OVWST2010, May 18-20, 2010
Barcelona, Spain

Design and Performance Simulation of a Ku-Band Rotating Fan-Beam Scatterometer

Xiaolong DONG, Wenming LIN, Di ZHU

Center for Space Science and Applied Research,
Chinese Academy of Sciences
(CSSAR/CAS)

PO Box 8701, Beijing, 100190, China
Tel: +86-10-62582841, Fax: +86-10-62528127
Emails: dxl@nmrs.ac.cn, xldong@ieee.org

Outline of the presentation

- Mission background
- Requirement for the scatterometer
- Design of key system parameters
- Simulation of system performances
- Summary

Mission background - Objectives & Payloads

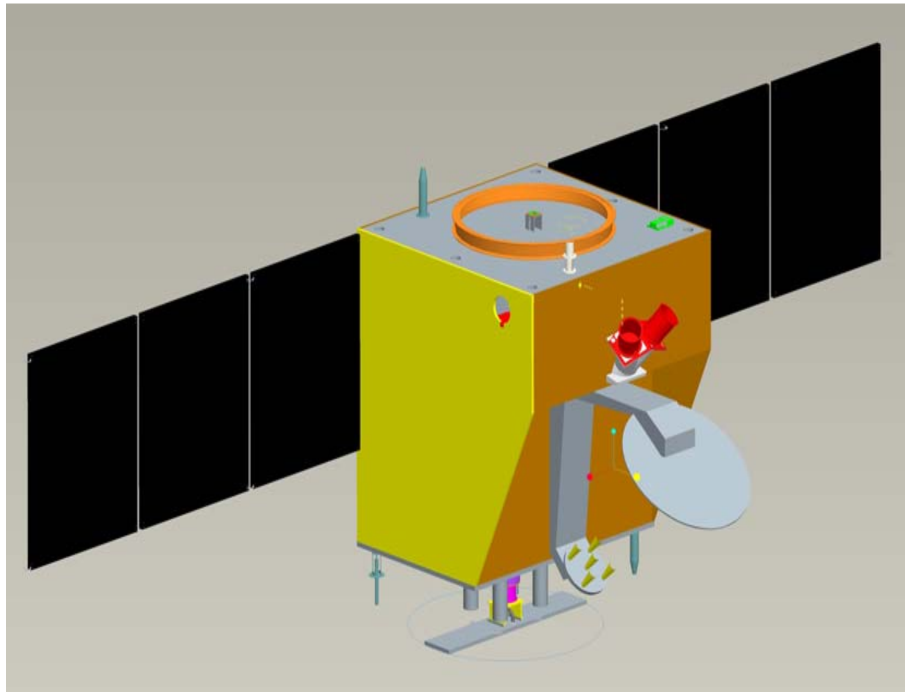
- Mission Objectives:

  monitoring the wind and waves at the ocean surface at the global scale in order to improve:
  - The wind and wave forecast for marine meteorology (including severe events)
  - the ocean dynamics modeling and prediction,
  - our knowledge of climate variability
  - fundamental knowledge on surface processes linked to wind and waves

- Payloads:
  - SWIM (Sea Wave Investigation and Monitoring by satellite)
    - A Ku-band real aperture radar for measurement of directional ocean wave spectra;
  - SCAT (SCATterometer)
    - A Ku-band rotating fan-beam radar scatterometer for measurement of ocean surface wind vector.

Mission background
–platform, orbit and schedule at satellite level

- Platform
  - Small sat less than 1000kg
- Orbit
  - ~500km
  - Sun synchronous polar orbit
  - Local descending time: 7:00am
- Ground station
  - 3 or 4 stations in China
  - 2 stations in arctic area
- Preliminary schedule
  - 2009.05 Mission definition
  - 2010.05 System design
  - 2011.12 Engineering model
  - 2013.06 Flight model
  - 1st half, 2014 Launch



Reqirments for the scatterometer

- Objectives:
  - Measurement of global σ°
  - Retrieval of global ocean surface wind vector
- Data requirements
  - Swath width: >1000km
  - Surface resolution: 50km (standard); 25km (goal)
  - Data quality (at 50km resolution)
  - σ° precision:
    - 1.0dB for wind speed 4~6m/s
    - 0.5dB for wind speed 6~24m/s
  - Wind speed: 2m/s or 10% @ 4~25m/s
  - Wind direction: 20deg @ 360deg for most part of the swath
- Life time: 3yrs

Center for Space Science
and Applied Research
Chinese Academy of Sciences

Design of key system parameters

- Key design principles
- Choice of system type
- System configuration
- Key system parameters
- Design of antenna

Key design principles

- Ku-band rotating fan-beam scatterometer
  - Platform dimension, available GMFs
- Long LMF pulse with de-ramp pulse compression
- Digital I-Q receiver with on-board pulse compression processing and resolution cell regrouping
- TX/RX channel except antenna and switch matrix identical primary/backup design to ensure liability

Choice of system type
-Why rotating fan beam?

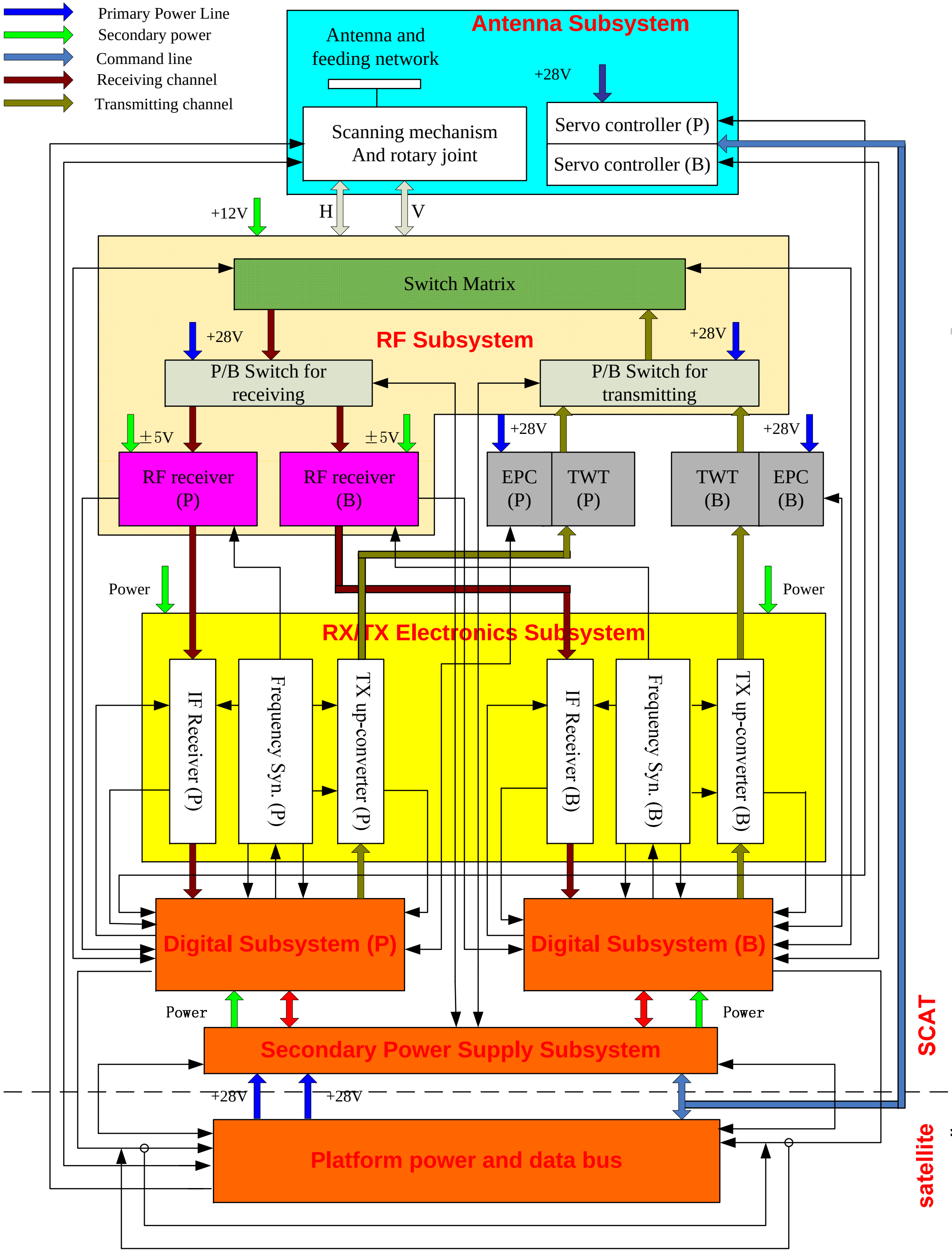
- Why rotating beam?
  - Overlap of surface coverage with SWIM is requirement, nadir gap should be avoided.
  - Deployment of multiple fan-beam antenna is not allowed due to platform capability.
  - Large swath at a relatively low orbit (~500km) requires scanning.
- Why rotating fan beam?
  - Lower rotating speed to ensure life time of rotating mechanism;
  - Multiple incident angles for better wind direction retrieval;
  - Large incident angle ranges (20~46°) for research of ocean surface scattering characteristics, by compensating with SWIM (0~10°)

System configuration

- Antenna subsystem
  - Antenna and feeding network;
  - Scanning mechanism;
  - Servo controller;
- RF subsystem
  - Switch matrix;
  - RF receiver;
- RX/TX electronics subsystem
  - IF receiver;
  - Frequency synthesizer;
  - TX up-converter
- Power amplifier subsystem
  - TWT and EPC
- Digital subsystem
  - Signal generator;
  - System controller;
  - DSP module;
  - Data communication controller;
- Secondary power supply subsystem
  - DC-DC power converter;
  - TC/TM module
- WG & cable assembly

Center for Space Science
and Applied Research
Chinese Academy of Sciences

System Diagram



Key system parameters

- Basic radar parameters
- Optimization of radar parameters
- Antenna parameters

Basic radar parameters

Parameter	Specifications
Frequency	13.256GHz
Signal bandwidth	0.5MHz
Internal calibration precision	Better than 0.15dB
Receiver NF	⩽2.0dB
Insertion loss of TX channel	⩽1.5dB
Insertion loss of RX channel	⩽3.0dB
Transmitting power (peak)	120W
Pulse width	1.35ms
PRF	2×75=150Hz

Optimization of radar parameters

- Optimization:

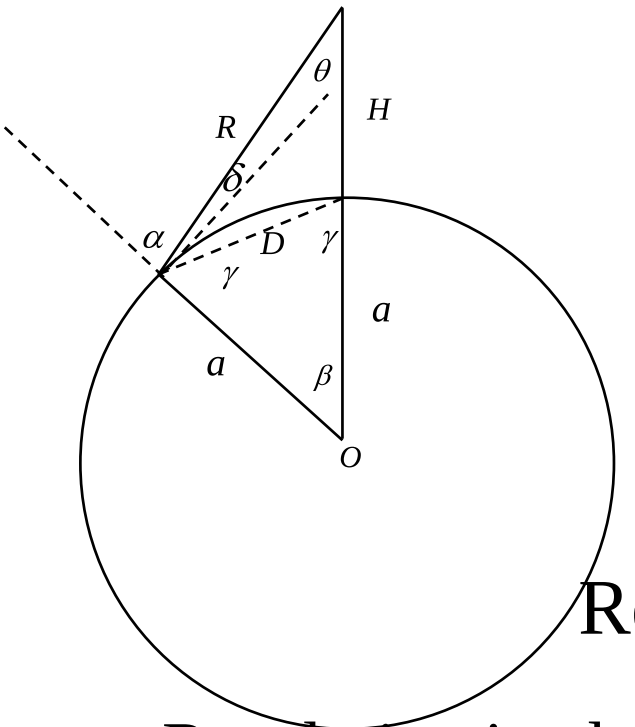
  trade-off between SNR and measurement samples and number of looks.

  maximization of wind vector retrieval performance

  - Surface resolution
  - Signal bandwidth
  - Rotating speed

Center for Space Science
and Applied Research
Chinese Academy of Sciences

Observation geometrical relationship



$$\alpha = \sin^{-1}\left[\left(1+\frac{H}{a}\right)\sin\theta\right] \qquad R = a\cdot\frac{\sin(\alpha-\theta)}{\sin\theta}$$

Half swathwidth: $D = a\sin\left(\alpha_1 - \theta_1\right)$

Resolution in azimuth direction: $\Delta D_a = R\cdot\Delta\theta_a$

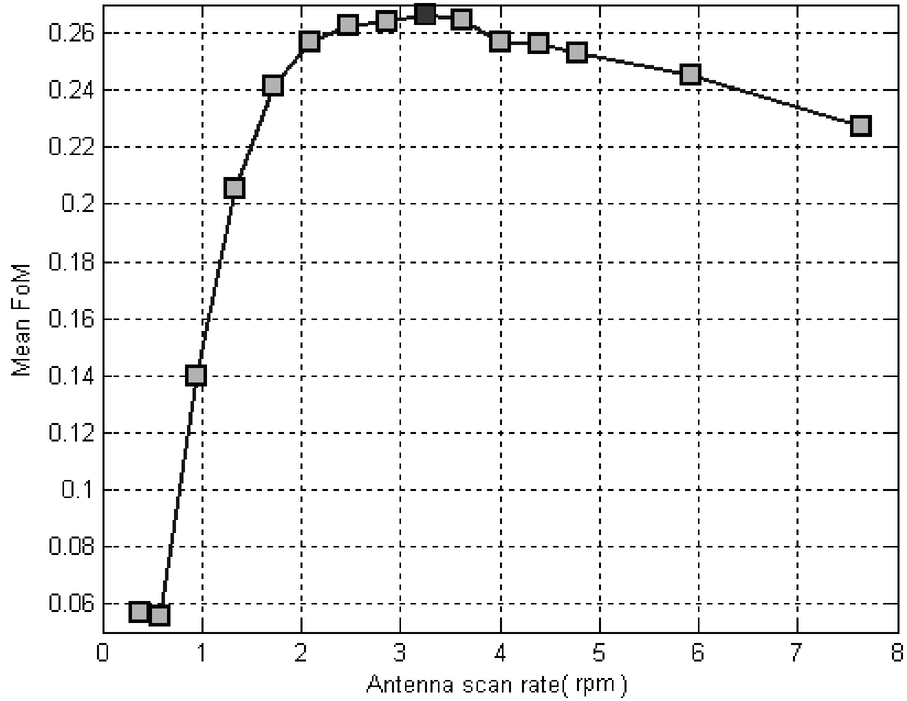
Resolution in elevation direction: $\Delta D_e = \dfrac{\Delta R}{\sin\alpha} = \dfrac{c\tau}{2\sin\alpha} = \dfrac{c}{2B\sin\alpha}$

