Impact of SLR Tracking on COMPASS/Beidou

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Introduction

- All COMPASS/Beidou satellites will be equipped with LRAs for precise orbit determination
- SLR can provide a unique tool to validate the orbital and gravity field solutions from microwave measurements and independently assess their quality
- SLR can provide SLR-based orbits
- We can get better orbits by combining the two different measurements when the whole system is completed

The COMPASS/Beidou Constellation

COMPASS/Beidou Constellation:

Phase I: regional satellite navigation system:

---12 satellites: 5 GEO ; 3 IGSO ; 4 MEO.

---two satellites have been launched till NOW.

--- ten satellites will be launched in future two years.

---It will be completed in 2011.

Phase II: global satellite navigation system:

---These will be 30 Beidou navigation satellites in future.

---It will be completed in 2020.

The COMPASS/Beidou Constellation

12 satellites Constellation for Phase I

•COMPASS-M1 launched in 14 April 2007 .

•COMPASS-G2 launched in 15 April 2009.

COMPASS-M1(MEO) orbit:

inclination：55°

altitude ： 21,500km

period : 12 hour

COMPASS-G2(GEO) orbit:

inclination：0°

altitude ： 36,000km

period : 24 hour

longitude : 80°E

Microwave data processing:

- **Software used:** SHODE
- **Dynamical models:**

Geopotential---JGM3 10×10

N-body---Mercury, Venus, Moon, Mars, Jupiter, Saturn, Uranus, Neptune and the sun (JPL DE403)

Solar radiation pressure---simple rectangle box model

Tidal forces---solid earth tides and Ocean tides

Albedo radiation--- applied

Relativity---- point-mass accelerations, Lense-Thirring effect

- **Measurement models:**

Troposphere: Saastamoinen model (Neill mapping function)

Site coordinate correction: tidal corrections

Phase center correction

Cutoff angle：10 degree

Sample：15s (for microwave measurements)

- **Estimated parameters:**

 -Solar radiation pressure coefficient (one parameter for three days)
- Clock error
- ybias

The microwave pseudo-range measurements likely contain large errors due to biases from the satellite-borne and the user's clocks besides observation noise.

Precise Orbit Determination of COMPASS-M1 and Its Accuracy Evaluation by SLR

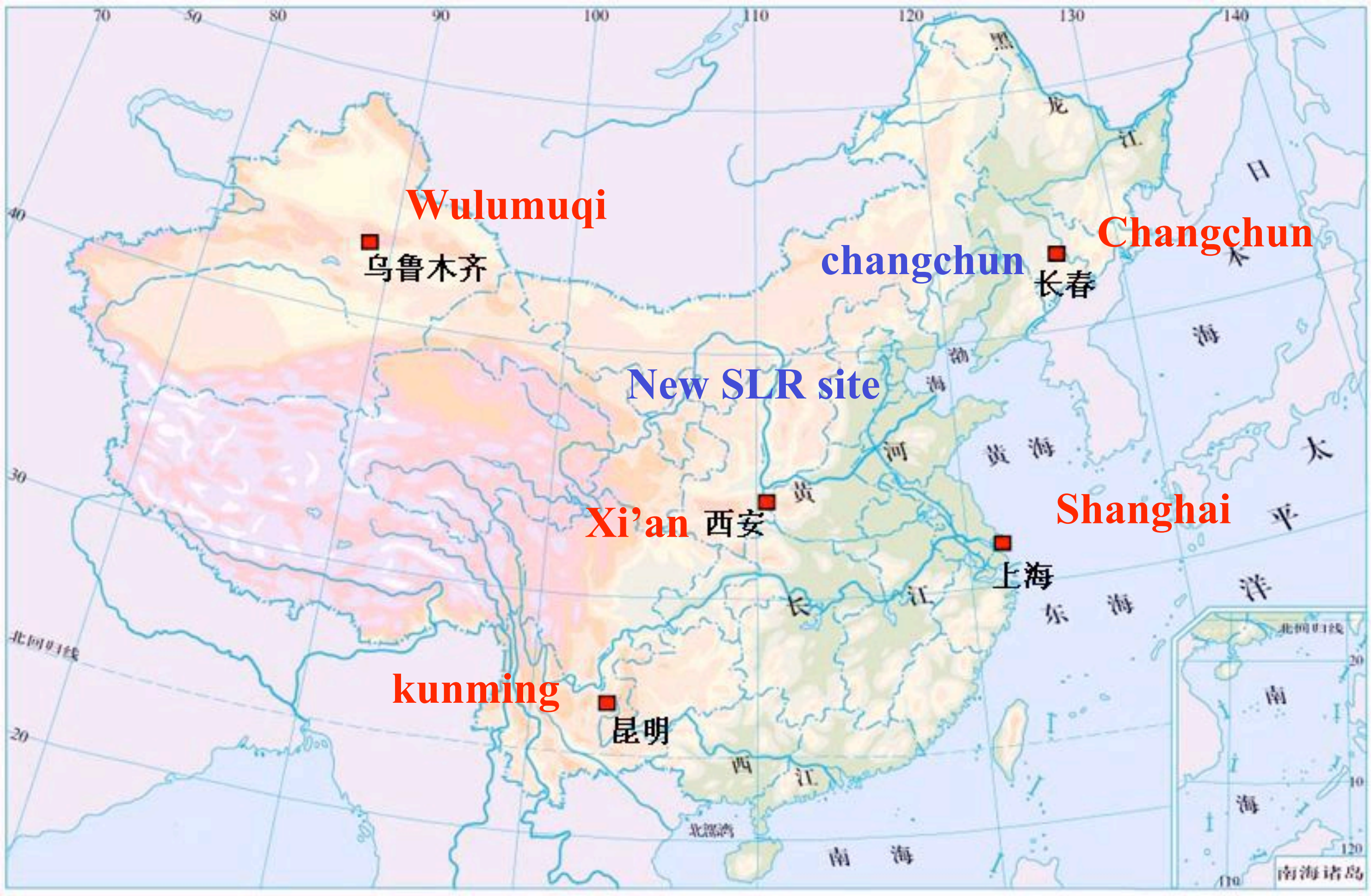
- **Method 1. Pass-by-pass clock biases (one constant bias plus one linear drift bias) for every site are estimated;**

- **Method 2. One constant clock bias plus one linear and one quadratic biases within the 3-day arc length for every site are estimated;**

- **Method 3. Only one constant clock bias within the 3-day arc length for every site and one common linear and one common quadratic for all sites are estimated;**

Regional microwave sites and SLR sites distribution

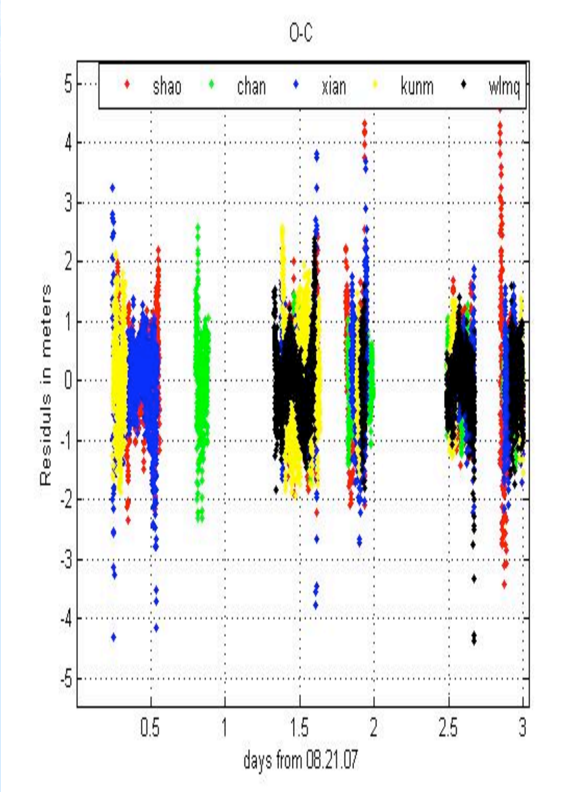
(red: microwave sites; Blue: SLR sites)

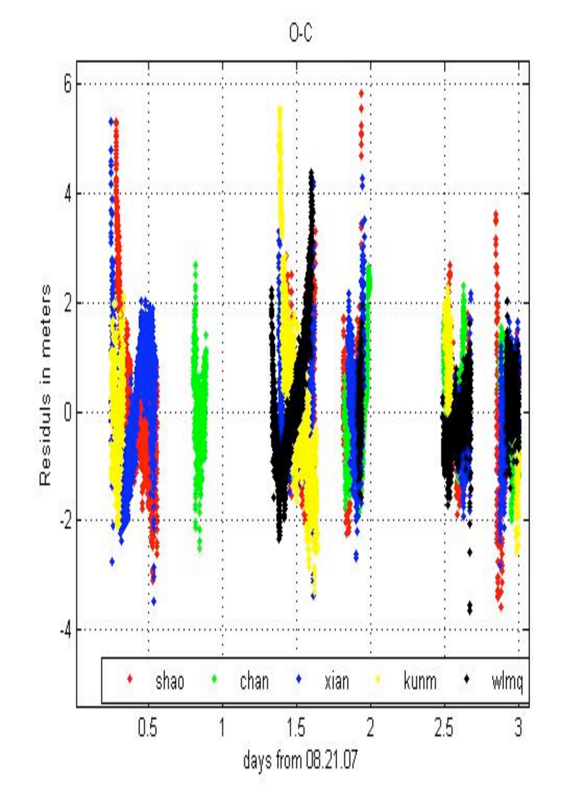


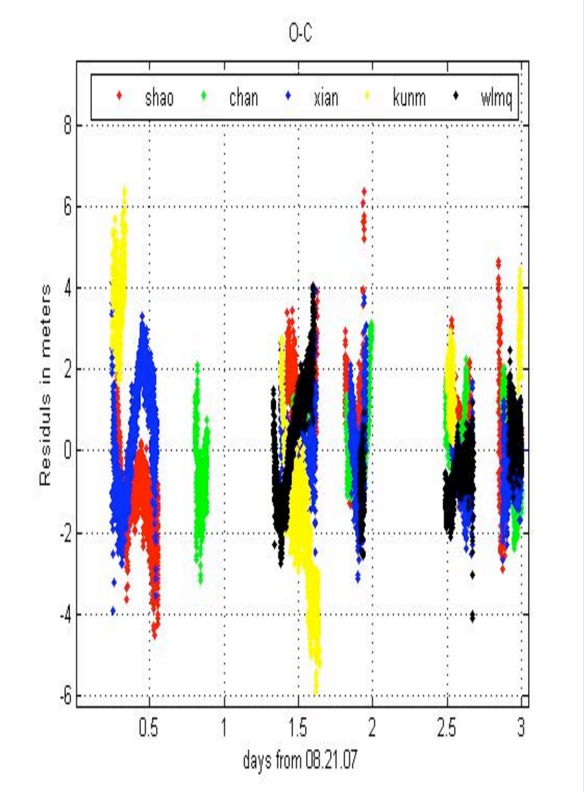
Precise Orbit Determination of COMPASS-M1 and Its Accuracy Evaluation by SLR

These three figures show the post-fit residual of microwave data orbit determination from the above three methods from left to right(2007-08-21).

