Researching and applicaiton of VLBI Differential PHase Delay in Lunar exploration

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LPA, SPAIN

outline

- Background

  Tracking and Data Relay Satellite System of CE04(TDRSS-C4)

  Same-beam VLBI(SBI)

- preparing

  orbit prediction, schedule, correlation process

- Data process

  Beacon, correlation phase,

  Differential Phase Delay（DPD） residual , Group delay(GD) residual,

  DPD, Differential Group Delay（DGD）, closure delay

  orbit determination using GD and DPD

- conclusion

TDRSS-C4

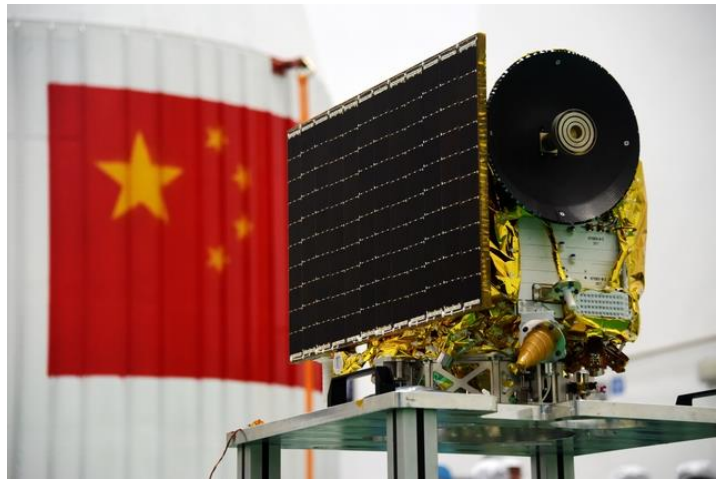
- TDRSS-C4 launched on May 21, 2018, and entered the Earth-Moon transfer orbit immediately.

- On June 14, it entered the Halo mission orbit at L2, Lagrange, about 65,000 kilometers from the moon.

- It was mainly responsible for receiving the signal transmitted by Chang'e-4 on the back of the moon and transmitting them back to the ground receiving station.

- Microsatellite B and TDRSS-C4 separated from the Rocket and then entered the Earth-Moon transfer orbit. During this period, the signal of microsatellite B was also received by CVN(BJ,KM,UR,TM) which pointted to TDRSS-C4. That is to say, the same-beam VLBI observations were carried out for the two detectors.

TDRSS-C4



microsatellite B

SBI Observation condition

- first, to ensure that both detectors can be simultaneously observed by ground radio telescopes
- second, the signal frequencies which two detectors transmit should be reasonable, because the influence of ionosphere is the main systematic error
- third, Two detectors need to be continuously observed so that the calculated DPD has a fixed offset, which can be calculated in the subsequent process.
- fourth, Data processing needs to process the data of two detectors separately, which challenges the real-time requirement.。

SBI:Historical Application

- Two microsatellites, Rstar and Vstar, were observed by the same-beam VLBI in the SELENE mission of Japan in 2008. The calculated DPD was applied to orbit determination and the accuracy of the two microsatellites reached 10 m order.

- During the CE03 mission in 2013, we successfully calculated the same-beam VLBI DPD between the lander and the rover, and used it to monitor the situation of rover. We can see the rover that turn around and moves slowly in the lunar surface.
- The relative position of the Rover and Lander is calculated by DPD, and the accuracy reaches 1m level

SBI application in CE04

In the Earth-Moon transfer section, the ground radio telescope receives S-band DOR signals of TDRSS-C4 and microsatellite B at the same time. In the observation data of several days, there are more than one hour continuous observation data on May 22, 2018. Here we report the analysis and research of the data on this day。

SBI : preparing

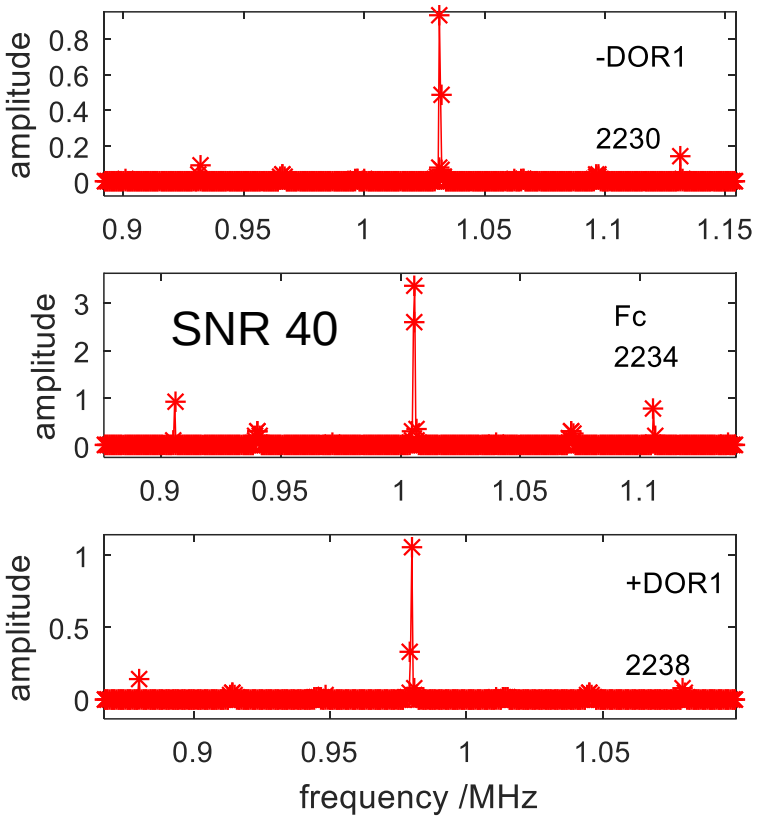
- prediction orbit: VLBI center had obtained the precise ephemeris of TDRSS-C4 and microsatellite B successfully, and calculated the predicted orbit of these two detectors.

- schedule： Job files for correlation process can be got here, including the delay of VLBI geometric model of two detectors

- correlation process： process the observed data recorded by Mark5B twice by the VLBI geometric model of two detectors, it cost too much time for computing.