Resolution in azimuth direction & azimuth beam-width

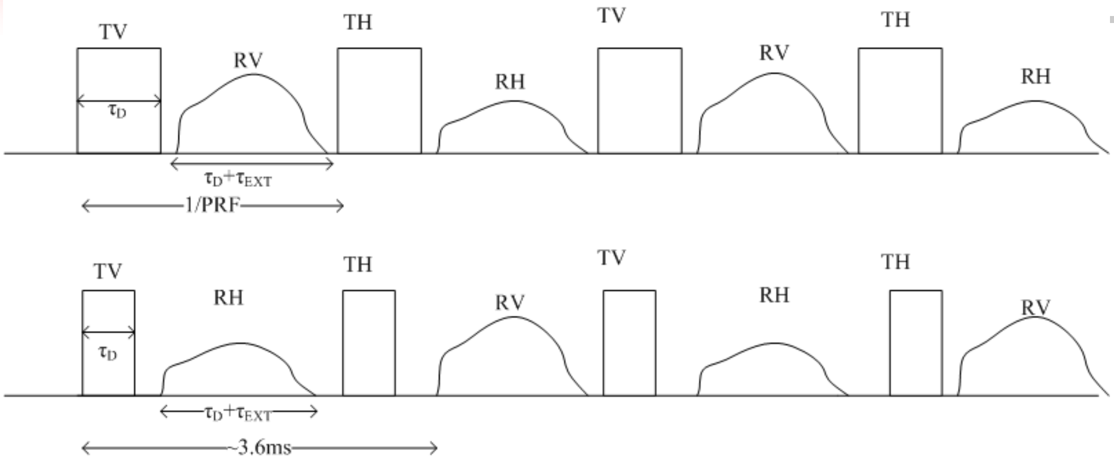
- Fan beam➔lower gain➔antenna as long as possible
- Decided by antenna beamwidth
- Limited by satellite dimension: ⩽1.2m
- Beamwidth ~1.1 deg➔ resolution in azimuth direction: 10.5~14.5km

Design of rotating speed

- Trade-off between independent σ° measuremrent samples for single look and number of looks
- Optimization of 3.4rpm



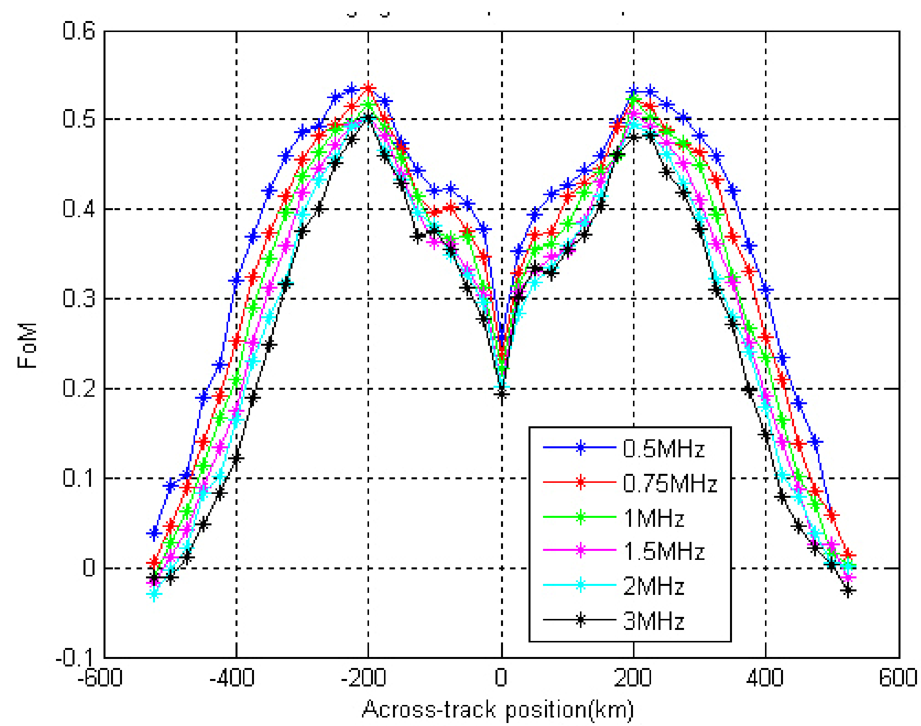
Optimization of PRF and pulse width by observation geometry



	PRF（Hz）	Pulse width（ms）	Duty ratio
Optimal result	**55×2=110**	**3.0**	**33.00%**
Best available TWTA	**75×2=150**	**1.35**	**20.25%**

Resolution in elevation direction & signal bandwidth

- Low SNR due to low antenna gain
- Bandwidth 0.5MHz➔
  resolution:380~650m
- On-board non-coherent re-grouping to improve σ° precision
  ➔resolution of 5km



Swath width and incident angle

- 1000km➔θ~44°
- 50km margin➔θ~46°
- σ° vs incident angle

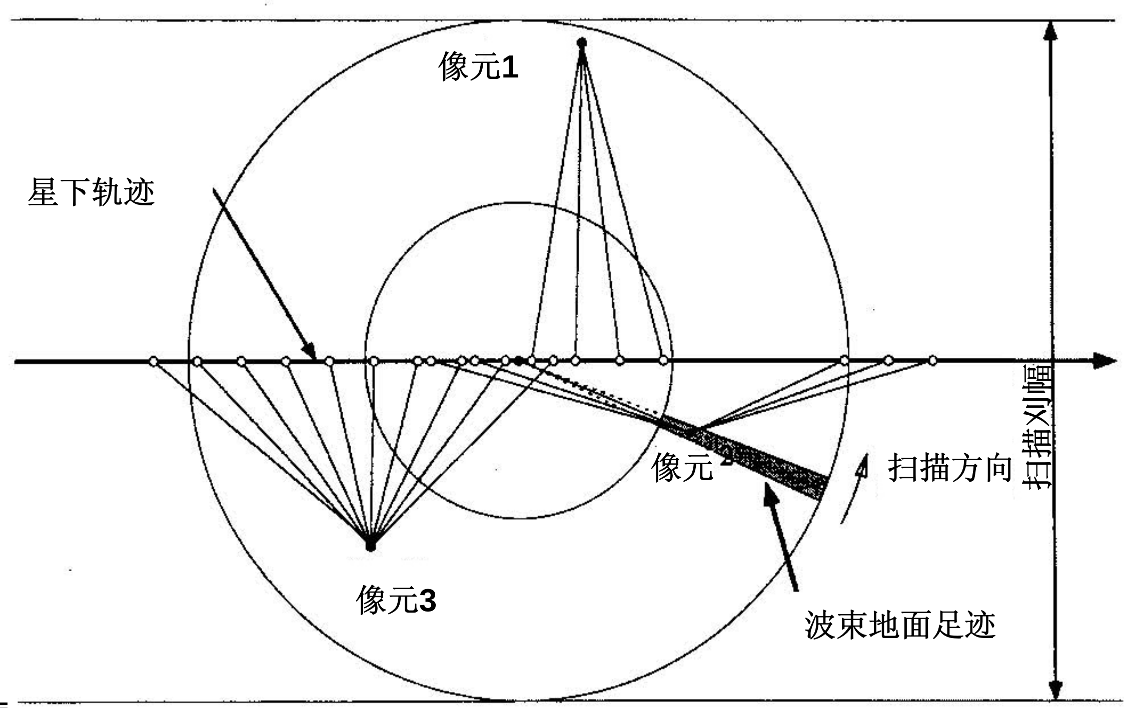
Bragg scattering：θ=20～70°

θ↑ ➔R↑ σ° ↓

➔SNR ↓

$\Delta\theta_e$↓

➔smaller incident angle

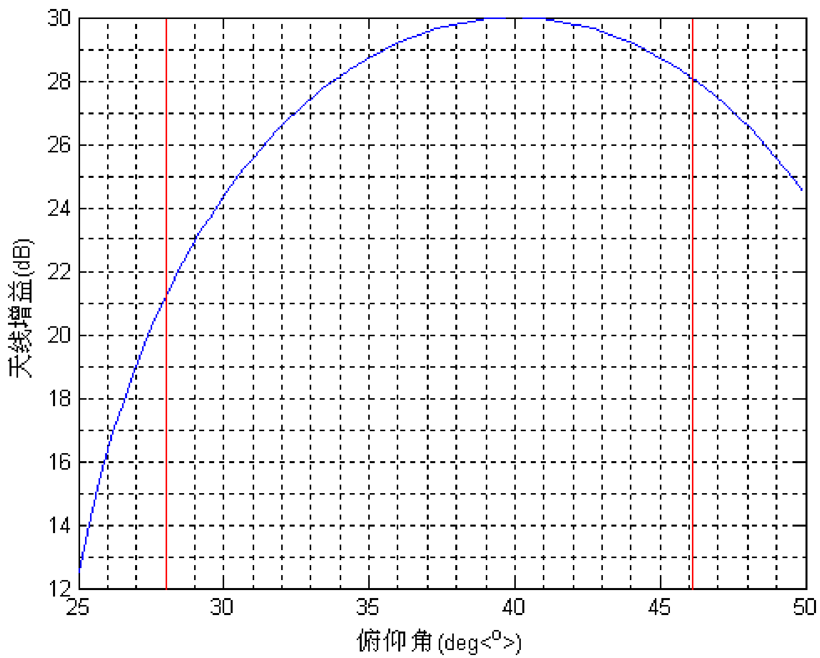


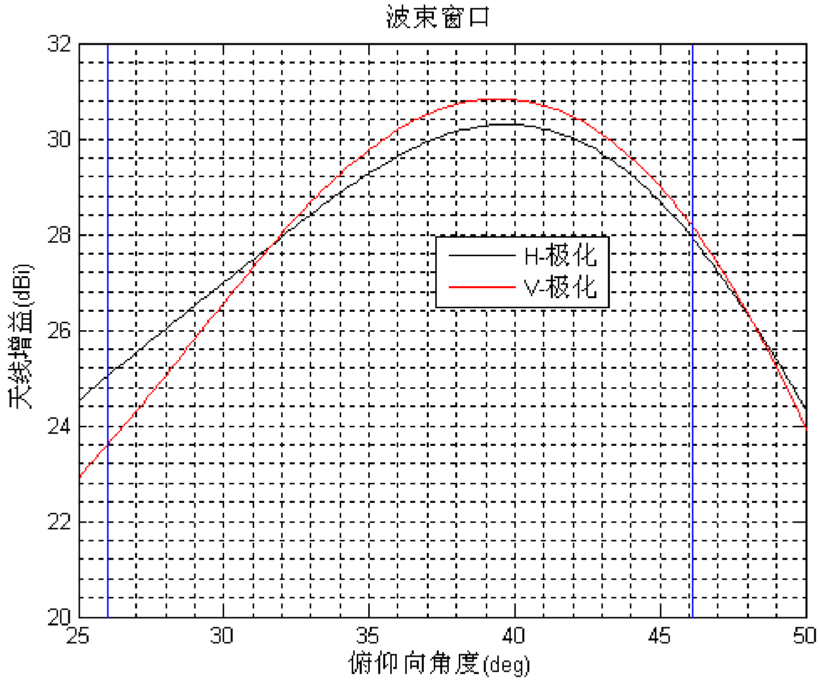
Center for Space Science
and Applied Research
Chinese Academy of Sciences

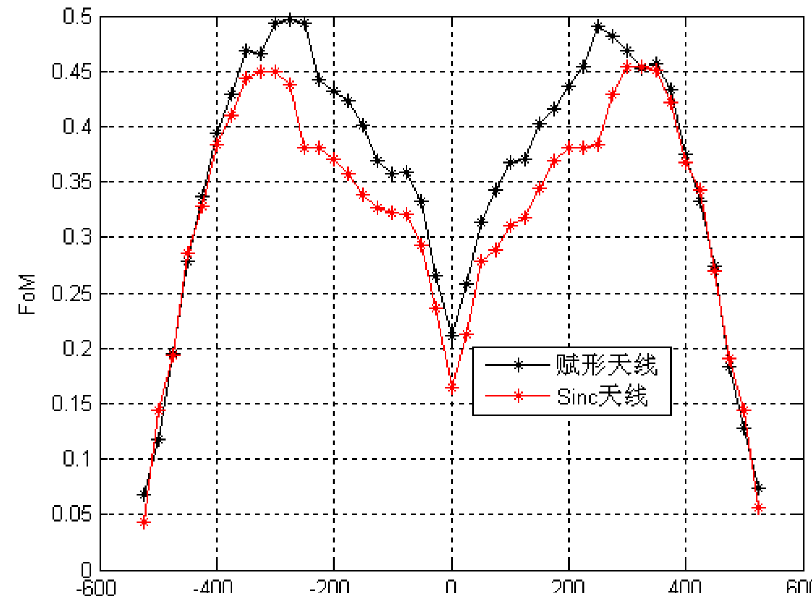
Optimization of antenna

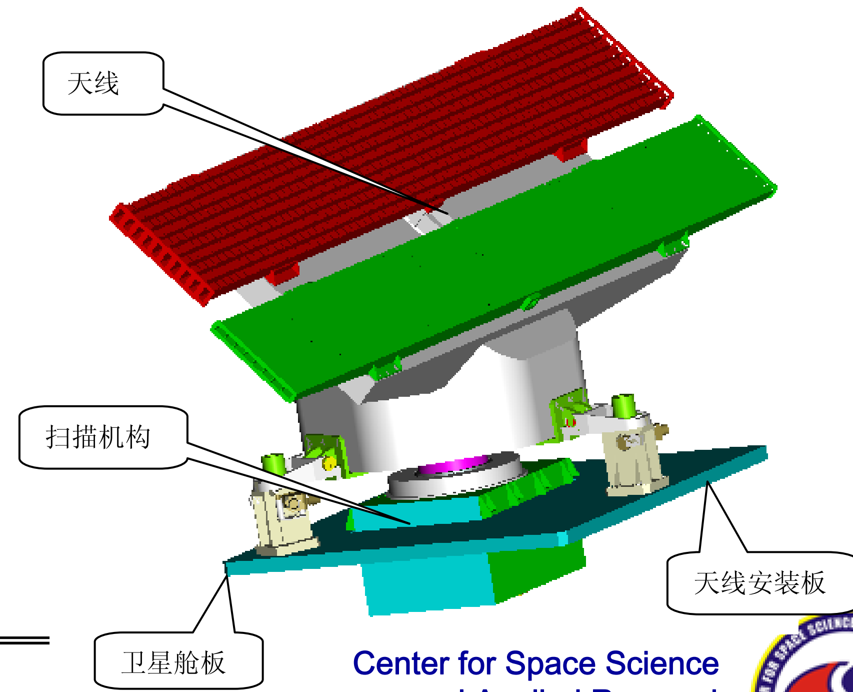
Symmetrical sinc beam pattern	Non symmetrical beam pattern
Azimuth BW (-3dB): ⩽1.1° Elevation BW (-3dB): ⩾15° Peak alignment: 40° off nadir	Azimuth BW (-3dB): ⩽1.1° (symmetrical) Elevation beam pattern: Near end gain: ⩾25dB@26° Far end gain: ⩾28dB@46°
Peak gain: ⩾30dB@40°	Peak gain: ⩾30dB@40°
Gain for 1000km swath outer boundary: ⩾29dB@44°	

