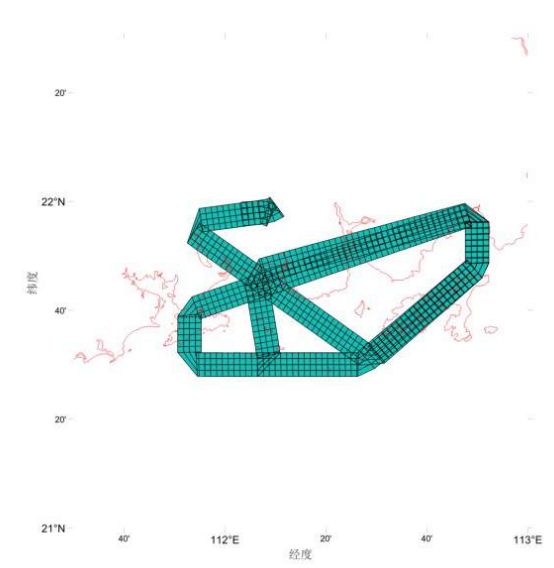
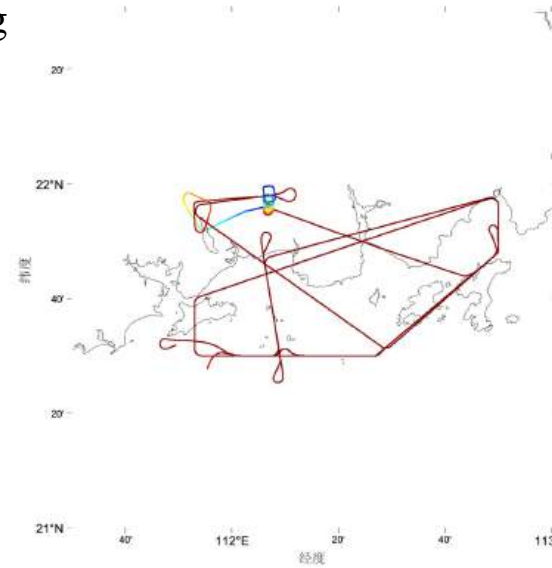
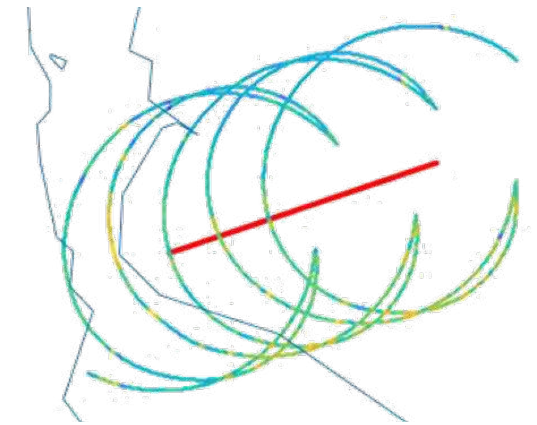


Calibration and inversion of the backscatter data from the Chinese OSCOM Doppler Scatterometer airborne prototype

Shilei Wang, Marcos Portabella, Xiaolong Dong, Wenming Lin, Qingliu Bao

OSCOM campaign: Rotating pencil-beam airborne doppler scatterometer

- Experiment year: 2020
 - August 6 14:30pm-17:30pm
 - August 11 14:30pm-17:10pm
 - August 15 14:00pm-18:00pm
- Experiment area:
 - Coastal area in south of Yangjiang River, Guangdong Province, China
 - Latitude: from 21°30'N to 22°00'N
 - Longitude: from 111°53'E to 112°50'E
- System parameters
 - Polarization: VV



The main system parameters are shown in Table I.

Table I System Parameters of
Airborne Doppler Scatterometer

Incidence Angle	50°
Flight Height	3000m
Carrier Frequency	35.9GHz
Signal Bandwidth	5MHz
Signal Form	Chirp Signal
Pulse Width	4us
Pulse Interval	4us
Central Frequency of IF	14MHz
Sampling Frequency	56MHz
Pulse Period	100us
Antenna Rotation Speed	40°/s

L1B Measurements → L2

- NRCS (σ_0)
- Doppler shift

- Cell size: 2 km
- Swath width: 8 km

1. Pre-process (quality control):

- **Land filtering:** Filter the land data using the GSHHG land-sea mask;
- **Incidence selection:** only consider data with incidence (46, 53) degree.
- **Density selection:** delete some data with noise
- **Leg division:** divide all data into several flight legs (according to time and location)

2. Calibration and wind inversion:

Assumptions:

- Same wind for each leg (both speed and direction);
 - The shift of azimuth angle between the measurement and the simulation indicates the ‘true’ wind direction.
1. Simulate sigma0 using collocated ECMWF winds and KaDPMoD GMF.
 2. Calculate the shift of azimuth angle, which is the ‘true’ wind direction.
 3. For each leg, reproduce simulated sigma0 using the ‘true’ wind direction and ECMWF wind speed.
 4. Calculate new simulated median curve for the whole region.
 5. Calibrate measurement using the ratio for each azimuth bin:

$$r = \sigma_s^0 / \sigma_m^0$$

3. Ongoing work

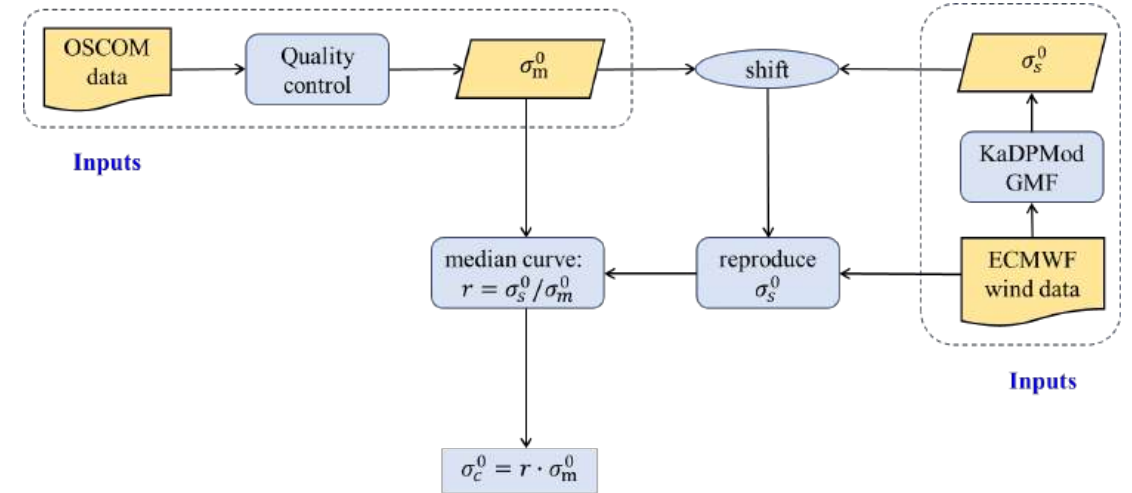


Figure 1. Flow diagram of calibration

1. Pre-process (quality control):

Land filtering: Filter the land data using the GSHHG land-sea mask;

Incidence selection: only consider data with incidence (46, 53) degree.

Density selection: delete some data with noise

Leg division: divide all data into several flight legs (according to time and location), and delete those legs with less data.

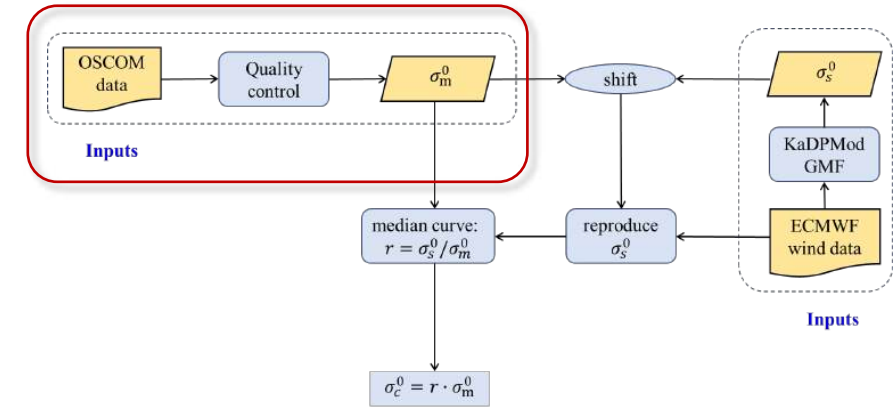
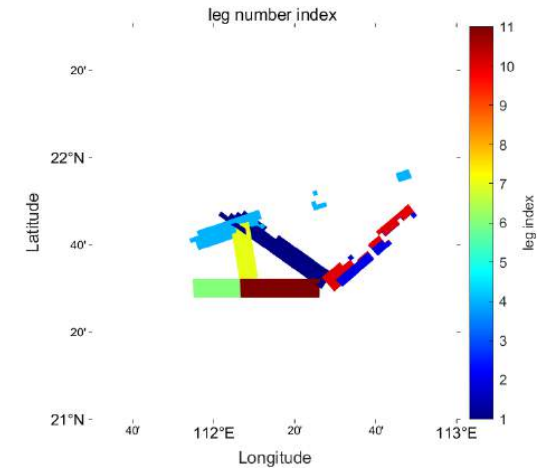
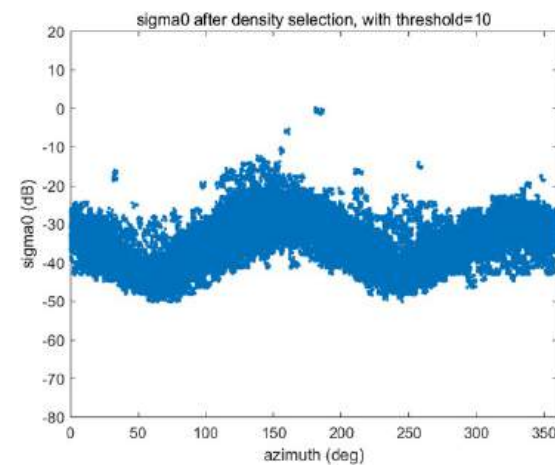
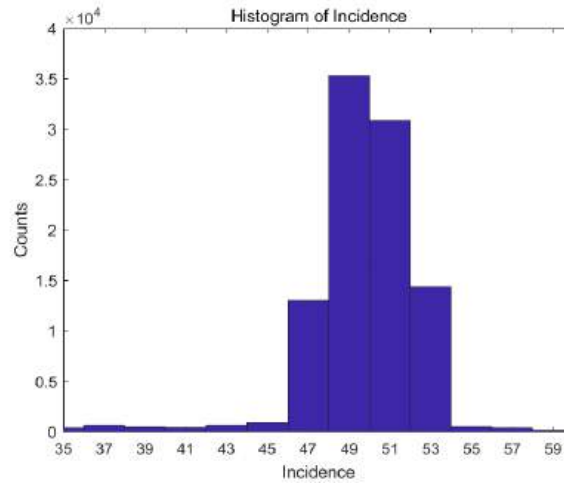
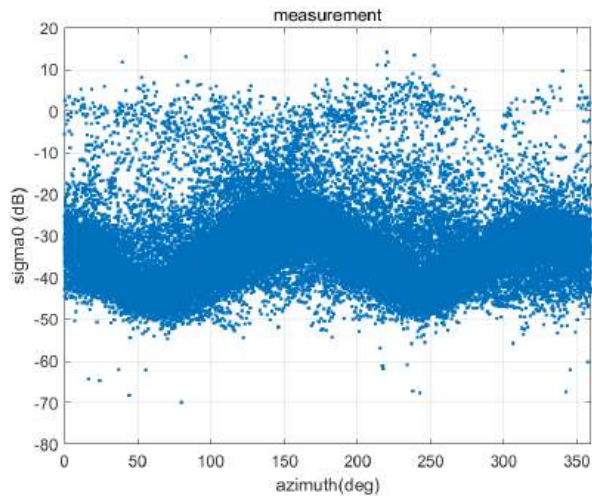


