Echo signal quality analysis during HY-2A radar altimeter calibration campaign using reconstructive transponder

Junzhi Wan, Wei Guo, Fei Zhao, Caiyun Wang, Peng Liu, Mingsen Lin, Hailong Peng and Chuan Xu

***Abstract*—A reconstructive transponder has been utilized for the in-orbit calibration campaign of the HY-2A radar altimeter since March, 2012. The precision of final calibration result is influenced by echo signal's quality in the HY-2A altimeter's range window. As an indicator of the signal's quality, echo signal dwell time is analyzed considering its influence on signal quality and its uncertainty. In HY-2A altimeter calibration, the echo signal dwell time is determined by the radial orbit prediction uncertainty and the real-time signal processing mechanism of the reconstructive transponder. The real-time signal processing mechanism of the reconstructive transponder utilizes some incoming signal samples without sending echo signals before transmitting. Comparing with the length of the HY-2A altimeter's range window, the radial orbit prediction uncertainty is large. Large radial orbit prediction uncertainty and signal processing mechanism of the reconstructive transponder are two main factors that limit the echo signal dwell time in HY-2A altimeter calibration. Finally, approaches for increasing echo signal dwell time are briefly proposed.**

***Index Terms*—Altimeter, reconstructive transponder, dwell time, signal quality**

I. Introduction

HY-2A radar altimeter in-orbit range absolute calibration campaign using a reconstructive transponder has been carrying out from March 2012. [1]–[3] present works on signal processing and utilization of the reconstructive transponder. Bao *et al.* utilized the HY-2A ultra stable oscillator (USO) drift calibration data from the calibration campaign using the reconstructive transponder, and successfully mitigated the significant sea surface height (SSH) drift exists in the HY-2A altimeter Interim Geophysical Data Records (IGDR) [4].

The basic requirement of a transponder for radar altimeter calibration is sending echo signals into the altimeter's range window. So far, there have been two types of transponders for in orbit radar altimeter calibration: bent-pipe transponder and reconstructive transponder. Bent-pipe transponder, a kind of transponder with relative simple system structure, have been utilized for in orbit radar altimeter calibration for more than 20 years. [5]–[15] have reported the principle of in orbit radar altimeter calibration utilizing a transponder and pertinent experimental results. Up to now, bent-pipe transponder has been utilized as an operational calibration approach for radar altimeter.

The conception of the reconstructive transponder was proposed by MacDoran *et al.* as an in orbit calibration approach for the TOPEX/Poseidon mission [16]. Mathews reported prototype research and development work as well as field experiment result of a reconstructive transponder, but difficulty in getting permission to transmit signal to TOPEX/Poseidon satellite prevented further calibration experiment [9]. No work about in orbit radar altimter calibration using a reconstructive transponder had been reported until the HY-2A altimeter calibration work utilizing a reconstructive transponder.

In the altimeter calibration using transponder, let the ranges from the altimeter observation be $R_a[n], n = 1, 2, ..., N$, the reference ranges from the precision orbit determination (POD) data be $R_0[n], n = 1, 2, ..., N$, and the standard deviation of $R_a[n]$ is σ_a, then the altimeter's range bias B_a can be estimated:

$$B_a = \frac{1}{N}(R_a[n] - R_0[n]). \tag{1}$$

If the altimeter can receive more echo signal samples, higher precision of final calibration results can be achieved:

$$\sigma_{B_a} = \frac{\sigma_a}{\sqrt{N}} \geqslant \frac{\sigma_a}{\sqrt{N+M}}, M \geqslant 0 \tag{2}$$

where σ_{B_a} is the standard deviation of B_a, and $N + M$ corresponds to more echo signal samples in the altimeter's range window.

σ_a in (2), which is determined by the system features of the radar altimeter and the reconstructive transponder, is regarded as a constant in this paper. The larger of $N + M$, the more signal samples are observed by the altimeter, and the longer echo signal dwell time in the altimeter's ranger window. Therefore, $N + M$ can be measured by echo signal dwell time. In HY-2A altimeter calibration campaign, the echo signal dwell time in (2) changed significantly in each calibration, and it was the main factor affecting σ_{B_a}. In this paper, we take echo signal dwell time as a main indicator of the echo signal quality of the reconstructive transponder. The maximum dwell time can be regarded as constant for a particular in orbit radar altimetry mission, hence the causes that reduce echo signal dwell time are important for calibration result improvement.

