	x	x	x	x	x
REYK	Reykjavik	x	x	x	x	x	x	x	x	x	x	x	x	x	x
SANT	Santiago	x	x	x	x	x	x	x	x	x	x	x	x	x	x
SUTH	Sutherland	x	x	x	x	x	x	x	x	x	x	x	x	x	x
THU1	Thule	x	x	x	x	x	x	x	x	x					
TRO1	Tromso	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WSRT	Westerbork	x	x	x	x	x	x	x	x	x	x	x	x	x	x
WUHN	Wuhan	x	x	x	x	x	x	x	x	x	x	x	x	x	x
YAR1	Yarragadee	x	x	x	x		x	x	x	x					
YELL	Yellowknife	x	x	x	x	x	x	x	x	x	x	x	x	x	x

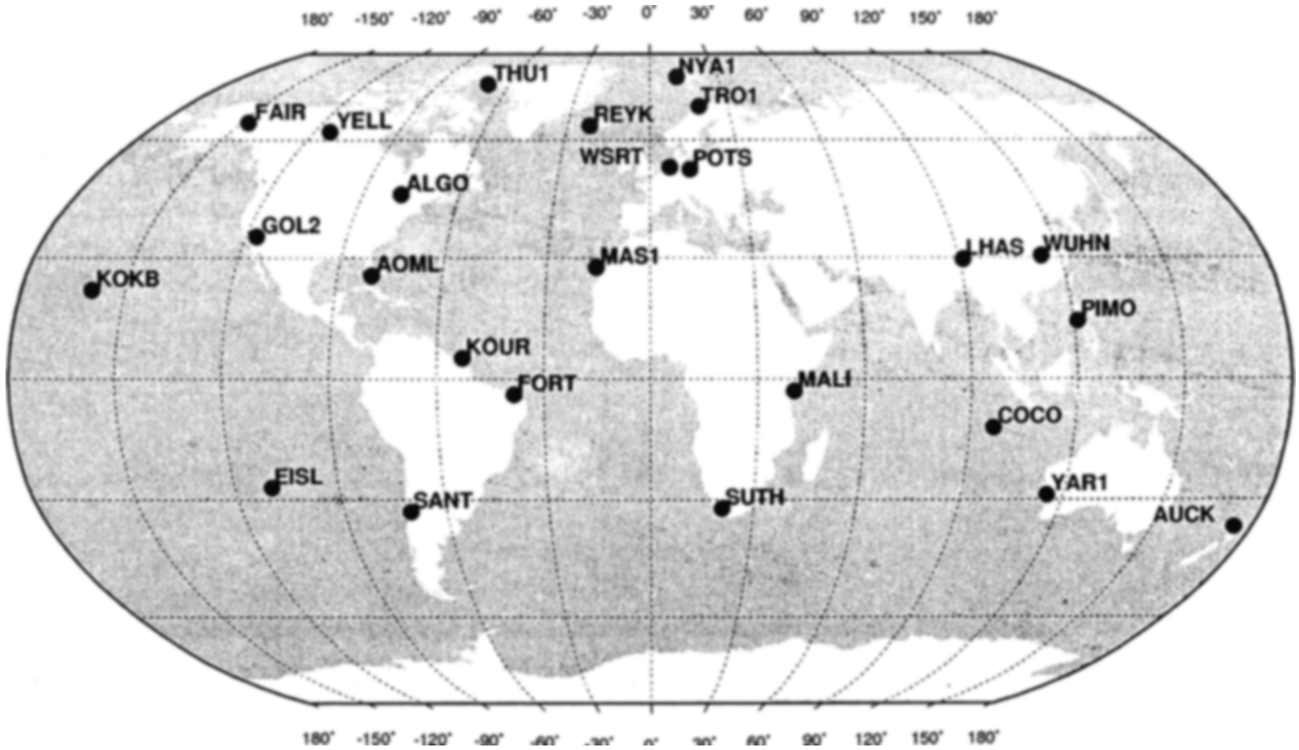

Fig. 2 Station distribution of the Testing Network

Table 2 Model and parameters for positioning test

Parameter	Model	Constraint
Observation	LC and PC	L1 0.02cycle, P1 1.0 m
Cutoff elevation	10 degree	—
Phase center pattern	None	—
Phase wrap	Yes	—
Tropospheric delay	Saastamoinen model + process	20 cm + 2 cm/sqrt(hour)
Satellite clock	Broadcast + Process / ALGO is fixed as	1 000 m + 10 m/sqrt(hour)
	reference	—
Receiver clock	Range estimating + White noise	300 m
EOP	Fixed to IERS	—
Satellite orbit	Fixed to IGS final orbit	—
Station position	Unknown / ALGO is fixed	10 m each component
Station displacement	Solid earth, pole tide, ocean loading	