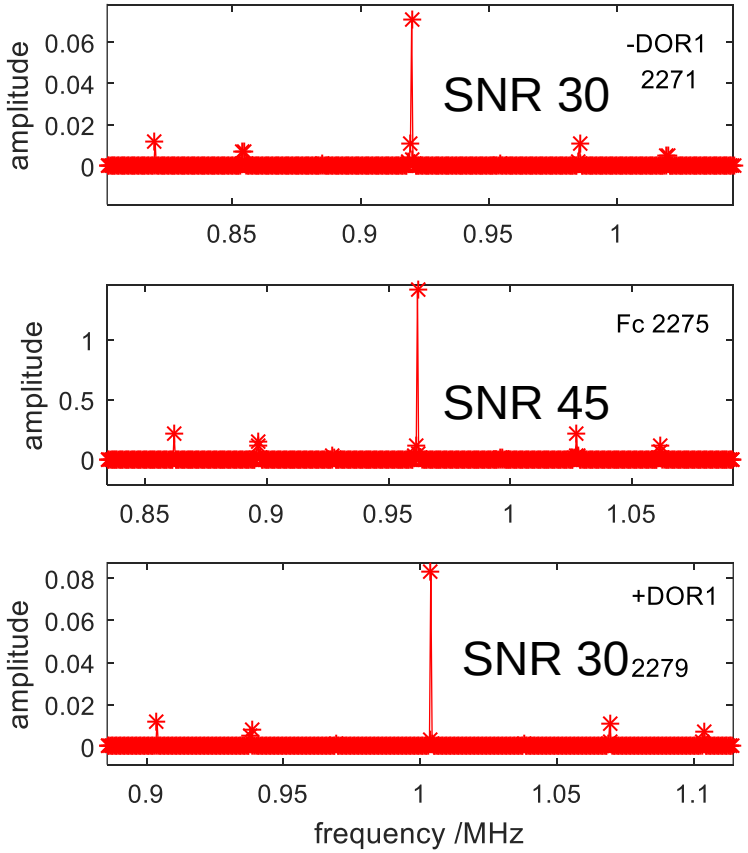
Data process : beacon

TDRSS-C4



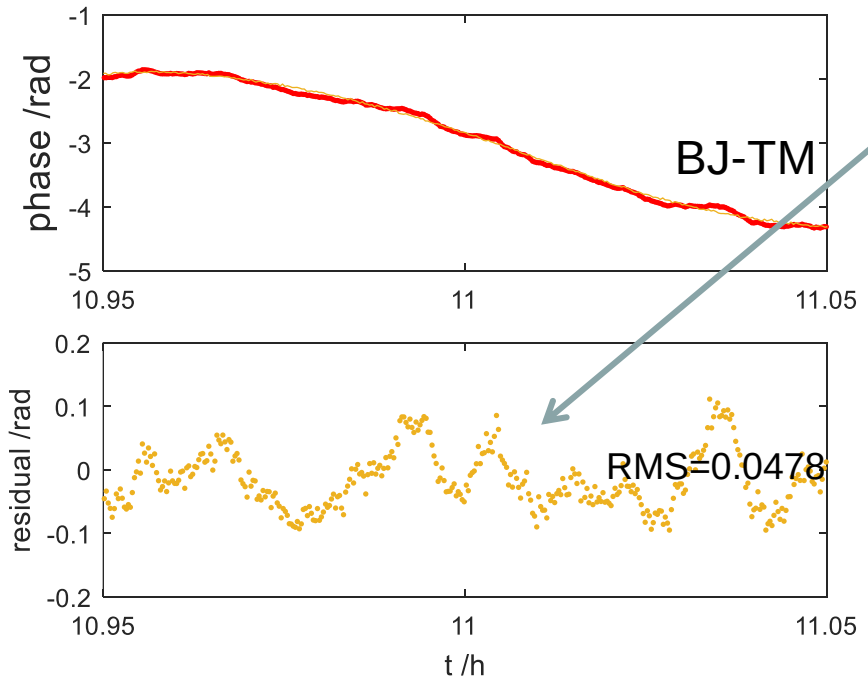
S band DOR signal
CDAS2
2MHz
16 channels
so it can record both two detectors all signal

microsatellite B

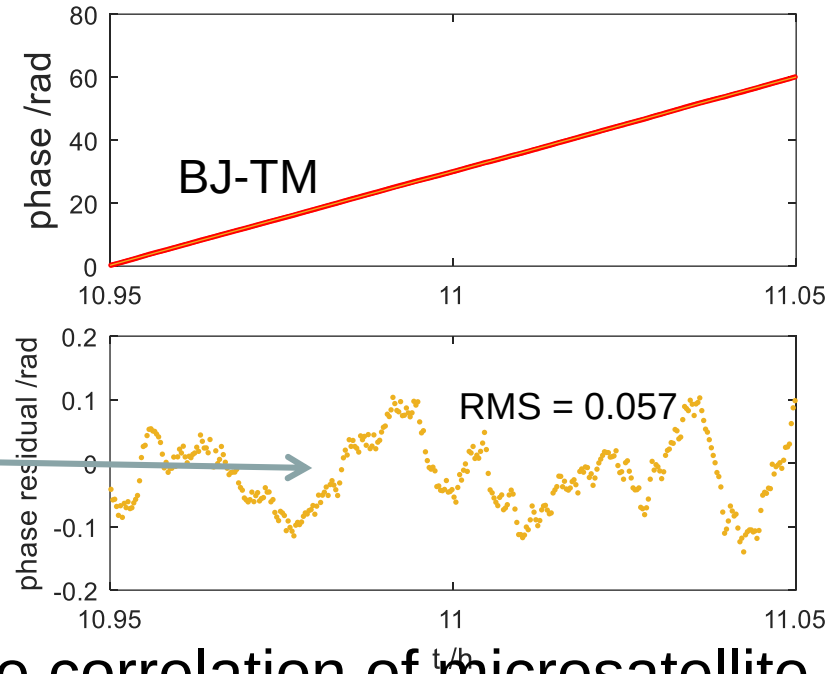


Data process： correlation phase

phase correlation of TDRSS-C4 main carrier and its 8-power polynomial fitting residual