Method1 RMS: 0.55m **Method2 RMS: 0.86m** **Method3 RMS: 1.31m**



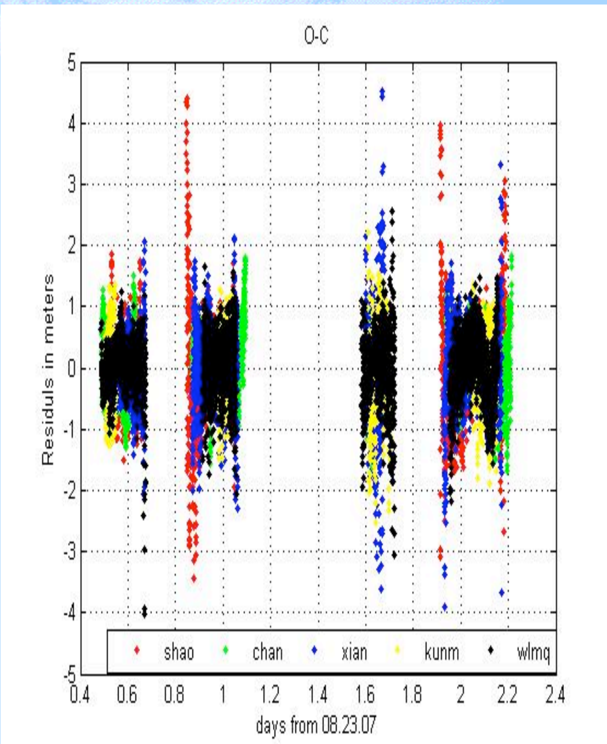


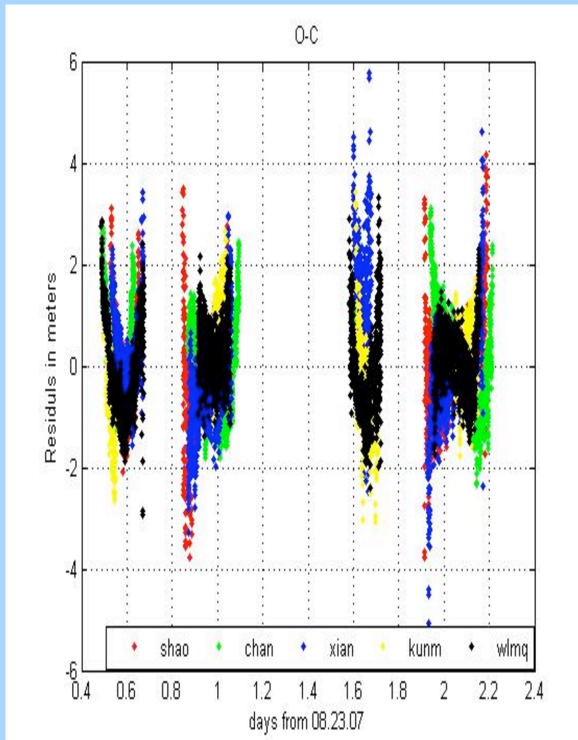


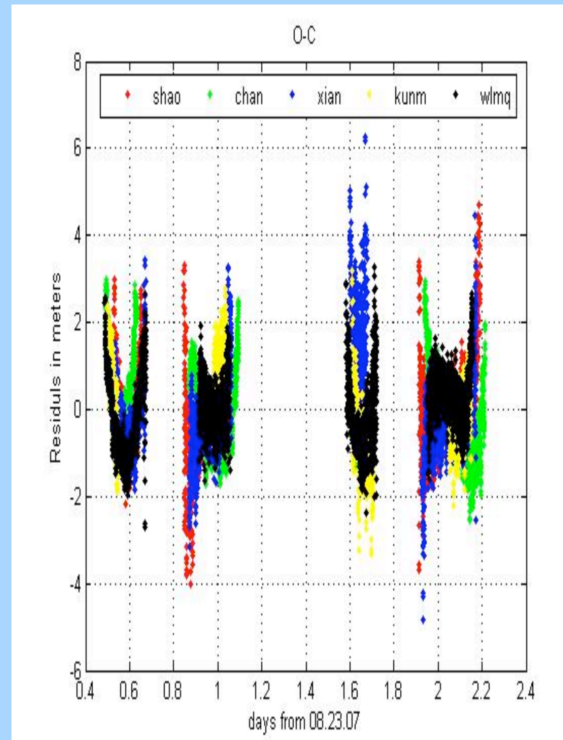
Precise Orbit Determination of COMPASS-M1 and Its Accuracy Evaluation by SLR

These three figures show the post-fit residual of microwave data orbit determination from the above three methods from left to right(2007-08-23).

Method1 RMS： 0.53m **Method2 RMS: 0.84m** **Method3 RMS: 0.89m**



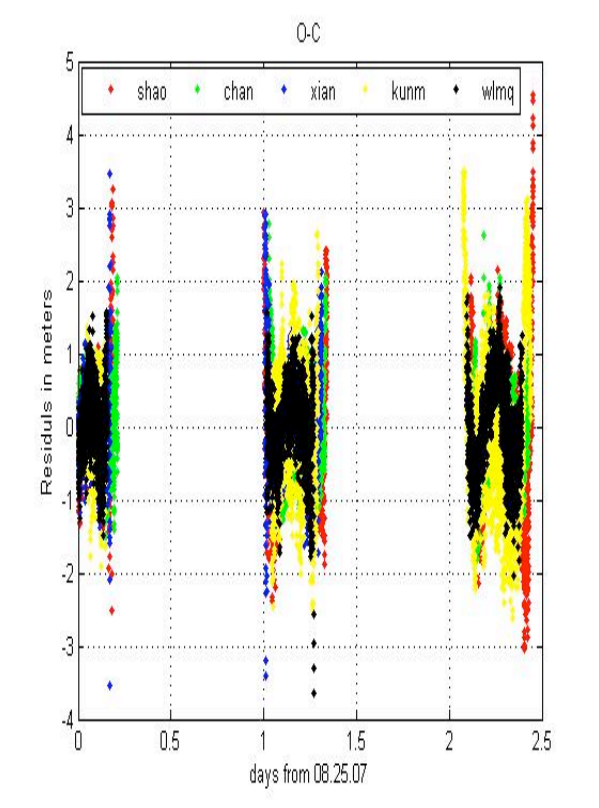


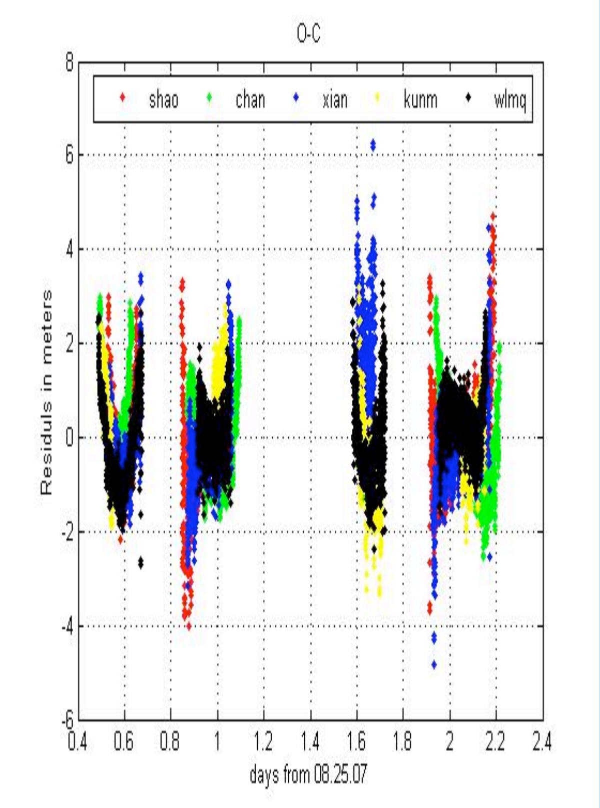


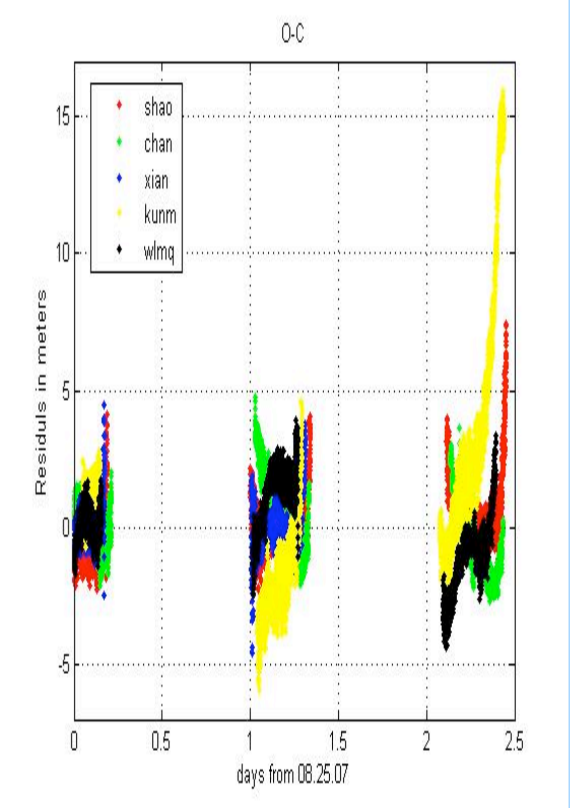
Precise Orbit Determination of COMPASS-M1 and Its Accuracy Evaluation by SLR

These three figures show the post-fit residual of microwave data orbit determination from the above three methods from left to right(2007-08-25).