Center for Space Science
and Applied Research
Chinese Academy of Sciences









Center for Space Science
and Applied Research
Chinese Academy of Sciences

Simulations of system performances

- Simulation of σ° precision
- Simulation of wind vector retrieval performance

Center for Space Science
and Applied Research
Chinese Academy of Sciences

Simulation of σ° precision

- Modeling
  - Radar equation
  - SNR
  - σ° precision

$$P_r = P_t \frac{\lambda^2}{(4\pi)^3 L} \iint_A \frac{G^2 \sigma^\circ}{R^4} dA$$

where:

$$P_t = 120W = 50.8dBm$$

$$\lambda = 2.263cm = -16.5dB$$

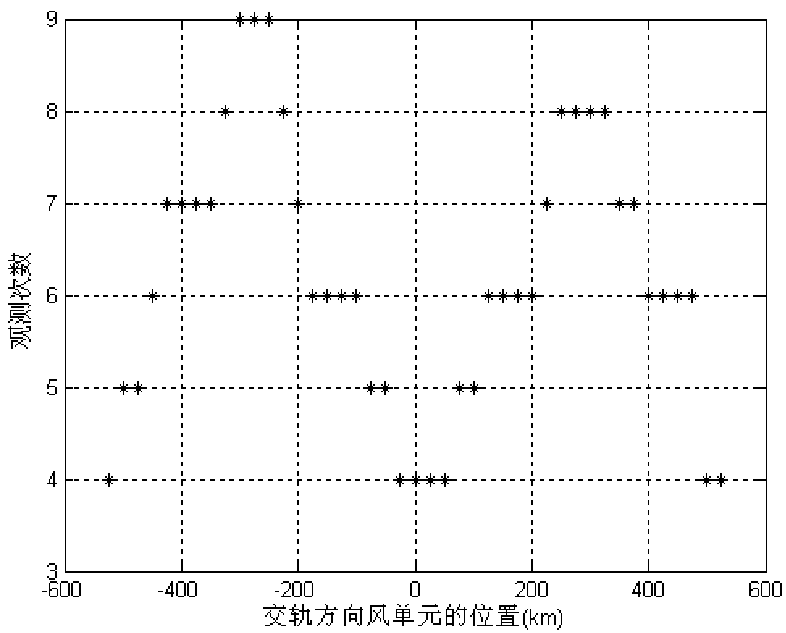
$$L = 3.5dB \quad \text{(insturment loss)}$$

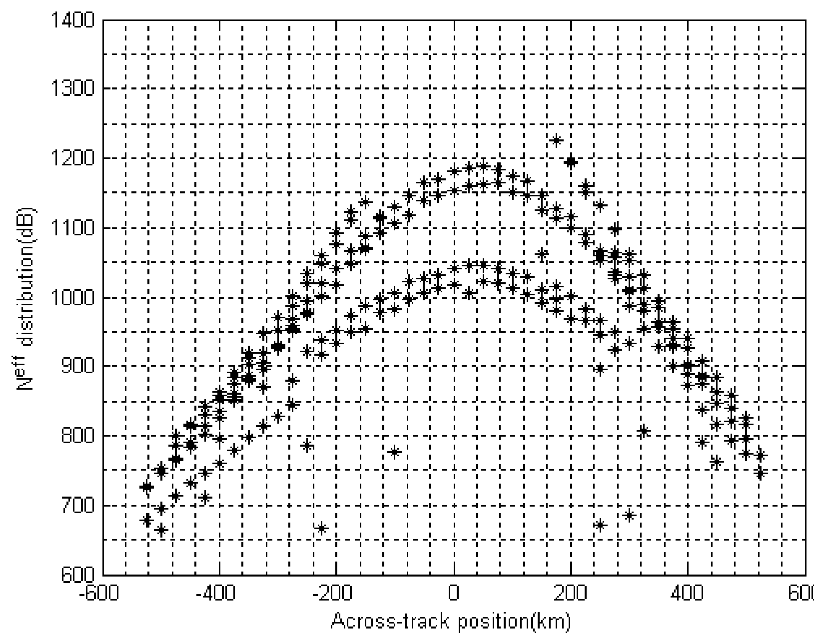
$$SNR = SNR' \cdot \sigma^\circ = \frac{\Pr}{N} = \frac{1}{kBT} \cdot P_t \frac{\lambda^2}{(4\pi)^3 L} \iint_A \frac{G^2 \sigma^\circ}{R^4} dA$$

$$Kp = \frac{\delta P}{P} = \frac{\delta \sigma^\circ_{true}}{\sigma^\circ_{true}} = \sqrt{\frac{1}{N_{eff}}\left(1 + \frac{1}{SNR' \cdot \sigma^\circ_{true}}\right)^2 + \frac{1}{N_{noise}}\left(1 + \frac{1}{SNR' \cdot \sigma^\circ_{true}}\right)^2}$$

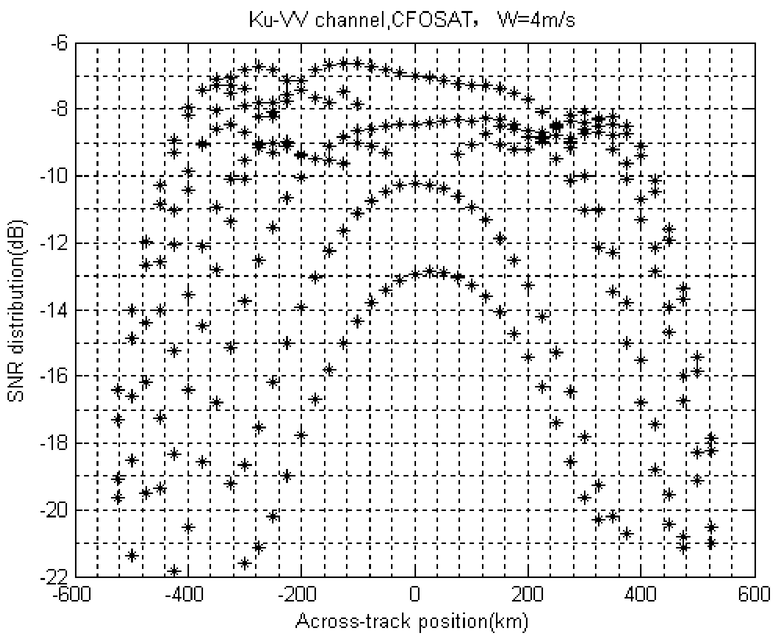
$$Kp(dB) = 10\log(1 + Kp)$$

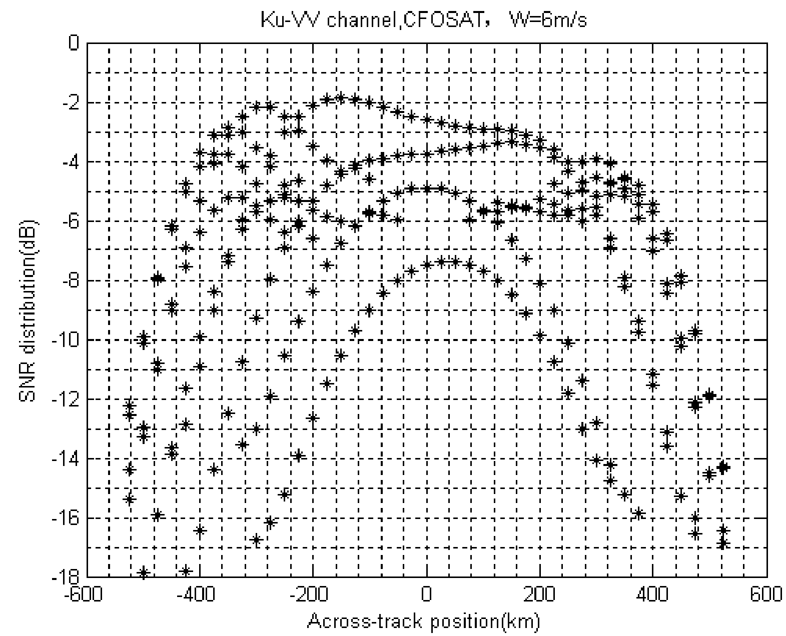
Number of looks and number of independent samples

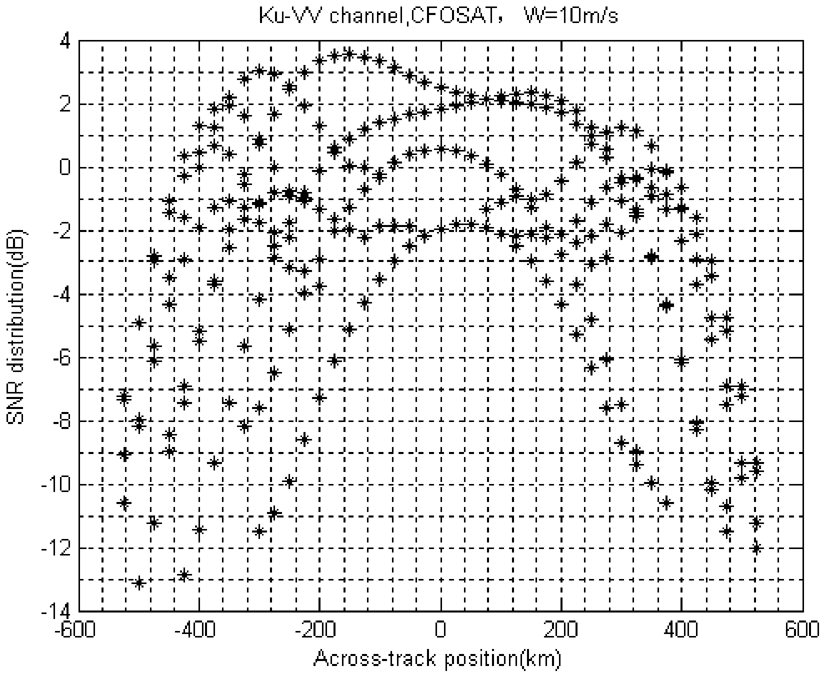


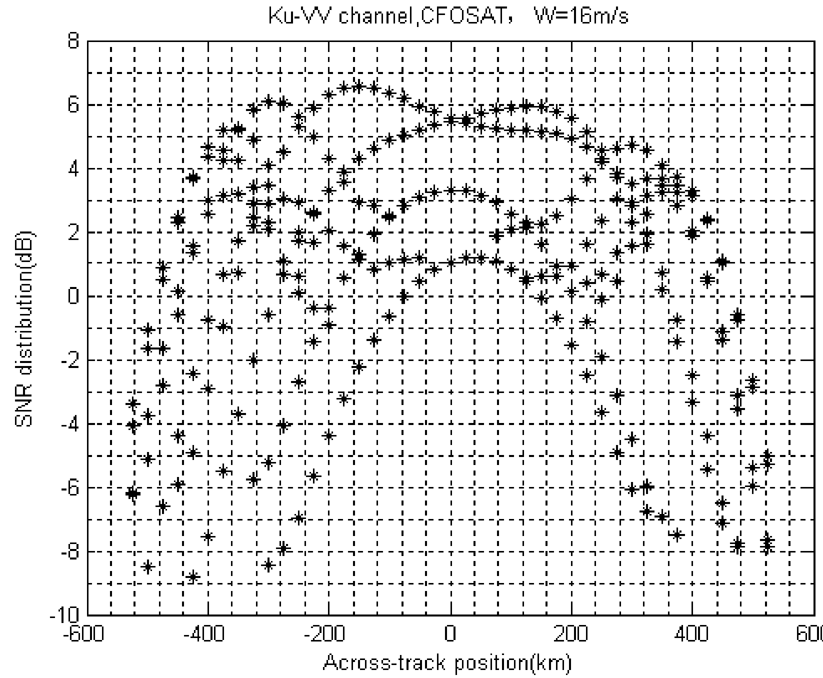


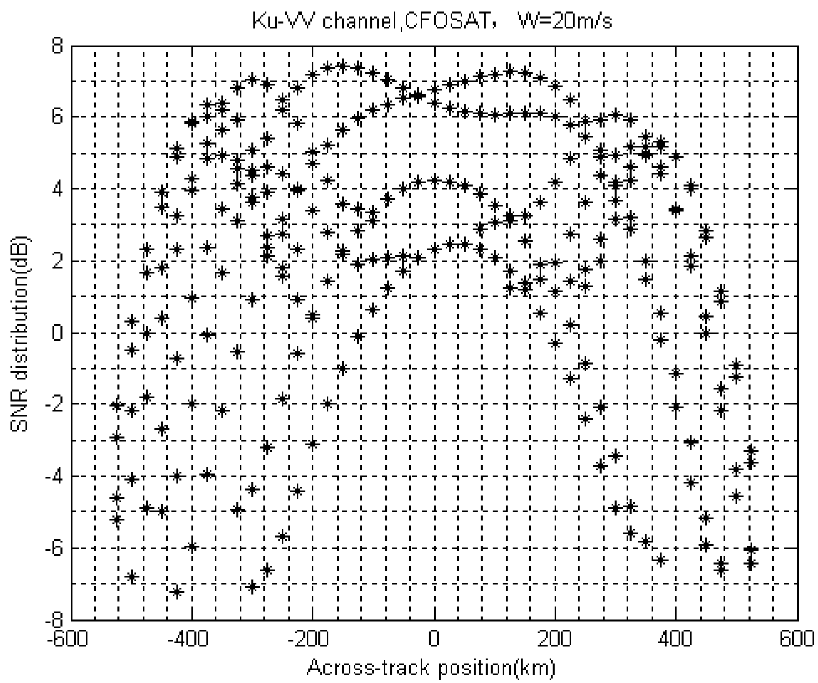
Distribution of SNR

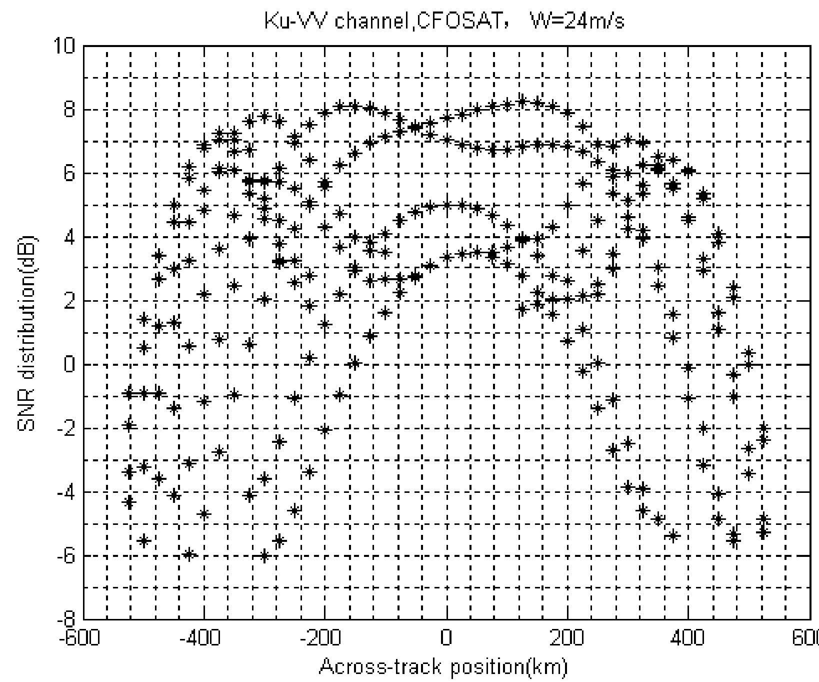




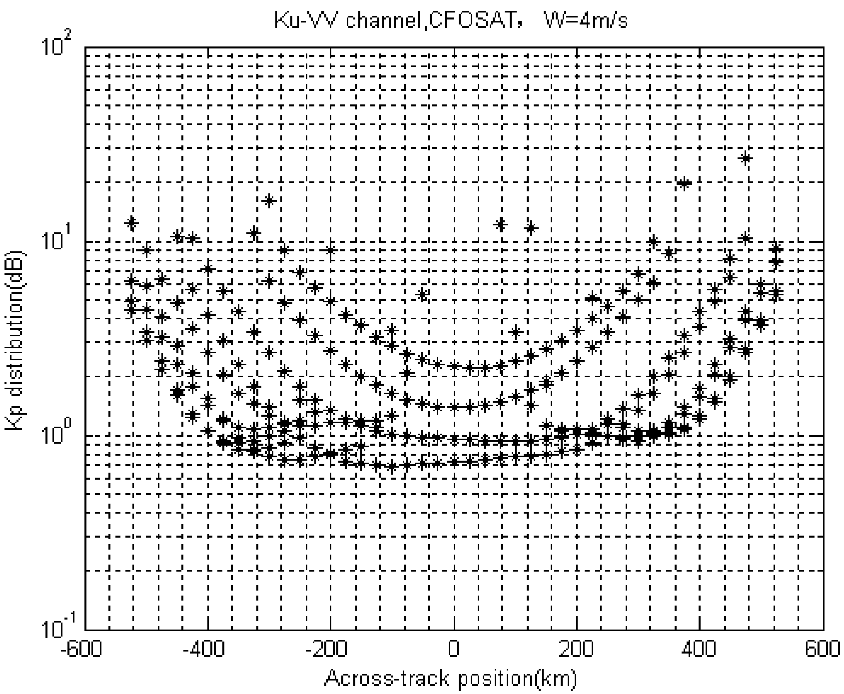

Ku-VV channel,CFOSAT， W=10m/s
SNR distribution(dB)
Across-track position(km)
4
2
0
-2
-4
-6
-8
-10
-12
-14
-600
-400
-200
0
200
400
600