Figure 1. Flow diagram of calibration



Land filtering

Incidence selection

Density selection

Leg division

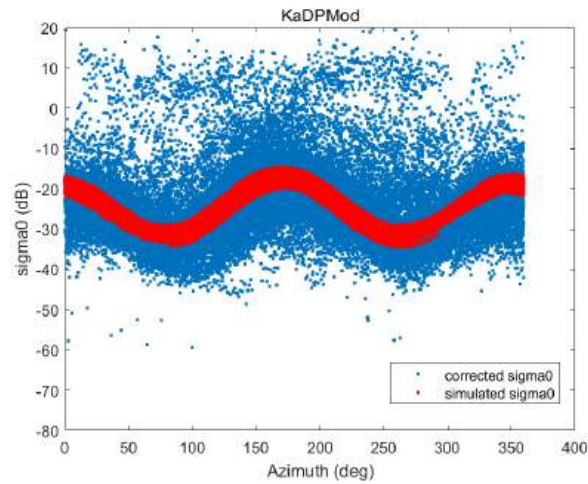
$K_p \approx 20\%$

1. 1 Pre-process (quality control): Density selection

Simulate noisy sigma0 with Monte-Carlo method:

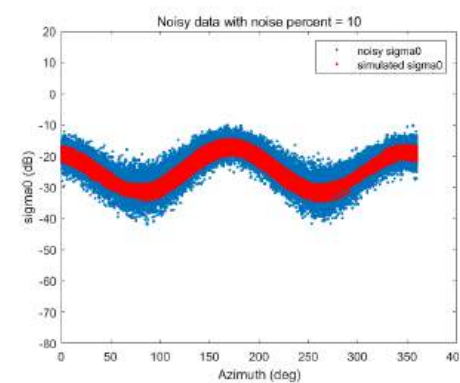
- normally distributed
- centered around the simulation
- standard deviation on σ_0 is

$$\Delta\sigma_0 = K_p \times \sigma_0$$

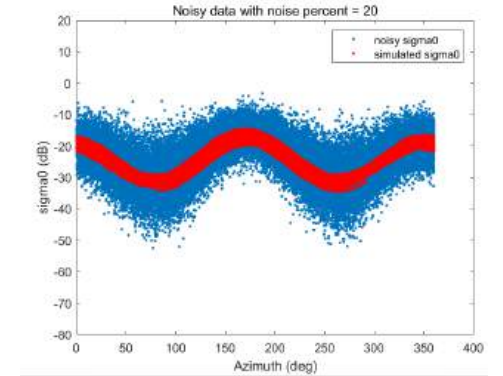


Measured sigma0

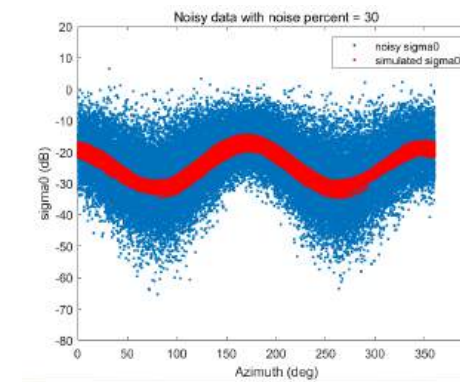
Closest: $K_p = 20\%$



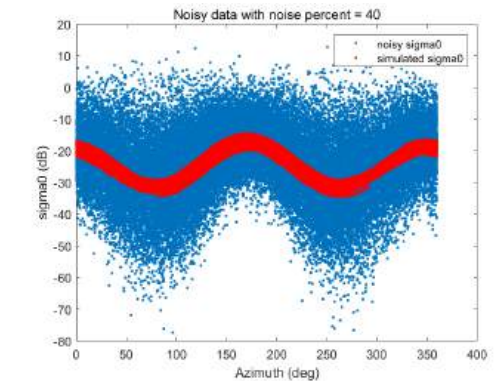
$K_p = 10\%$



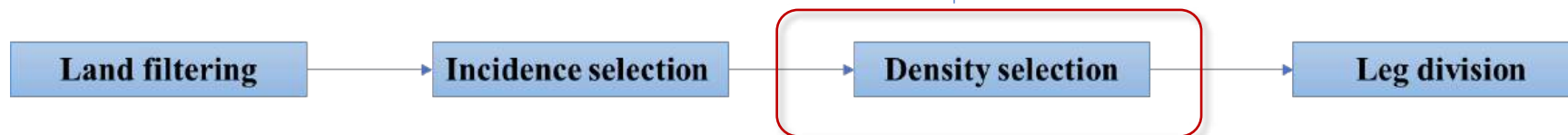
$K_p = 20\%$



$K_p = 30\%$



$K_p = 40\%$

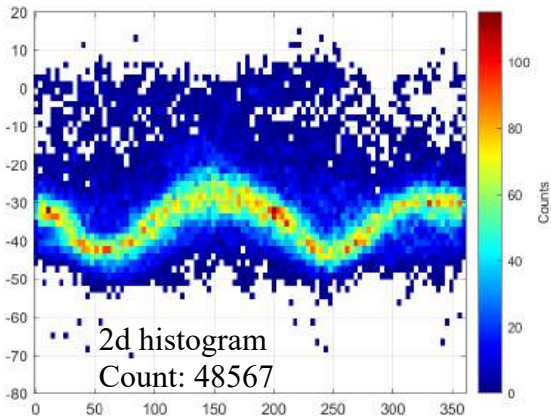


1.1 Pre-process (quality control): Density selection

Aim: Exclude the noise

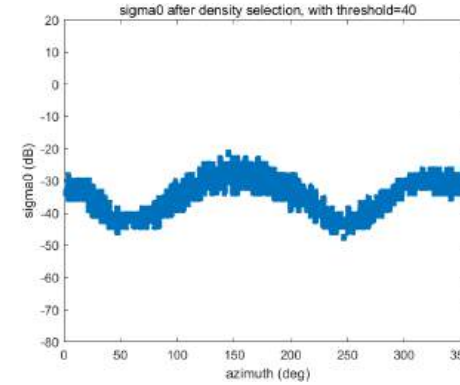
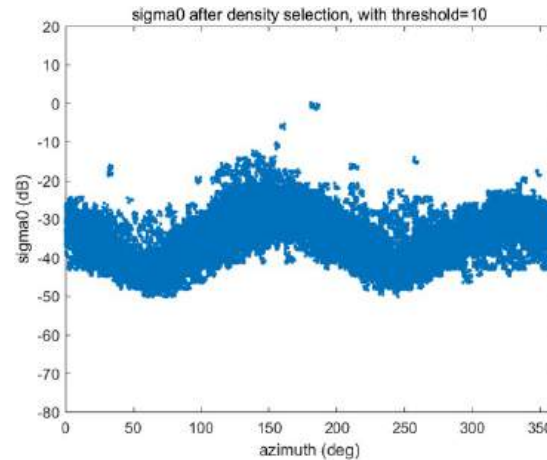
Method :

- Split the whole range of x and y into several bins
- At a certain bin: count how many points are within this bin.

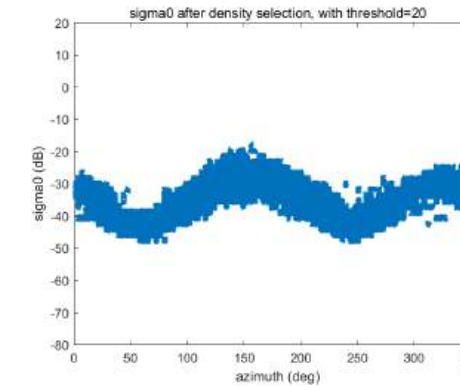


Density selection

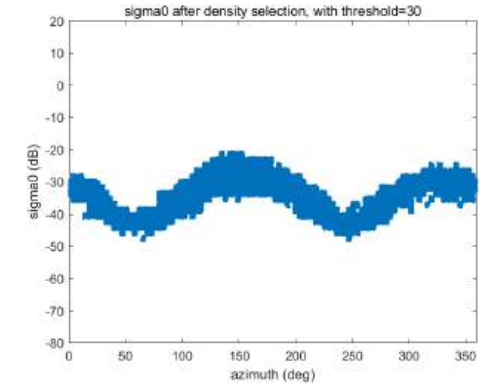
Threshold=10



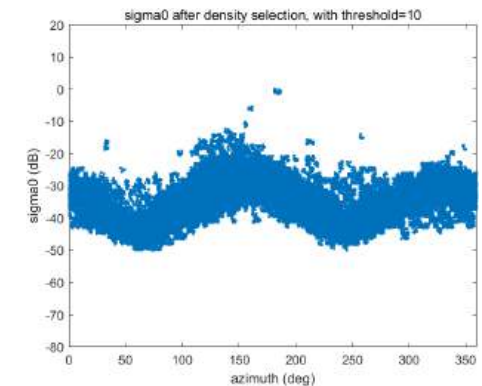
Density > 40
Count: 27797



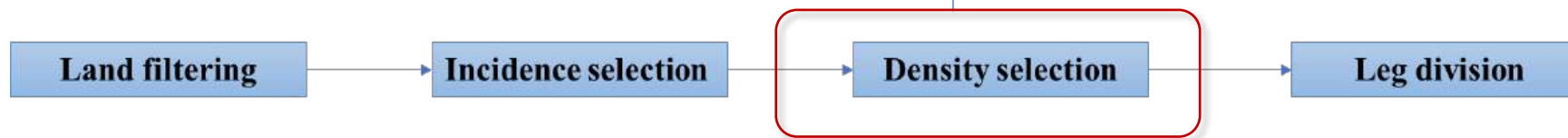
Density > 20
Count: 36755



Density > 30
Count: 32471



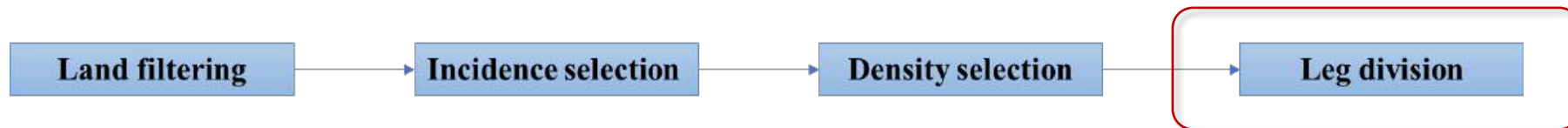
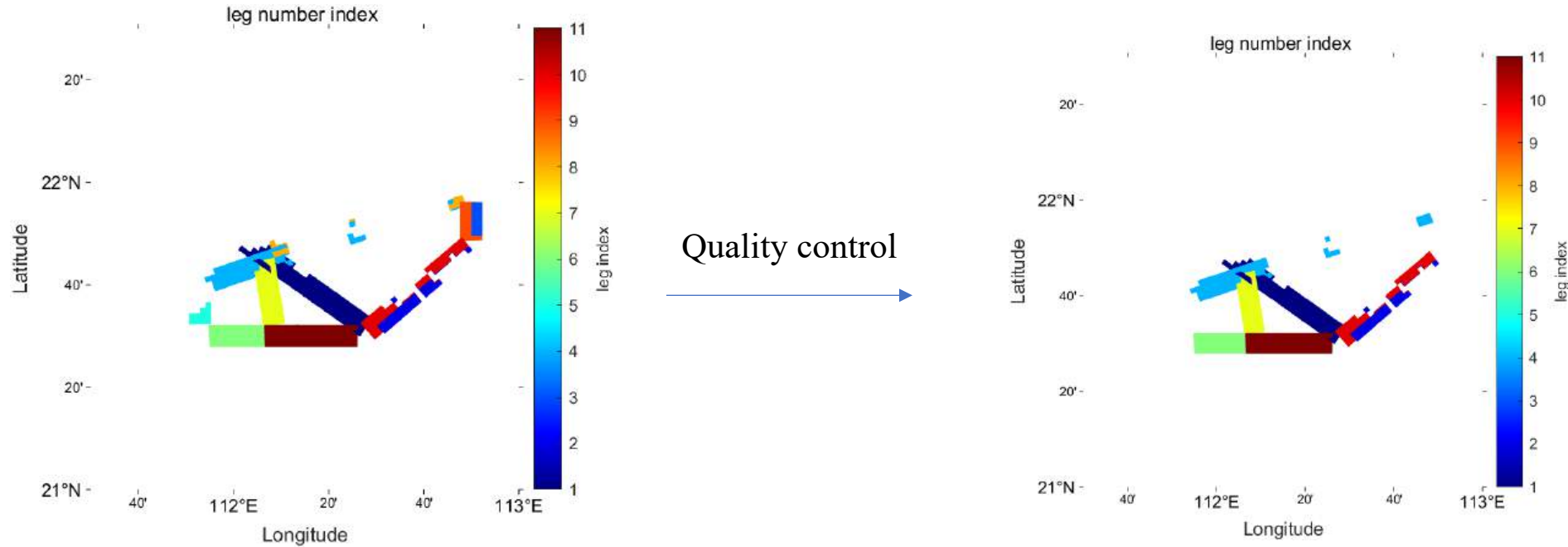
Density > 10
Count: 42384



