Improved Calibration Method for System Phase Bias of Chungli VHF Radar

Ting-Han Lin,[1] *Yen-Hsyang Chu,*[1] *Chien-Lung Su,*[1] *Chien-Ya Wang,*[2] *Kuo-Feng Yan*[3]

[1] Institute of Space Science, National Central University, Taoyuan, Taiwan
[2] Department of Physics, Chinese Culture University, Taipei, Taiwan
[3] Chung-Shan Institute of Science and Technology, Taoyuan, Taiwan
E-mail: 996403009@cc.ncu.edu.tw

Abstract

In the past decade, the radar interferometry technique has been the primary method we used at Chungli VHF radar to identify and locate irregularities. In the interferometry method, the real phase difference of echoes was the most important experimental result we sought. However, the phase difference would be changed in transmission through cables and be affected by weather, temperature or humidity changing. Therefore, the received phase difference would not be the true phase difference.

For the sake of finding true phase difference of signals, the method of expected echoing region has been introduced for estimating initial system phase bias. This method utilizes the field-aligned properties of sporadic E irregularities to calculate the reasonable region we expect to observe irregularities inside. By comparing the expected echoing region and received echoes in phase plane, the initial system phase bias could be easily determined via a manual operation. In 2015, the initial system phase biases had been calculated, the phase bias between array C and B in Chungli VHF radar is about 8 degrees and 15 degrees between array B and A.

In order to locate Es irregularities more accurately, we have improved the aforementioned method in this study. In the new method, automatic algorithm is being substituted for manual operation, and the initial system phase bias could be automatically obtained without any artificial error.