Method1 RMS: 0.66m **Method2 RMS: 1.01m** **Method3 RMS: 1.38m**



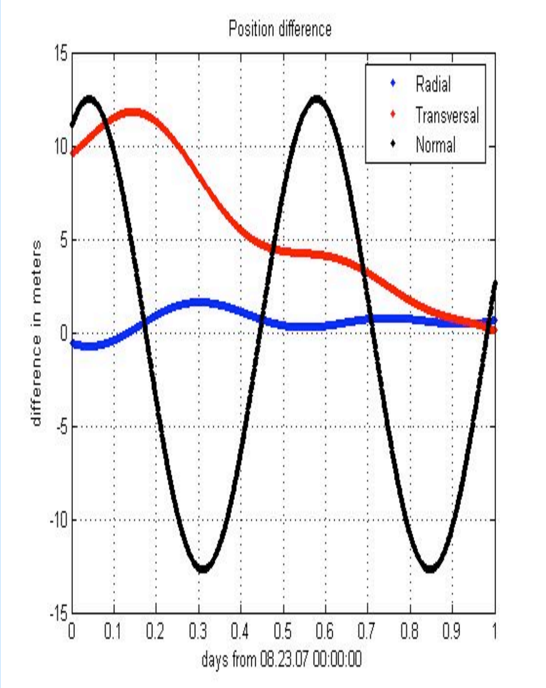




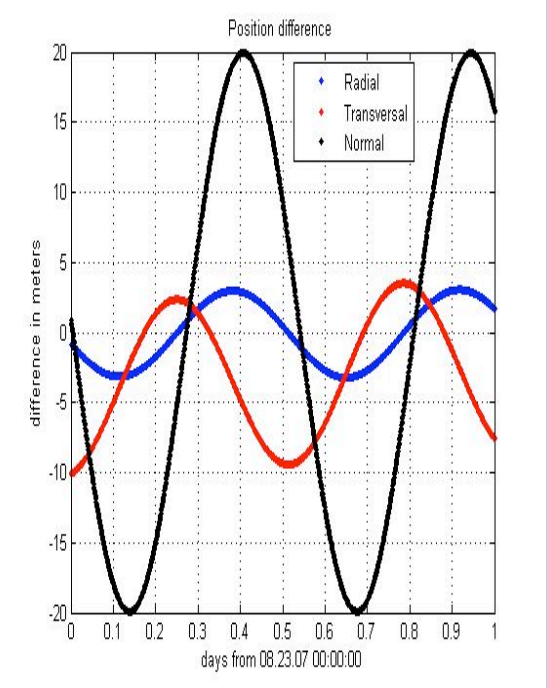
Precise Orbit Determination of COMPASS-M1 and Its Accuracy Evaluation by SLR

These three figures show the orbit overlap errors of microwave data orbit determination from the above three methods from left to right. (The first orbit is done based on data from Aug.21-23 and another orbit is based on data from Aug.23-25. So, the August 23 orbit is the overlap arc.)

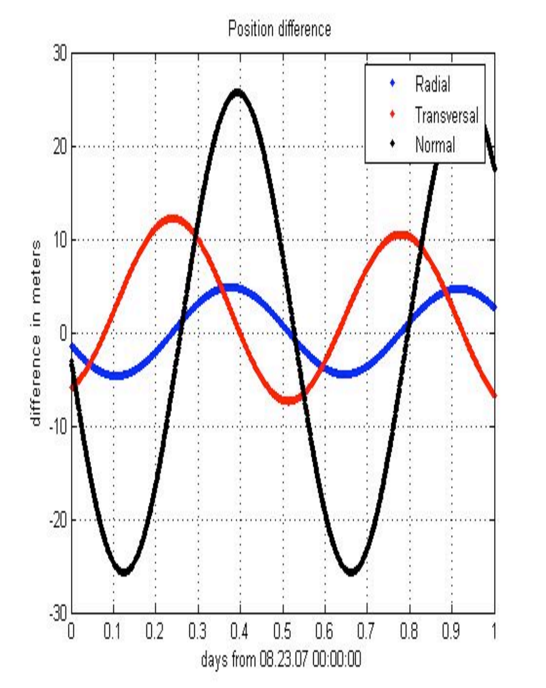
Method1 Rms_R = 0.82m, rms_T = 6.77m, rms_N = 9.00m，rms_Pos = 11.28m



Method2 Rms_R = 2.25m, rms_T = 5.15m, rms_N = 14.35m，rms_Pos = 15.42m



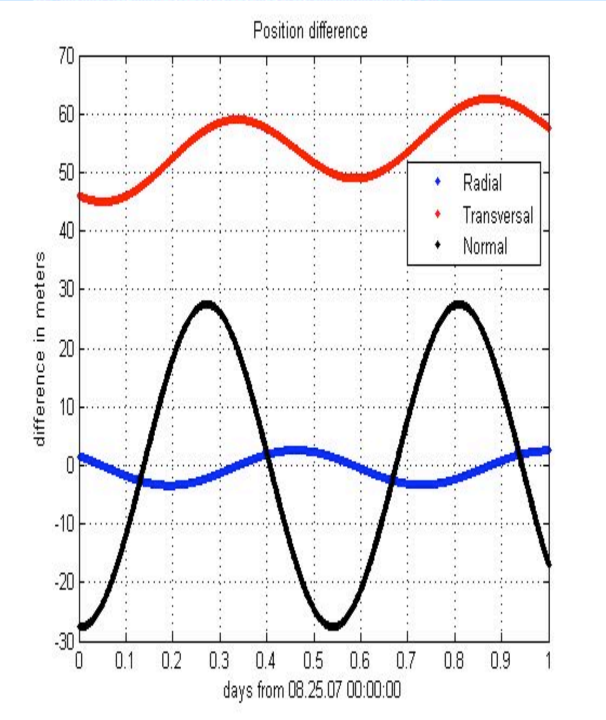
Method3 Rms_R = 3.41m, rms_T = 6.93m, rms_N = 18.64m，rms_Pos = 20.18m



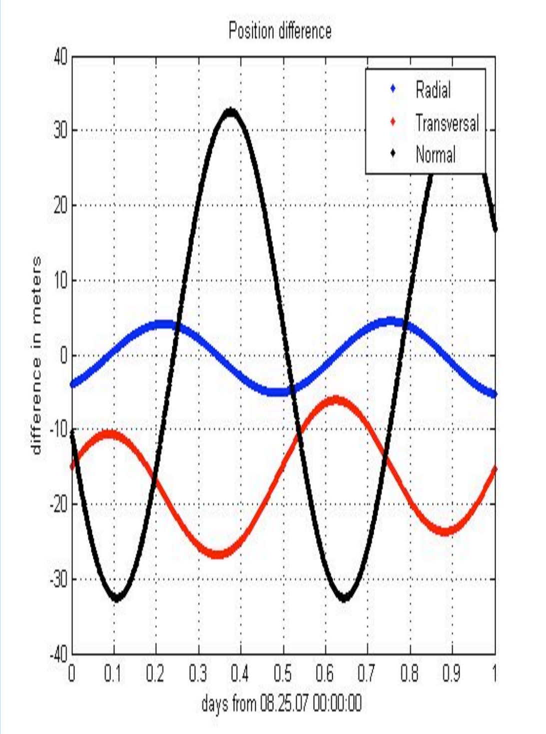
Precise Orbit Determination of COMPASS-M1 and Its Accuracy Evaluation by SLR

These three figures show the orbit overlap errors of microwave data orbit determination from the above three methods from left to right. **(The first orbit is done based on data from Aug.23-25 and another orbit is based on data from Aug.25-27. So, the August 25 orbit is the overlap arc.)**

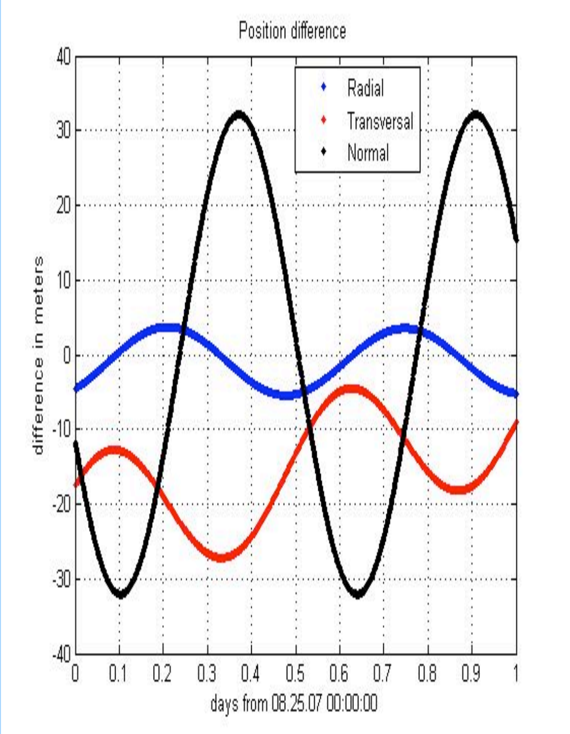
Method1 Rms_R =2.13m, rms_T =54.63m, rms_N = 19.10m， rms_Pos = 57.91m



Method2 Rms_R = 3.22m, rms_T = 17.89m, rms_N = 23.72m， rms_Pos = 29.89m



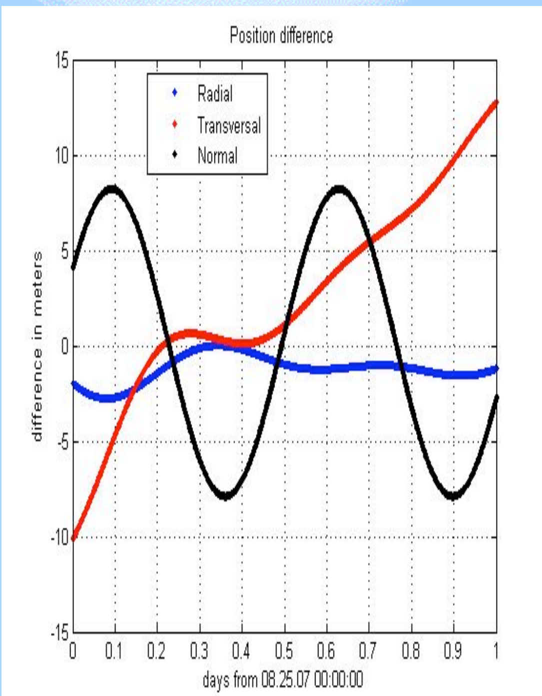
Method3 Rms_R =3.15m, rms_T = 16.79m, rms_N = 23.42m， rms_Pos = 28.99m



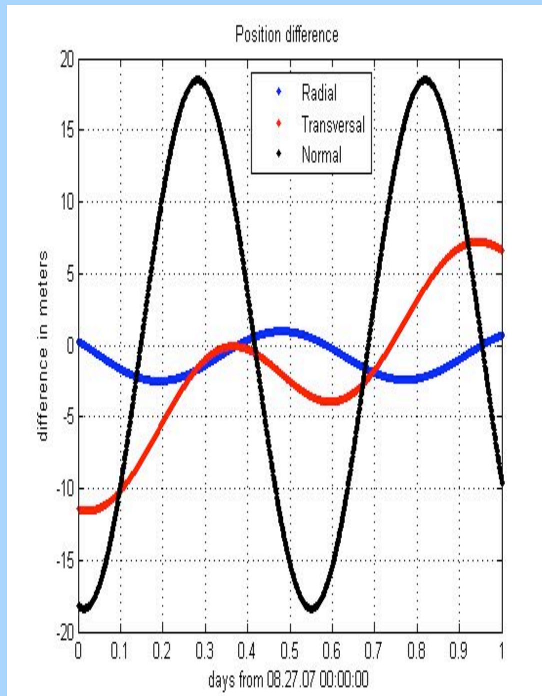
Precise Orbit Determination of COMPASS-M1 and Its Accuracy Evaluation by SLR

These three figures show the orbit overlap errors of microwave data orbit determination from the above three methods from left to right. (The first orbit is done based on data from Aug.25-27 and another orbit is based on data from Aug.27-29. So, the August 27 orbit is the overlap arc.)