atmosphere error

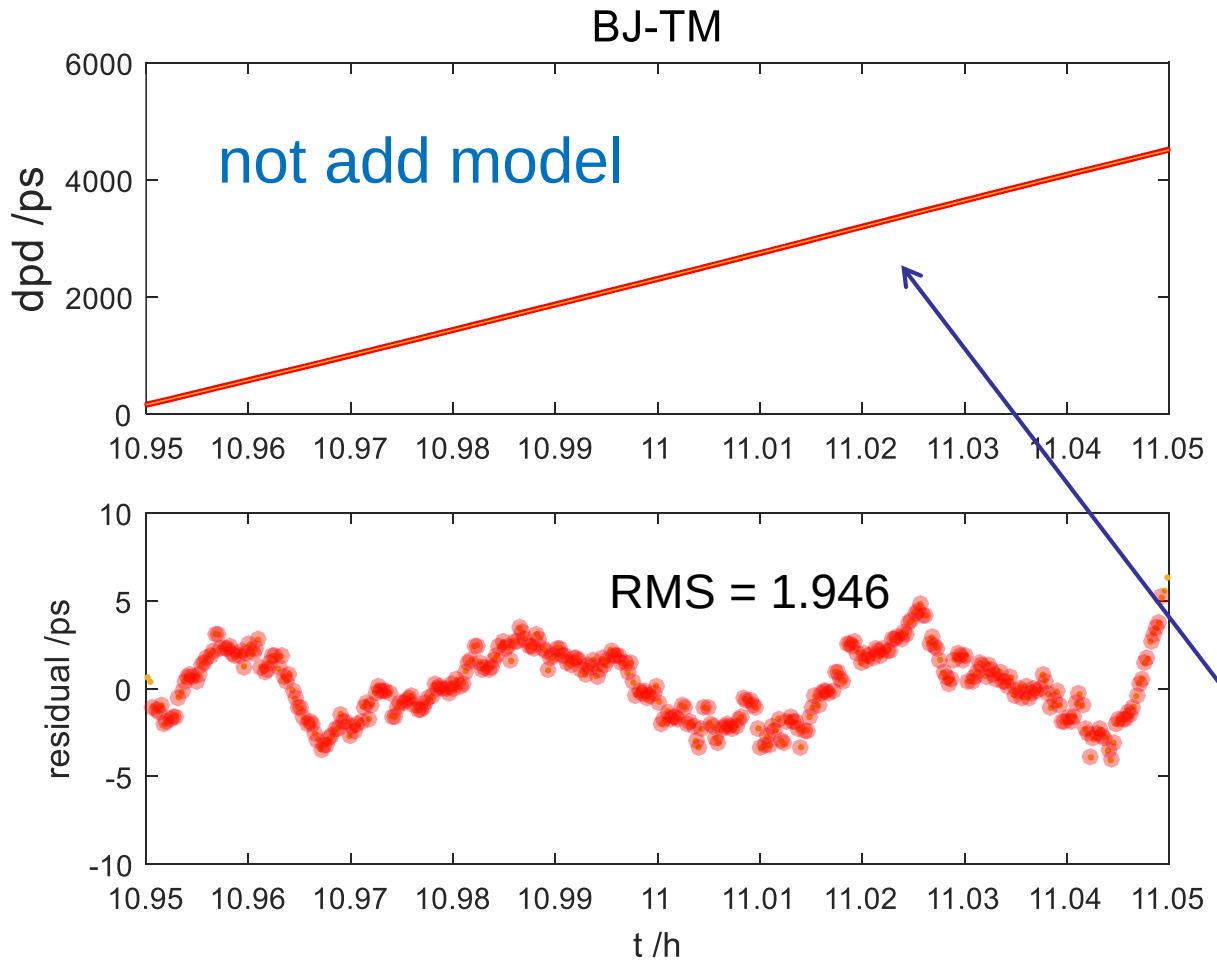


phase correlation of microsatellite B and its 8-power polynomial fitting residual

equation $\sigma_{pd} = \sigma_{\varphi} / (2 \times pi \times f)$

the accuracy of Phase delay of TDRSS-C4 was about 3.4ps, and the accuracy of microsatellite B was about 3.99ps

Data process：residual of DPD



The residual of DPD was about 1.946ps, which is less than 3.4 PS and 3.99 PS of the phase delay of the two detectors.

The differential process cancels out the systematic errors such as atmospheric errors, but still have systematic error