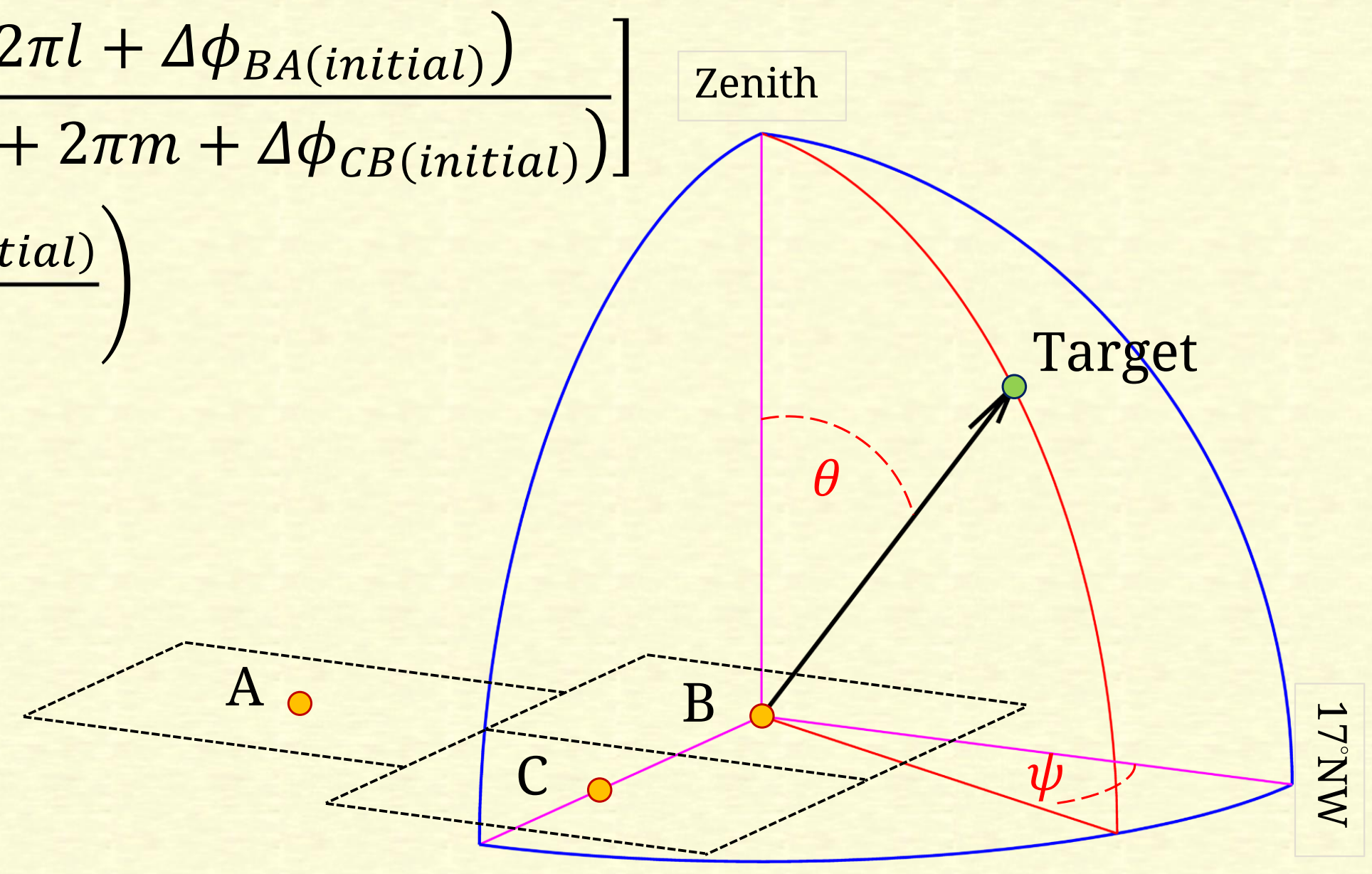
Introduction

The echo power, Doppler spectral width, and mean Doppler velocity of radar returns from field-aligned irregularities (FAI) in sporadic E (Es) region have long been topics of interest to the researchers in the community of the ionospheric irregularities. And the location of irregularities is also the important characteristic interest researchers. As we know, the 52 MHz Chungli VHF Radar (24.9°N, 121°E) is a powerful coherent scatter radar for observing mid-latitude Es irregularities. With the interferometry technique implemented at Chungli VHF radar, the location of irregularities can be easily calculated via interferometry equations below:

$$\psi = \cot^{-1}\left[\tan\beta + \frac{d_{BC}\left(\Delta\phi_{BA} + 2\pi l + \Delta\phi_{BA(initial)}\right)}{d_{BA}\cos\beta\left(\Delta\phi_{CB} + 2\pi m + \Delta\phi_{CB(initial)}\right)}\right]$$

$$\theta = \cos^{-1}\left(\frac{\Delta\phi_{CB} + 2\pi m + \Delta\phi_{CB(initial)}}{kd_{BC}\sin\psi}\right)$$

$$dx = r\cos\theta\sin\psi$$
$$dy = r\cos\theta\cos\psi$$
$$dz = (r^2 + R_e^2 + 2rR_e\sin\theta)^{1/2} - R_e$$



In these equations, the initial system phase biases $\Delta\psi_{BA(initial)}$ and $\Delta\psi_{CB(initial)}$ are necessary to calculate the true location of Es irregularities. [Chu and Wang, 1997] provide a method for estimating initial system phase bias. This method utilizes the International Geomagnetic Reference Field (IGRF) model and field-aligned properties of Es irregularities to calculate the reasonable region we expect to observe irregularities inside. The only one thing we need to do is make a perfect match between the expected echoing region and radar returns in phase plane, and the manual shift of radar returns can be regarded as the initial system phase biases. A question raised, can we obtain the initial system phase automatically?

Improved Calibration Method

At first, a group of Es layer irregularity echoes (red points) with random distribution in space and its projections (black points) have been simulated as shown in Fig. 1. The uniform distribution is applied in the group of echoes in horizontal plane, and a normal distribution with mean of 105 km and standard deviation of 10 km is applied in vertical plane. Second, according to the calculation with IGRF model, the echoes (blue points) which satisfy the field-aligned property can be filtered out.