- Test less constrained noise filtering on both calibration and wind retrieval

1.2 Pre-process (quality control): Leg division

- Divide all data into several flight legs (according to time and location)
- Delete those legs with less data: leg index= 3, 5, 8 & 9

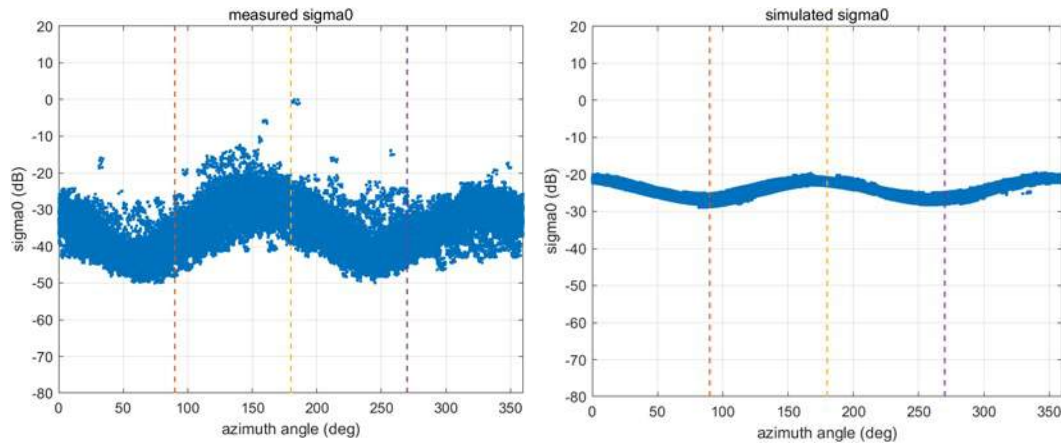


2.1 Calibration: Simulate sigma0

Assumptions:

- Same wind for each leg (both speed and direction);
- The shift of azimuth angle between the measurement and the simulation indicates the ‘true’ wind direction.

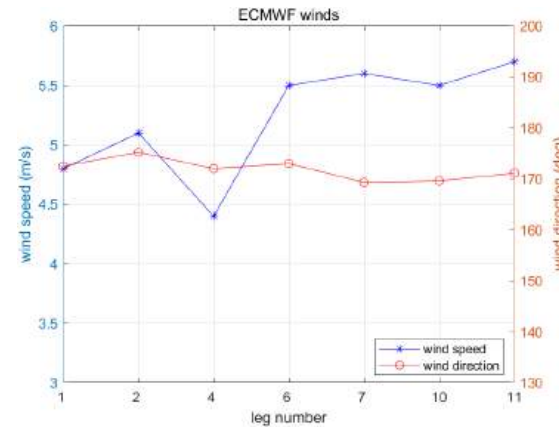
Simulate sigma0 using collocated ECMWF winds and KaDPMoD GMF.



Measured sigma0

Simulated sigma0

- an obvious shift of azimuth angle
- Different directional modulation



Model winds

KaDPMoD GMF



$$\log \sigma_o = A_0(\theta, U) + A_1(\theta, U) \cos \phi + A_2(\theta, U) \cos 2\phi,$$

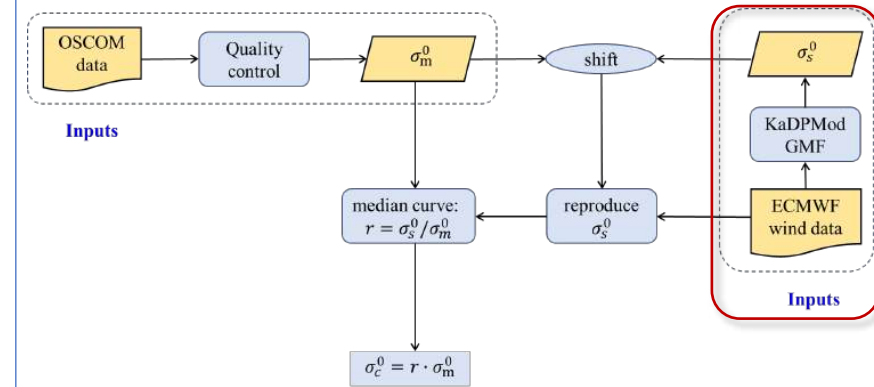


Figure 1. Flow diagram of calibration

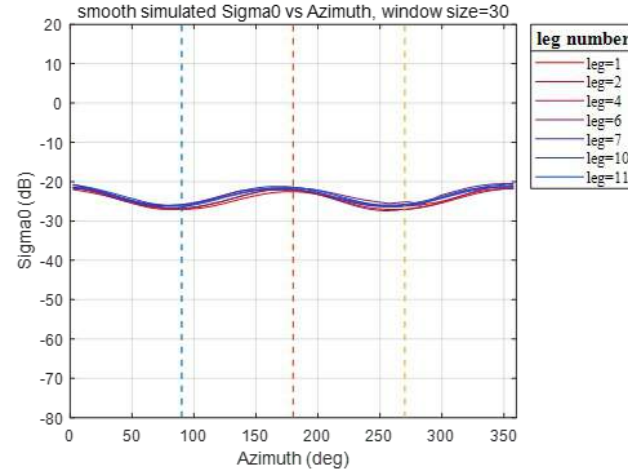
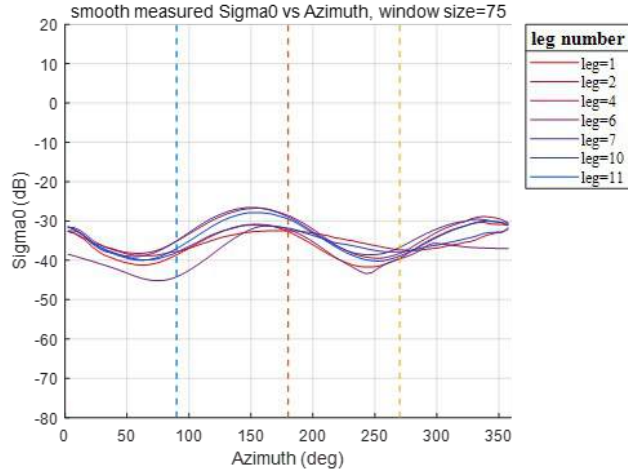
Reference:

Y. Y. Yurovsky, V. N. Kudryavtsev, S. A. Grodsky and B. Chapron, "Ka-Band Dual Copolarized Empirical Model for the Sea Surface Radar Cross Section," in IEEE Transactions on Geoscience and Remote Sensing, vol. 55, no. 3, pp. 1629-1647, March 2017, doi: 10.1109/TGRS.2016.2628640.

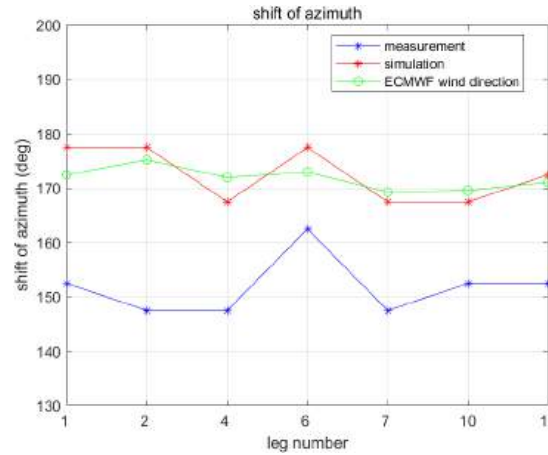
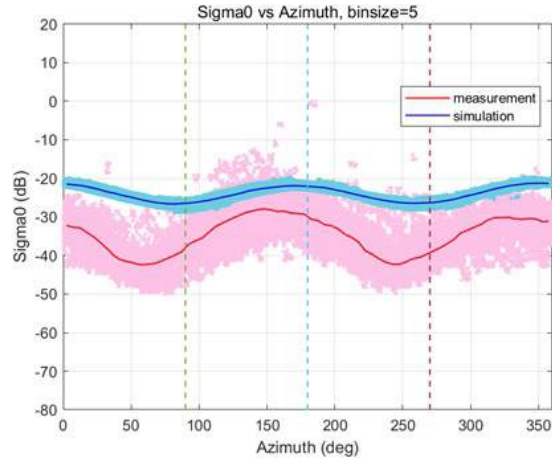
2.2 Calibration: Calculate the shift

Calculate the shift of azimuth angle, which is the ‘true’ wind direction.

1) Calculate and smooth median curves for each leg using low-pass filter



2) Calculate the shift for all legs



Shift: ‘True’ wind direction

- measurement = 155°
- Simulation = 175°

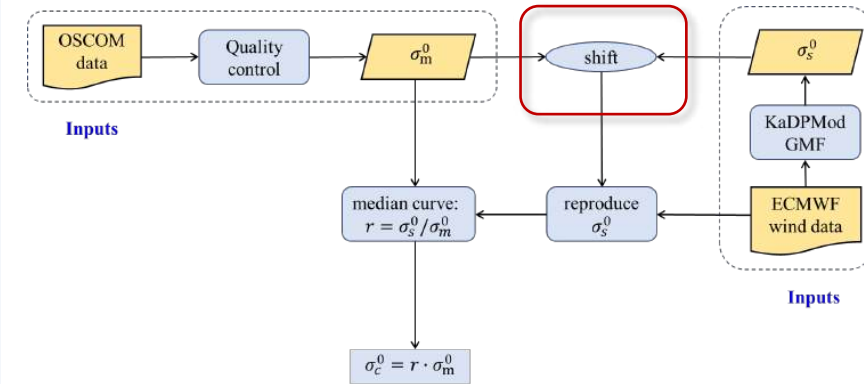


Figure 1. Flow diagram of calibration

2.3 Calibration: calibrate sigma0 using the shift

1. For each leg, reproduce simulated sigma0 using the ‘true’ wind direction and ECMWF wind speed
2. Calculate new simulated median curve for the whole region
3. Calibrate measurement using the calibration ratio for each azimuth bin:
 (1) a overall calibration: $r = \sigma_s^0 / \sigma_m^0$