$$\frac{\varphi_1}{2\pi f_1} - \frac{\varphi_2}{2\pi f_2}$$

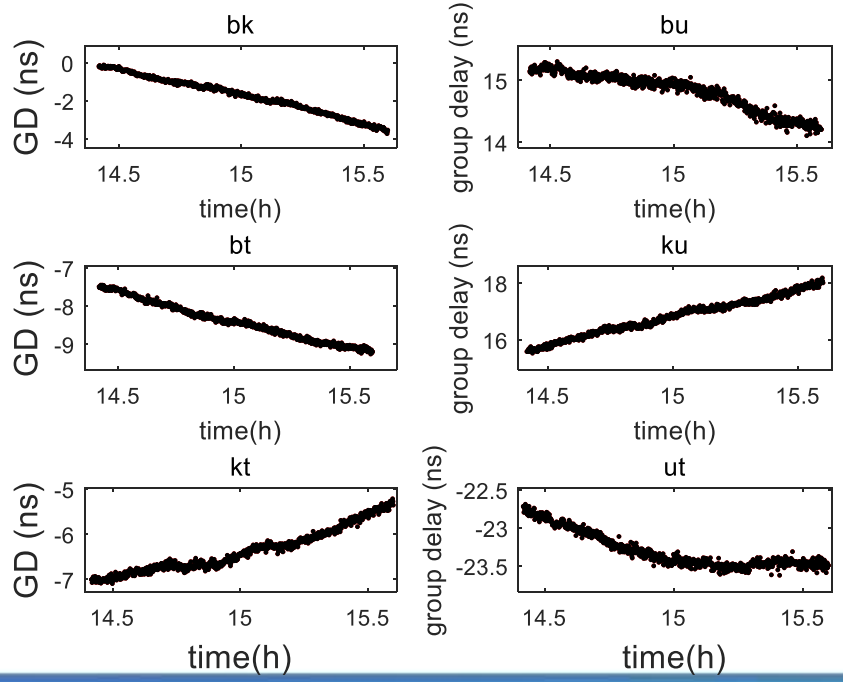
Data process：residual delay of GD

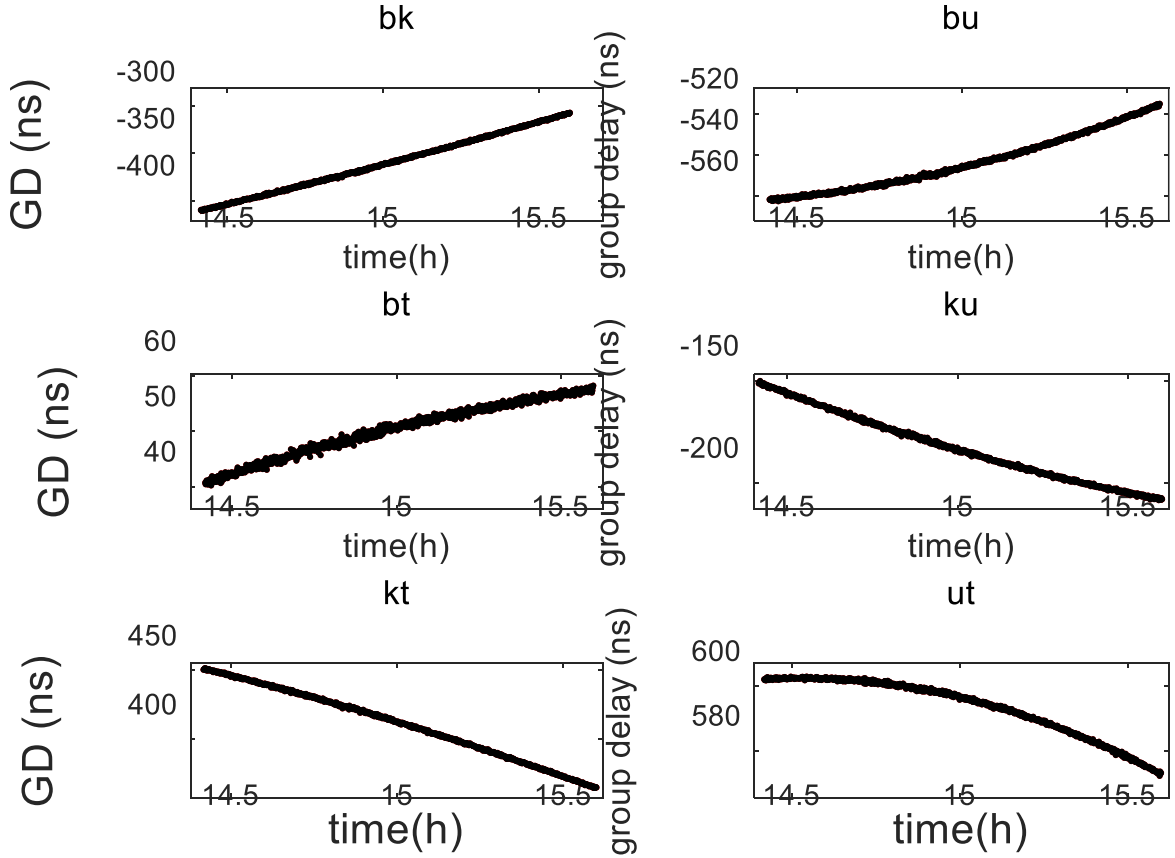
TDRSS-C4

residual delay of Group delay

calculated by corelation data

so small because of the high accuracy of prediction satellite orbit





microsatellite B residual delay

prediction orbit was bad

Data process : DPD