Fig.3 and Fig.4 display the station coordinate bias and standard derivation of our solution compared to the IGS combined solution in *x*, *y* and *z* directions of the earth-fixed 3D coordinate system.

From Fig.3, the maximum bias is −33 mm in the y-component at KOKB and most of bias are within 10 mm. The standard derivation of the bias is 12, 10 and 9 mm at the right end of Fig. 3 (I do not understand here). The standard derivation in Fig. 4 actually reflects the repeatability of the station coordinate. The maximum STD is 32 mm in the y-component at MALI and most of them are within 15 mm and the average STD over all stations are 12, 15 and 12 mm in *x*, *y* and *z* directions, respectively. Merging the bias and the standard derivation together, The station coordinate accuracy of 17, 18 and 15 mm in *x*, *y* and *z* component of the earth-fixed coordinate system can be concluded by using PANDA software in this test campaign.

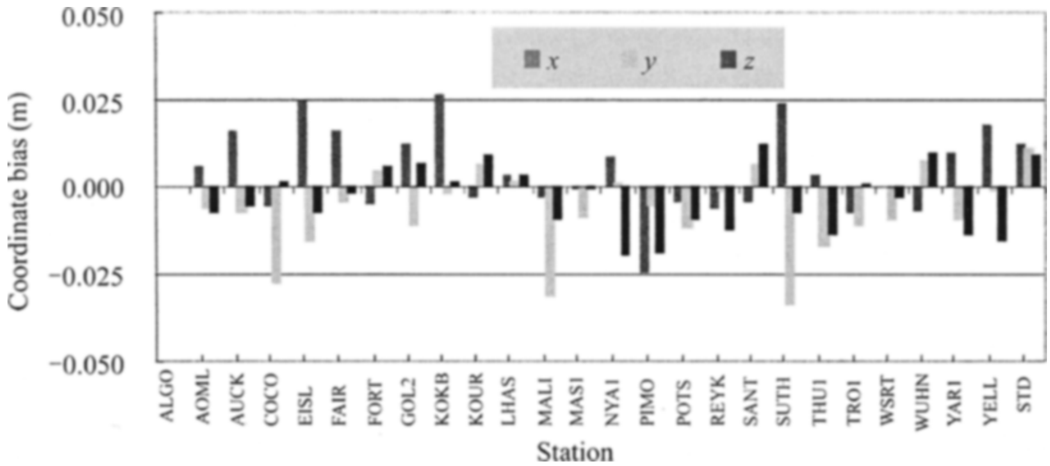

Fig. 3 Station coordinate bias from PANDA compared to IGS combined

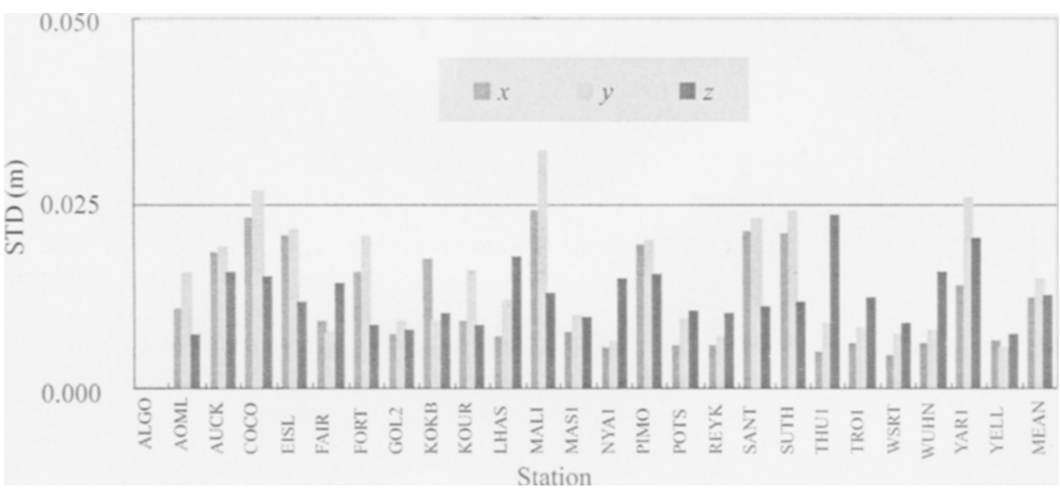

Fig. 4 Standard derivations of coordinate difference between PANDA and IGS combined solutions

Looking into JPL time series plots at http://sideshow.jpl.nasa.gov/mbh/series.htm, the typical station position repeatability is about 5, 6, 10 mm in north, east and vertical directions after removing trend. It is noticed that the repeatability of station coordinates, for example MALI, EISL, SANT and YAR1 etc., is worse than the typical numbers as the results obtained from PANDA software. For example, the coordinate repeatability of MALI is 4, 14, 18 mm, and EISL 4, 10, 17 mm and SANT 5, 9, 15 mm in north, east and vertical directions respectively. This might be a good explanation of the large standard derivation on Fig.4.

Even so, the result obtained from PANDA is several millimeters worse than the IGS one. Except for the possible software problems, one major reason might be that a very sparse network is employed in this test campaign. From Fig. 1, one can see that there is no station in the Antarctic area, which might also be the reason that most of the stations on the south hemisphere have a worse accuracy than the north one. Another possibility is that the result is derived with a forward filter without repeated data cleaning in the test processing procedure.