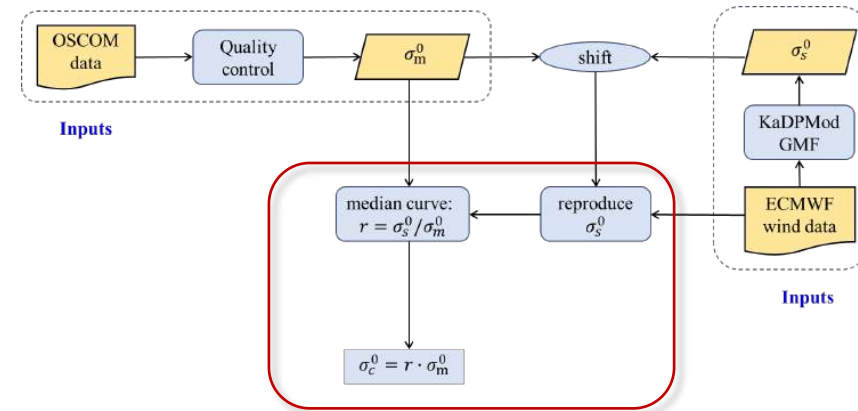
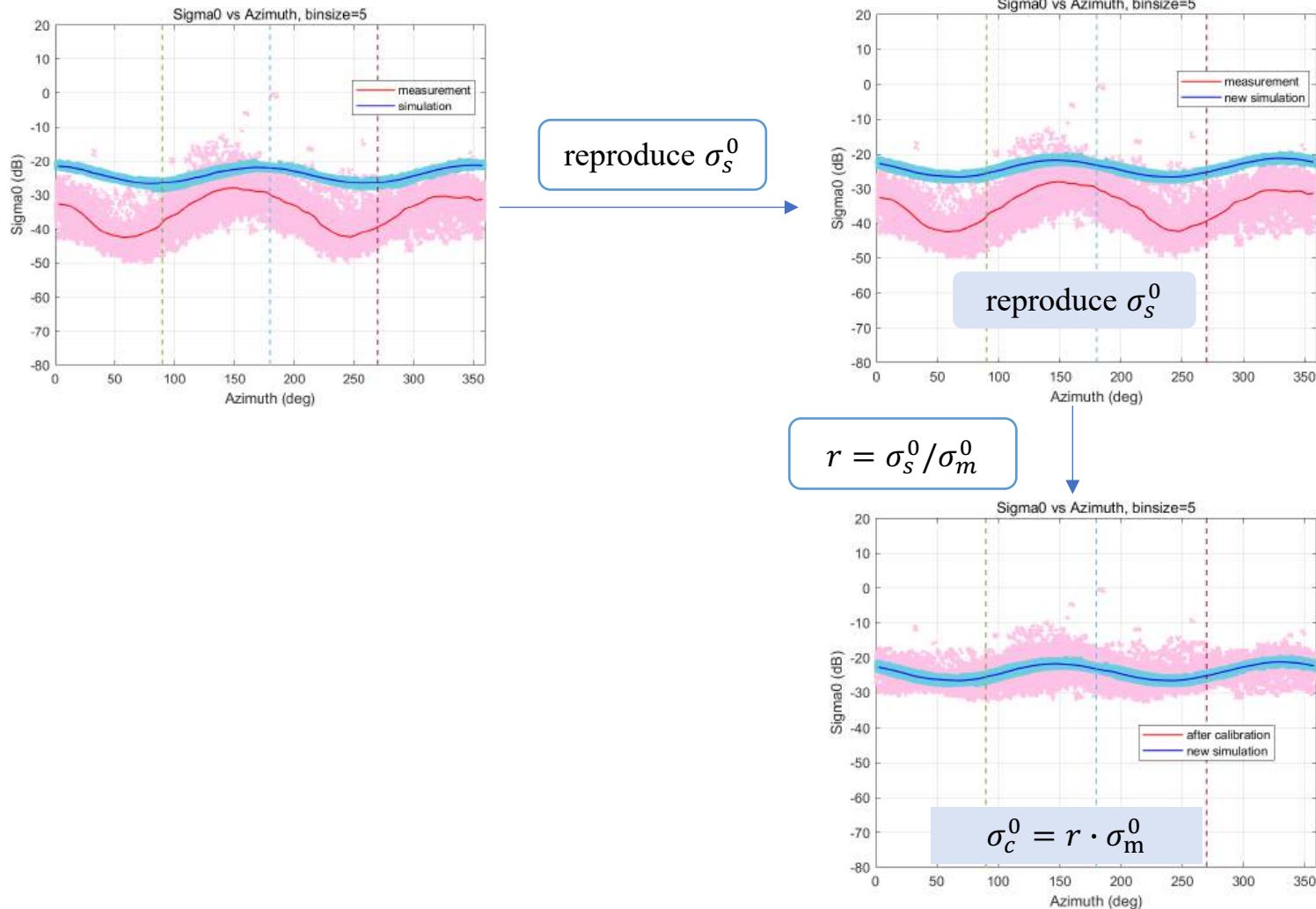


Figure 1. Flow diagram of calibration

2.3 Calibration: calibrate sigma0 using the shift

1. For each leg, reproduce simulated sigma0 using the 'true' wind direction and ECMWF wind speed
2. Calculate new simulated median curve for the whole region
3. Calibrate measurement using the calibration ratio for each azimuth bin:
(2) calibrate each leg individually: $r_i = \sigma_{s,i}^0 / \sigma_{m,i}^0$

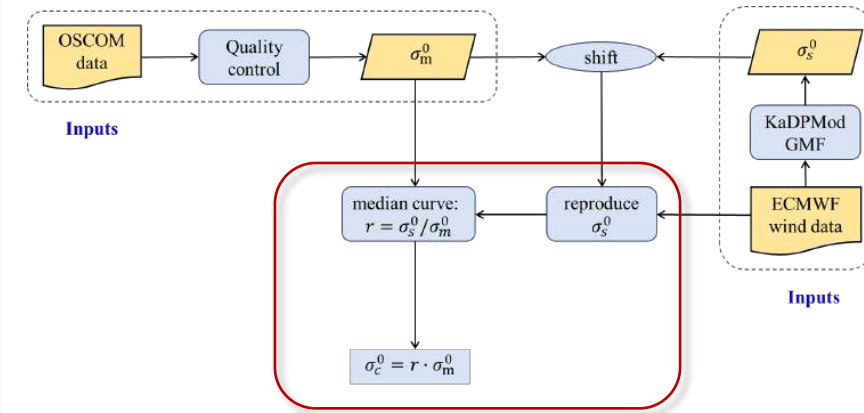
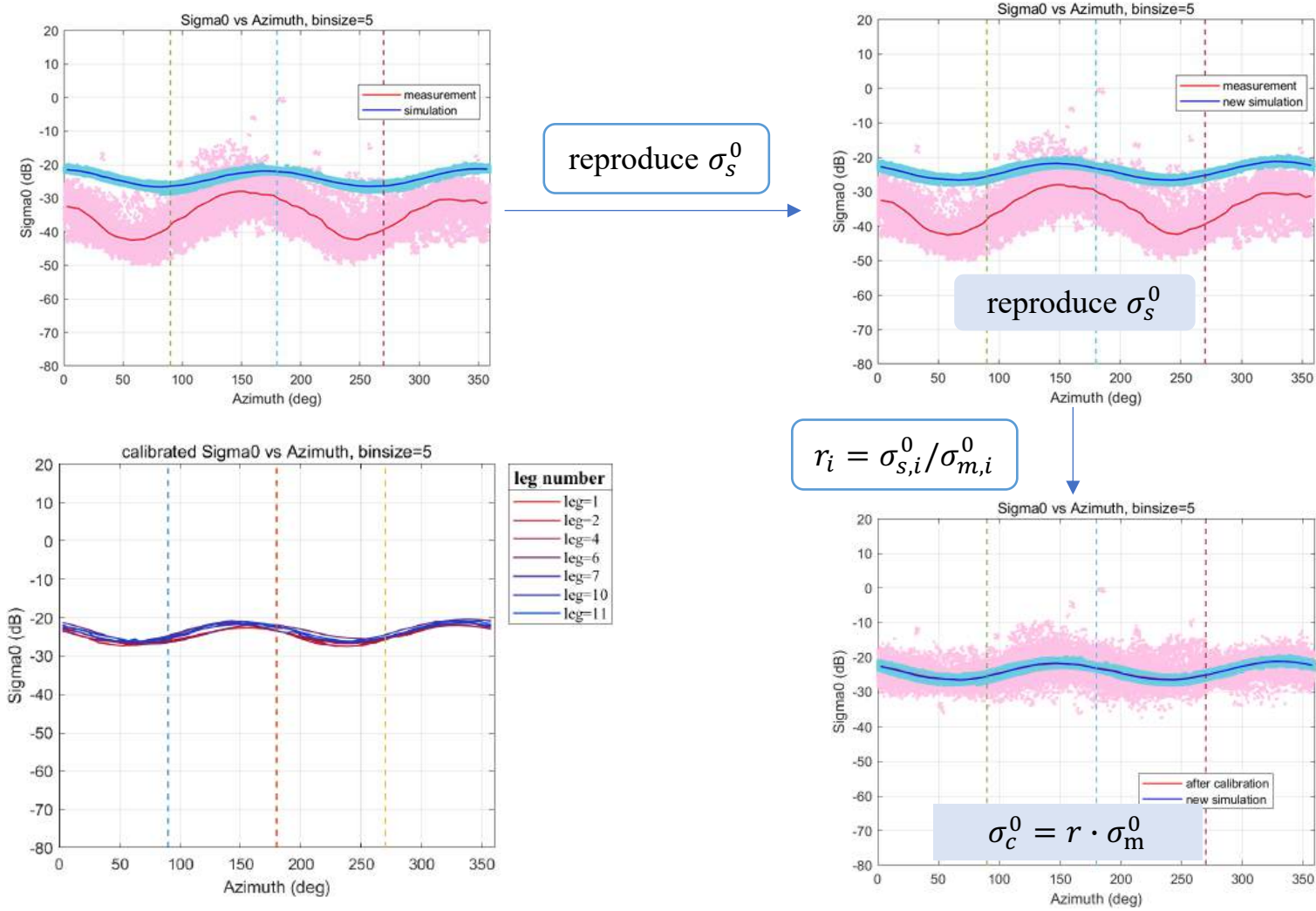
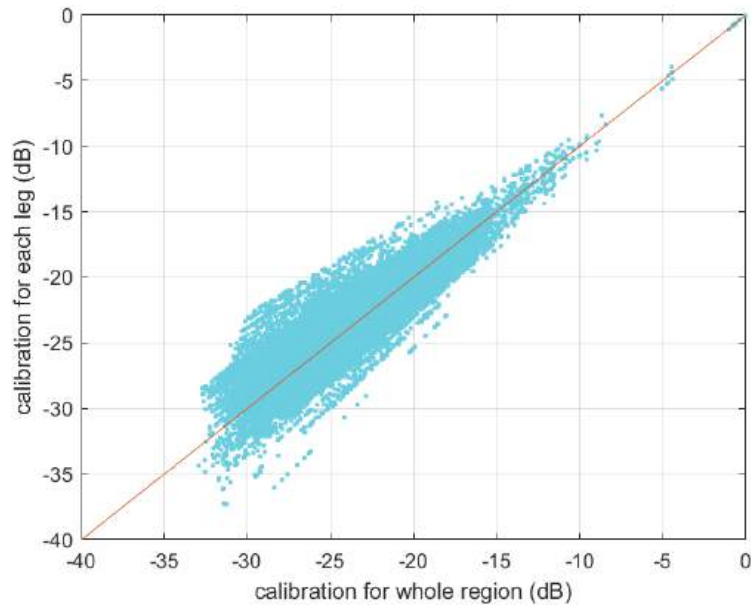


Figure 1. Flow diagram of calibration

2.3 Calibration: calibrate sigma0 using the shift

1. For each leg, reproduce simulated sigma0 using the 'true' wind direction and ECMWF wind speed
2. Calculate new simulated median curve for the whole region
3. Calibrate measurement using the calibration ratio for each azimuth bin:
 - (1) a overall calibration: $r = \sigma_s^0 / \sigma_m^0$
 - (2) calibrate each leg individually: $r_i = \sigma_{s,i}^0 / \sigma_{m,i}^0$