J. Wan, W. Guo, F. Zhao, C. Wang and P. Liu are with the CAS Key Laboratory of Microwave Remote Sensing, National Space Science Center, Chinese Academy of Sciences, Beijing 100190, China (e-mail: wanjunzhi@mirslab.cn; guowei@mirslab.cn; wangcaiyun@mirslab.cn; zhaofei@mirslab.cn; liupeng@mirslab.cn).

M. Lin and H. Peng are with National Satellite Ocean Application Service, Beijing 100081, China (e-mail:mslin@mail.nsoas.org.cn; phl@mail.nsoas.org.cn).

C. Xu is with the Key Laboratory-for Fault Diagnosis and Maintenance of Spacecraft in Orbit, Xian Satellite Control Center, Xi'an 710043, China (e-mail:10663548@qq.com).

Corresponding author: Fei Zhao.

As will be discussed below, the range between the altimeter and the transponder is a parabolic function of time t, the shape of the range curve in the altimeter's range window reflects the echo signal dwell time, i.e., non-ideal range curve indicates a shorter dwell time. (2) applies to both a bent-pipe transponder and a reconstructive transponder. So far, discussion on echo signal dwell time and the shape of signal curve in altimeter calibration utilizing a bent-pipe transponder is little.

The rest of the paper is organized as follows: In Sec. II, the distance between the satellite and the reconstructive transponder is modeled as a function of time. Based on this, several possible echo signal curves are shown. Furthermore, The actual echo signal dwell time results obtained from calibration are given. In Sec. III, the differeces between the responding mechanism of a bent-pipe transponder and a reconstructive transponder are discussed, and real-time signl processing mechanism of the reconstructive transponder is discussed as a cause of non-ideal echo signal curve. Radial orbit prediction uncertainty as another cause of non-ideal range parabola are discussed in Sec. IV. In Sec. V, analysis of orbit prediction uncertainty at Beijing calibration site are given. Finally, Sec. VI concludes the paper and proposed possible approach to obtain more signal samples in altimeter range window.

II. Dwell time of echo signal

$R(t)$, the distance between the altimeter and the reconstructive transponder, can be modeled as a parabolic function of time t [1]:

$$R(t) = (R_0 - H) + \frac{(R_e + H)GM}{2(R_0 - H)(R_e + R_0)^2} t^2 \tag{3}$$

where R_e is the radius of the Earth, R_0 is the height of the altimeter, H is the height of the transponder relative to the Earth's surface, and $GM = 3.986 \times 10^{14}\ m^3 s^{-2}$ is a constant. During calibration, HY-2A altimeter operates at search mode that provides a 240 meters long two-way range window. In HY-2A actual calibrating overpass at Beijing, $R_0 = 971km$, $R_e = 6371km$, $H = 55$ meters, and the theoretical maximum dwell time of $R(t)$ in the HY-2A altimeter's range window is 4.5 seconds. [1] discusses the approach to indemnifying an error because of varied Doppler effect delays. However, in the discussion of echo signal visibility during calibration, the error from Doppler effect can be ignored safely.

Fig.1 shows the theoretical range curve with maximum dwell time and other kinds of non-ideal range curves. The maximum dwell time parabola can provide the maximum number of signal samples in the altimeter's range window then minimize σ_{B_a} in (2), but it is almost impossible to be obtained in actual calibration. A symmetric parabola with smaller dwell time, an asymmetric parabola with visible apex and an asymmetric parabola with invisible apex are three kinds of curves that apper in actual calibration data. Both real-time signal processing mechanism of the reconstructive transponder and radial orbit prediction uncertainty affect the shape of the parabola, and will be discussed in the following contents in detail. Fig.2 shows how the two factors affect the curve shape in the altimeter's range window.

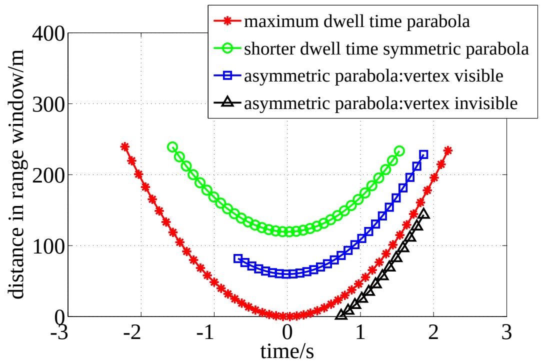


Fig. 1. ideal and non-ideal range curves.