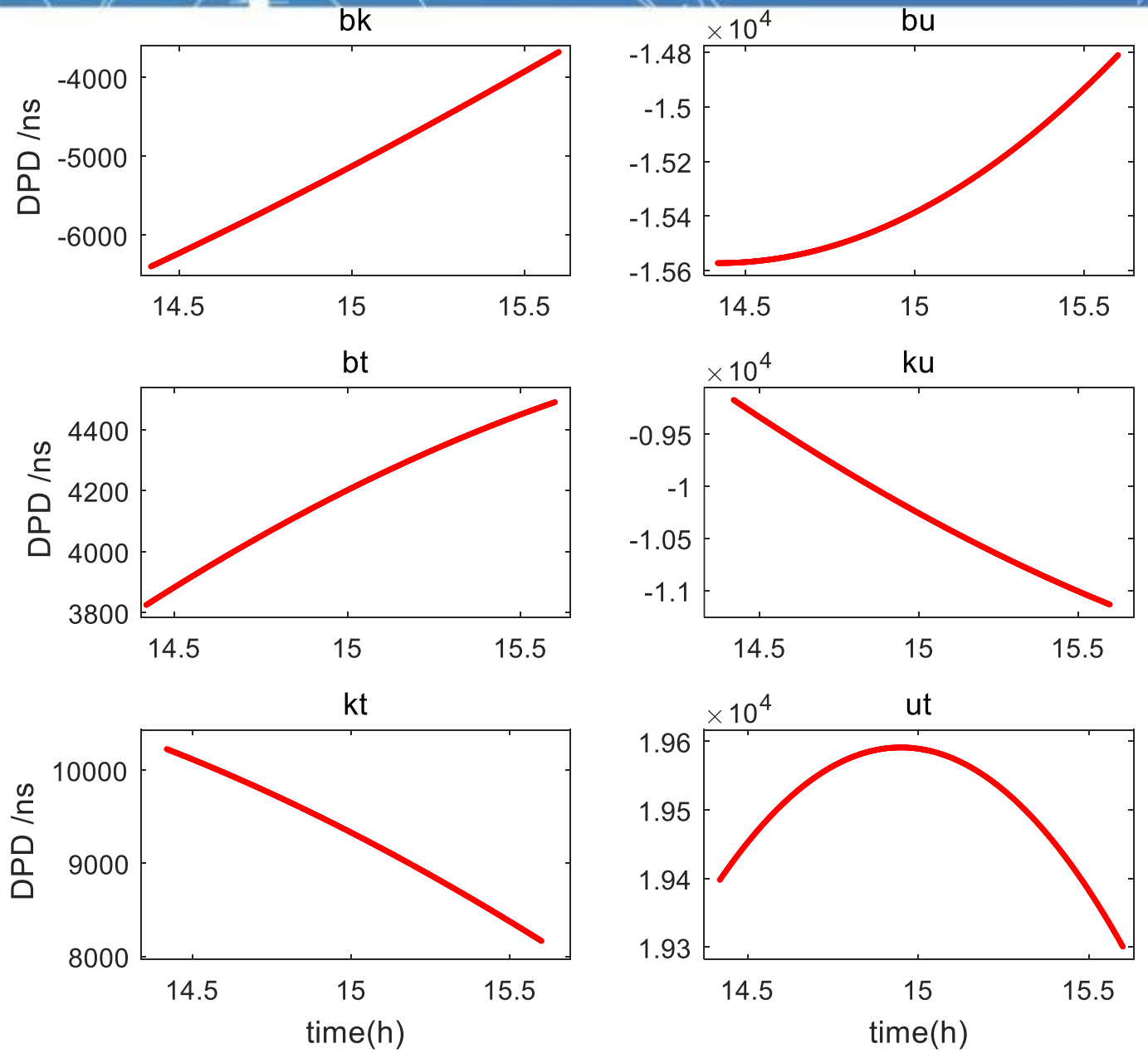
22,May,2018 observated by CVN

In the middle of DGD, so have a constant bias each baseline

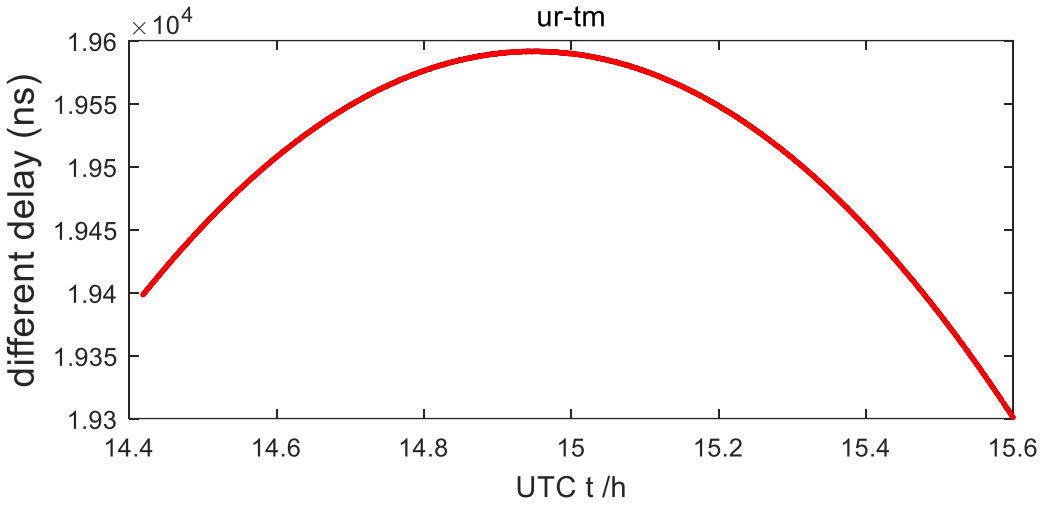
more than 1 hour continued data

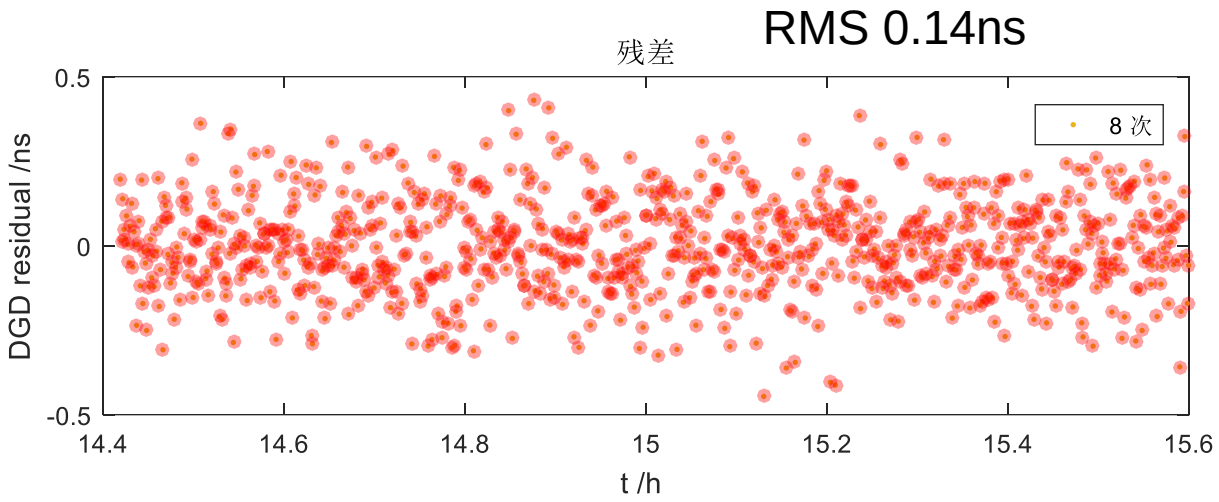
Two detectors not maneuver

total DPD
add model and residual



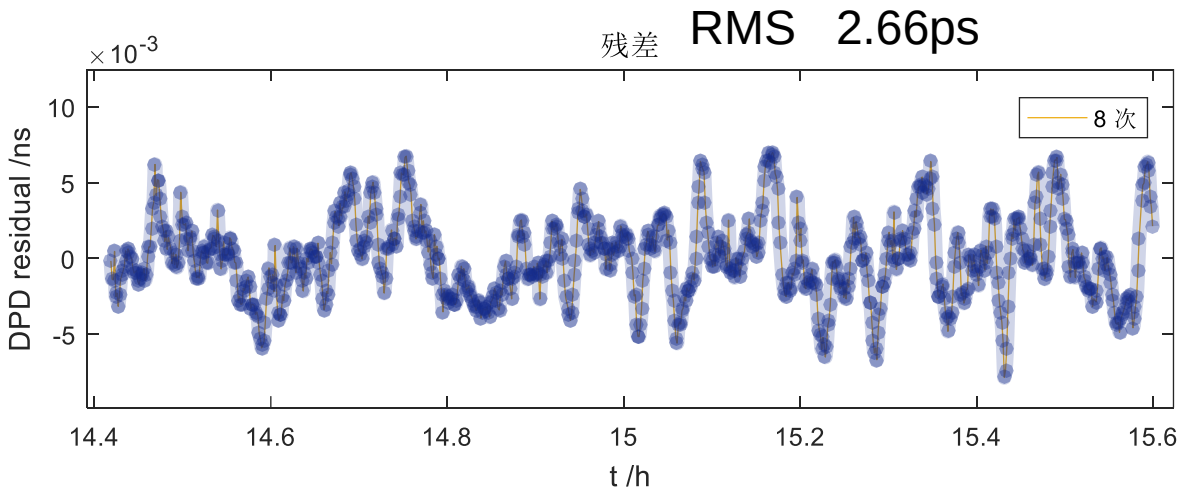
Data process：residual of DPD and DGD