Correlation Coefficient = 0.8966
 $R^2 = 0.8002$

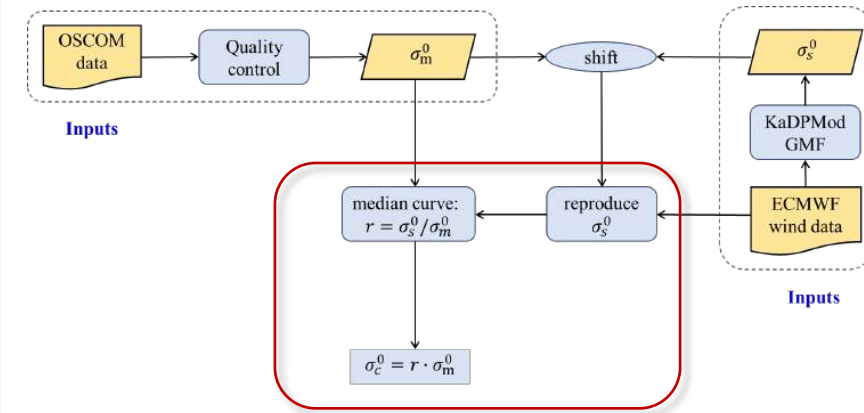
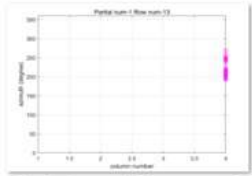
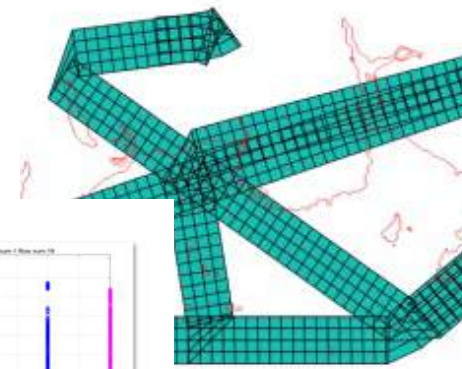


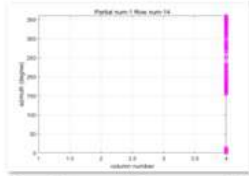
Figure 1. Flow diagram of calibration

2.4 Wind Inversion: with calibrated sigma0

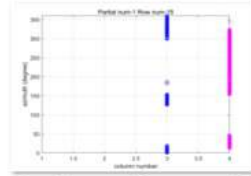
Azimuth Separation: take leg 1 as an example



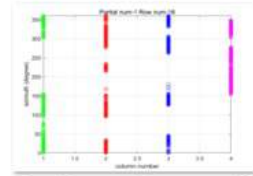
Partial num-1 Row num-13



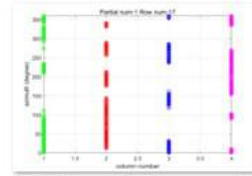
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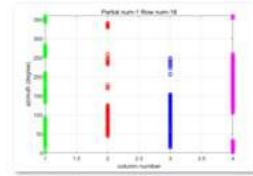
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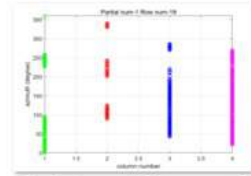
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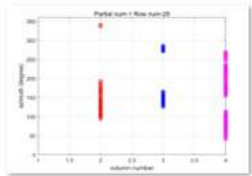
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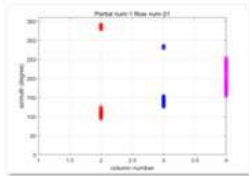
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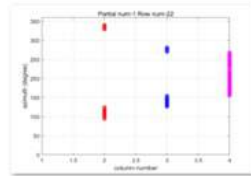
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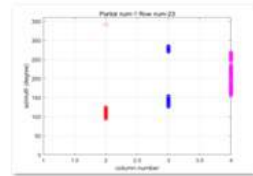
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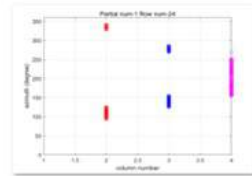
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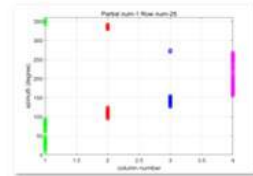
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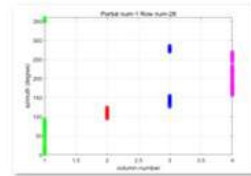
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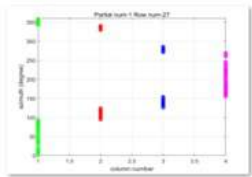
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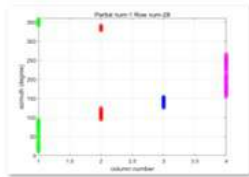
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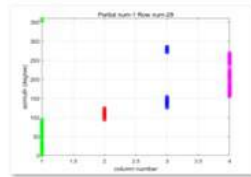
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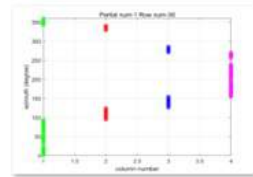
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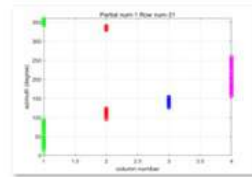
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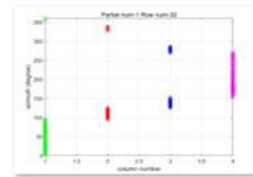
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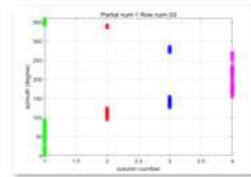
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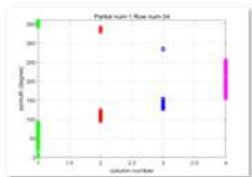
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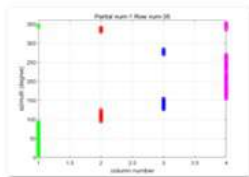
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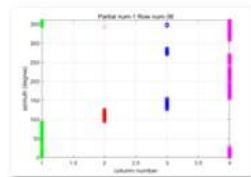
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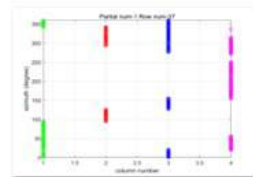
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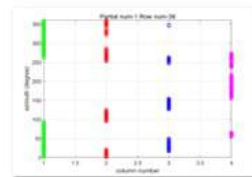
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Partial num-1 Row num-36



Partial num-1 Row num-37



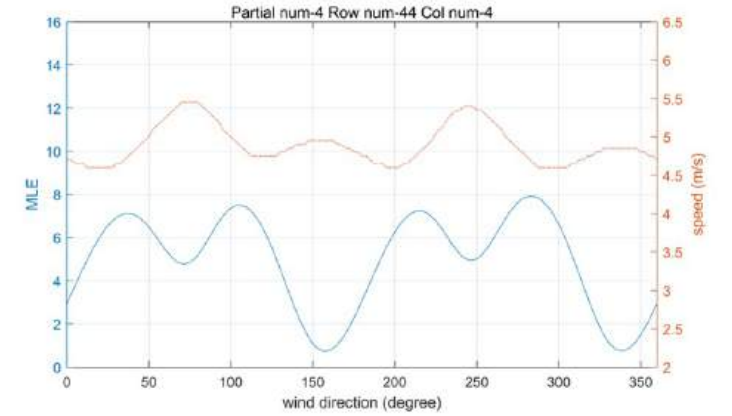
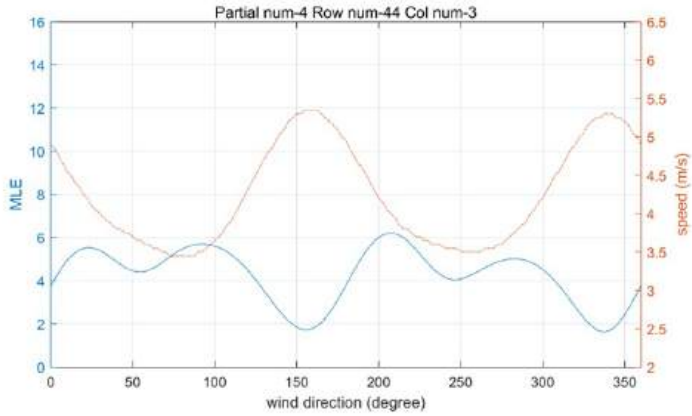
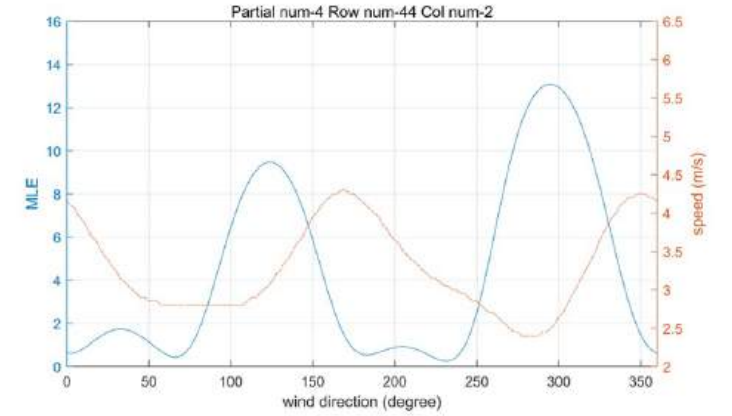
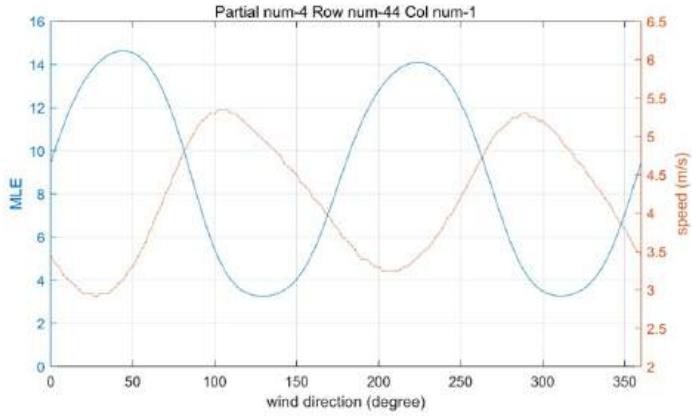
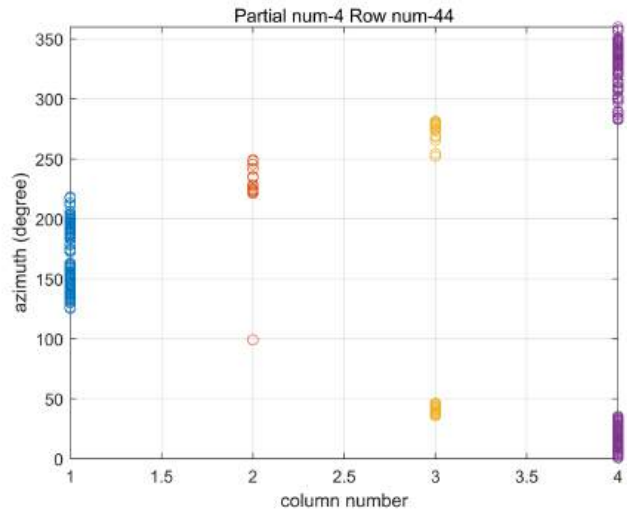
Partial num-1 Row num-38

Sweet region: Node 2 & 3 which have relatively good azimuth separation between fore and aft views

Outer region: Node 1 & 4 where azimuth separation between fore and aft views is small, but they have continuous azimuth

2.4 Wind Inversion: with calibrated σ_0

MLE: take one row in leg 4 as an example



4 ambiguous solutions

Number of ambiguous solutions depends on geometry

2.4 Wind Inversion: with calibrated sigma0

- Sampling issues: OSCOM viewing geometry (platform attitude?)
- Relatively high measurement noise; sigma0 averaging in 2.5° bins