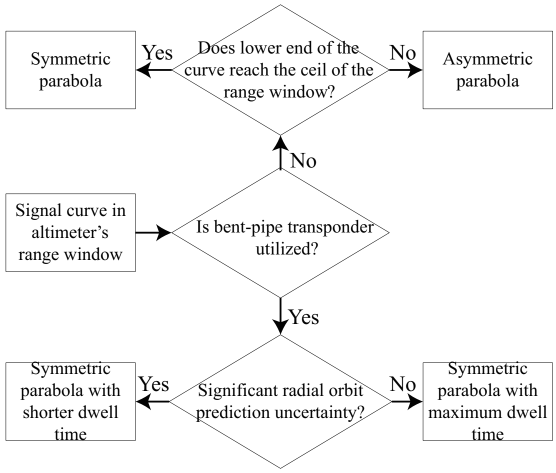


Fig. 2. factors that affect the curve shape in the altimeter's range window.

The actual echo signal dwell times in calibration are shown in Fig. 3. It is clear that most of calibration results are far from theoretical maximum dwell time.

III. Real time signal processing mechanism and asymmetric parabola

A transponder for in-orbit radar altimeter calibration has to guarantee a controlled time interval between incoming signal and responding signal during calibration. Responding mechanisms between bent-pipe transponder and reconstructive transponder are different. A bent-pipe transponder with central frequency f_c simply amplifies and retransmits any signal with central frequency f_c at any time. Therefore, no matter how weak the incoming signal's power from the altimeter, it will be captured, amplified and transmitted to the altimeter by the bent-pipe transponder, although the signal may not be properly processed because of low signal-to-noise ratio (SNR). A bent-pipe transponder does not need to determine whether the signal from the altimeter has arrived or not.

It is necessary for a reconstructive transponder to determine the arrival time of the signal from the altimeter, because the reconstruction and transmission of the responding signal must be triggered by the signal from the altimeter during calibration. The reconstructive transponder for HY-2A altimeter in-orbit calibration utilizes a real-time signal processing mechanism to achieve this goal, which contains three sub mechanisms. During those steps, no responding signal is transmitted:

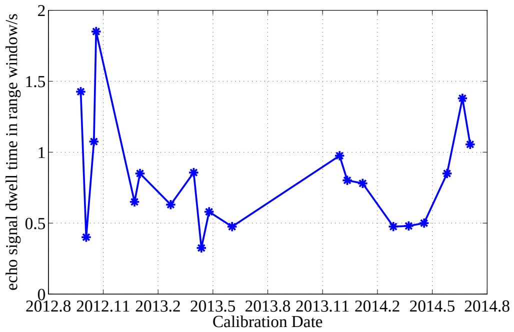


Fig. 3. echo signal dwell time in HY-2A altimeter's range window.

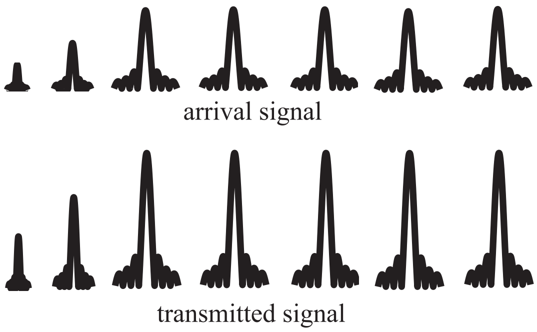


Fig. 4. arrival and transmitted signals of a bent-pipe transponder.

1) Low SNR rejection: Any incoming signal whose SNR is lower that the power threshold of the reconstructive transponder will not be processed.

2) Repeated confirmation: If signal with enough power is appeared, several such signals are analyzed to make sure that the signals from the altimeter do appear.

3) Tracking establishment: After repeated confirmation, precise measurement of incoming signal arrival time requires that several signals are processed to establish stable tracking.

Fig.4 shows how the bent-pipe transponder receives, amplifies and transmits all incoming signal. Fig.5 shows the process that a reconstructive transponder starts to transmits signal before several incoming signal are processed without transmission for low SNR rejection, repeated confirmation and tracking establishment. It is certain that the relative simple signal processing mechanism of a bent-pipe transponder preserves the maximum amount of responding signal. Improvements of signal processing mechanism of the reconstructive transponder for HY-2A altimeter calibration can increase the number of responding signals in the altimeter's range window, but a responding signal number like a bent-pipe transponder is difficult to be obtained.