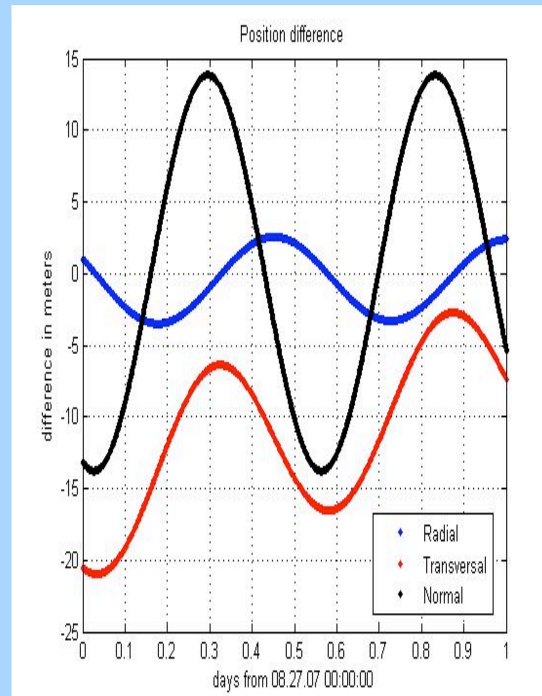
Method1 rms_R: 1.43m, rms_T = 5.74m, rms_N = 5.88m, rms_POS = 8.35m



Method2 rms_R: 1.49m, rms_T = 5.53m, rms_N = 12.88m, rms_POS = 14.10m



Method3 rms_R: 2.15m, rms_T = 12.25m, rms_N = 9.74m, rms_POS = 15.80m



Precise Orbit Determination of COMPASS-M1 and Its Accuracy Evaluation by SLR

This table shows the rms of the orbit difference from three methods at R, T, N and Position. (Those orbits are also determined by microwave data. Unit: m).

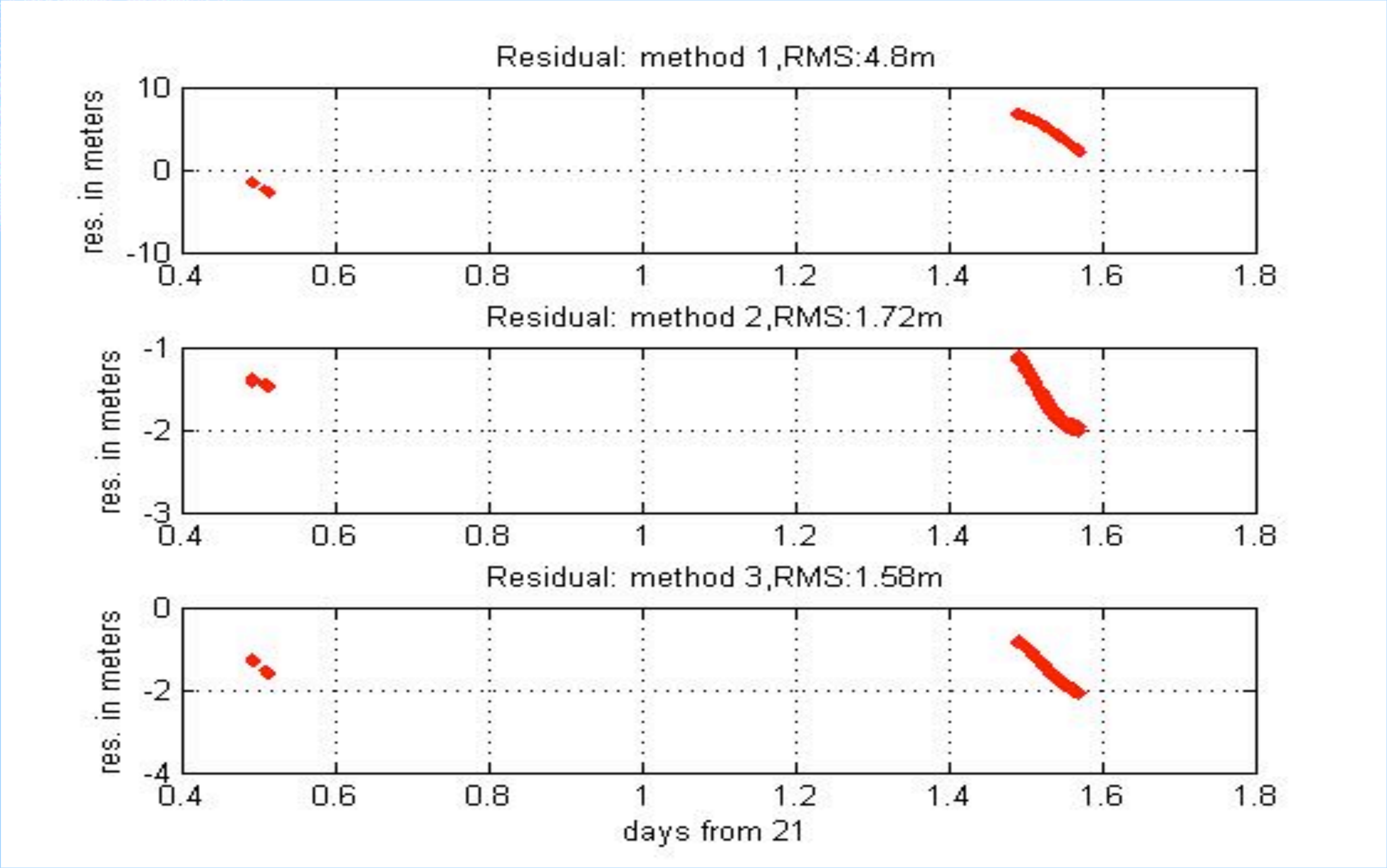
date	method	R	T	N	POS
8.21-8.23	1 and 2	1.58	25.85	27.83	38.01
8.21-8.23	1 and 3	1.96	22.9	32.62	39.91
8.21-8.23	2 and 3	0.99	3.69	4.79	6.13
8.23-8.25	1 and 2	2.96	28.48	10.1	30.36
8.23-8.25	2 and 3	0.35	2.45	3.44	4.24
8.25-8.27	1 and 2	1.17	24.50	14.25	28.37
8.25-8.27	2 and 3	0.53	4.88	1.12	5.04
8.27-8.29	1 and 2	1.28	10.77	4.04	11.59
8.27-8.29	2 and 3	0.54	2.66	3.47	4.40

- Method 1 has a big difference from other two methods. The biggest difference is about 40m.
- We have SLR data in two periods from Aug.21-Aug.22 2007 and Aug.28-Aug.29 2007. So we can check the two orbits by SLR data.

Precise Orbit Determination of COMPASS-M1 and Its Accuracy Evaluation by SLR

This figure shows the NAV orbit residuals of three methods by SLR measurements evaluation during Aug.21-Aug.22 2007 (unit=m)

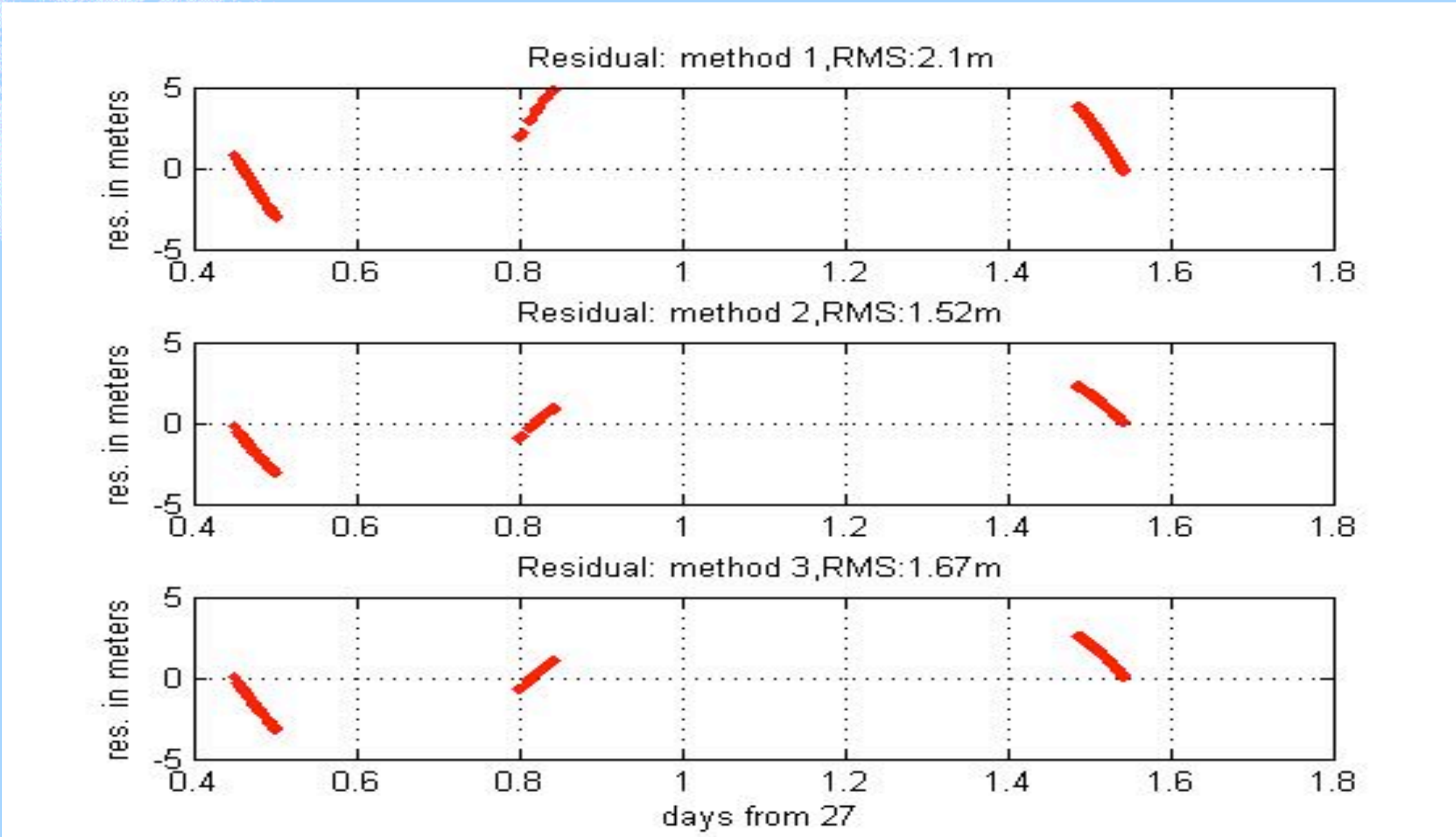
SLR site: Changchun only at that time



Precise Orbit Determination of COMPASS-M1 and Its Accuracy Evaluation by SLR

This figure shows the orbit residual from three methods by SLR measurements evaluation during Aug.28-Aug.29 2007 (unit=m)