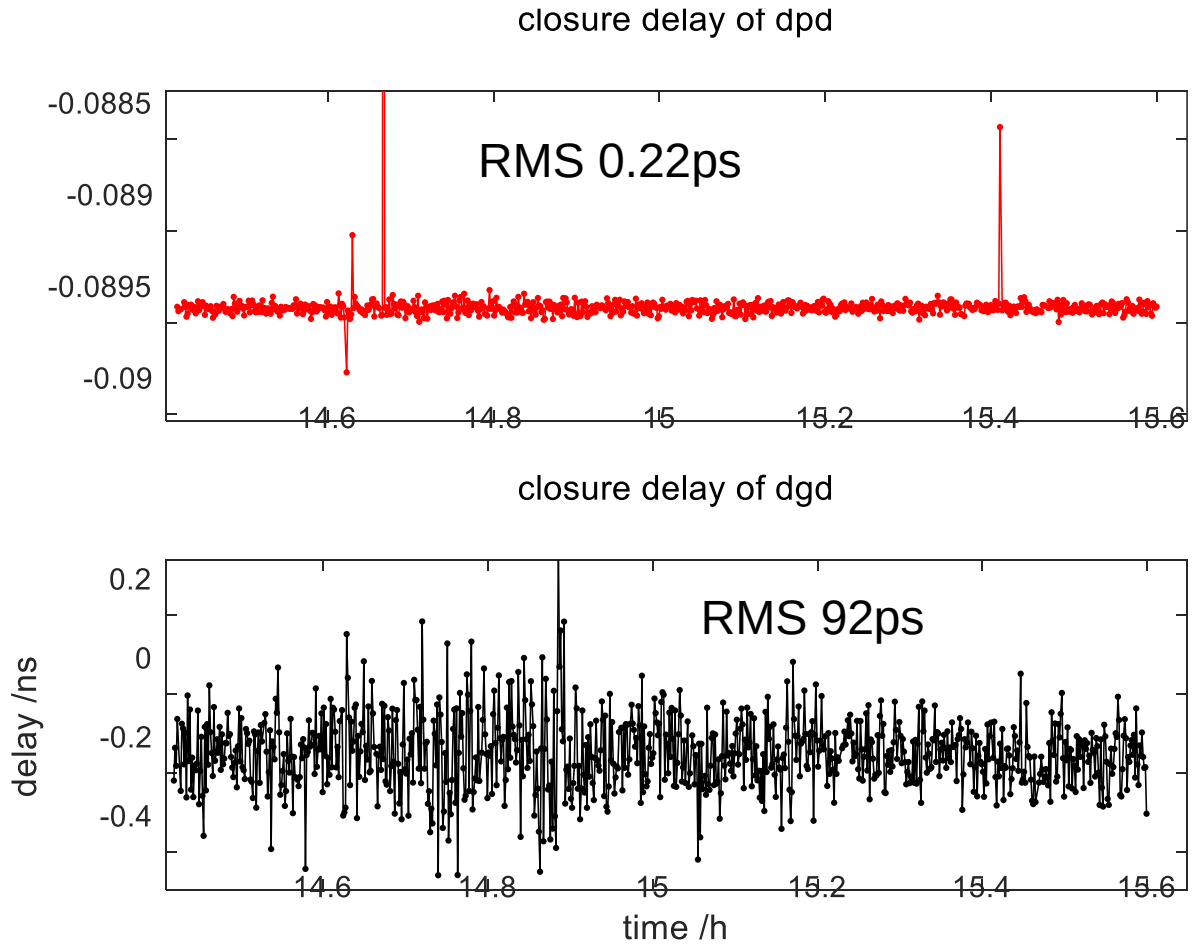
the DPD and DGD was correctly computed

The residual error of DGD was 50 times larger than ther error of DPD



Data process：the closure delay of three baselines

Station: BJ, KM, TM
quite good but still have constant bias

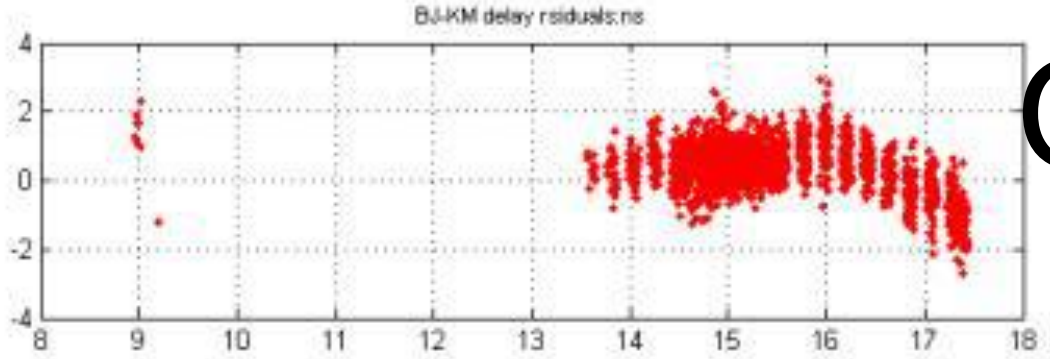


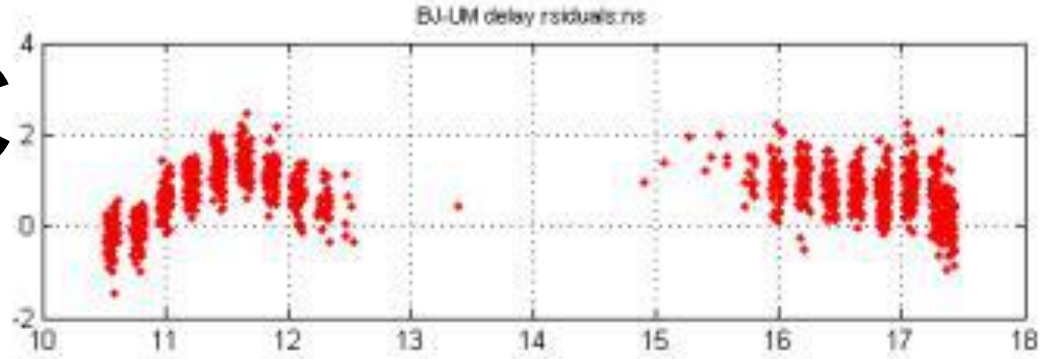
Data process ： orbit determination Group delay