When the reconstructive transponder receives the HY-2A altimeter's transmitting signal, it tries to establish signal tracking. Before stable tracking is established, the reconstructive transponder doesn't transmit echo signal. When stable tracking is established, the reconstructive transponder starts to transmit echo signal. During the transmitting procedure, a time delay is added on each echo signal to make sure that they can be sent into the HY-2A altimeter's range window. As previously described, a part of echo signal parabola is utilized to establish

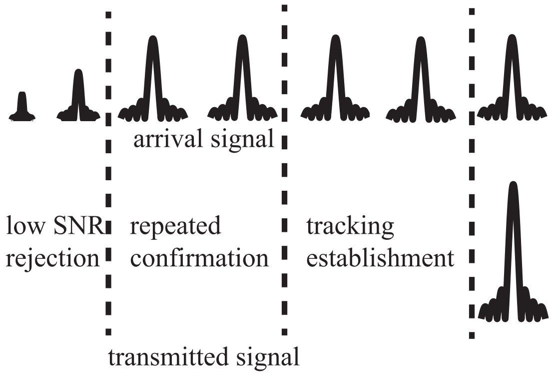


Fig. 5. arrival and transmitted signals of a reconstructive transponder.

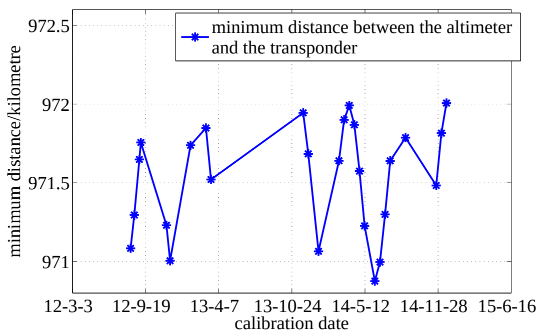


Fig. 6. minimum distances between the HY-2A altimeter and the reconstructive transponder during calibration campaign.

stable tracking, and no responding signal is sent into the range window of the altimeter during this procedure.

Let the altimeter's tracking height be T, the height of the altimeter be H, the relative height between the reconstructive transponder and the surface of reference ellipsoid be h, the time delay of reconstructive transponder be D_{trans}. T and h are constants at a particular place, and H changes in each calibration overflight. Fig. 6 shows the minimum distances between the HY-2A altimeter and the reconstructive transponder during calibration campaign from Aug. 9, 2012 to Dec. 21, 2014.

Therefore, let H be $H(t)$, t is time. The responding signal can be seen by the altimeter, if the following equation holds [17]:

$$H(t) = T + 2h - D_{trans}. \tag{4}$$

Before HY-2A altimeter calibration, D_{trans} is derived from (4) and fed to the reconstructive transponder. T and h are precisely known. However, during the HY-2A altimeter calibration, the uncertainty of $H(t)$ from the orbit prediction is significant compared with the range window length of the altimeter. Fig.7 shows how large $H(t)$ uncertainty affects the shape of the parabola in the altimeter's range window: Larger responding delay of the reconstructive transponder may provides a symmetric parabola, and smaller one may provides a asymmetric parabola. More discussions about the uncertainty of $H(t)$ can be found in Sect. V.

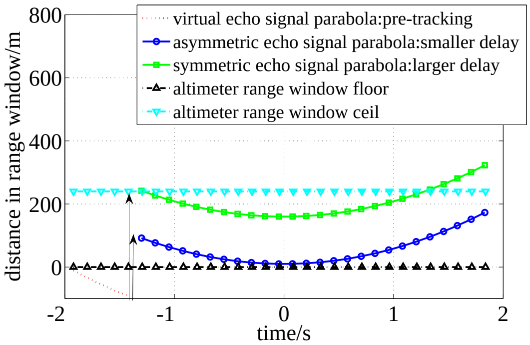


Fig. 7. reconstructive transponder's different signal delay and corresponding parabola in the altimeter's range window.

IV. Radial Orbit Prediction Error and Shorter Dwell Time

Equation (4), Fig. 1 and Fig. 7 indicate that the uncertainty of $H(t)$, orbit height, have significant influence on the echo signal dwell time in the altimeter's range window. State-of-art precise orbit determination approaches provide precise orbit determination (POD) data of the altimetry satellite with no more than 3 cm radial root mean square (RMS) error [18]–[21]. The radial orbit error on such a small magnitude compared with the tens of meters long range window of the radar altimeter, hence the shape of signal curve is not affected. However, in actual calibration, D_{trans} in (4) has to be calculated and fed to the reconstructive transponder before the satellite overflight, and $H(t)$ is provided by orbit prediction data.

In different radar altimeter working mode during calibration, there are different ways to make equation (4) hold.

1) T is determined by tracking algorithm. In this case, to send responding signal into altimeter's range window, D_{trans} satisfies

$$D_{trans} = 2h_r \tag{5}$$

where h_r is the distance between the transponder and the surface. The advantage of surface tracking mode calibration is that $H(t)$ is not required before calibration, and the uncertainty of $H(t)$ does not affect the dwell time of echo signal range curve in the altimeter's range window. However, the transponder has to be placed at a calibration site where the radar altimeter can keep tracking. Furthermore, changing internal delay of the bent-pipe transponder by changing hardware component to satisfy (5) is difficult. It is easy for a reconstructive transponder to change internal delay by digital signal processing.