SLR site: Changchun only at that time

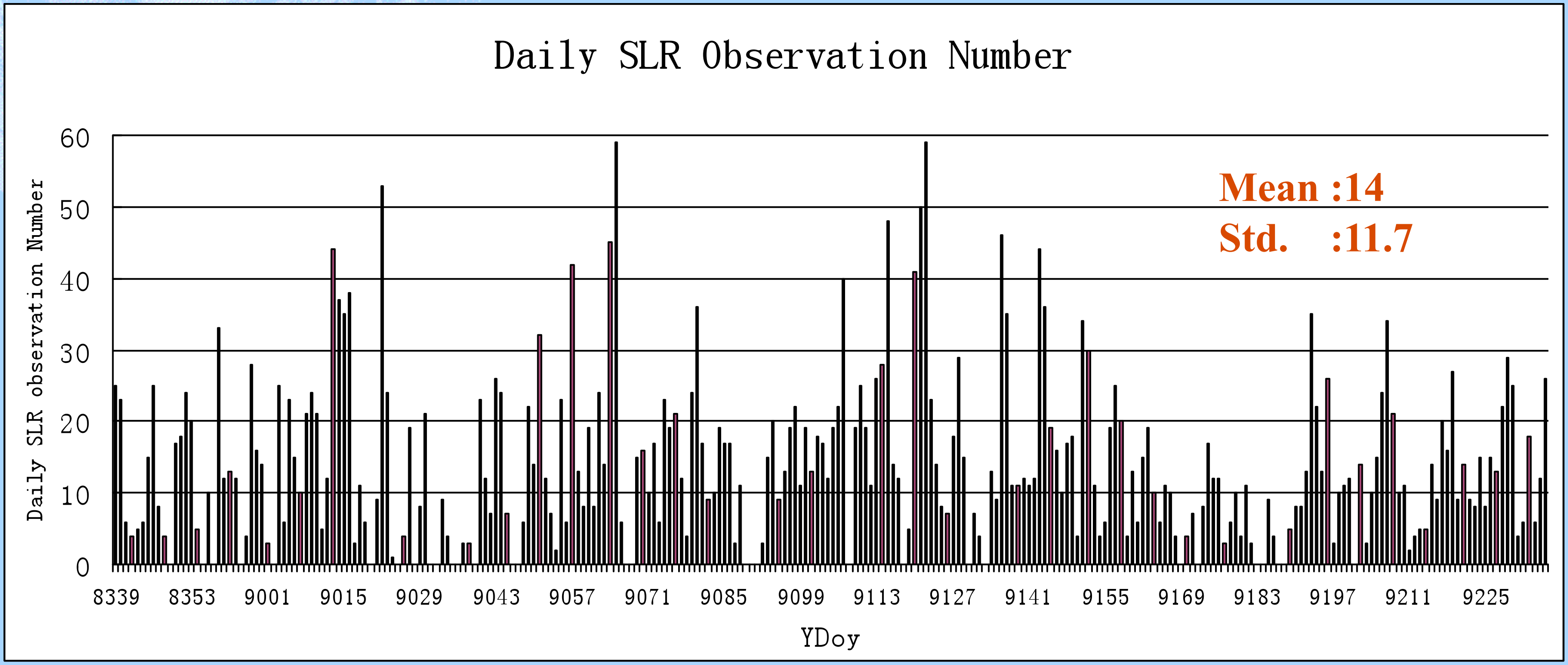


Summary

- Different methods show different post-fit residual rms and orbit overlap errors. Method 1 has the smallest post-fit residual rms and better orbit overlap error. But its SLR evaluation is the worst during the two evaluation periods.
- The post-fit residual rms of NAV orbits is often 1m or so(0.5m-3.0m).
- The orbit overlap rms is often 10m or so(5m-60m). Bad overlap rms results from the explicit lack of data.
- The NAV orbit residual rms is meter order by SLR measurements.

Precise Orbit Determination of COMPASS-M1 from SLR Data

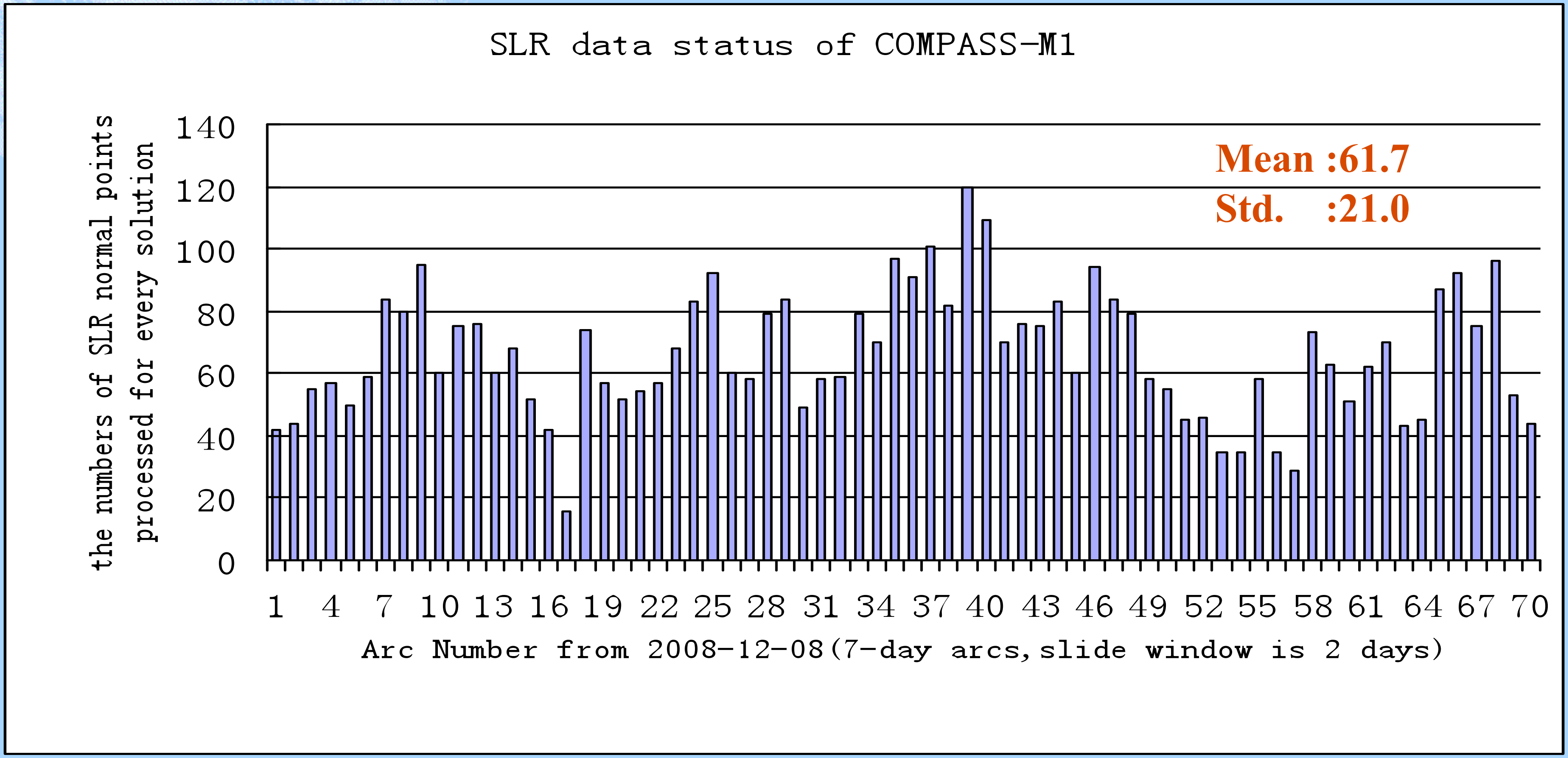
The plot below shows the numbers of SLR normal points from ILRS SLR network for COMPASS-M1 in every day.



There are some gaps. It makes daily parameter estimates very tedious and difficult. Some gaps make daily parameter estimate impossible or make the solution worse.

Precise Orbit Determination of COMPASS-M1 from SLR Data

This plot below shows the numbers of SLR normal points from ILRS SLR network for COMPASS-M1 processed in each 7-day arcs.