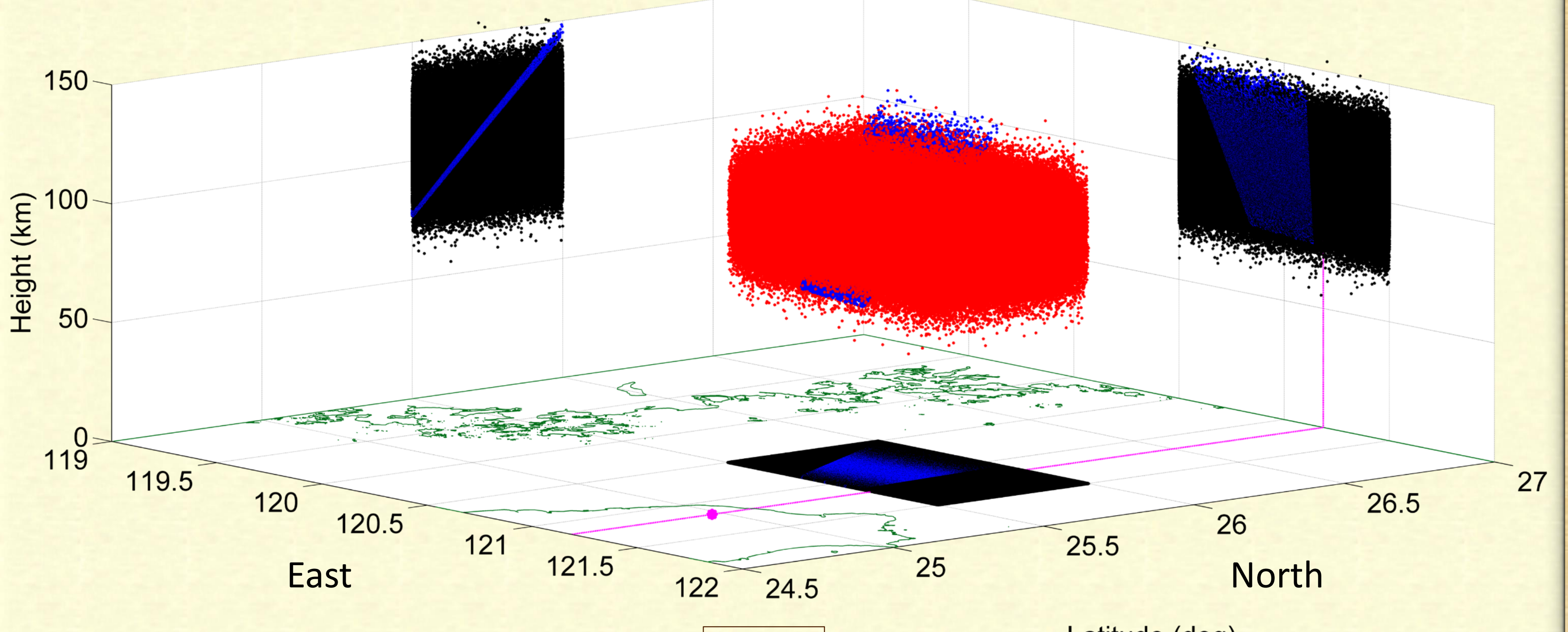


Fig. 1

Third, the locations of echo (blue points) which satisfy the field-aligned property can be converted to the phase differences via equations below:

$$\Delta\phi_{CB} = -kd_{CB}[\cos\theta\sin\psi\sin\theta_1 + \cos\theta\cos\psi\cos\theta_1]$$
$$\Delta\phi_{BA} = -kd_{BA}[\cos\theta\sin\psi\sin(\theta_1+\theta_2) + \cos\theta\cos\psi\cos(\theta_1+\theta_2)]$$

Where the $\Delta\phi_{BA}$ and $\Delta\phi_{CB}$ are phase differences of simulated echo, θ_1 is the angle between geography north and $\overrightarrow{BC}$, θ_2 is the angle between $\overrightarrow{BA}$ and $\overrightarrow{BC}$.