Jason-1 Poseidon-2 radar altimeter in orbit calibration campaign utilizing a bent-pipe transponder at Gavdos island, Greece utilized this mode. All attempts to transmit signal into Jason-1 altimeter's range window failed, because the altimeter tracks the sea surface at calibration site and the bent-pipe transponder at the shore is too high with respect to the ocean surface [10], [11]. The reconstructive transponder carried out several experimental calibrations of HY-2A altimeter utilizing surface tracking mode whose tracking height is determined by tracking mechanism, but no reliable calibration result was obtained. HY-2A altimeter keeping tracking at calibration site was proved to be difficult, and echo signal from rough surface interferenced with the echo signal from the reconstructive transponder.

2) T is determined by an approach independent with surface tracking. In this case, it is necessary to obtain $H(t)$ before calibration. In HY-2A altimeter calibration, variation of the range between the satellite and the transponder in each calibration is significant compared with the range window length of the radar altimeter. As Fig.6 shows, the range of minimum distance between the HY-2A satellite and the reconstructive transponder is from 971km to 972km, the two-way range window length of the HY-2A altimeter during calibration is 240 meters. Internal delay adjusting of a bent-pipe transponder by component replacement before each satellite overflight is difficult, and no report about the utilization of this approach in calibration has been seen. Altimeter tracker height adjustment and reconstructive transponder internal delay adjustment are two approaches to compensating the orbit height variation. Fig.8 briefly shows the relationship of the two approaches.

a) Altimeter tracker range adjustment. In this case, before each calibration, $H(t)$, h and D_{trans} are constant. T is obtained from (4). Setting T by ground command is a traditional way and had been used for several altimetry mission calibration campaign using bent-pipe transponder [6], [7], [9]. Another approach is DIODE/DEM (DORIS Immediate Orbit on-board Determination/Digital Elevation Model) mode of the DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) system. DIODE is a real-time orbit determination mode which can provide orbit data with about 5 cm radial component RMS [22]. In DIODE/DEM mode, DIODE provides $H(t)$, and DEM provides h, then T is obtained from (4) and fed to the altimeter before calibration overflight. DIODE/DEM mode was implemented on Jason-2 mission for the first time as an experimental mode [23]. DIODE/DEM mode has been proven to be effective during Jason-2 calibration campaign carried out at Gavdos island, Greece utilizing a bent-pipe transponder [11], and provided orbit determination data with less than one centimeter accuracy on the radial component [24]. There is no report about the influence on echo signal range curve introduced by the uncertainty of $H(t)$ in calibration campaigns of other radar altimetry missions.

b) Reconstructive transponder internal time delay adjustment. During this case, the altimeter tracker height T is the same for each calibration, h is a known constant, D_{trans} is calculated and fed to the reconstructive transponder before calibration. HY-2A altimeter calibration using reconstructive transponder adopted this approach for the first time. The uncertainty of $H(t)$ from the POD data during HY-2A altimeter calibration is discussed in Sec. V.

V. Analysis of Orbit Prediction Uncertainty at Calibration Site

HY-2A altimeter operates in search mode during calibration. In this mode, the HY-2A altimeter's tracker range is fixed at a preset value T. There is $T > H(t)$ for getting rid of reflection from earth surface. If there is a bias in $H(t)$, according to

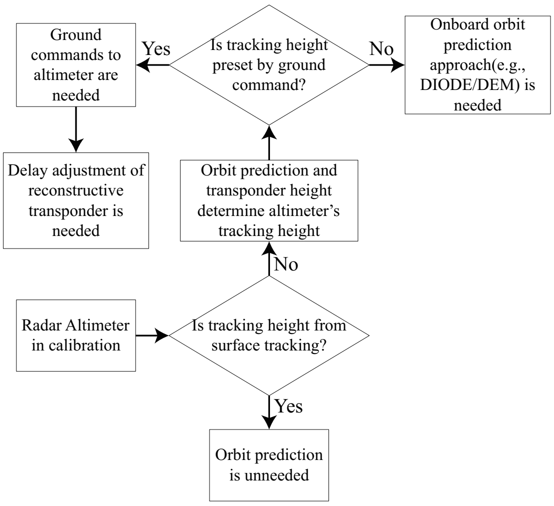


Fig. 8. Altimeter operation mode diagram during calibration.