Precise Orbit Determination of COMPASS-M1 from SLR Data

SLR NERC solution:

software : SATAN

data length: 7-day arc

estimated parameters: the satellite initial state vector;
an empirical along-track drag acceleration;
a multiplicative solar radiation coefficient

SLR SHAO solution:

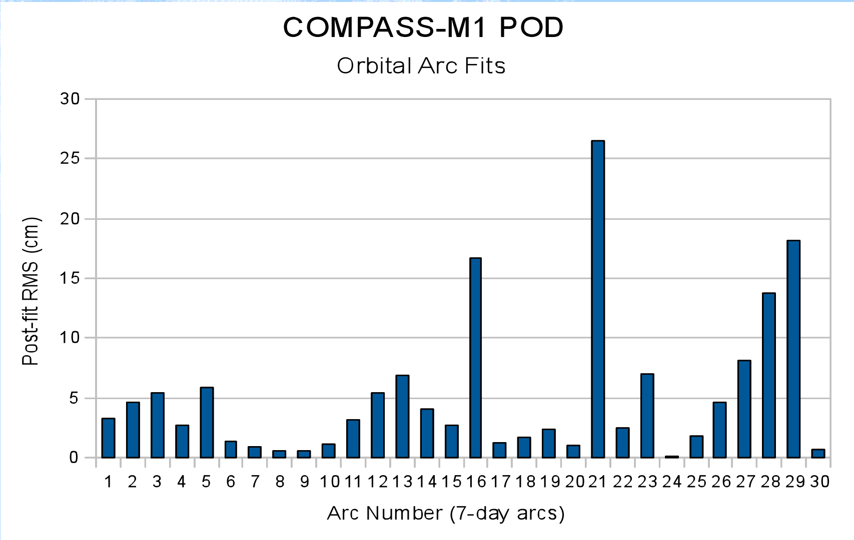
software : SHODE

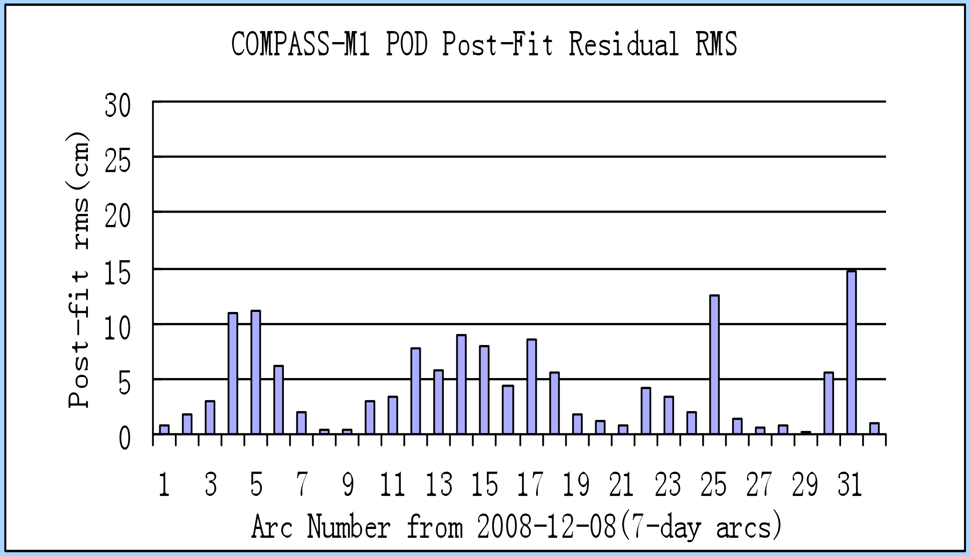
data length: 7-day arc

estimated parameters: the satellite initial state vector;
two empirical transverse acceleration and
two normal acceleration with 7-day arc
(an empirical along-track drag acceleration);
one or three solar radiation coefficient;
occasional individual sites bias

Precise Orbit Determination of COMPASS-M1 from SLR Data

These figures show Post-fit residual RMS values for seven-day orbital arcs in the period 2008 December – 2009 June. (The left one is given by NERC. The right one is given by SHAO.)

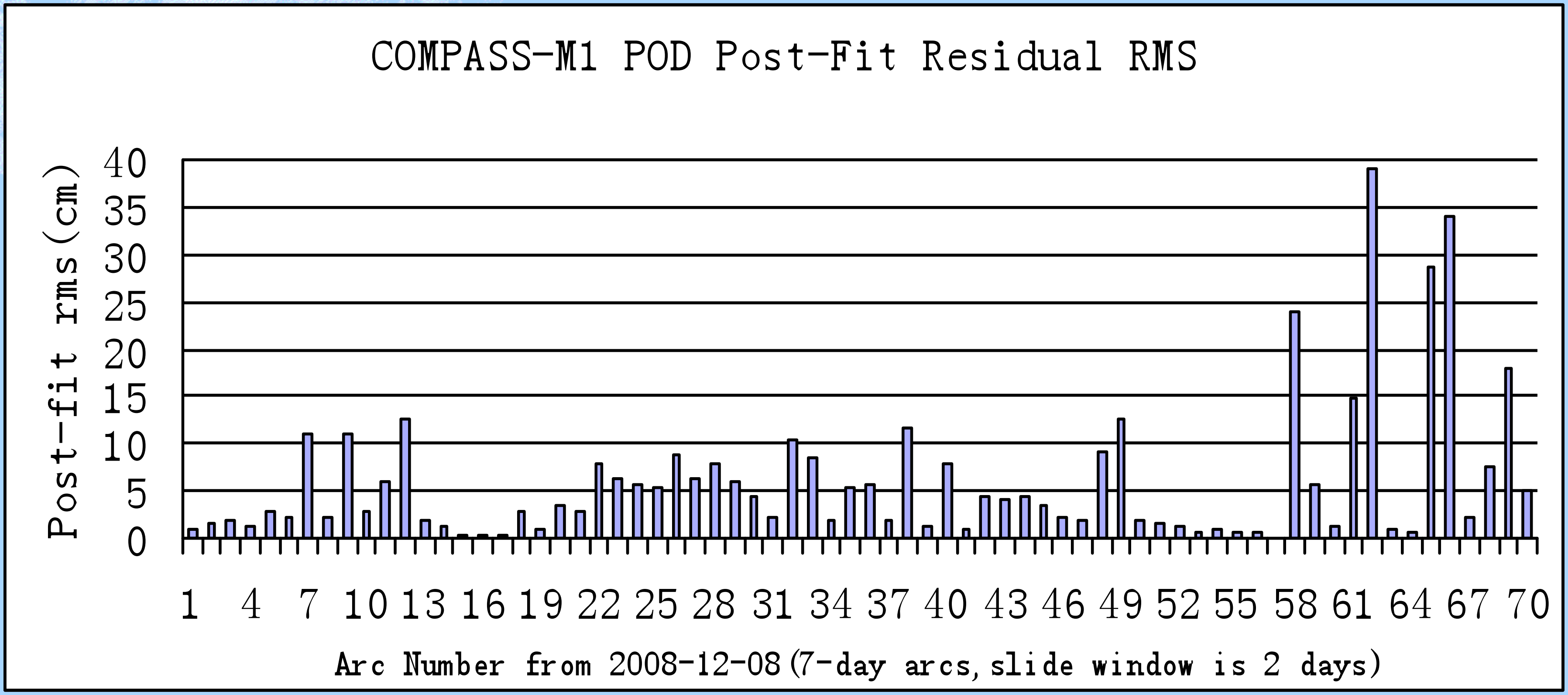




- During each seven-day arc, the typical post-fit residual RMS values is between 2-5cm for NERC and between 1-6cm for SHAO.
- The rms values don't always show the same behaviour. That means different methods and different models can absorb different errors.
- Better fit results can no doubt be obtained by careful comparison of models and estimated parameters and other factors in the treatment of SLR data.

Precise Orbit Determination of COMPASS-M1 from SLR Data

This figure shows Post-fit residual RMS values for seven-day slide orbital arcs in the period 2008 December 08 – 2009 August 17.

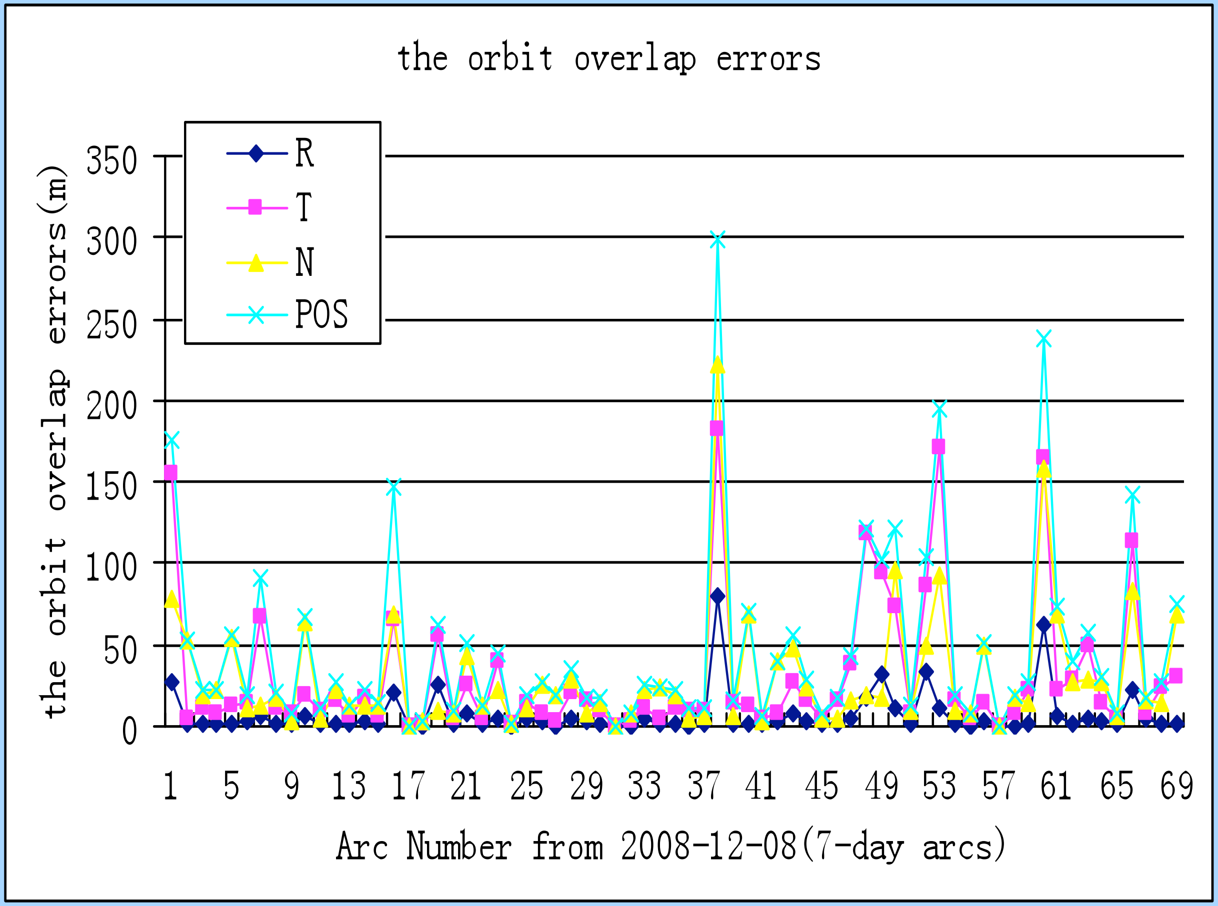


- **Two–day slide window means the arc 2 covers the data span from day#3 of the first arc and goes for 7 days.**

Precise Orbit Determination of COMPASS-M1 from SLR Data

This figure shows the rms of orbit overlap errors from 7-day orbital slide arcs from 2008 December 08 – 2009 August

- The estimated SLR orbit accuracy of COMPASS-M1 is basically 20m to 40m.
- Those abnormal accuracy often means bad orbit although they show smaller post-fit residual rms.