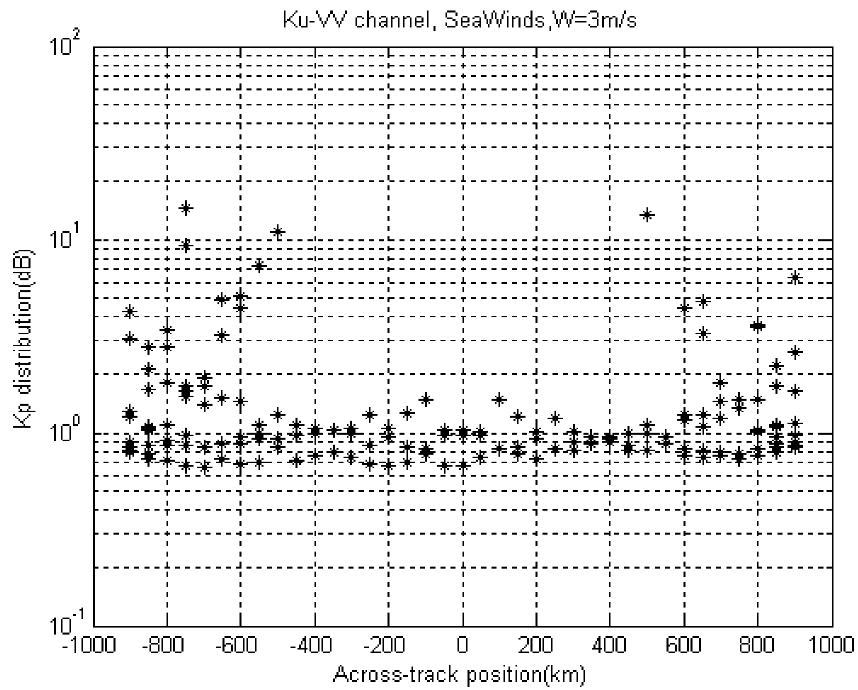

Ku-VV channel,CFOSAT， W=16m/s
SNR distribution(dB)
Across-track position(km)
8
6
4
2
0
-2
-4
-6
-8
-10
-600
-400
-200
0
200
400
600

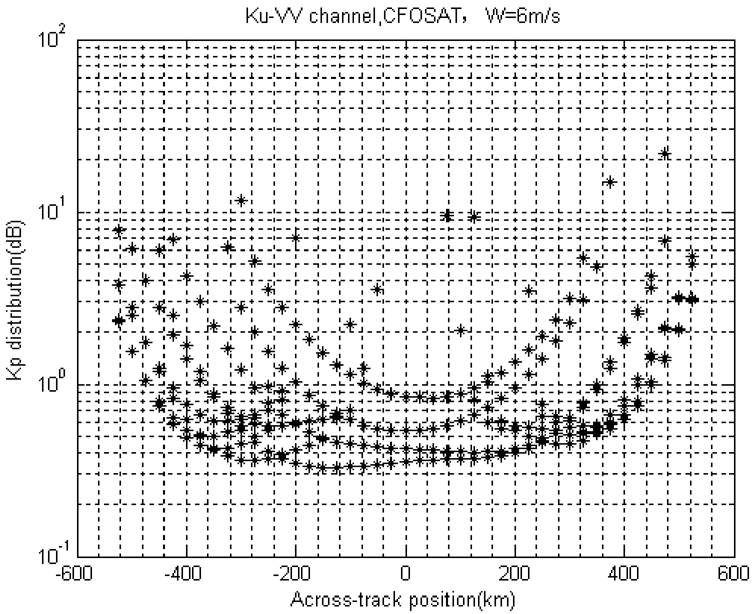

Ku-VV channel,CFOSAT， W=20m/s
SNR distribution(dB)
Across-track position(km)
8
6
4
2
0
-2
-4
-6
-8
-600
-400
-200
0
200
400
600

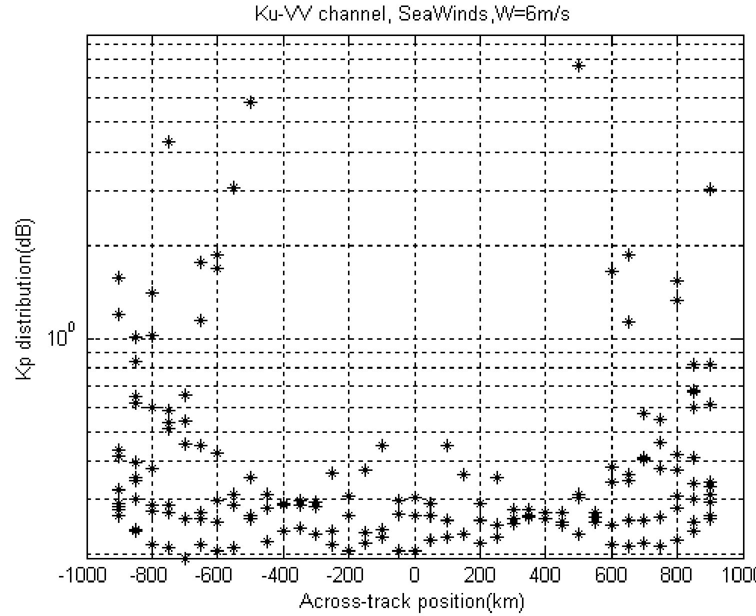

Ku-VV channel,CFOSAT， W=24m/s
SNR distribution(dB)
Across-track position(km)
10
8
6
4
2
0
-2
-4
-6
-8
-600
-400
-200
0
200
400
600

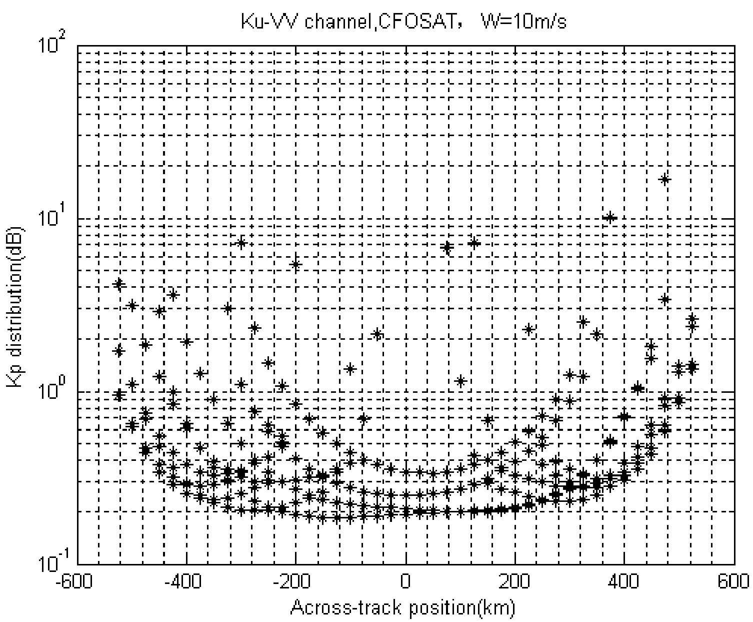
σ° Precision (compared with Seawinds)

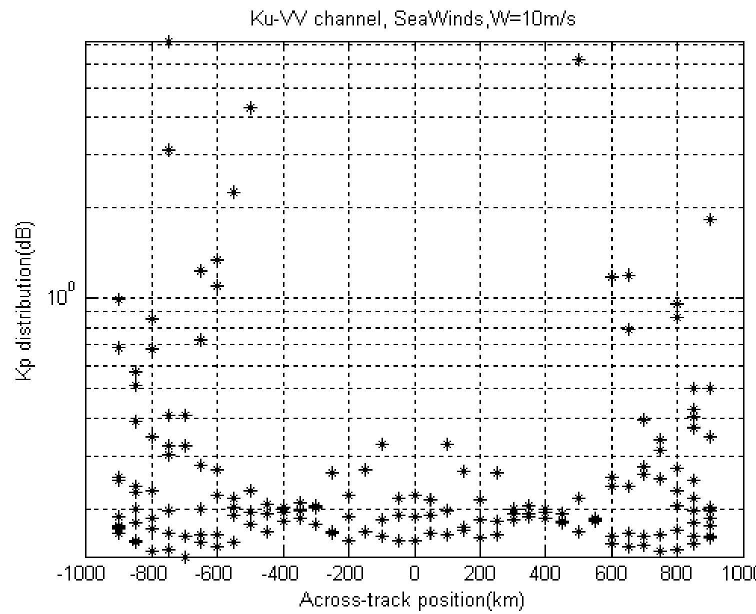


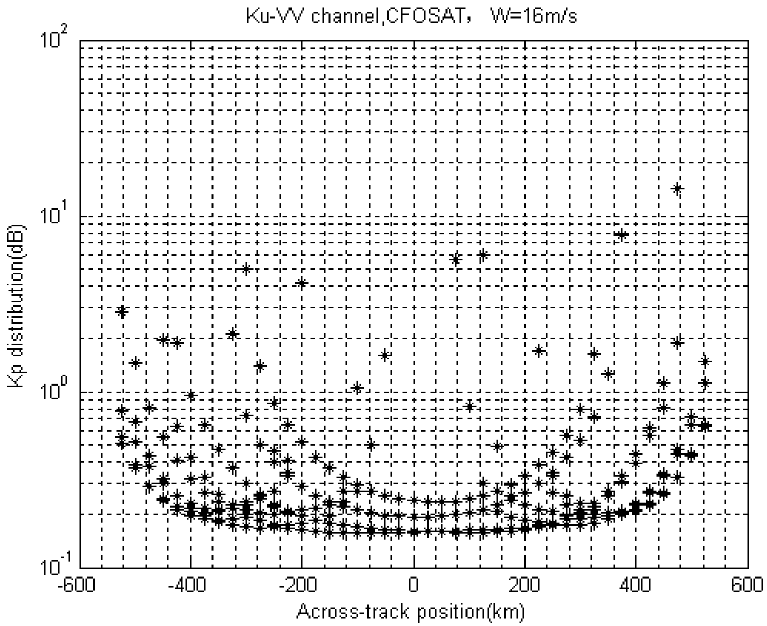


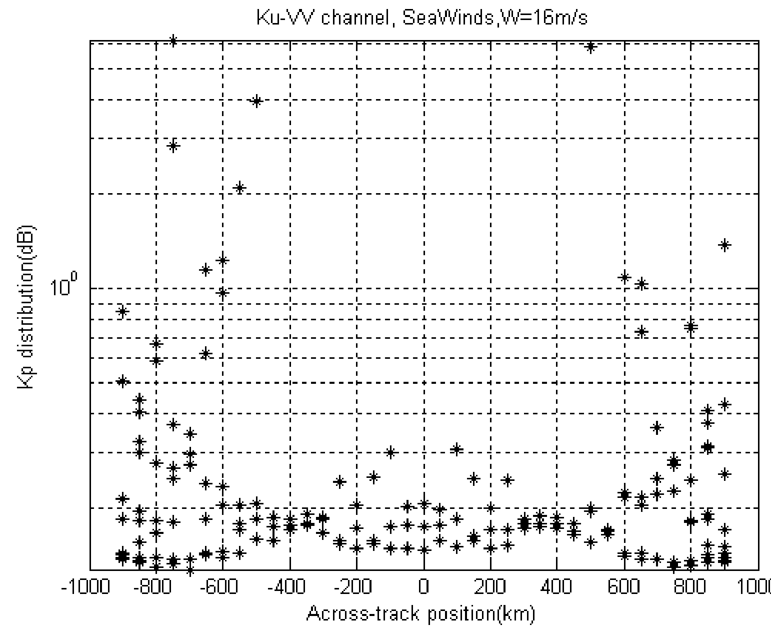

Ku-VV channel,CFOSAT，W=6m/s
Kp distribution(dB)
Across-track position(km)
-600
-400
-200
0
200
400
600

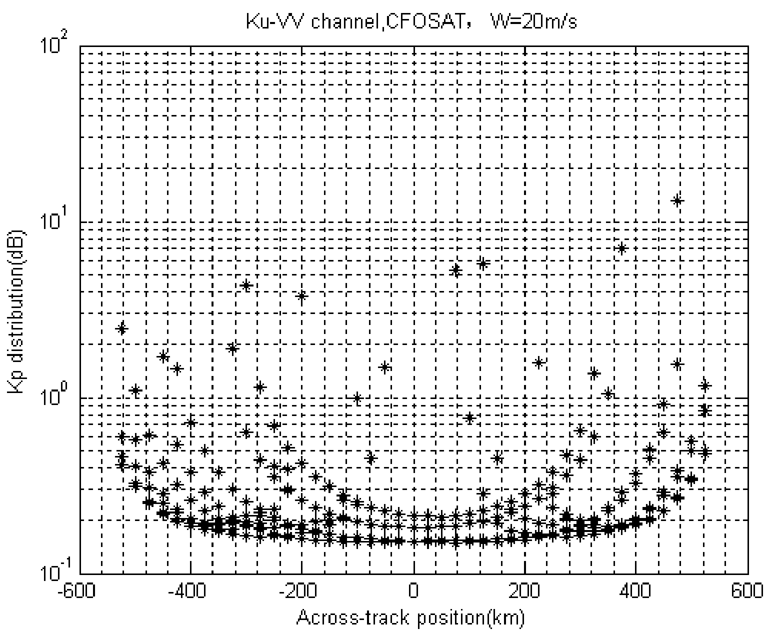

Ku-VV channel, SeaWinds,W=6m/s
Kp distribution(dB)
Across-track position(km)
-1000
-800
-600
-400
-200
0
200
400
600
800
1000