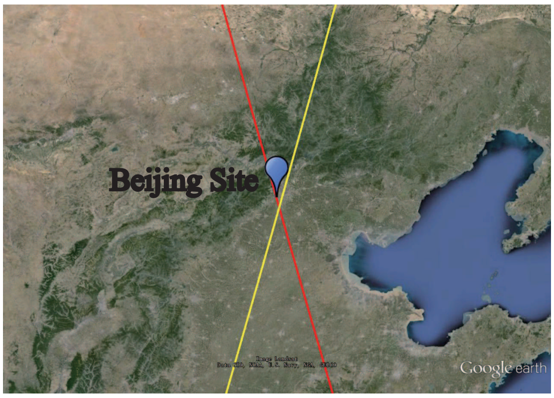


Fig. 9. Beijing calibration site and ground tracks of HY-2A satellite. Dark line is ascending pass and bright one is descending.

(4), the ideal echo signal range curve in HY-2A altimeter's range window cannot be obtained. The uncertainty of $H(t)$ at Beijing is discussed below.

The calibration session at Beijing were from March, 2012 to March 2015, and a new experimental calibration session at Mudanjiang, Heilongjiang Province, China began since March, 2015. Fig.9 shows the location of the calibration site. Beijing site is far from descending pass and all calibrations were carried out on ascending pass.

We define $\hat{R_m}$ is the minimum distance between the altimeter and the reconstructive transponder from the orbit prediction, and R_m is the minimum distance from the POD. Calibration site is near the sub-track position of the satellite, hence assumption

$$R_m = H(t) - h \tag{6}$$

is used here.

We define

$$B_R = R_m - \hat{R_m} \tag{7}$$

where B_R is the bias between R_m and $\hat{R_m}$.

It is preferable for reconstructive transponder calibration if B_R is predictable, i.e., if $B_R[n]$ at days n is known, then $B_R[m], m > n$ can be estimated with acceptable small uncertainty compared with the length of the altimeter's range window. Fig.10 shows B_R sequences at Beijing calibration site. More than two years of B_R observations at Beijing shows that it is highly unpredictable. Therefore, only limited calibration at Beijing met a B_R with relative small bias. As Fig.10 shows, there are only 1 B_R observation in 26 B_R observations whose absolute value is less than 5 meters. There are only 11 B_R observations in 26 B_R observations whose absolute value are less than 60 meters, and $\pm 60m$ are the limits of the HY-2A altimeter's range window. Both the cause of the unpredictable behavior of B_R and effective approach for mitigating the uncertainty of B_R at Beijing site need further investigation.

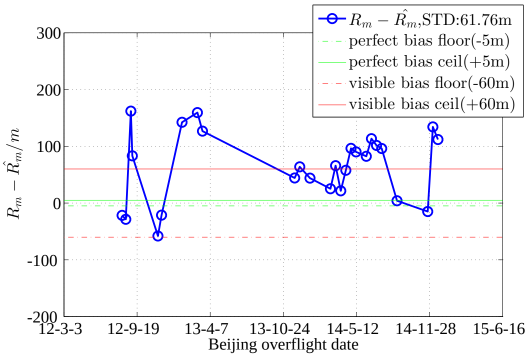


Fig. 10. orbit prediction bias at Beijing.

VI. CONCLUSION

The reconstructive transponder provides a novel approach to calibrate the in-orbit radar altimeter. However, significant uncertainty of orbit prediction and real-time signal processing mechanism of the reconstructive transponder limit the echo signal number in the HY-2A altimeter's range window. Reduction of orbit prediction uncertainty is a straightforward way to provide more echo signal samples. Improvement of signal processing mechanism for the reduction of time consuming before transmitting is also under development.

ACKNOWLEDGEMENT

This work is supported by 1) CNES AVISO for providing the Jason-1 and OSTM/Jason-2 GDR data, which were produced and distributed by Aviso (http://www.aviso.altimetry.fr/), as part of the Ssalto ground processing segment; 2) National Satellite Ocean Application Service (NSOAS) for providing assistance during experimental calibration, the HY-2A altimeter IGDR and auxiliary data.

REFERENCES

[1] J. Wan, W. Guo, C. Wang, and F. Zhao, "A matching method for establishing correspondence between satellite radar altimeter data and transponder data generated during calibration," *Geoscience and Remote Sensing Letters, IEEE*, vol. 11, no. 12, pp. 2145–2149, Dec 2014.

[2] J. Wan, W. Guo, F. Zhao, and C. Wang, "Hy-2a altimeter time tag bias estimation using reconstructive transponder," *Geoscience and Remote Sensing Letters, IEEE*, vol. 12, no. 7, pp. 1431–1435, July 2015.