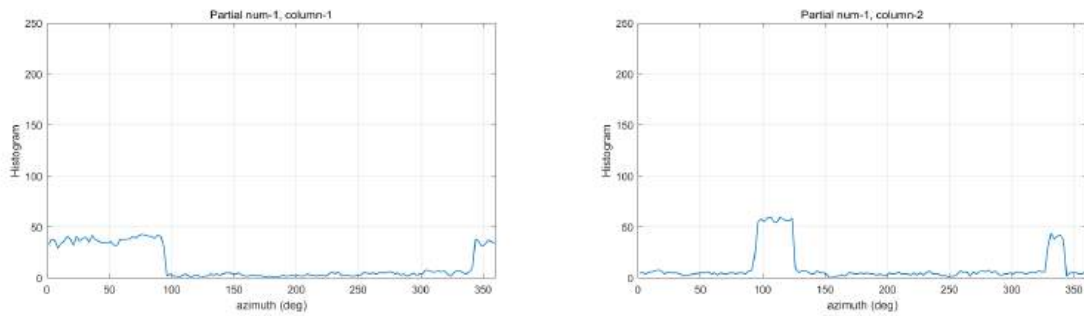


Figure 2.7.1 The Histogram of azimuth for each column before filtering.

filtering

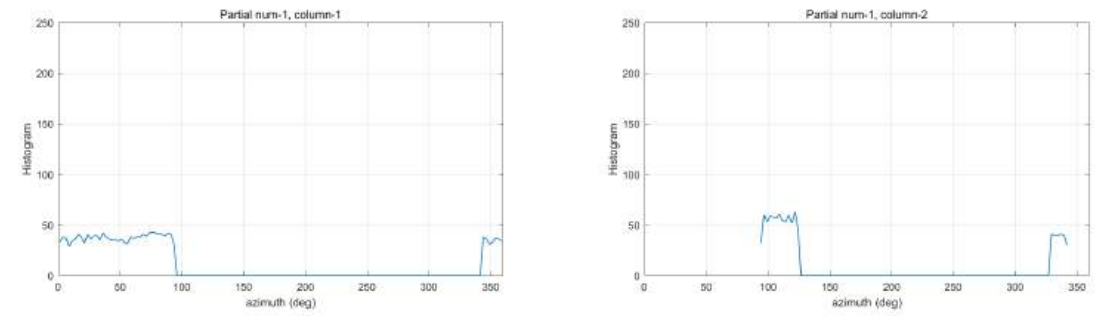


Figure 2.7.2 The Histogram of azimuth for each column after filtering.

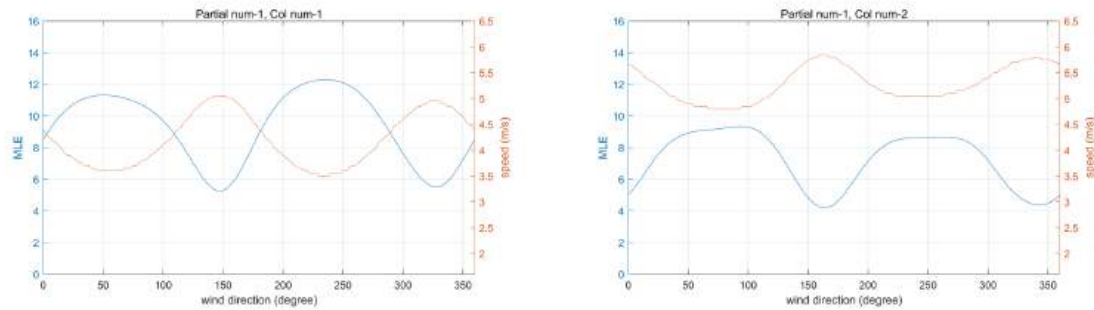


Figure 2.7.3 The MLE cost function (blue curve) and speed (orange curve) before filtering.

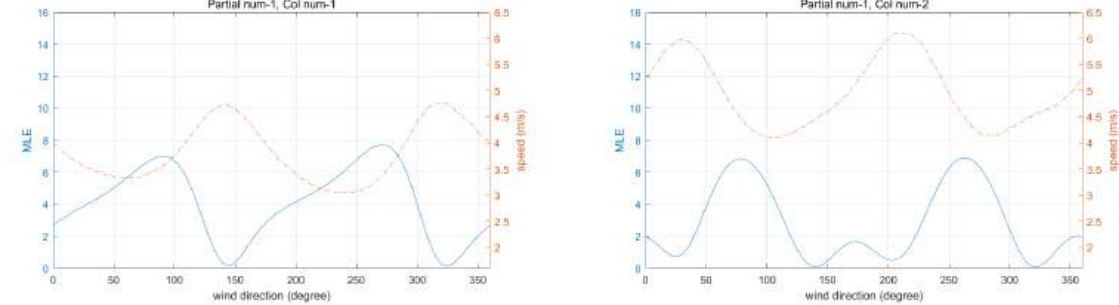
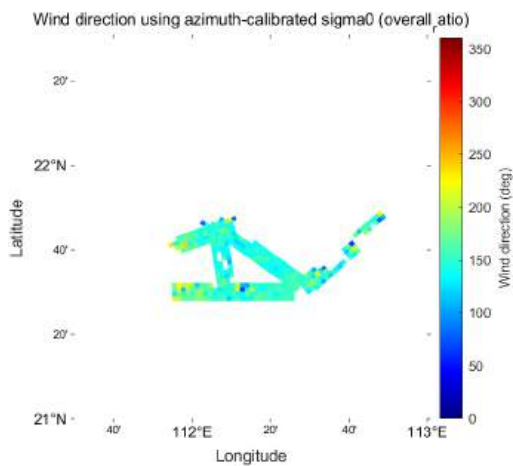
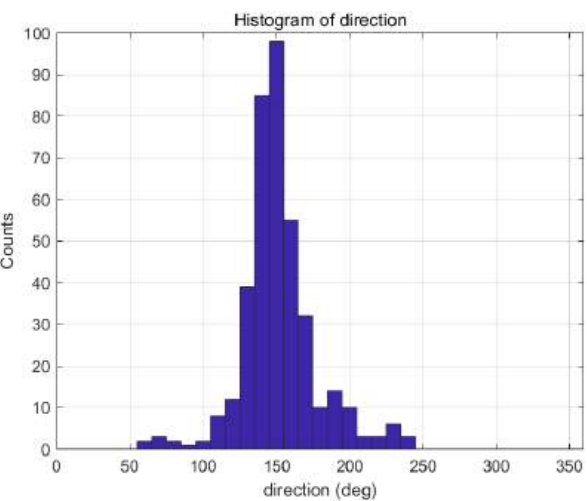
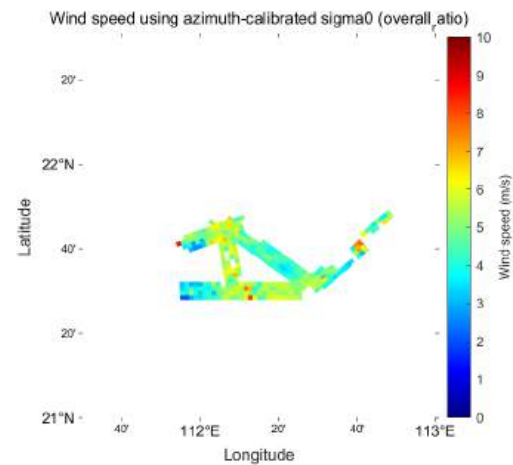
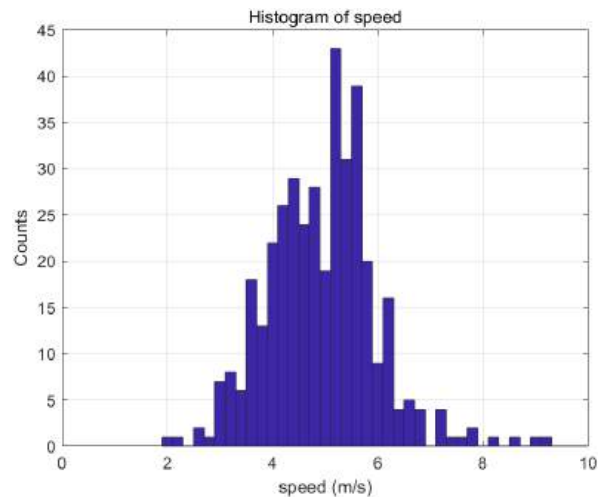


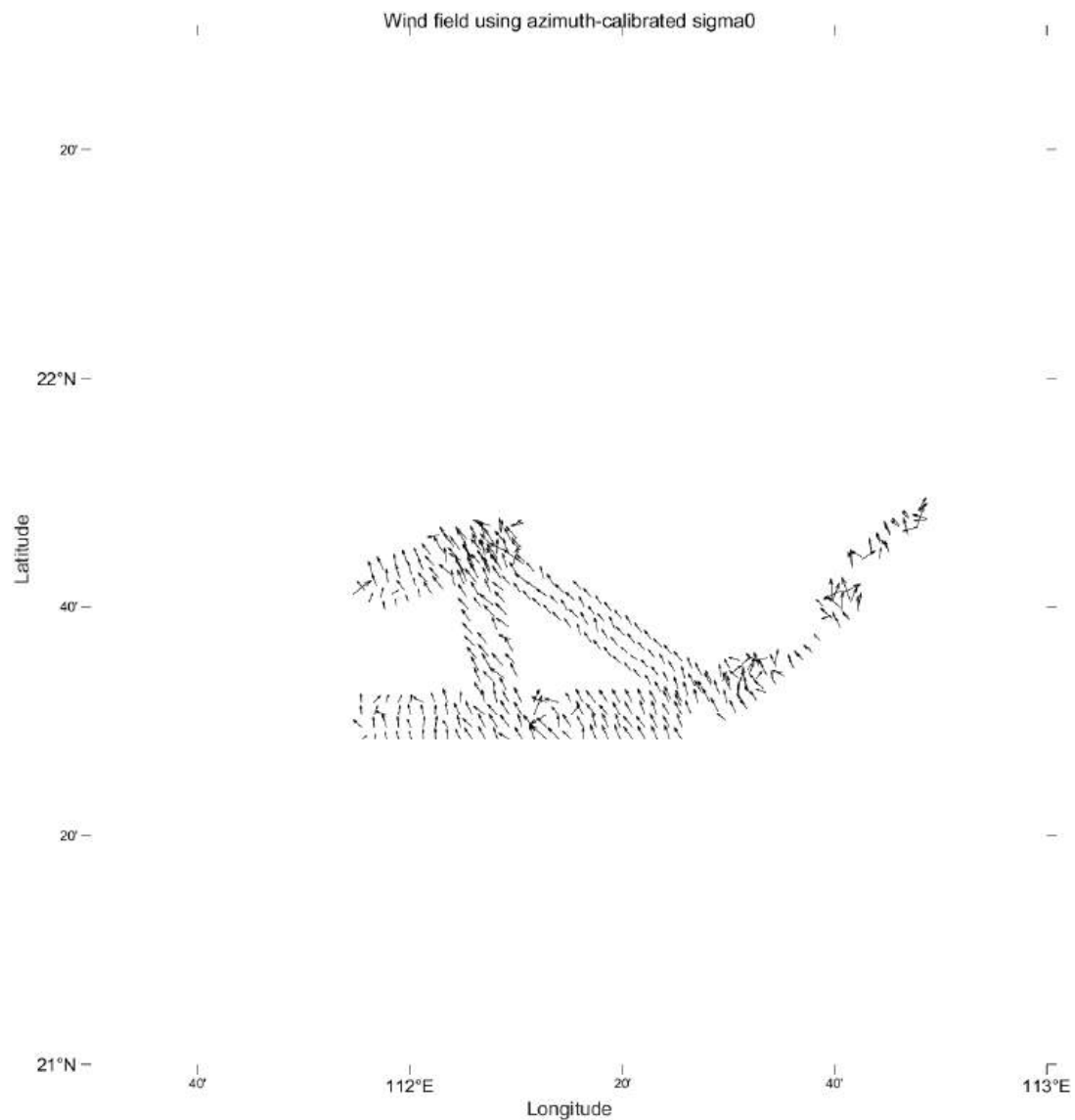
Figure 2.7.4 The MLE cost function (blue curve) and speed (orange curve) after filtering.