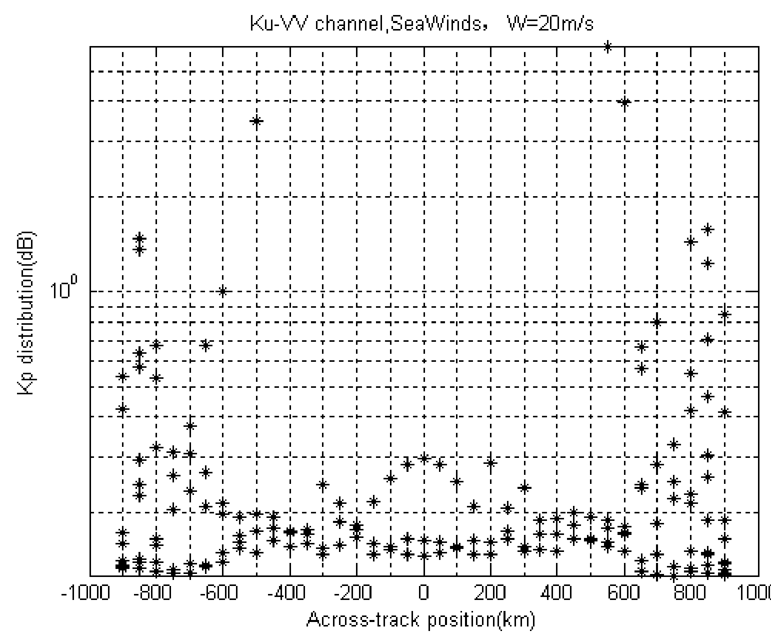

Ku-VV channel,CFOSAT，W=10m/s
Kp distribution(dB)
Across-track position(km)
-600
-400
-200
0
200
400
600

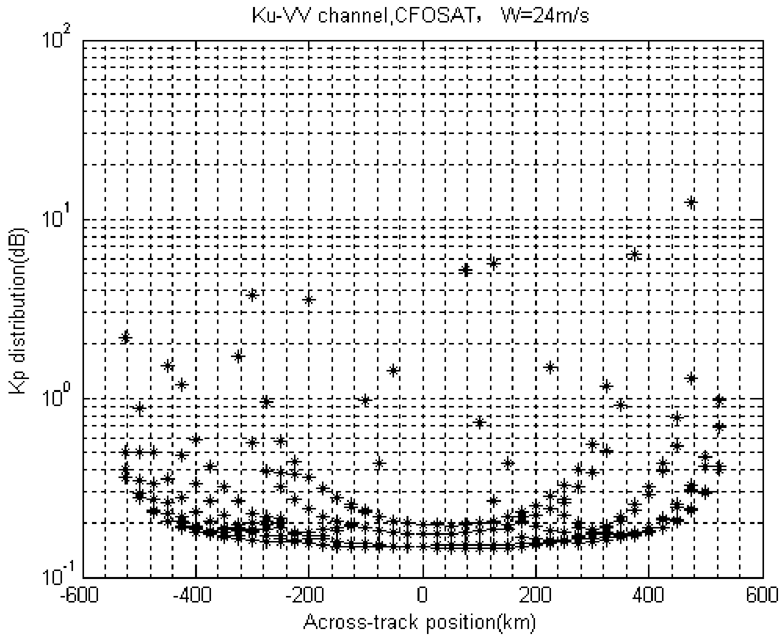

Ku-VV channel, SeaWinds,W=10m/s
Kp distribution(dB)
Across-track position(km)
-1000
-800
-600
-400
-200
0
200
400
600
800
1000


Ku-VV channel,CFOSAT， W=16m/s
Kp distribution(dB)
Across-track position(km)

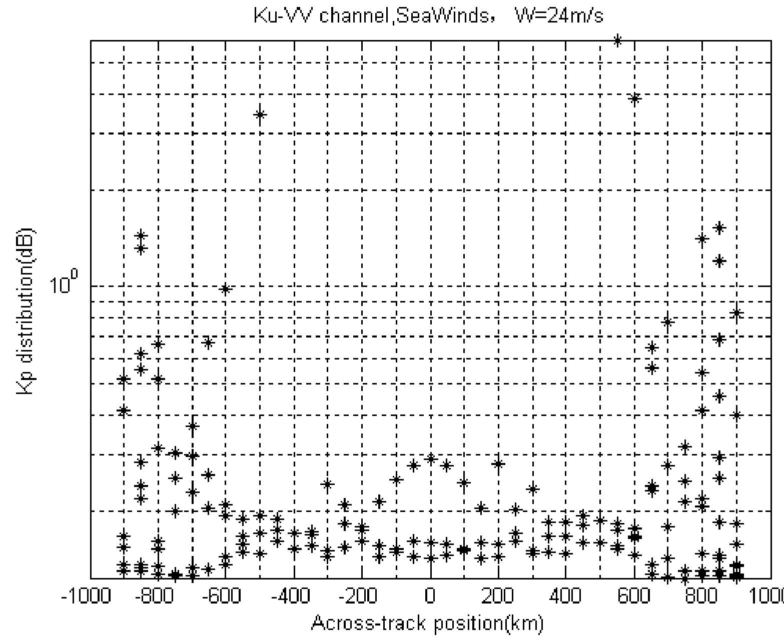

Ku-VV channel, SeaWinds,W=16m/s
Kp distribution(dB)
Across-track position(km)


Ku-VV channel,CFOSAT， W=20m/s
Kp distribution(dB)
Across-track position(km)


Ku-VV channel,SeaWinds， W=20m/s
Kp distribution(dB)
Across-track position(km)



Ku-VV channel,CFOSAT, W=24m/s
Kp distribution(dB)
10^2
10^1
10^0
10^-1
-600
-400
-200
0
200
400
600
Across-track position(km)



Ku-VV channel,SeaWinds, W=24m/s
Kp distribution(dB)
10^0
-1000
-800
-600
-400
-200
0
200
400
600
800
1000
Across-track position(km)

Analysis:

- Except for wind cells in the outer part within the swath, identical Kp can be obtained within the swath;
- For wind speed of 4～6m/s, σ° measurement with precision better than 1.0dB can be obtained within most part of the swath, which will have positive contributions for wind vector retrieval;
- For wind speed of 6~24m/s, σ° measurement with precision better than 1.0dB can be obtained within most part of the swath;
- Compared with Seawinds, Ku-RFSCAT can obtain σ° precision for wind speed of 4m/s similar to the σ° precision obtained by seawinds with wind speed of 3m/s; but wind direction retrieval can be better due to the increased number of incident azimuth angles.

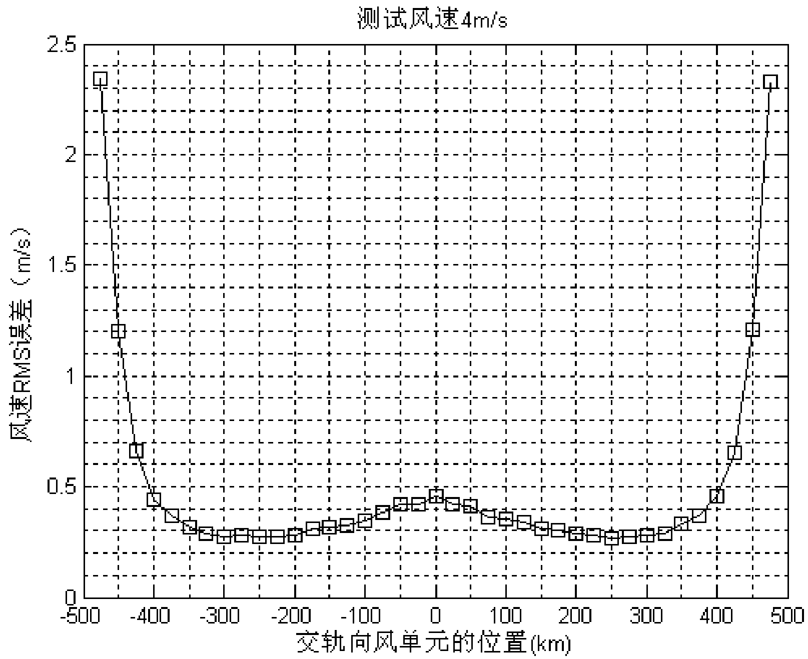
Wind vector retrieval performance

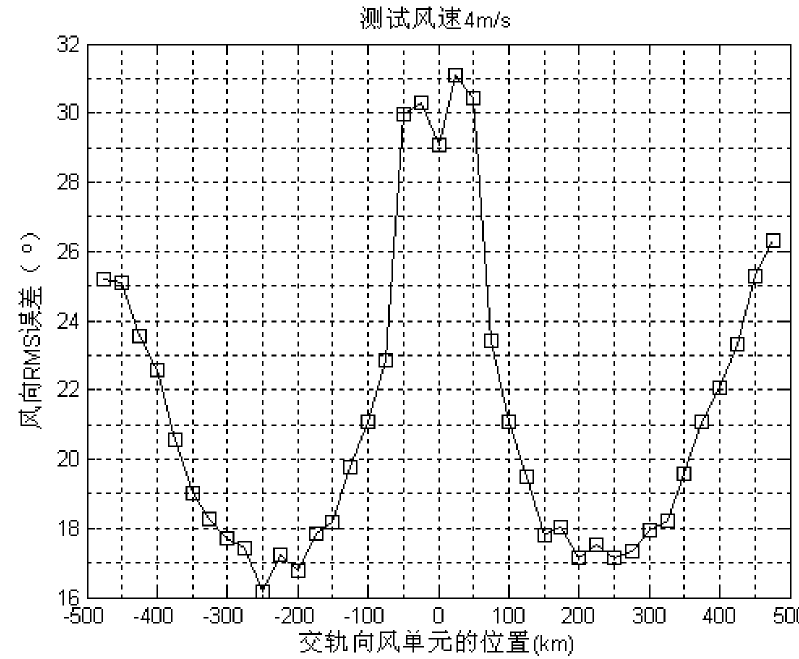
- Only σ° data with precision better than 1.0dB will be used for wind retrieval;
- Standard MLE method and NSCAT GMF are used for simulation;
- Median filter algorithm for wind direction ambiguity removal

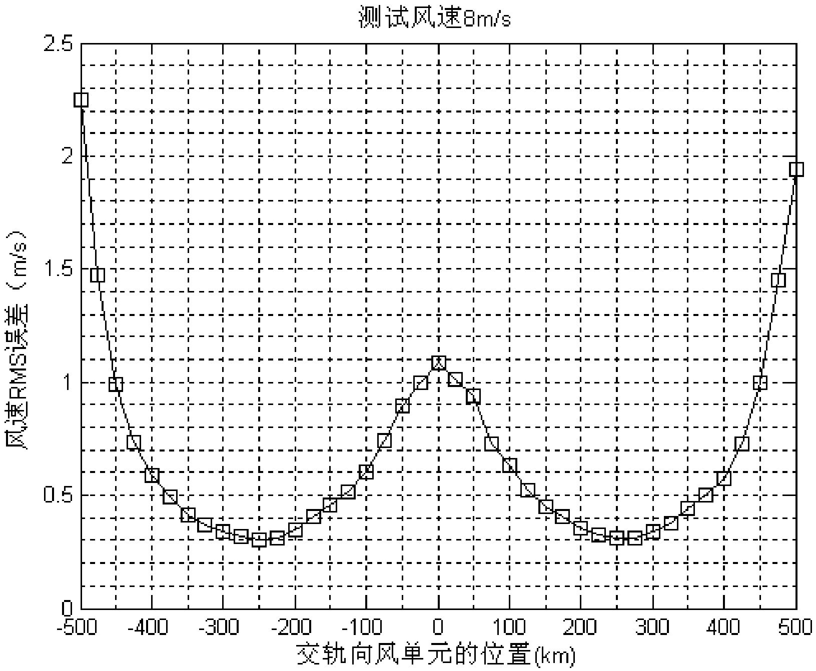
$$MLE = \sum_{views} \frac{(\sigma^0_m - \sigma^0_c)^2}{(Kp \cdot \sigma^0_m)^2}$$

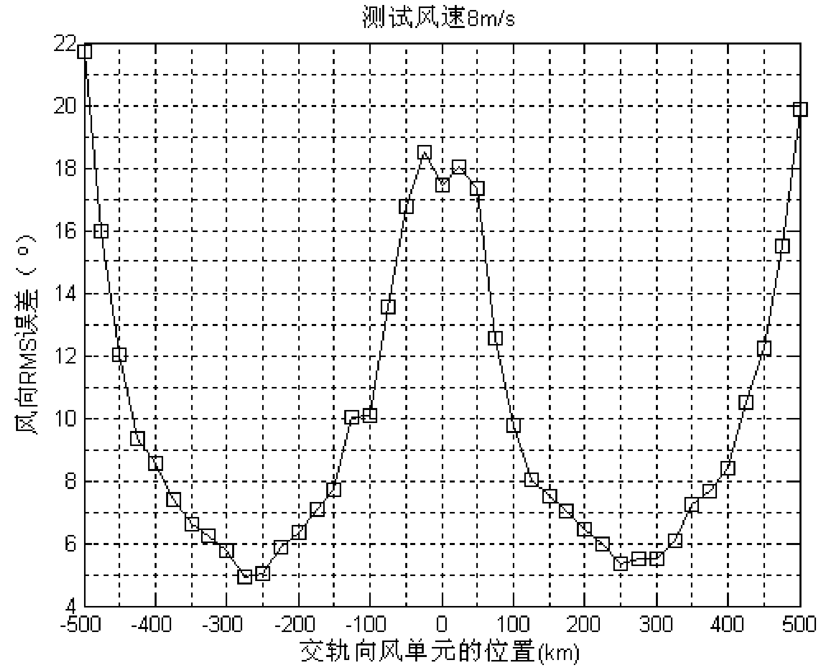
Center for Space Science
and Applied Research
Chinese Academy of Sciences