[3] J. Wan, W. Guo, F. Zhao, C. Wang, and P. Liu, "Hy-2a radar altimeter ultrastable oscillator drift estimation using reconstructive transponder with its validation by multimission cross calibration," *Geoscience and Remote Sensing, IEEE Transactions on*, vol. 53, no. 9, pp. 5229–5236, Sept 2015.

[4] L. Bao, P. Gao, H. Peng, Y. Jia, C. Shum, M. Lin, and Q. Guo, "First accuracy assessment of the hy-2a altimeter sea surface height observations: Cross-calibration results," *Advances in Space Research*, vol. 55, no. 1, pp. 90 – 105, 2015.

[5] R. Powell, "Relative vertical positioning using ground-level transponders with the ERS-1 altimeter," *IEEE Trans. Geosci. Remote Sens.*, vol. GE-24, no. 3, pp. 421–425, May. 1986.

[6] P. Denys, A. Birks, P. Cross, J. Powell, and B. Brki, "Transponder altimetry: Precise height measurements over land," *Journal of Geophysical Research: Solid Earth*, vol. 100, no. B12, pp. 24 347–24 359, 1995.

[7] G. Haardeng-Pedersen, K. Keller, G. Tscherning, and N. Gundestrup, "Modeling the signature of a transponder in altimeter return data and determination of the reflection surface of the ice cap near the grip camp, greenland," *Journal of Glaciology*, vol. 44, no. 148, pp. 625–633, 1998.

[8] A.R.Birks and P. Pesec, "Transponder observations with ers-1 and ers-2," in *3rd ERS SYMPOSIUM*. Florence, Italy: ESA, 1997.

[9] M. B. Mathews, "Design, testing, and performance analysis of transponders for use with satellite altimeters." Ph.D. dissertation, Department of Aerospace Engineering Sciences, University of Colorado, Boulder, the USA, 1995.

[10] E. C. PAVLIS and S. P. MERTIKAS, "The gavdos mean sea level and altimeter calibration facility: Results for jason-1," *Marine Geodesy*, vol. 27, no. 3-4, pp. 631–655, Aug. 2004.

[11] W. Hausleitner, F. Moser, J.-D. Desjonqueres, F. Boy, N. Picot, J. Weingrill, S. Mertikas, and A. Daskalakis, "A new method of precise Jason-2 altimeter calibration using a microwave transponder," *Marine Geodesy*, vol. 35, no. sup1, pp. 337–362, Dec. 2012.

[12] E. Cristea and P. Moore, "Altimeter bias determination using two years of transponder observations," in *Proceedings of the Envisat symposium*, Apr. 2007, pp. 23–27.

[13] HAUSLEITNER, MOSER, DESJONQUERES, BOY, PICOT, WEINGRILL, MERTIKAS, and DASKALAKIS, "Precise jason-2 absolute altimeter calibration by means of a microwave transponder," in *Presentation at 2012 Ocean Surface Topography Science Team Venice Meeting*. Venice-Lido, Italy: OSTST 2012, 2012.

[14] M. Roca, M. Fornari, A. Garcia, P. N. Garcia, and M. Reche, "Cryosat-2 - siral fbr, stack & l1b calibration with transponder," in *Cryosat third user workshop abstract book*, Dresden, Germany, Mar. 2013, p. 3.

[15] C. R. Francis and G.Ratier, "Cryosat in-flight calibration approach," ESA, Noordwijk, The Netherlands, Tech. Rep. CS-TN-ESA-SY-0354, Jan. 2005.

[16] P. MacDoran and G. Born, "Time, frequency and space geodesy: impact on the study of climate and global change," *Proc. IEEE*, vol. 79, no. 7, pp. 1063–1069, Jul. 1991.

[17] J. Wan, "Study on hy-2 altimeter system delay in-orbit absolute calibration using reconstructive transponder," Ph.D. dissertation, the CAS Key Laboratory of Microwave Remote Sensing, National Space Science Center, Chinese Academy of Sciences, Beijing, China, 2015.

[18] J. Guo, Q. Zhao, X. Guo, X. Liu, J. Liu, and Q. Zhou, "Quality assessment of onboard gps receiver and its combination with doris and slr for haiyang 2a precise orbit determination," *Science China Earth Sciences*, vol. 58, no. 1, pp. 138–150, 2015.

[19] F. Gao, B. Peng, Y. Zhang, N. H. Evariste, J. Liu, X. Wang, M. Zhong, M. Lin, N. Wang, R. Chen, and H. Xu, "Analysis of {HY2A} precise orbit determination using {DORIS}," *Advances in Space Research*, vol. 55, no. 5, pp. 1394 – 1404, 2015.