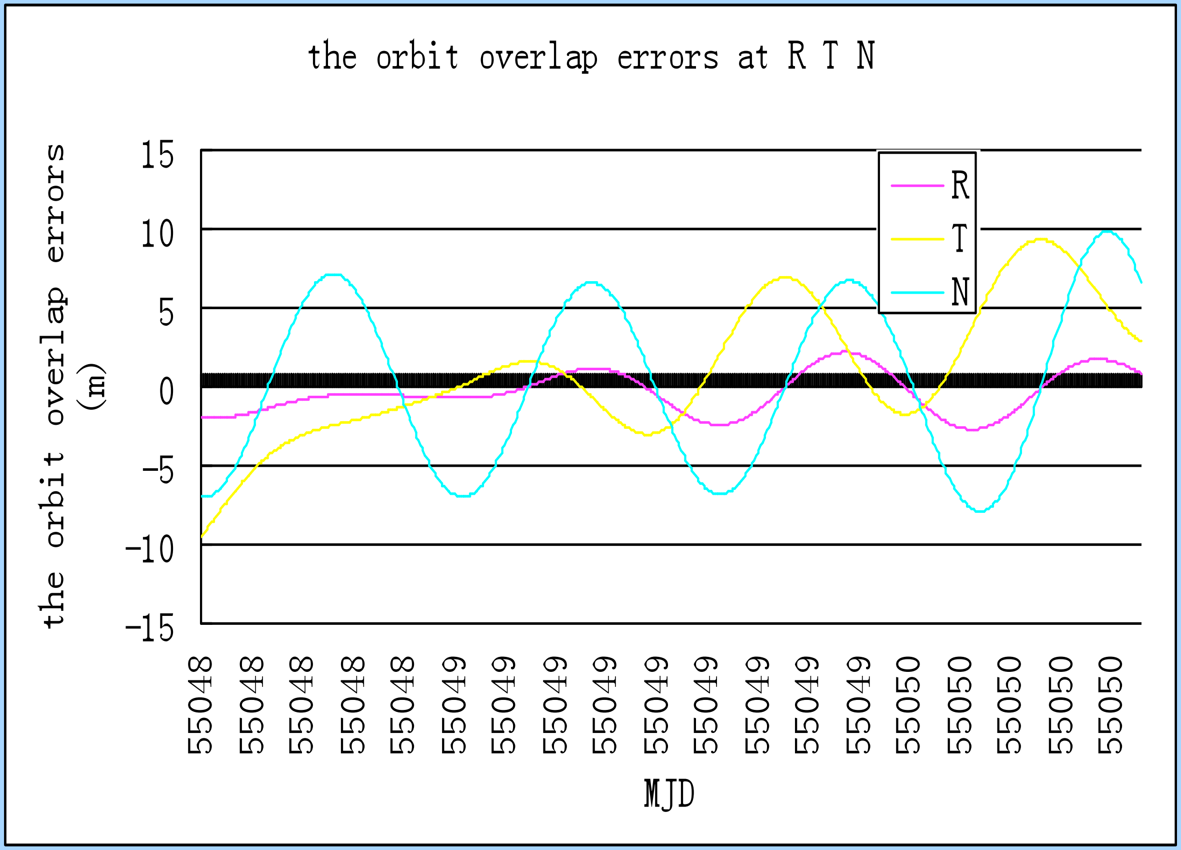


Precise Orbit Determination of COMPASS-M1 from SLR Data

This figure shows the orbit overlap errors of 2009 August 03 solution and August 05 solution. The orbit overlap error is almost smallest. But their post-fit residual rms are both big.

Sol	obs	Postffit rms
Aug.03	87	28.7cm
Aug.05	92	33.9cm

- This shows that big post-fit residual rms doesn't mean worse orbit results.



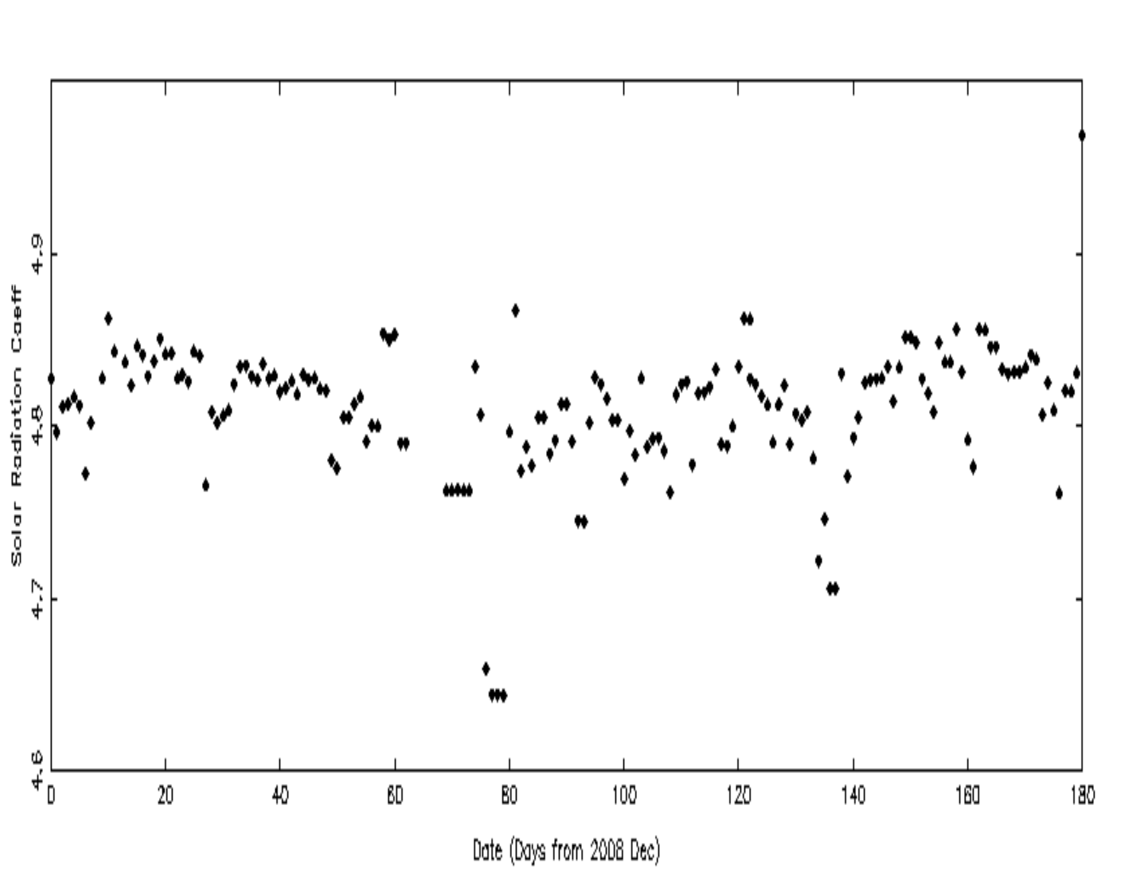
Solar radiation coefficients check

- The resulting series of solar radiation coefficient values act as a quality check on the solutions
- It is also as being potentially a test of the stability of the vehicle. Each value is sensitive to the true attitude of the spacecraft relative to the direction to the Sun during each orbital arc.

Precise Orbit Determination of COMPASS-M1 from SLR Data

This figure shows NERC daily time-series of derived solar radiation coefficients from seven-day orbital arcs in the period 2008 December – 2009 June.

- The periodic (~140-day) variation in the solar radiation coefficient values is by some 2%.
- The presence of smooth probably reflects the lack of a suitably complex radiation pressure model that should for example take account of the effect of the varying direction of the Sun relative to the precessing orbital plane of COMPASS-M1.

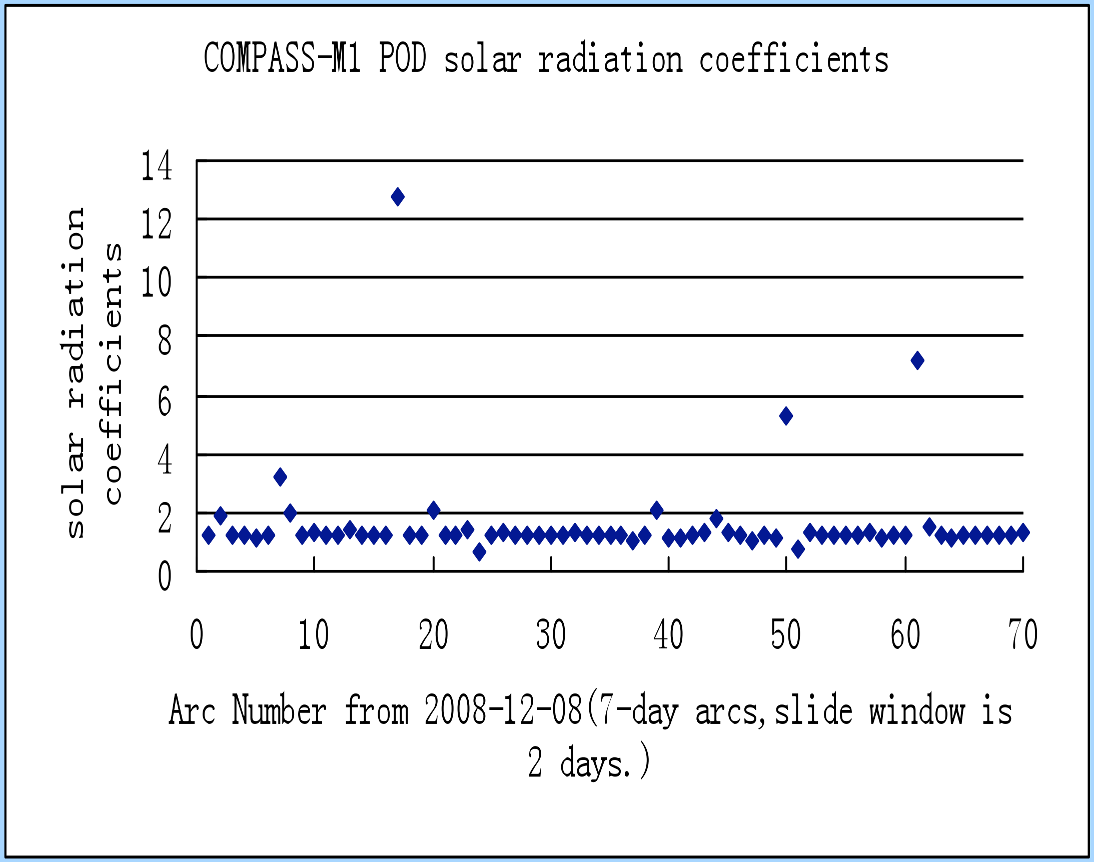


- **The 'spike' in the values at around day 135 (mid April 2009) is again most probably caused by the same deficient model and occurs at a time when the Sun is normal to the orbital plane.**
- **Similar behaviour has been seen during POD of the GLONASS vehicles.**
- **It is likely that a more complex solar radiation model would account properly for these changes in radiation pressure, and hence 'flatten' the empirical coefficients.**

Precise Orbit Determination of COMPASS-M1 from SLR Data

This figure shows SHAO time-series of derived solar radiation coefficients from seven-day orbital arcs from 2008 December 08 – 2009 August 17.