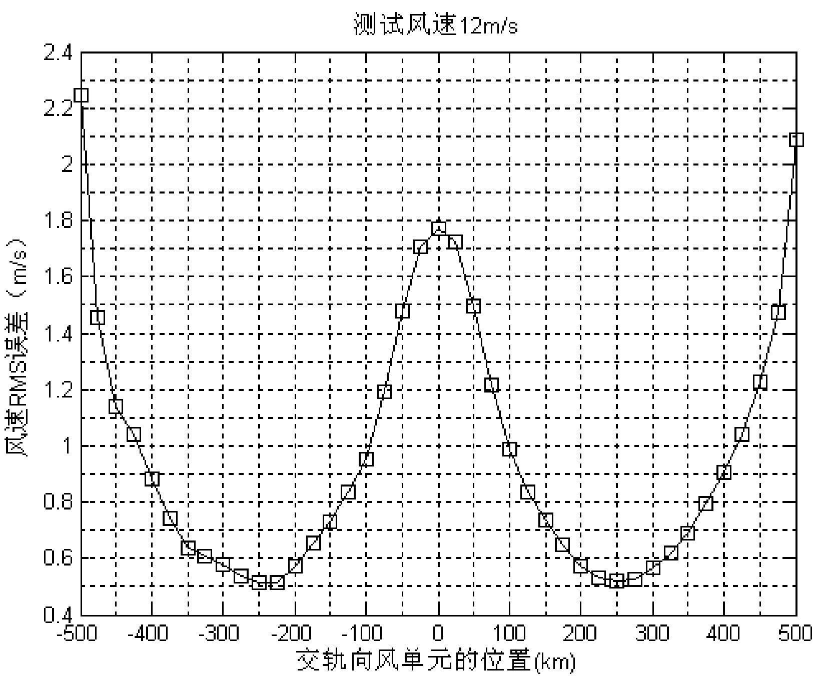
Wind retrieval for resolution of 25km

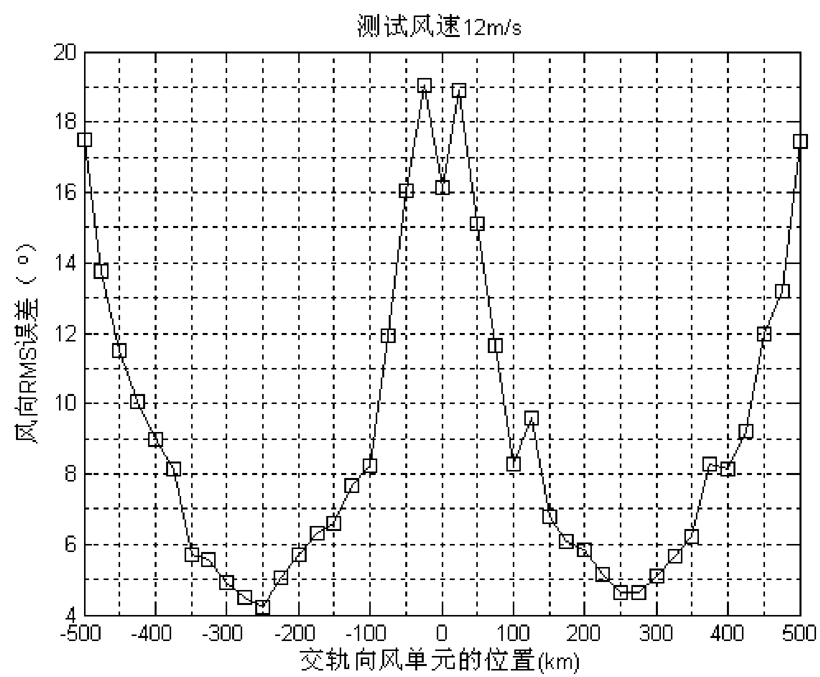


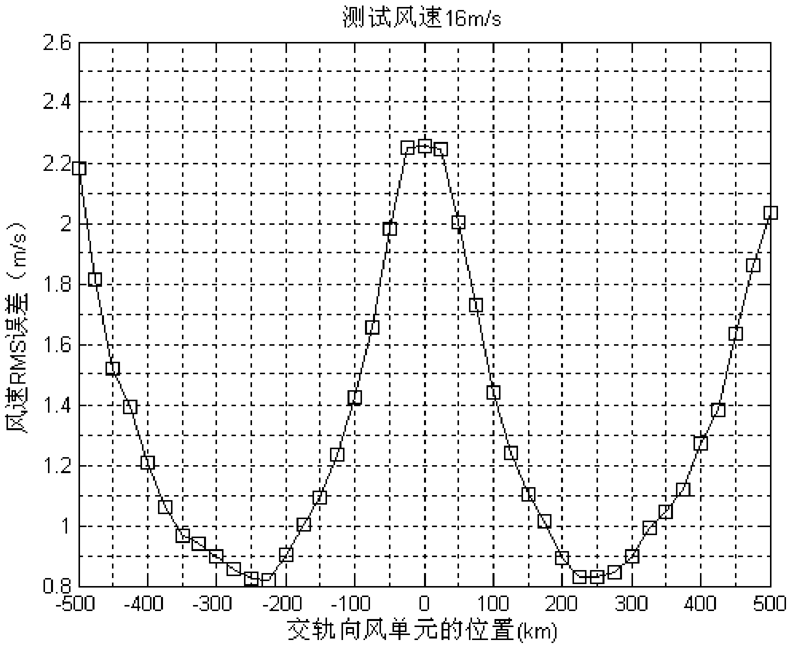


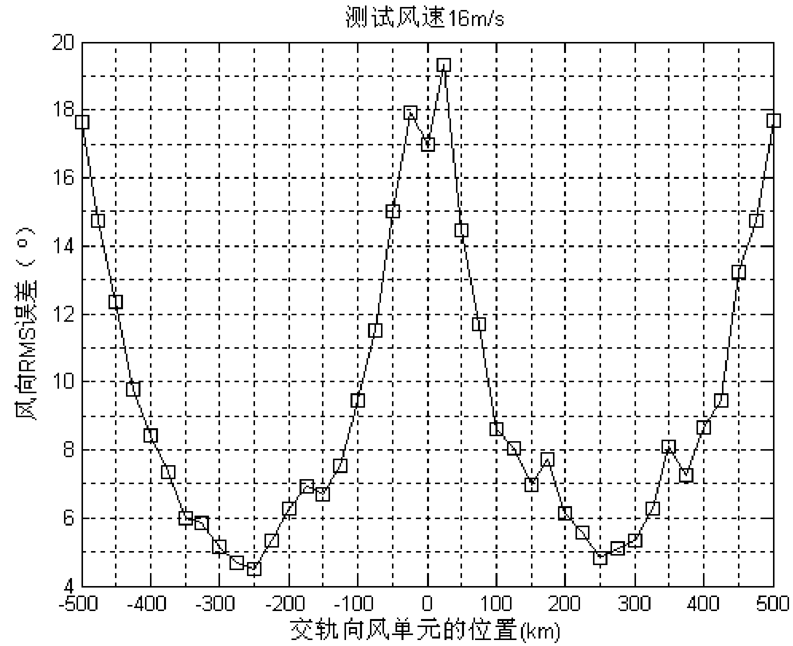

测试风速8m/s
风速RMS误差（m/s）
交轨向风单元的位置(km)
0
0.5
1
1.5
2
2.5
-500
-400
-300
-200
-100
0
100
200
300
400
500

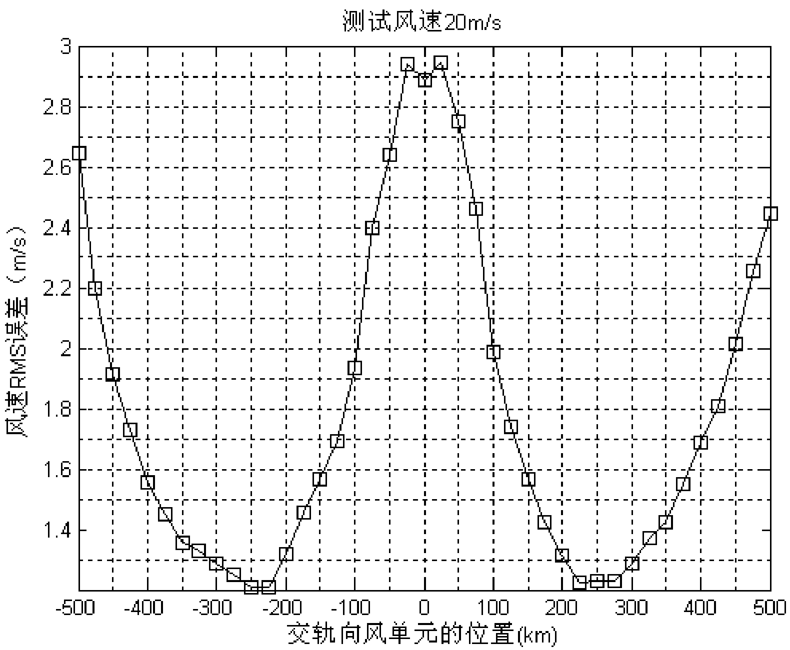

测试风速8m/s
风向RMS误差（°）
交轨向风单元的位置(km)
4
6
8
10
12
14
16
18
20
22
-500
-400
-300
-200
-100
0
100
200
300
400
500

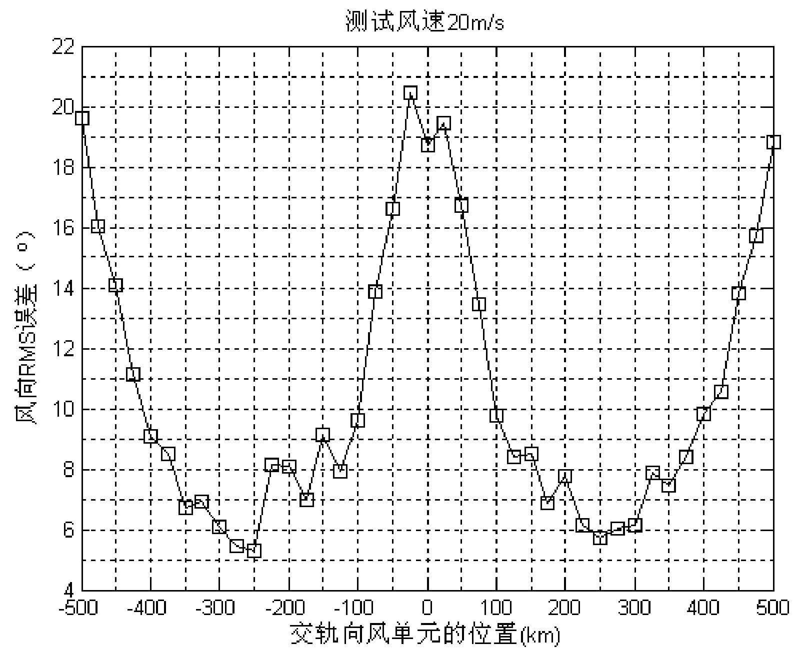

测试风速12m/s
风速RMS误差（m/s）
交轨向风单元的位置(km)
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
-500
-400
-300
-200
-100
0
100
200
300
400
500

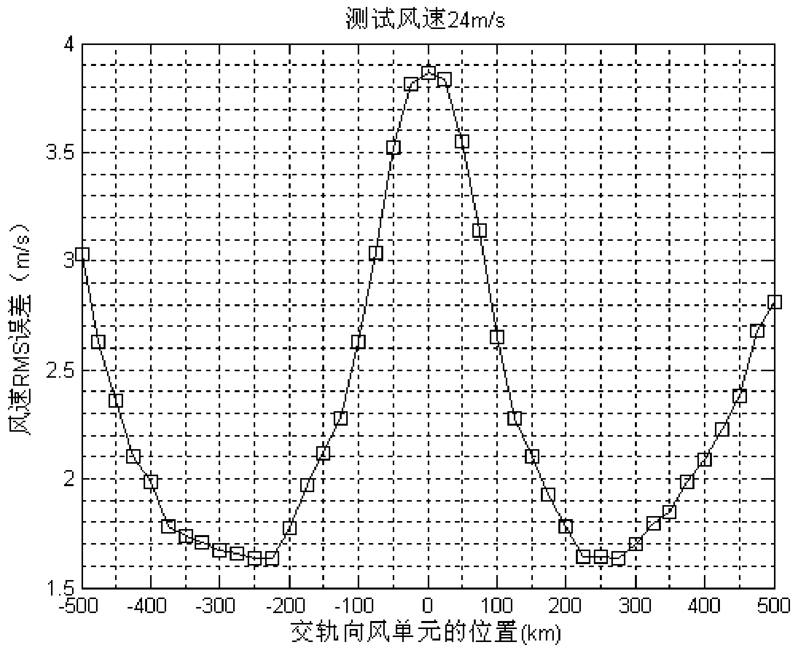

测试风速12m/s
风向RMS误差（°）
交轨向风单元的位置(km)
4
6
8
10
12
14
16
18
20
-500
-400
-300
-200
-100
0
100
200
300
400
500

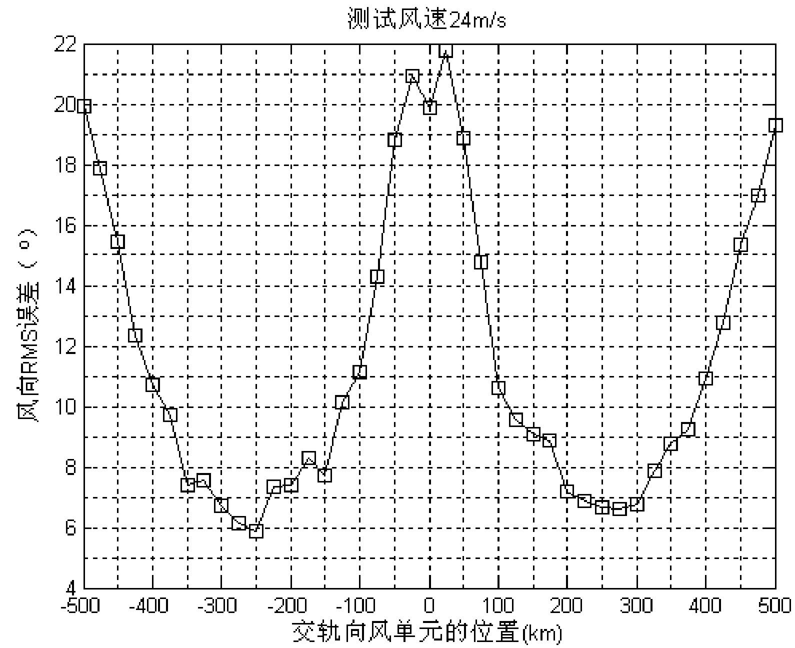

测试风速16m/s
风速RMS误差（m/s）
交轨向风单元的位置(km)


测试风速16m/s
风向RMS误差（°）
交轨向风单元的位置(km)

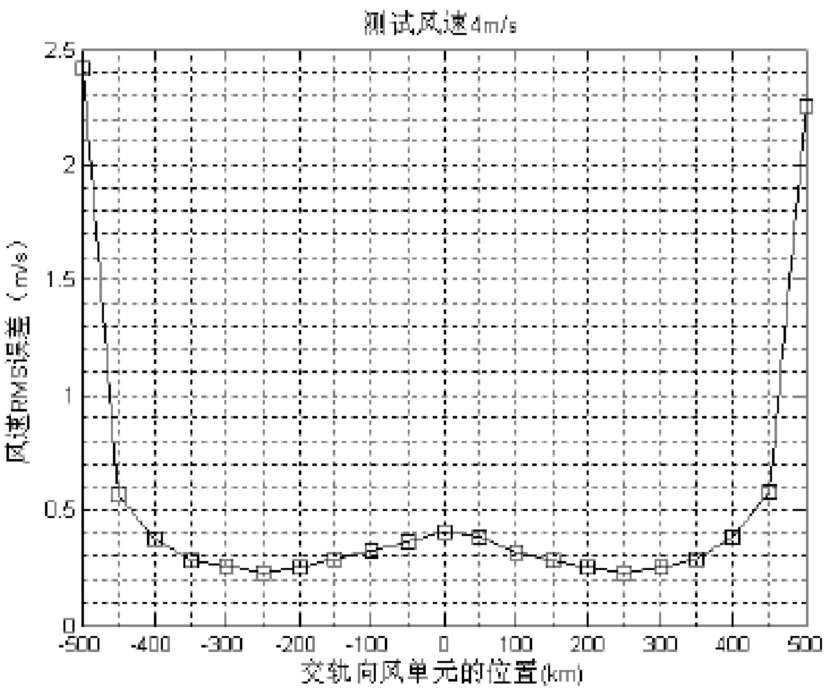

测试风速20m/s
风速RMS误差（m/s）
交轨向风单元的位置(km)