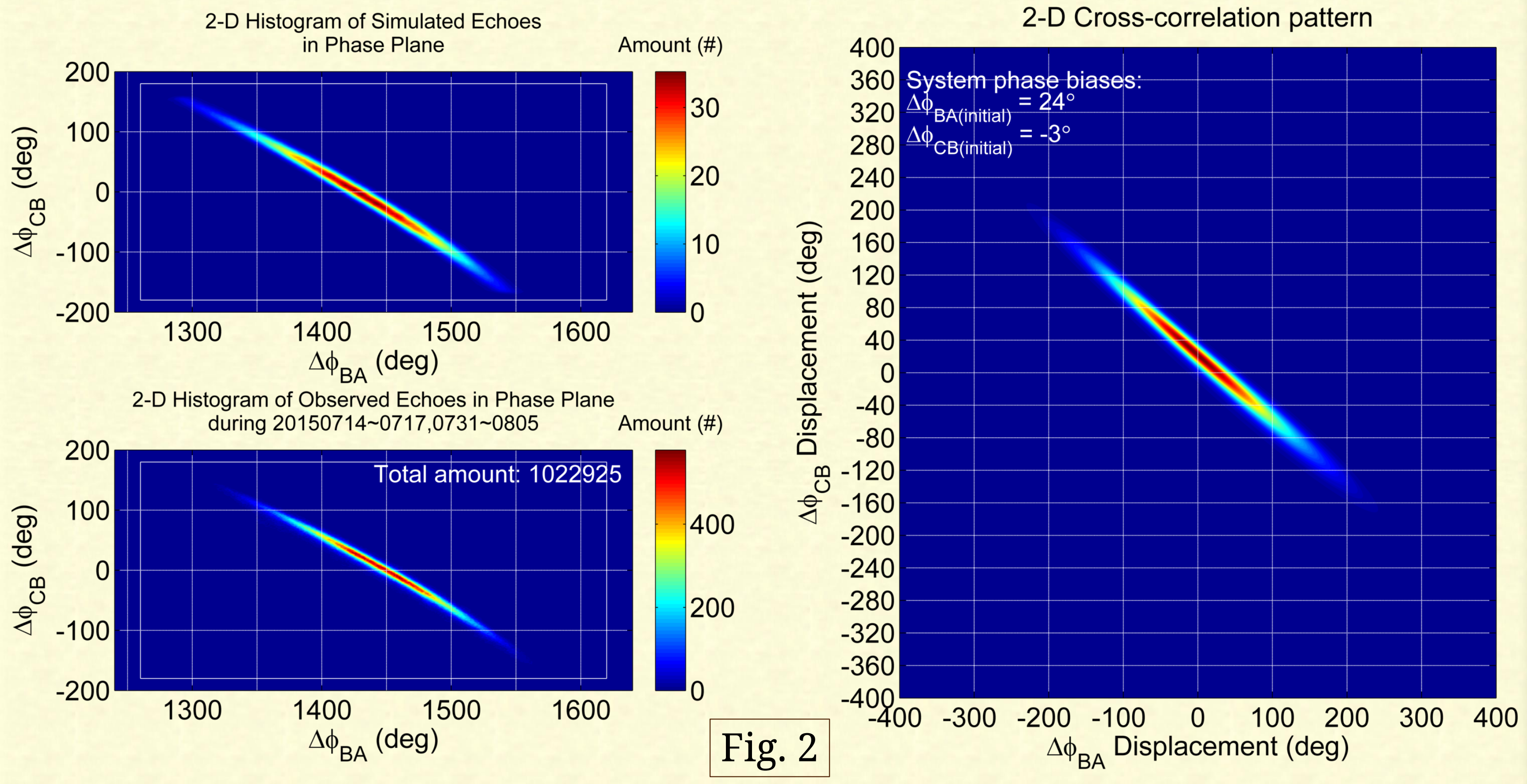


Fig. 2

Finally, the phase differences of simulated field-aligned echoes has been shown as a contour plot on top left panel of Fig. 2, the radar returns is also shown on bottom left panel of Fig. 2. In this step, we need to find the offset (so-called initial system phase biases) between these two contour patterns, so the 2-D cross-correlation method has been used here. The right panel of Fig. 2 shows 2-D cross-correlation pattern calculated from left two contours, it's easy to understand that the offset of location of peak value of 2-D cross-correlation pattern from origin can indicate the offset between two source contours. In this case, the initial system phase biases are $\Delta\psi_{BA(initial)} = +24°$ and $\Delta\psi_{CB(initial)} = -3°$.

Discussion

As mentioned above, the 2-D cross-correlation method can be used to estimate initial system phase biases automatically without artificial error, but it's not the only advantage of this method. In fact, the peak value of 2-D cross-correlation pattern represents how similar between two source patterns, this property could be used to adjust the radar returns pattern to meet the pattern of simulated field-aligned echoes. Moreover, if the shape of both patterns totally match, the peak value of 2-D cross-correlation pattern will approach the maximum value. In order to make a perfect match between two source patterns, the correction $\Delta\beta$ has been introduced here and the equations we mentioned before are modified as below:

$$\Delta\phi_{CB} = -kd_{CB}[\cos\theta\sin\psi\sin\theta_1 + \cos\theta\cos\psi\cos\theta_1]$$
$$\Delta\phi_{BA} = -kd_{BA}[\cos\theta\sin\psi\sin(\theta_1+\theta_2-\Delta\beta) + \cos\theta\cos\psi\cos(\theta_1+\theta_2-\Delta\beta)]$$

As shown in bottom panel of Fig. 3, the peak value of 2-D cross-correlation pattern as a function of $\Delta\beta$ and the maximum value occurs at $\Delta\beta = 1.4$. The top panel of Fig. 3 also shows the whole trend of initial system phase biases as a function of $\Delta\beta$. Obviously, the radar returns pattern totally meets the pattern of simulated field-aligned echoes when $\Delta\beta = 1.4$ and the corresponding initial system phase biases are $\Delta\psi_{BA(initial)} = +15°$ and $\Delta\psi_{CB(initial)} = +8°$.