The solar radiation coefficient values basically change between 1.1 and 1.4. There are three abnormal changes. The first one is 090202 solution. That solution only has 16 data. The other two solutions(090720 and 090603) can become normal after we change the estimated parameters from the normal acceleration estimation to the drag acceleration estimation and also add site bias estimation.



Precise Orbit Determination of COMPASS-M1 from SLR Data

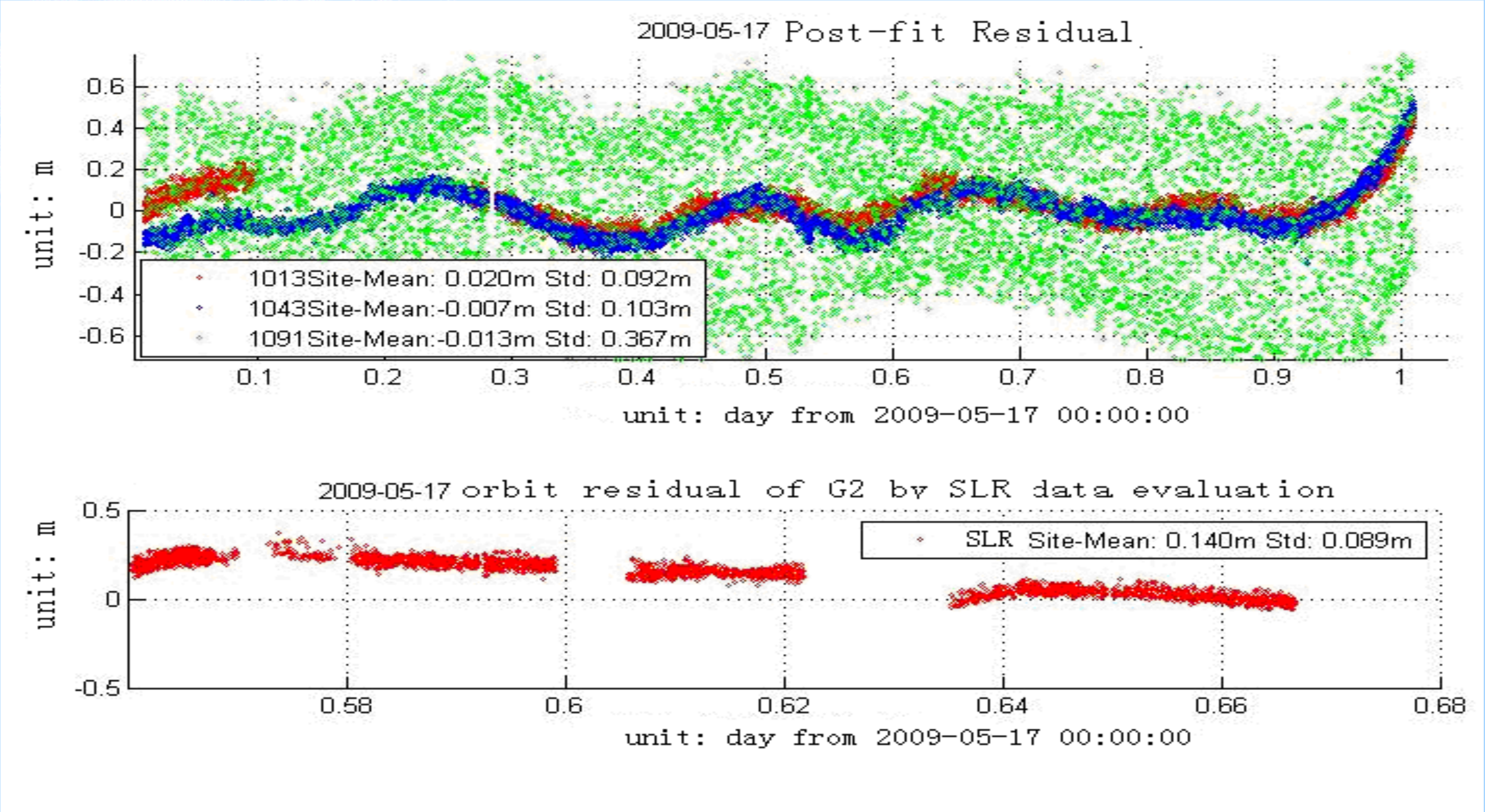
This table shows the derived solar radiation coefficients from 3-day microwave NAV orbits.

date	NAV RAD Coeff.
20080729	0.9632
20080730	0.9525
20080731	0.9374
20080801	0.9346
20080802	0.9421
20080803	0.9347
20080804	0.9478

The radiation pressure model for NAV orbit determination is the same as that of SLR data processing. But the results are different. We still need do more study. Do different data or different methods make such differences? Our results for NAV orbits show 3% or so change within 7 days. Is our model an enough suitable solar radiation model for COMPASS-M1? We are not sure.

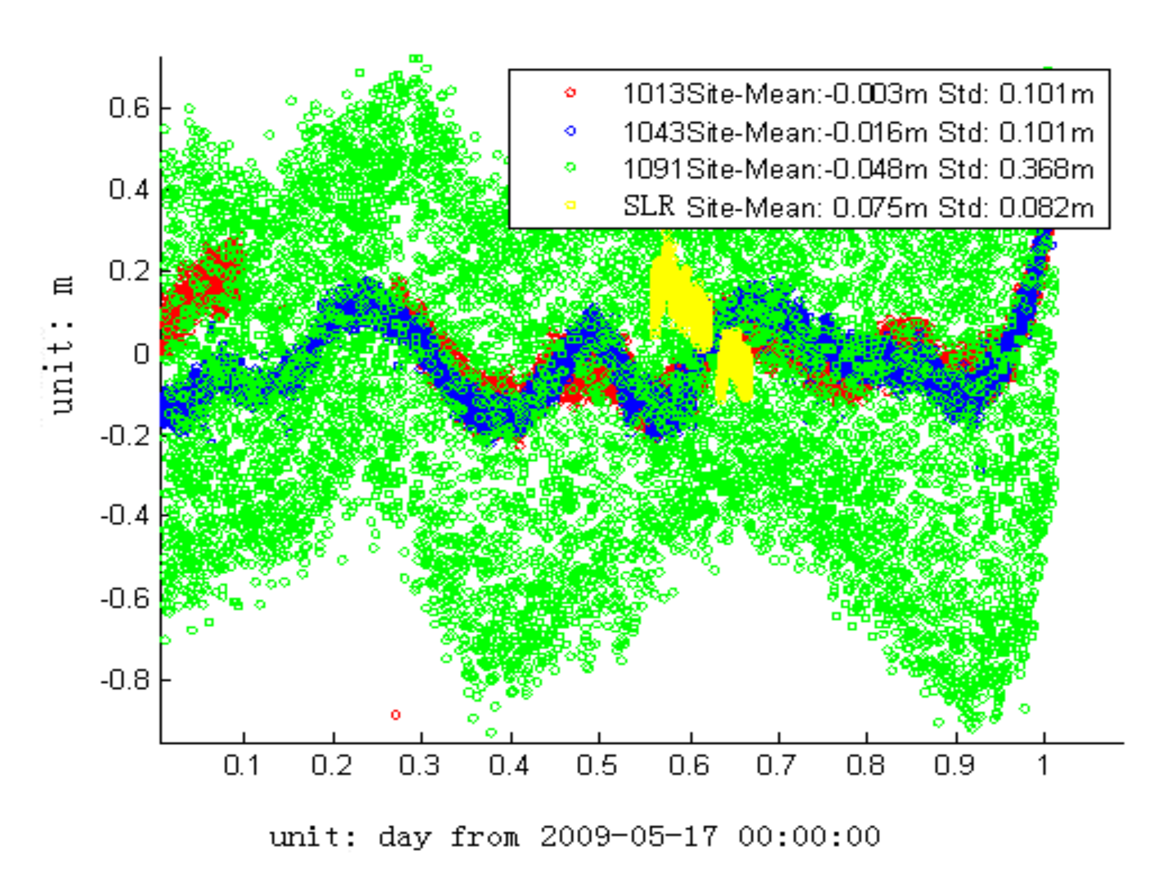
Precise Orbit Determination of COMPASS-G2 from Microwave Measurements and Its Accuracy Evaluation

This figure shows the post-residual of G2 and its orbit residuals by SLR data evaluation. (Only new SLR site)



This figure shows the orbit post-fit residual of G2 orbit determination by both of SLR and microwave measurements.
(Only new SLR site)

- **The site 1091 is more noisy due to the equipment with poor performance. The equipments for the other two sites are the same.**



Conclusion

- **SLR can be used to evaluate the COMPASS-M1 NAV orbits and determine what kind of analytic method is better. This is very important especially when the whole navigation system has not been completed (a few satellites only) and there are many unstable error sources that make orbit determination difficult and complicated.**
- **SLR data can also provide the independent orbits of navigation satellites. We need do more work to design better methods to get improved results. Perhaps by directly comparing the SLR and microwave orbits we will improve our models and methods.**

Conclusion

- The NAV orbit accuracy of COMPASS was evaluated by SLR measurements and it was of meter order.
- Continuous SLR observations are important for POD. When there are data gaps for some days the adopted methods need to be changed. The choice of estimated parameters are important for SLR data processing especially for sparse data.

Future Needs

1) SLR data: Could it be available in near real time (less than 6 hours)? If it is possible it can be used to evaluate the orbit of NAV in real time and rapidly find any systematic errors and perhaps aid real time applications.
2) Continuous observations are important. They can determine SLR orbit with higher precision.
3) We need to quantify ‘continuous’