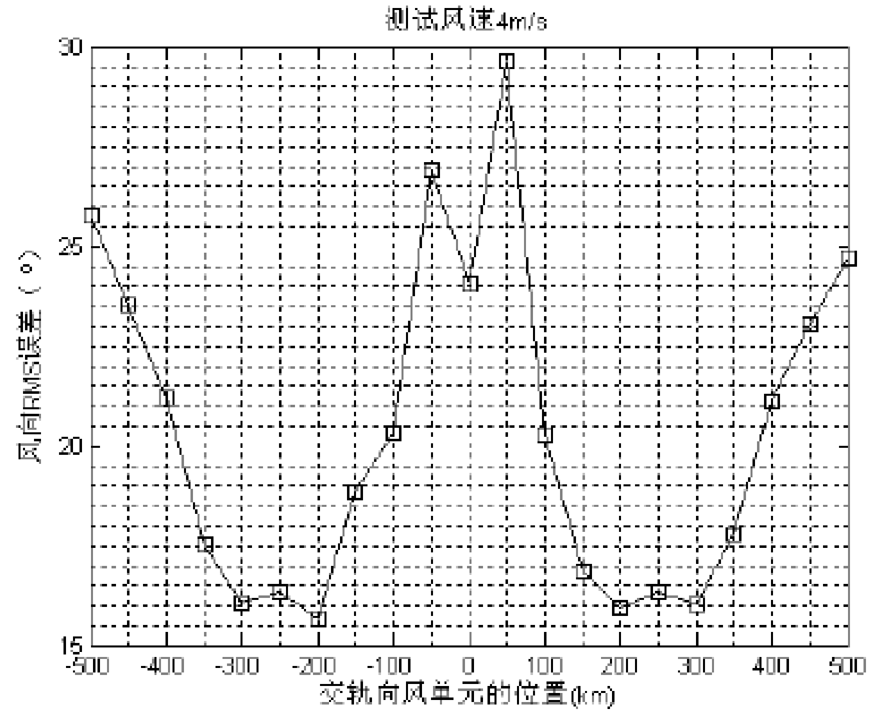

测试风速20m/s
风向RMS误差（°）
交轨向风单元的位置(km)

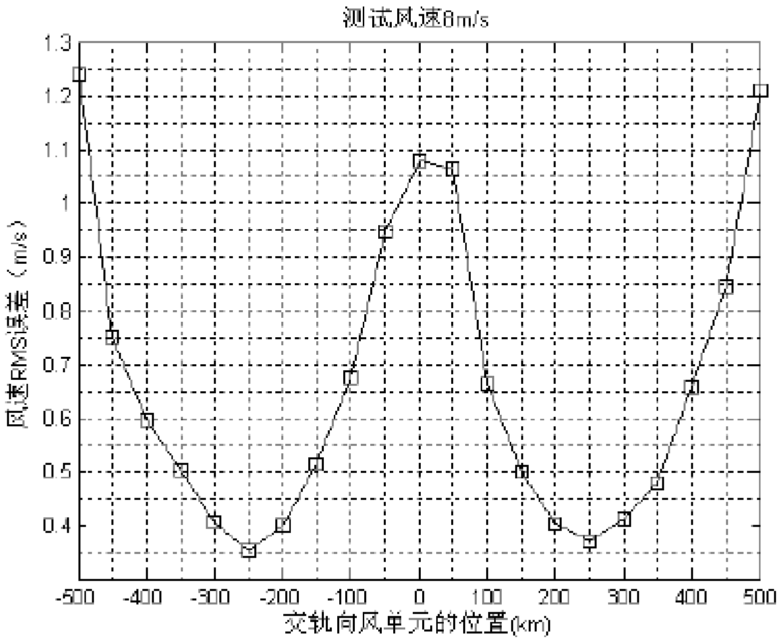

测试风速24m/s
风速RMS误差（m/s）
交轨向风单元的位置(km)
4
3.5
3
2.5
2
1.5
-500 -400 -300 -200 -100 0 100 200 300 400 500

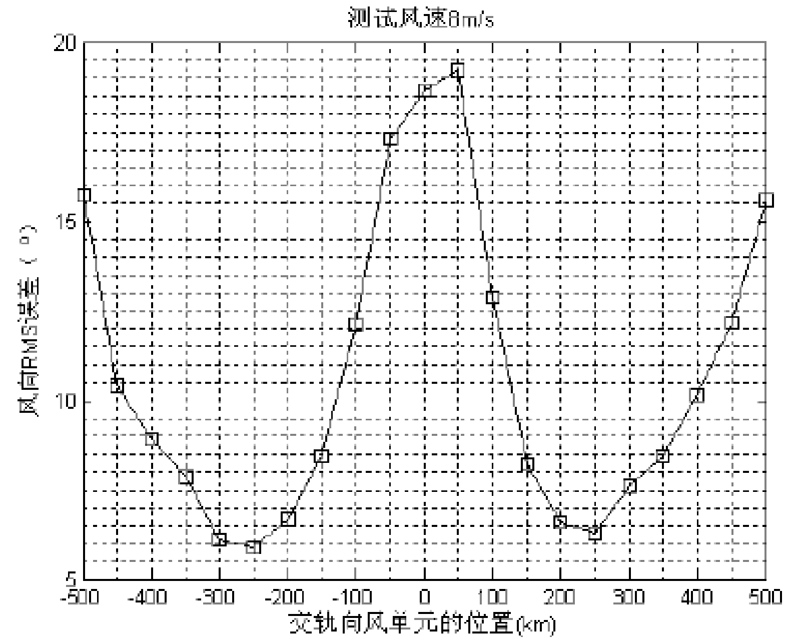

测试风速24m/s
风向RMS误差（°）
交轨向风单元的位置(km)
22
20
18
16
14
12
10
8
6
4
-500 -400 -300 -200 -100 0 100 200 300 400 500

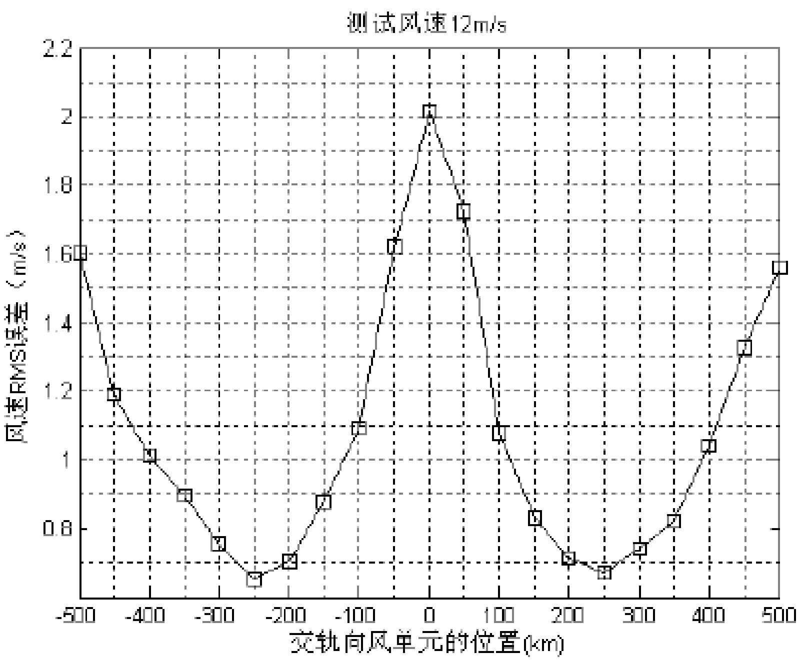
Wind retrieval for resolution of 50km

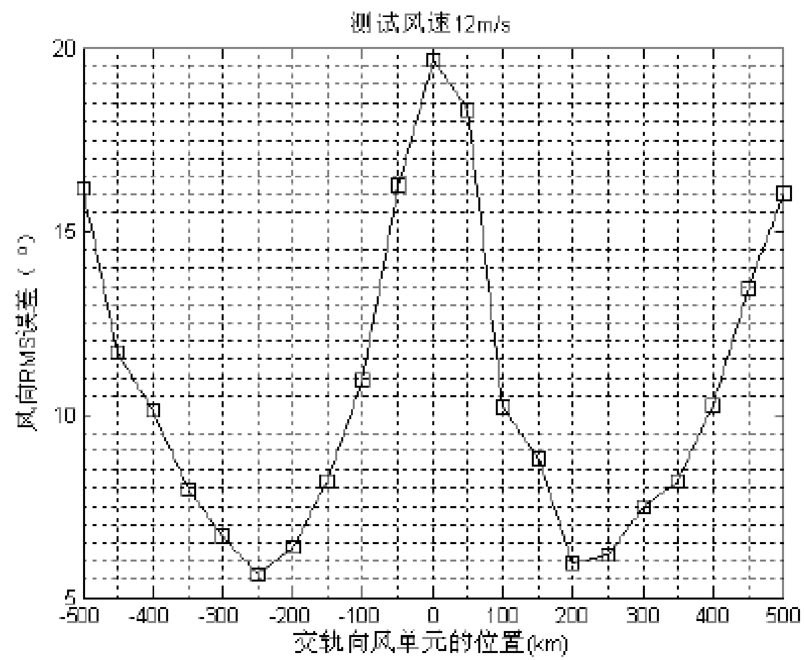


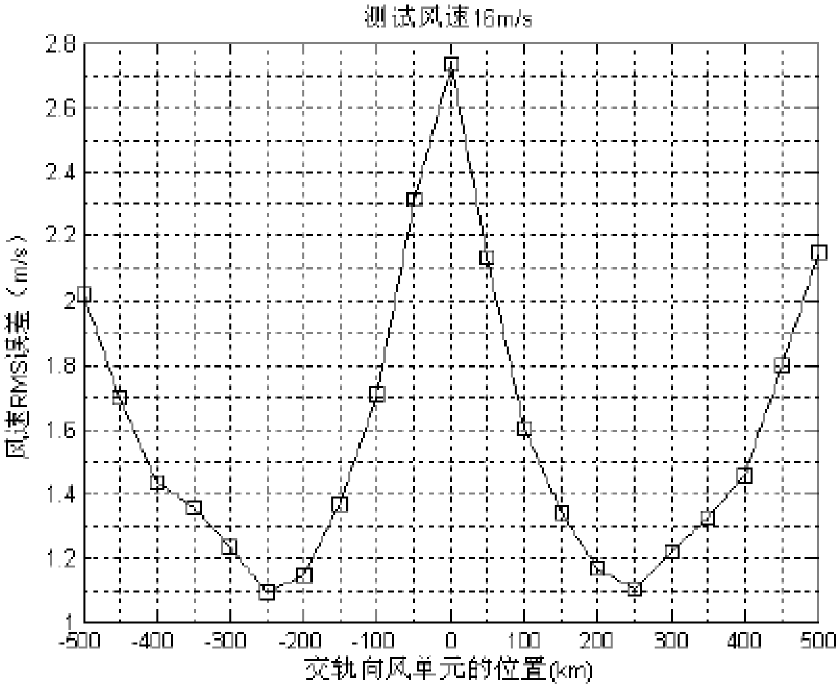


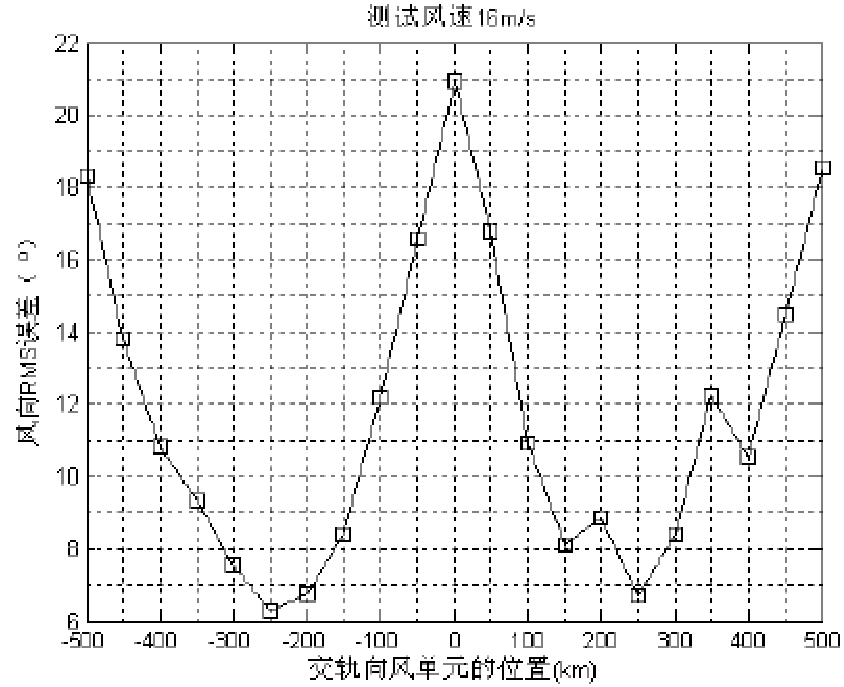

测试风速8m/s
风速RMS误差（m/s）
交轨向风单元的位置(km)
1.3 1.2 1.1 1 0.9 0.8 0.7 0.6 0.5 0.4
-500 -400 -300 -200 -100 0 100 200 300 400 500

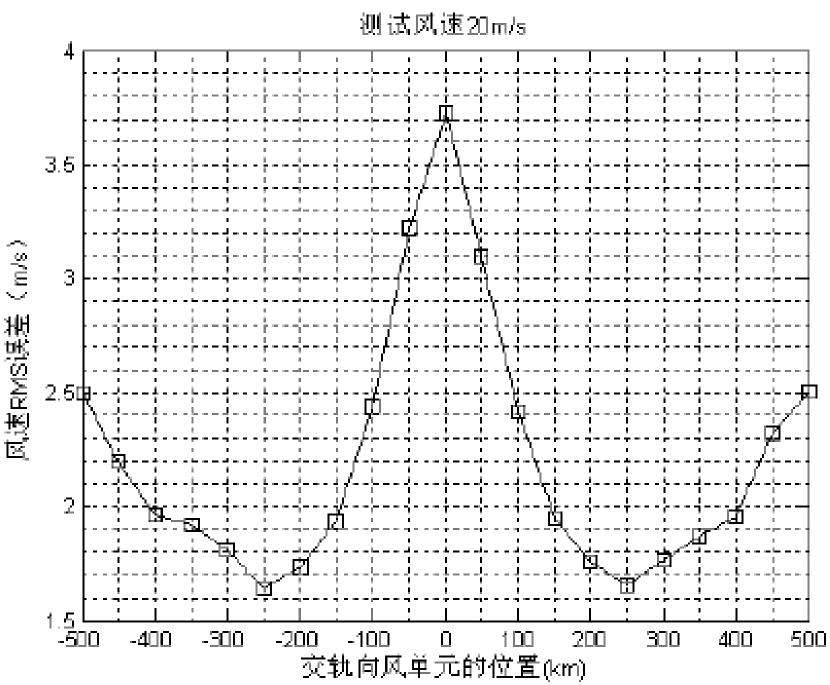

测试风速8m/s
风向RMS误差（°）
交轨向风单元的位置(km)
20 15 10 5
-500 -400 -300 -200 -100 0 100 200 300 400 500