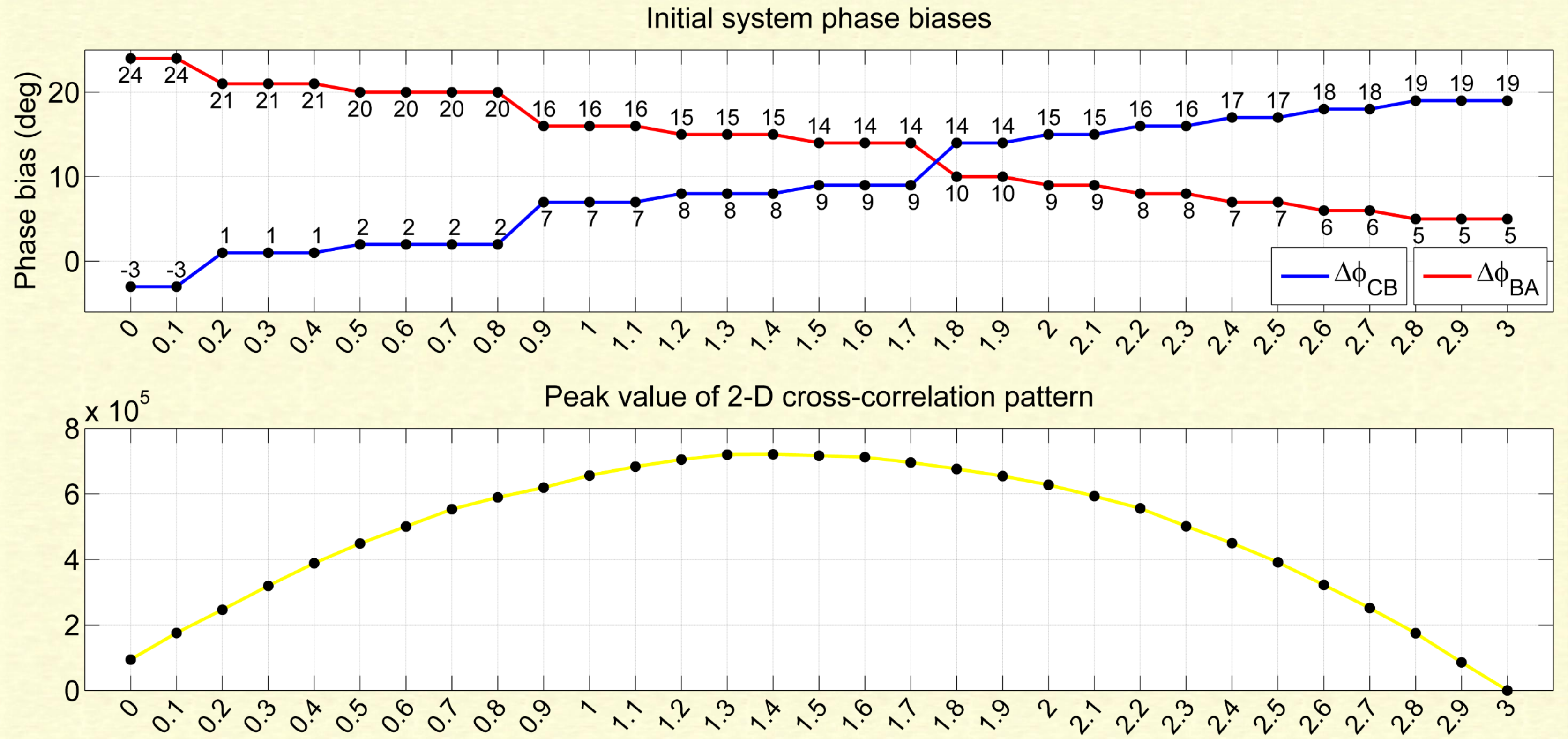


Fig. 3

Summary and future works

- Automatic algorithm has been substituted for manual operation, and the initial system phase bias could be automatically obtained.
- The correction $\Delta\beta$ could be used to match the shape of simulated field-aligned echoes to observation data.
- In the future, a easily detectable multirotor with GPS tracker will be employed to acquire the phase of echoes. By comparing the temporal variation of both radar returns and GPS locations of multirotor, the true initial system phase bias could be calculated.

References

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