[20] J. Dumont, V. Rosmorduc, N. Picot, S. Desai, H. Bonekamp, J. Figa, J. Lillibridge, and R. Scharroo, *OSTM/Jason-2 products handbook*, CNES, France, and EUMETSAT, Europe and JPL, USA and NOAA/NESDIS, USA, 2011.

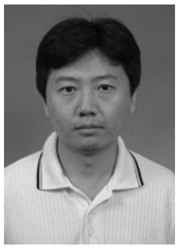
[21] E. Bronner, A. Guillot, N. Picot, and J. Noubel, "Saral/altika products handbook," CNES, France and ISRO, India, 2013.

[22] C. Jayles, J. Chauveau, and F. Rozo, "Doris/jason-2: Better than 10cm on-board orbits available for near-real-time altimetry," *Advances in Space Research*, vol. 46, no. 12, pp. 1497 – 1512, 2010, dORIS: Precise Orbit Determination and Applications to Earth Sciences.

[23] J. D. Desjonqures, G. Carayon, N. Steunou, and J. Lambin, "Poseidon-3 radar altimeter: New modes and in-flight performances," *Marine Geodesy*, vol. 33, no. sup1, pp. 53–79, 2010.

[24] C. Jayles, J.-P. Chauveau, and A. Auriol, "Doris/diode: Real-time orbit determination performance on board saral/altika," *Marine Geodesy*, vol. 38, no. sup1, pp. 233–248, 2015. [Online]. Available: http://dx.doi.org/10.1080/01490419.2015.1015695

Wan Junzhi received the B.Eng. degree from Huazhong University of Science and Technology, Wuhan, China, in 2010, and the Ph.D. degree in Electromagnetic Filed and Microwave Technology from National Space Science Center, Chinese Academy of Sciences, Beijing, China, in 2015. His research interests include data processing and calibration method for microwave remote sensor.



Guo Wei received the B.Eng. degree in electrical engineering from Xian Jiaotong University, Xian, China, in 1989, the M.S. degree in geographic information system from Changchun Institute of Geography, Chinese Academy of Sciences (CAS), Jilin, China, in 1994, and the Ph.D. degree in electrical engineering from Institute of Electronics, Chinese Academy of Sciences(CAS), in 1999. He did postdoctoral work in sea surface returned signal simulator (RSS) development for radar altimeter calibration at the Center for Space Science and Applied Research (CSSAR), CAS, from 1999 to 2001. He became interested in calibration for HY- 2 satellite altimeter using reconstructive transponder in 2010. His research interests include the microwave remote sensor development and calibration

Zhao Fei received the B.Eng. degree in electrical engineering from Jilin University, Changchun, China, in 2008, and the M.S. degree in Electromagnetic Filed and Microwave Technology from University of Chinese Academy of Sciences, Beijing, China, in 2011. He is currently working in Key Laboratory of Microwave Remote Sensing, Chinese Academy of Sciences. His research interests include development of calibration equipment and calibration algorithm for microwave remote sensor.

Wang Caiyun received the B.Eng. and M.Eng. degrees in communication and information engineering from Xidian University, Xian, China, in 1997 and 2001, respectively. She is an associate professor of the Nation Space Science Center, Chinese Academy of Sciences. Her current research interests include calibration and validation of satellite-borne altimeter, calibration of synthesized aperture radar.

Lin Mingsen received the Doctor in Mathematics from Computing Center, Chinese Academy of Sciences(CAS), Beijing, China, in 1992. He is a Professor with the National Satellite Ocean Application Center, Beijing, China. His research interests include microwave remote sensing of ocean wind.

Peng Hailong works at the National satellite ocean application service. He is a Ph.d Candidate in ocean geography of Ocean University of China, Qingdao, China. He is currently conducting his research at the Radar altimeter calibration and validation.

Xu Chuan received the B.Eng. degree in electrical engineering from Jilin University, Changchun, China, in 2002. He works at the Key Laboratory-for Fault Diagnosis and Maintenance of Spacecraft in Orbit, China Xian Satellite Control Center. His research interests include fault diagnosis and repair, reliability growth, and longevity.

Liu Peng received the Masters degree in Electromagnetic Filed and Microwave Technology from the University of Chinese Academy of Sciences, Beijing, China, in 2009. He is pursuing the Ph.D. degree in the electronic engineering, University of Chinese Academy of Sciences. He is currently an Assistant Professor with the Department of Electronic Engineering, National Space Science Center, Chinese Academy of Sciences. His research interests include high speed digital signal processing and radar altimeter.