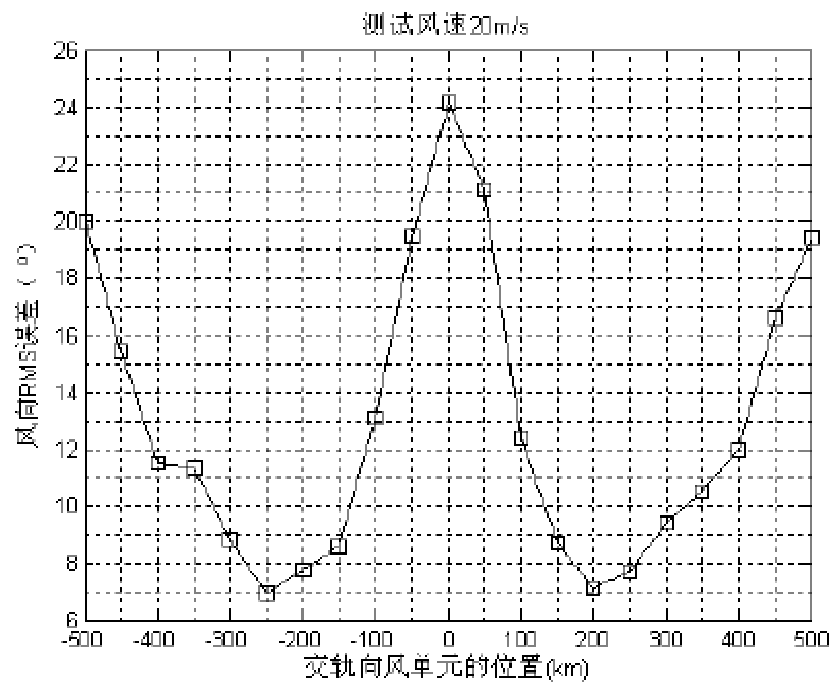

测试风速12m/s
风速RMS误差（m/s）
交轨向风单元的位置(km)
2.2 2 1.8 1.6 1.4 1.2 1 0.8
-500 -400 -300 -200 -100 0 100 200 300 400 500

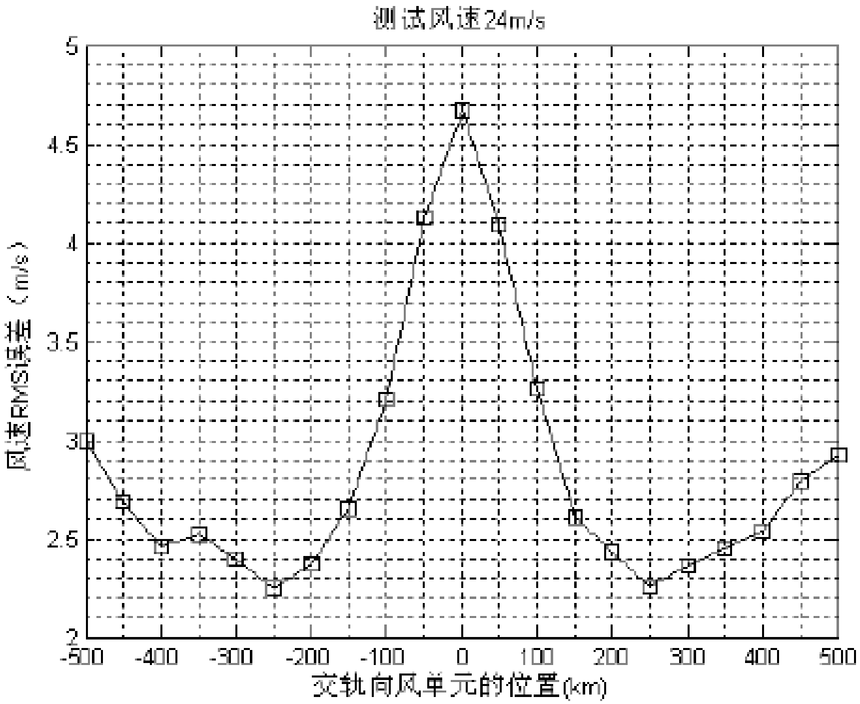

测试风速12m/s
风向RMS误差（°）
交轨向风单元的位置(km)
20 15 10 5
-500 -400 -300 -200 -100 0 100 200 300 400 500

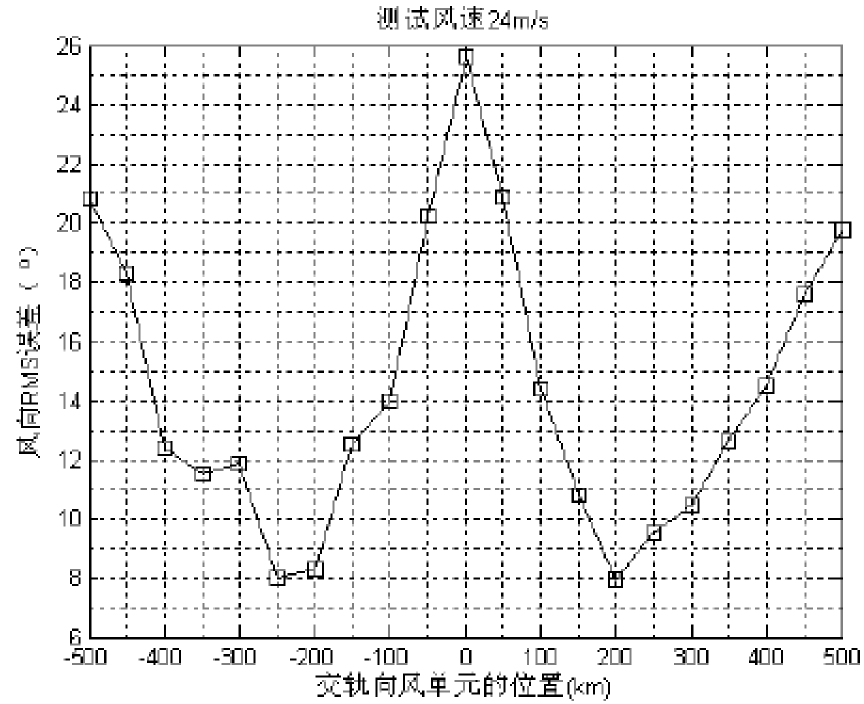

测试风速16m/s
风速RMS误差（m/s）
交轨向风单元的位置(km)


测试风速16m/s
风向RMS误差（°）
交轨向风单元的位置(km)


测试风速20m/s
风速RMS误差（m/s）
交轨向风单元的位置(km)

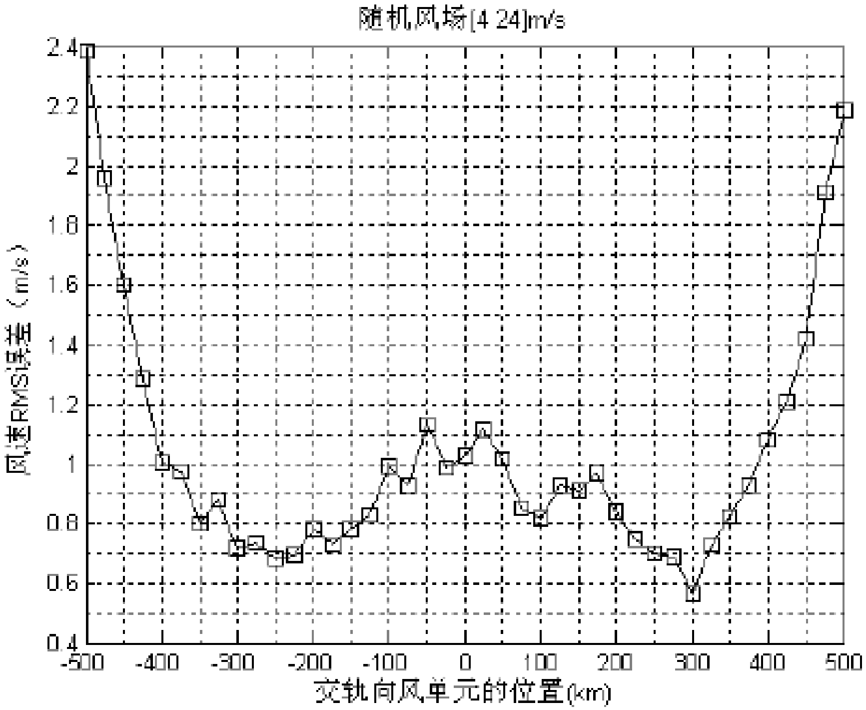

测试风速20m/s
风向RMS误差（°）
交轨向风单元的位置(km)

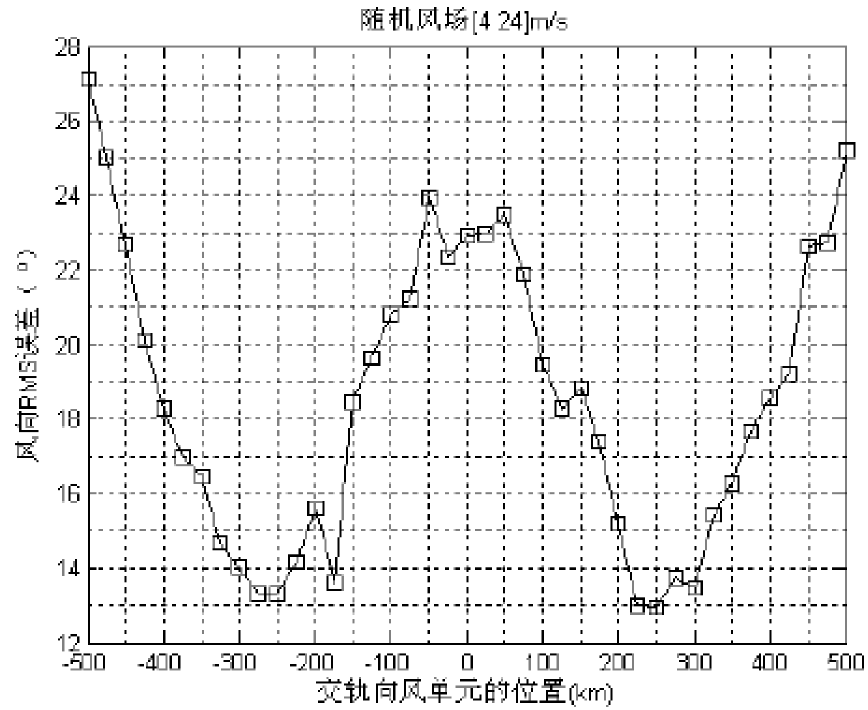




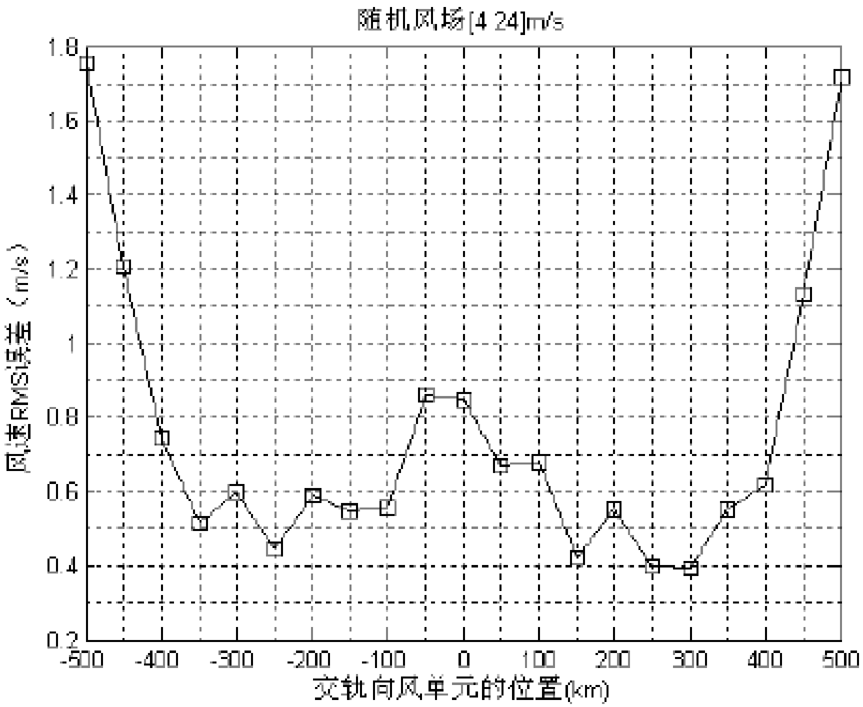
Center for Space Science
and Applied Research
Chinese Academy of Sciences

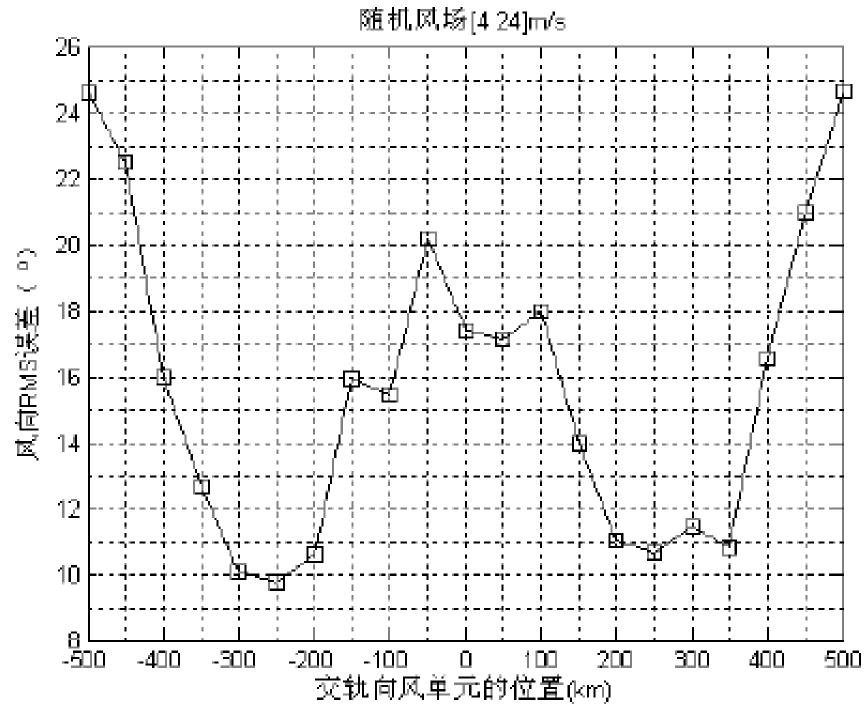
25km resolution for statistical random wind field





25km resolution for statistical random wind field





Summary

- With 50km resolution, wind retrieval performance requirement can be satisfied for most part within the swath;
- When wind speed <=12m/s， 50km resolution data can have obvious better performance than the result with 25km resolution, which is due to the increase of number of independent samples;
- When wind speed >=16m/s, the difference of wind retrieval performance between 25 km and 50km resolutions will become neglectable, even for outer part of the swath;
- With increase of wind speed, performance for center part of the swath becomes worse, due to error of GMF for high speed;
- For scanning fan-beam scatterometer, it is expected to improve the wind retrieval performance by developing wind retrieval algorithms for low SNR, multiple incident angle σ° measurements.

Thanks！