2.2 GPS Satellite Orbit Determination

With the same data set, the satellite orbit is estimated with the parameter and models listed in Table 3.

Fig.5 shows the daily total orbit rms and rms in radial, along-track and cross-track directions with IGS final orbit as the reference. The average rms is at the right end of the plot. The total rms is defined as the mean of the rms at the three directions. The maximum total rms is below 20 cm, and the average total rms is 16 cm.

Compared to the 2-5 cm orbit accuracy of IGS final products, the major reason of the accuracy degradation is the network geometry. IGS final product is usually obtained with more than 50 global distributed stations, but Only 25 stations with gaps in the Pacific and Europe-Asia area are employed in this test campaign. A recent study on GALILEO orbit determination at GFZ [8] shows the significant impact of ground station geometry on satellite orbit, and the adjusted orbit with 10 cm total rms is obtained using a similar network. Another cause of the accuracy degradation is the day boundary problem. In IGS data processing, daily solutions are combined together to improve result at the day boundary. Fig. 6 shows the orbit difference between PANDA and IGS final product for PRN 1 and PRN 8 over the two weeks. Clearly large difference appears usually at the day boundary. With the combination software, the orbit accuracy will be improved in the test.

Table 3 Model and parameters for satellite orbit determination test

Parameter	Model	Constraint
Observation	LC and PC	L1 0.02 cycle, P1 1.0 m
Cutoff elevation	10 degree	—
Phase center pattern	None	—
Phase wrap	Yes	—
Tropospheric delay	Saastamoinen model + process	20 cm + 2 cm/sqrt(hour)
Satellite clock	Broadcast + Process / ALGO is fixed as	1 000 m + 10 m/sqrt(hour)
	reference	—
Receiver clock	Range estimating + White noise	300 m
Station displacement	Solid earth, pole tide, ocean loading	—
Station coordinate	Constraint to IGS coordinate	2 2 2 mm, or 10 10 10 mm
Satellite orbit	Solve for initial position and velocity + 9	10 10 10 m, 0.1, 0.1, 0.1 m/s
	Bernese solar radiation model parameters	0..1 for all 9 model parameters
EOP	Solve for *x*-pole *y*-pole and rates and LOD,	3 mars, 0.3mars/day
	constraint to IERS time series	3 ms/day