2.4 Wind Inversion: with calibrated sigma0

(1) a overall calibration: $r = \sigma_s^0 / \sigma_m^0$



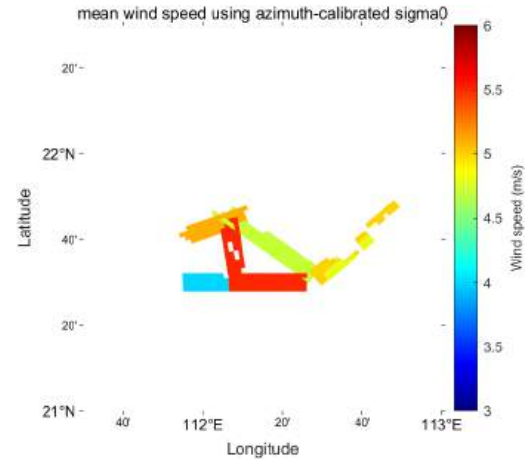
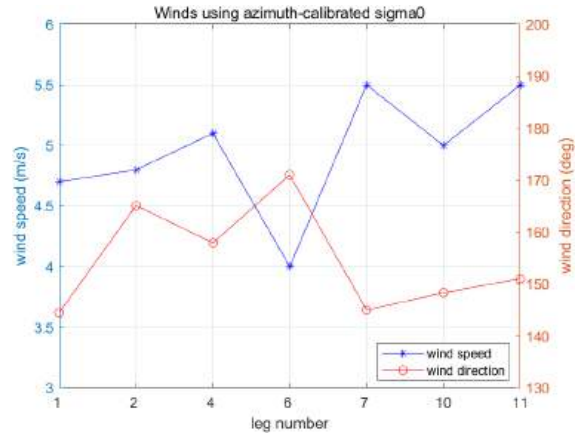
Wind field using azimuth-calibrated sigma0



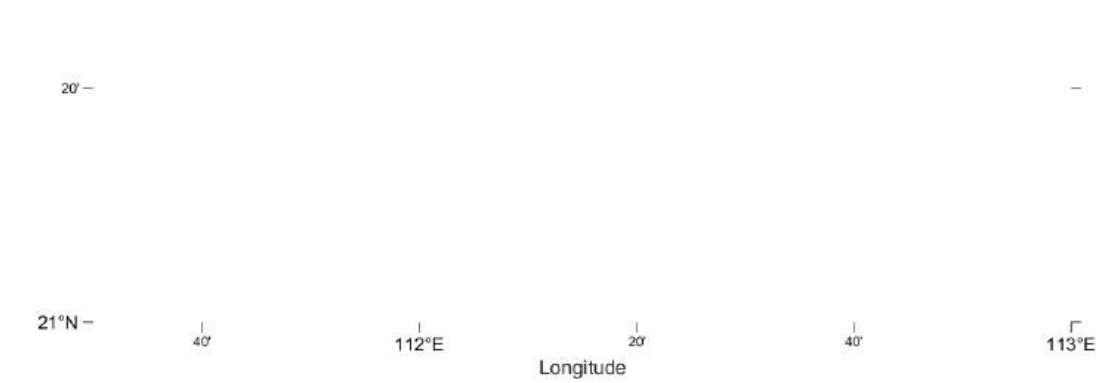
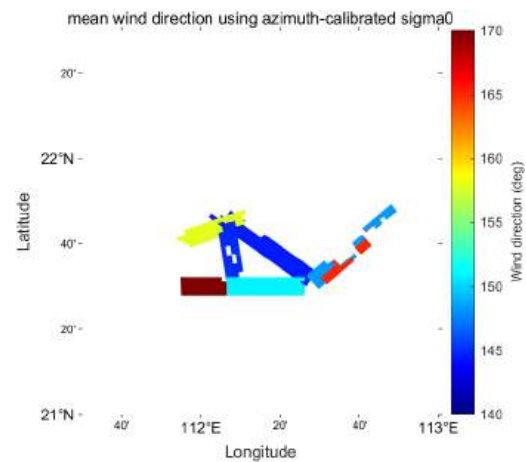
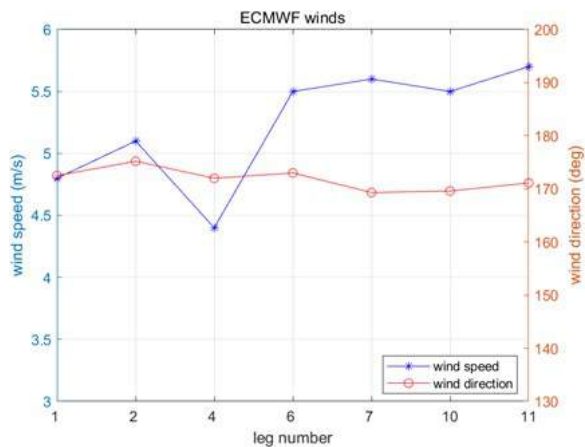
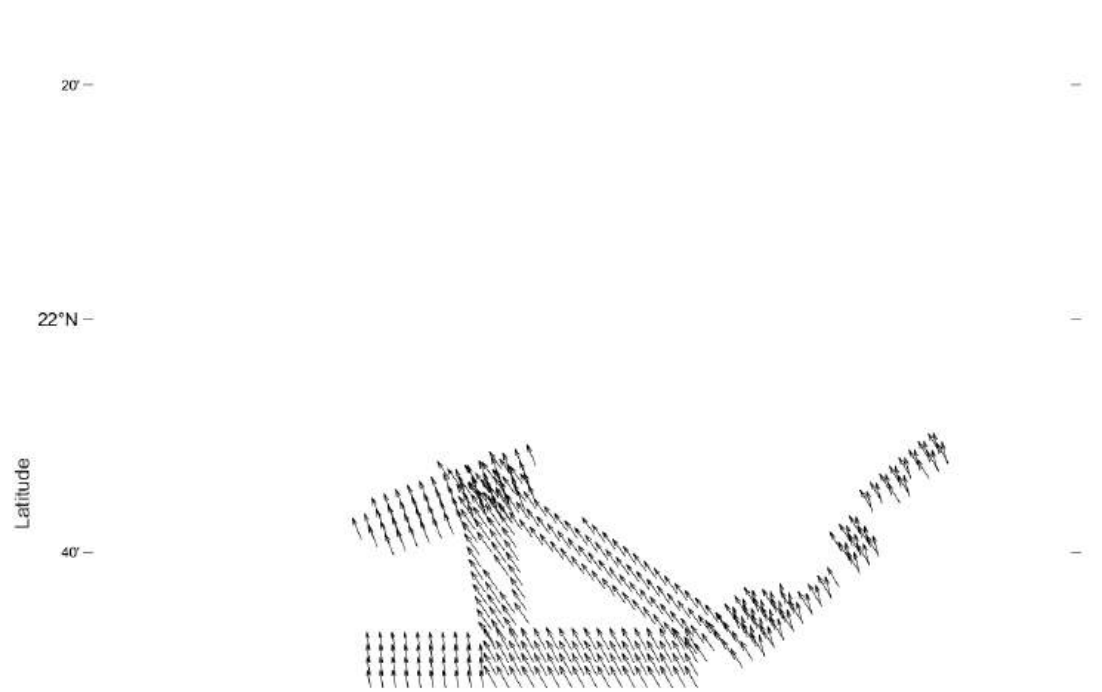
2.4 Wind Inversion: with calibrated sigma0

(1) a overall calibration: $r = \sigma_s^0 / \sigma_m^0$

Mean wind for each leg



mean wind field using azimuth-calibrated sigma0



2.5 Wind Inversion: with modified GMF

Assumptions:

- Same wind for each leg (both speed and direction);
 - The shift of azimuth angle between the measurement and the simulation indicates the ‘true’ wind direction.
1. Simulate sigma0 using collocated ECMWF winds and KaDPMoD GMF.
 2. Calculate the shift of azimuth angle, which is the ‘true’ wind direction.
 3. For each leg, reproduce simulated sigma0 using the ‘true’ wind direction and ECMWF wind speed.
 4. Calibrate measurement using NOC method.
 5. Modify KaDPMoD GMF using mean sigma0 of new simulation and calibration.
 6. Inverse wind field with calibrated sigma0 and modified GMF.

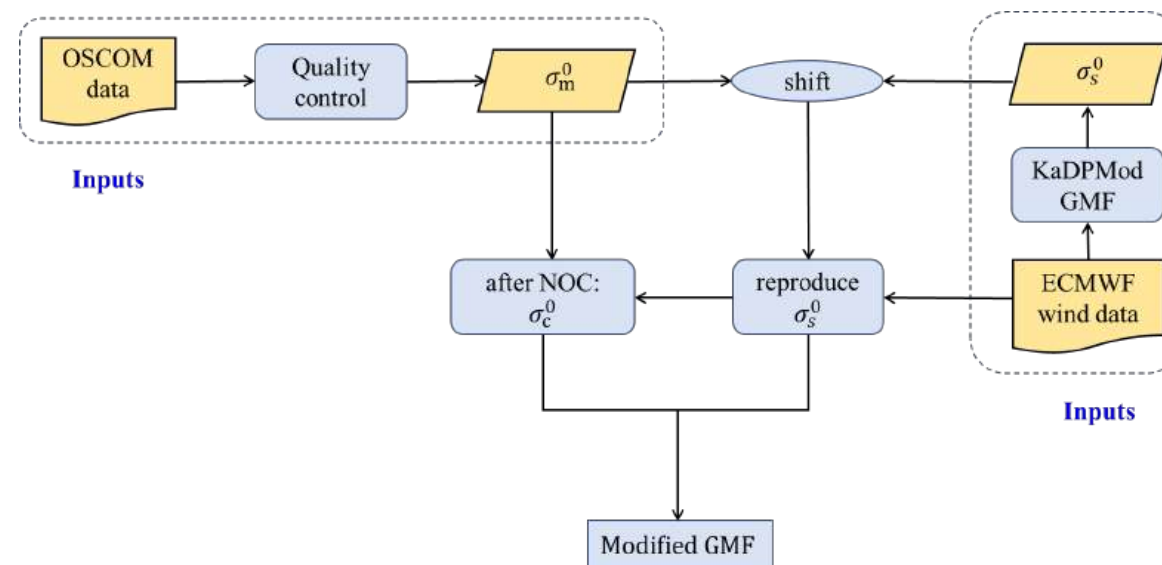
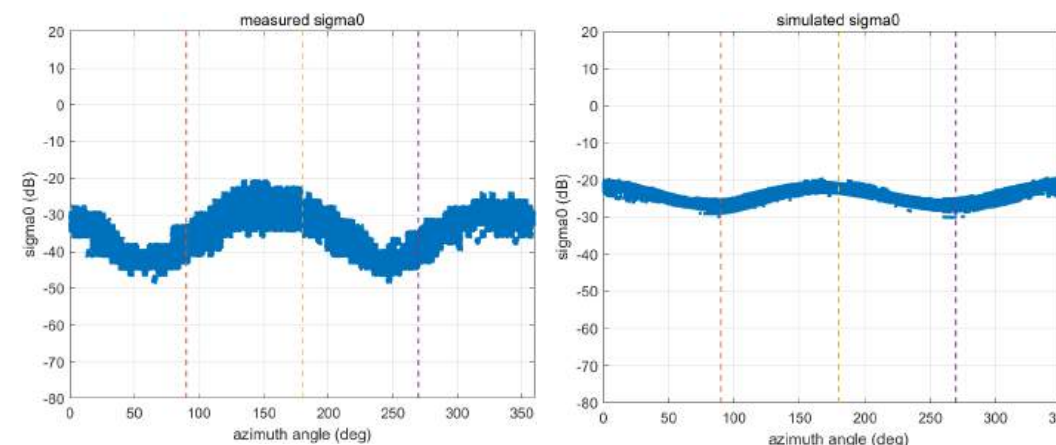