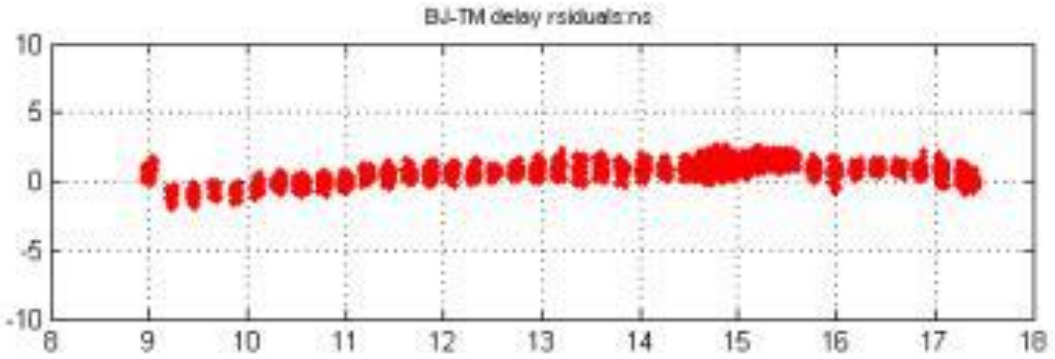
O-C

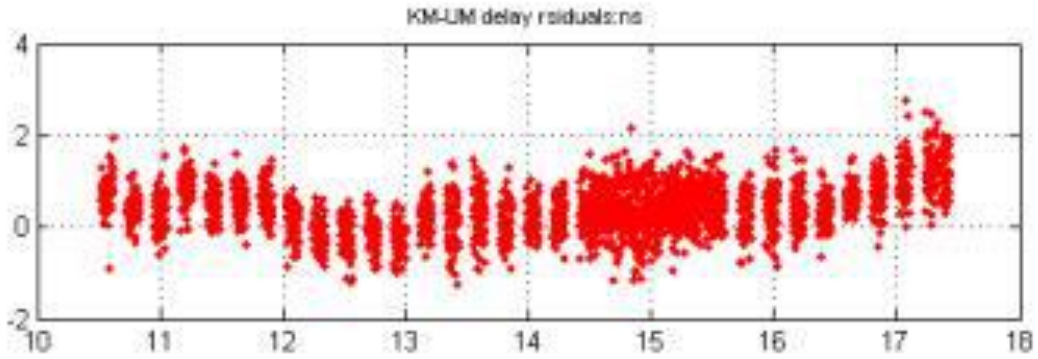
unit

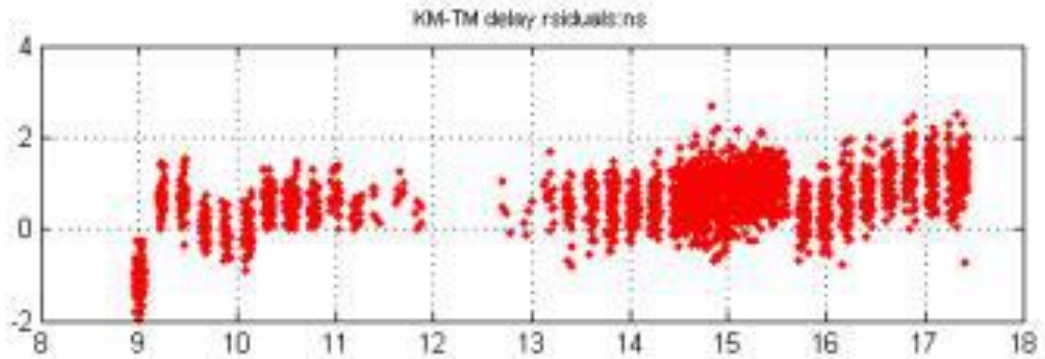
ns

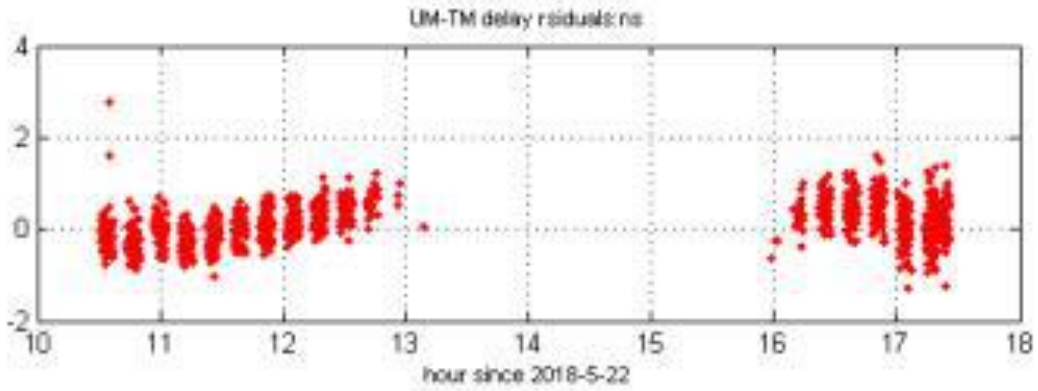




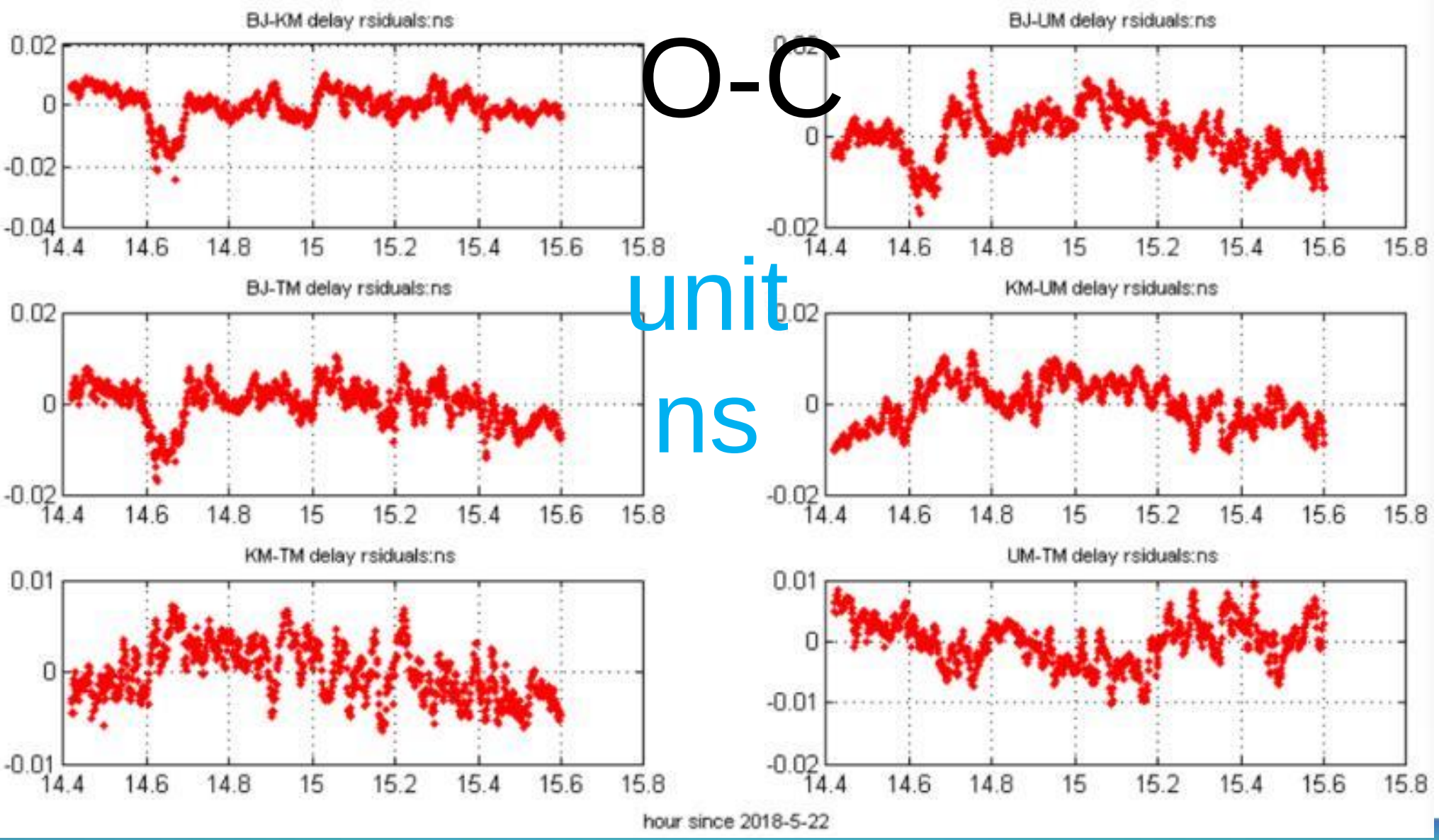








Data process：orbit determination DPD



O-C

unit

ns

this week calculated

Data process：orbit determination DPD

```
bias0_91  - 1  =          -0.18096
bias0_91  - 2  =          -0.20236
bias0_91  - 3  =           0.03543
bias0_91  - 4  =           0.00482
bias0_91  - 5  =           0.12883
bias0_91  - 6  =           0.12471
```

constant bias of DPD each baseline computed during the orbit determination
unit meter

```
        rms91     =              0.00133
       rmsp91     =              0.00133
       nobs91     =                 5075
SAT-1OBS.
    rms_sta    2    3    =          0.00149
    rms_sta    2    4    =          0.00161
    rms_sta    2    5    =          0.00132
    rms_sta    3    4    =          0.00146
    rms_sta    3    5    =          0.00089
    rms_sta    4    5    =          0.00109
SAT-2OBS.
```

average RMS is about 4.3ps
good result
unit meter

conclusion

- we correctly calculated the DPD data in TDRSS-C4 mission which existed two detectors during the Earth-Moon transfer orbit

- we successfully used the DPD data for orbit determination for these two detectors

Thank you for your attention