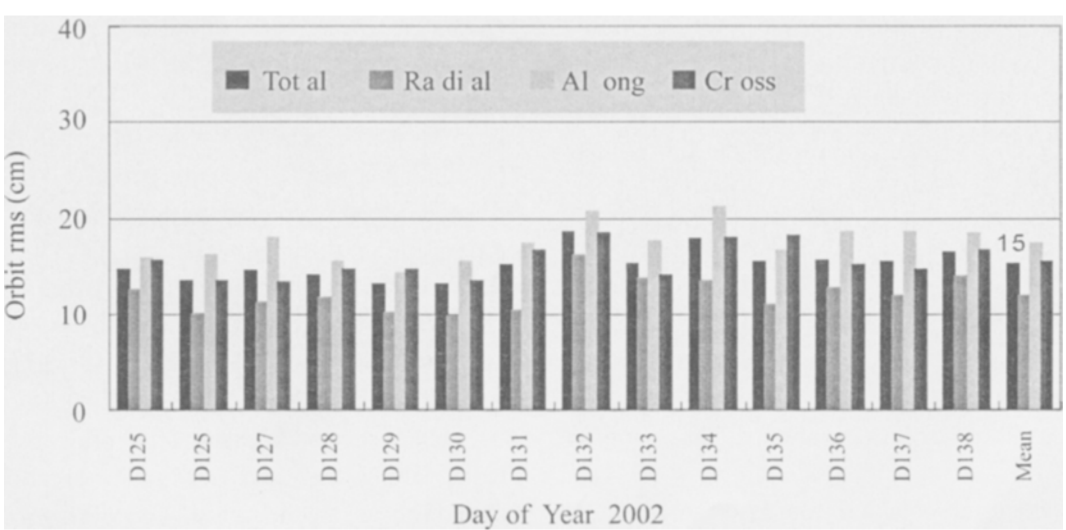

Fig. 5 Daily Total Orbit rms and Orbit rms in Radial, along-track and cross track Directions. Last column is the mean over all days

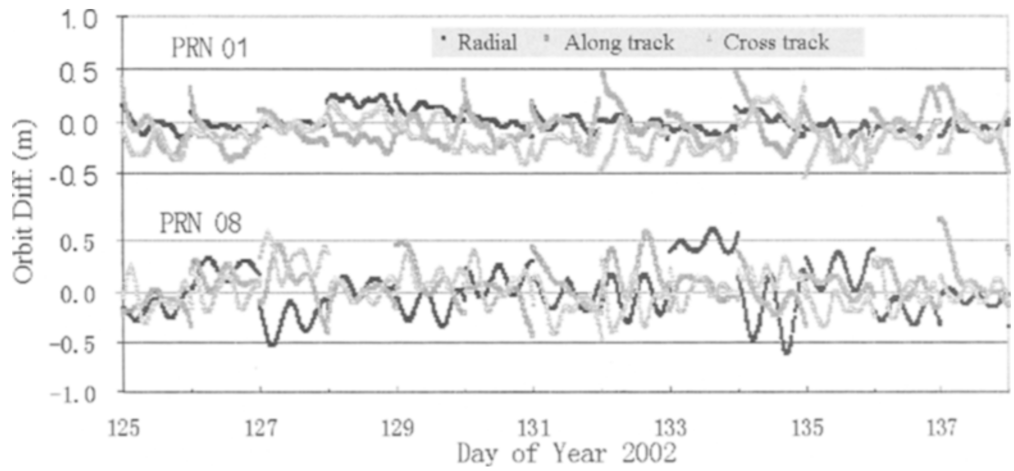

Fig. 6 Orbit Difference for PRN01 and PRN08. Large difference appears clearly at day boundary

3 Conclusions

We have been working on PANDA software since 2000. Thanks to our previous research and software development experience, most of the modules have been finished in the software system.

A test network with 25 IGS stations is processed for both positioning and orbit determination purpose. Station coordinate accuracy obtained with PANDA software is about 17 mm in each component compared to IGS combined solution. GPS satellite orbit accuracy is about 16 cm in average related to IGS final orbit. Added more stations to the test network and with our combination software, the accuracy will be improved. It must be mentioned here that a straight forwards filter with a new quality control technology is employed in the software. The result confirmed the efficiency of the technology and on the other hand, further data editing would lead to a better result.

We are going to refine the test data processing and extend it to GPS meteorology and validate clock and earth orientation parameter estimates. At the same time, we will continue our work on trajectory determination of moving platform, especially for low earth satellite. The first LEO result with PANDA is expected to obtain in the middle of 2003.

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