Figure 2. Flow diagram of GMF modification



Measured sigma0

Simulated sigma0

- an obvious shift of azimuth angle
- Different directional modulation

2.5 Wind Inversion: with modified GMF

Modification of KaDPMoD GMF

1. Assume two correction coefficient in the model: **a2_coef** and **a3_coef**.

KaDPMoD:

$$\log \sigma_o = A_0(\theta, U) + A_1(\theta, U) \cos \phi + A_2(\theta, U) \cos 2\phi, \quad (1)$$

Modified GMF:

$$\log \sigma_0 = A_0 + A_1 * \cos \varphi * \mathbf{a2_coef} + A_2 * \cos 2\varphi * \mathbf{a3_coef} \quad (2)$$

2. Calculate the mean sigma0 as a function of azimuth for both measurement and simulation (as shown in Fig. 1).

3. Fit two curves with equation (3).

4. Calculate **a2_coef** and **a3_coef** with equation (4).

5. New GMF is generated.

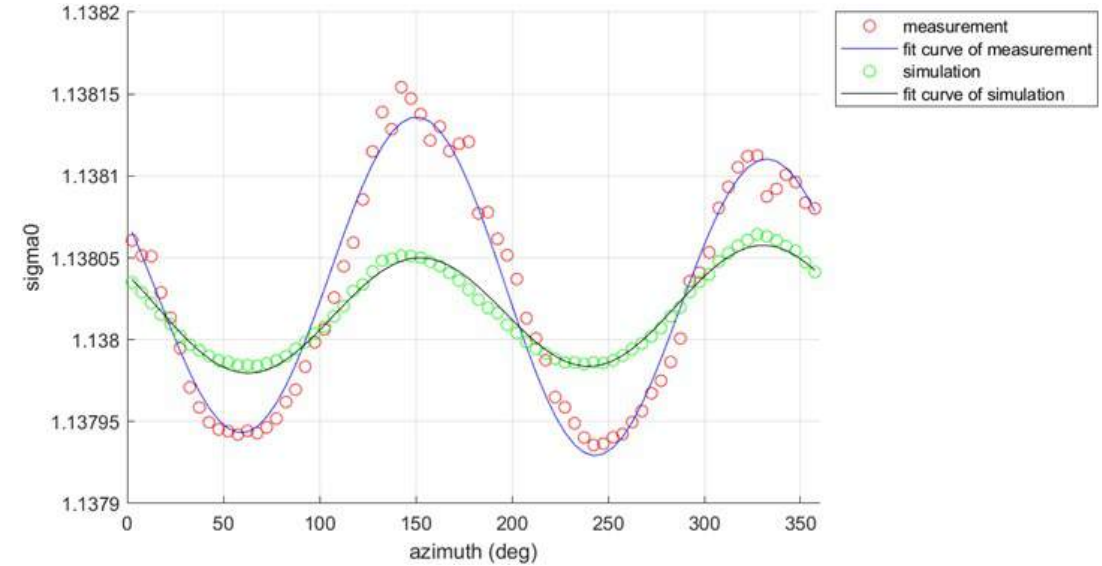


Fig. 1. mean sigma0

$$f(x) = a_1 + a_2 * \cos(x + b) + a_3 * \cos(2 * x + b) \quad (3)$$

```
General model:
fitted_curve_measurement(x) = a1+a2*cos(x+b)+a3*cos(2*x+b)
Coefficients (with 95% confidence bounds):
a1 = 1.138 (1.138, 1.138)
a2 = -1.461e-05 (-1.856e-05, -1.037e-05)
a3 = 9.337e-05 (8.912e-05, 9.762e-05)
b = 1 (0.9551, 1.045)
```

```
General model:
fitted_curve_GMF(x) = a1+a2*cos(x+b)+a3*cos(2*x+b)
Coefficients (with 95% confidence bounds):
a1 = 1.138 (1.138, 1.138)
a2 = 4.36e-06 (3.217e-06, 5.504e-06)
a3 = 3.608e-05 (3.494e-05, 3.723e-05)
b = 1 (0.9685, 1.031)
```

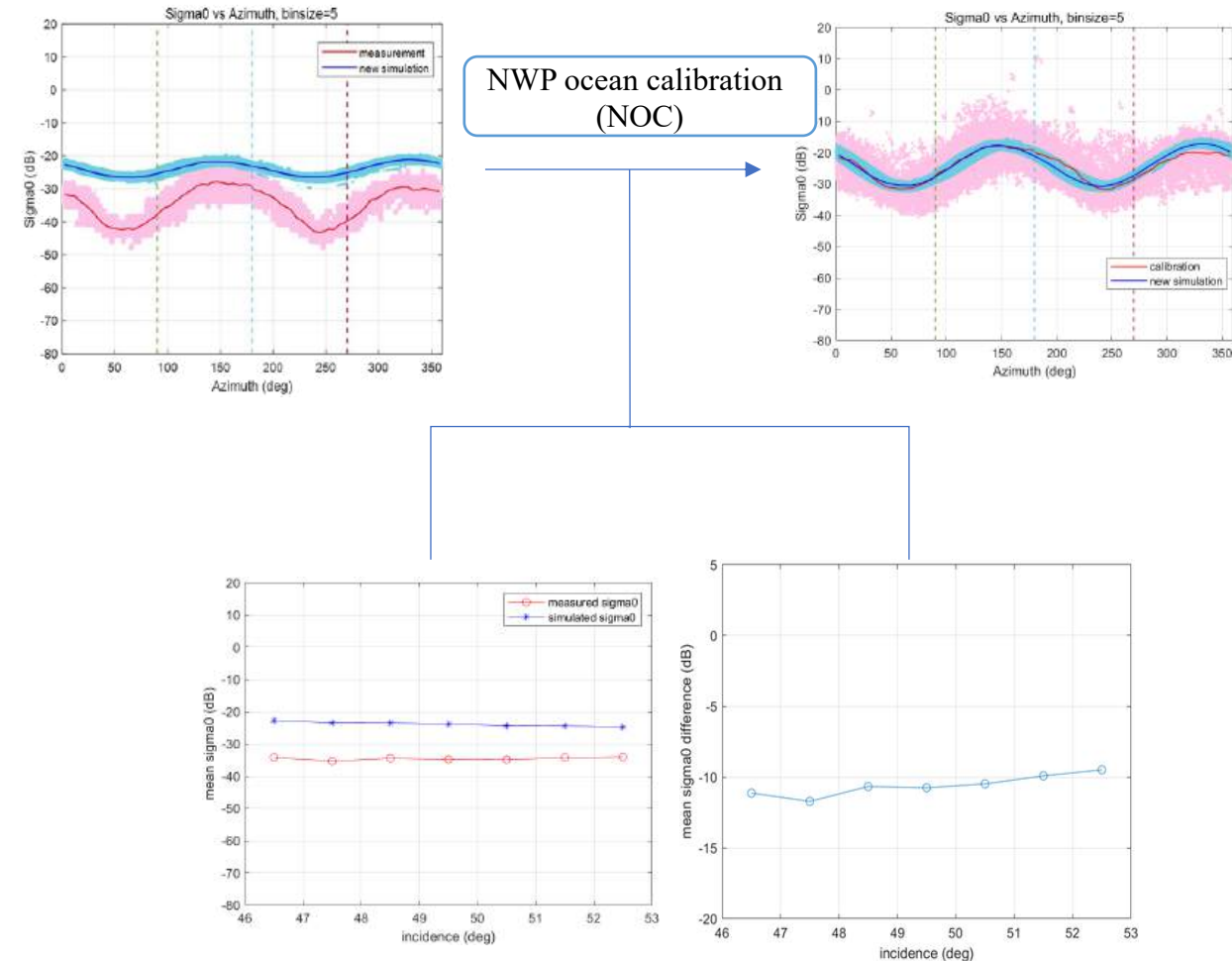
$$\begin{aligned} \mathbf{a2_coef} &= \mathbf{a2_measurement} / \mathbf{a2_GMF} \\ \mathbf{a3_coef} &= \mathbf{a3_measurement} / \mathbf{a3_GMF} \end{aligned} \quad (4)$$

2.5 Wind Inversion: with modified GMF

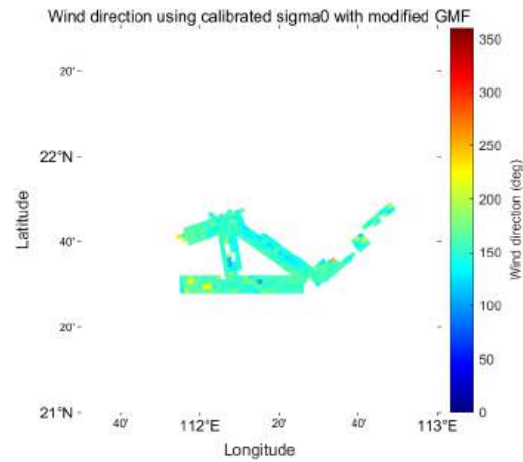
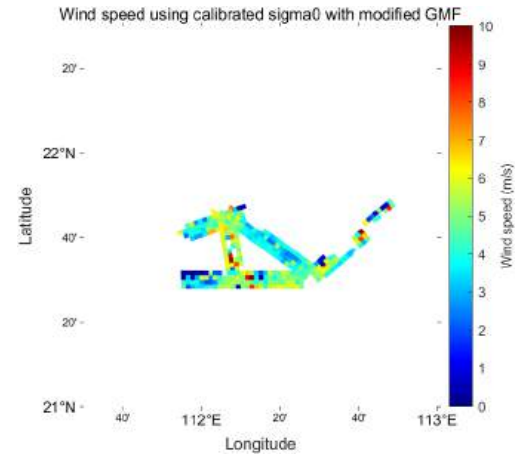
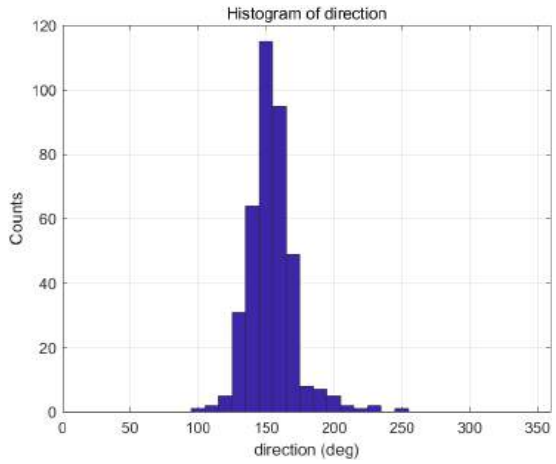
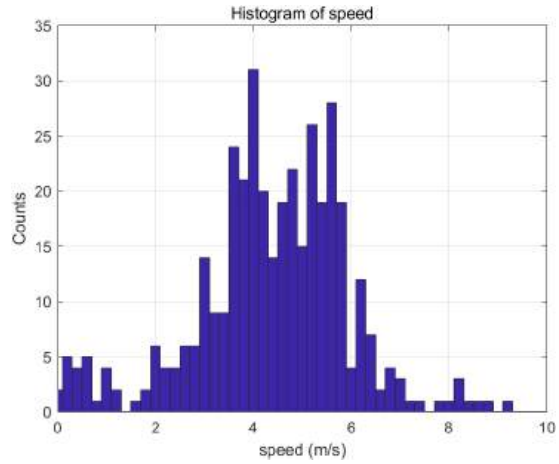
Assumptions:

- Same wind for each leg (both speed and direction);
- The shift of azimuth angle between the measurement and the simulation indicates the 'true' wind direction.

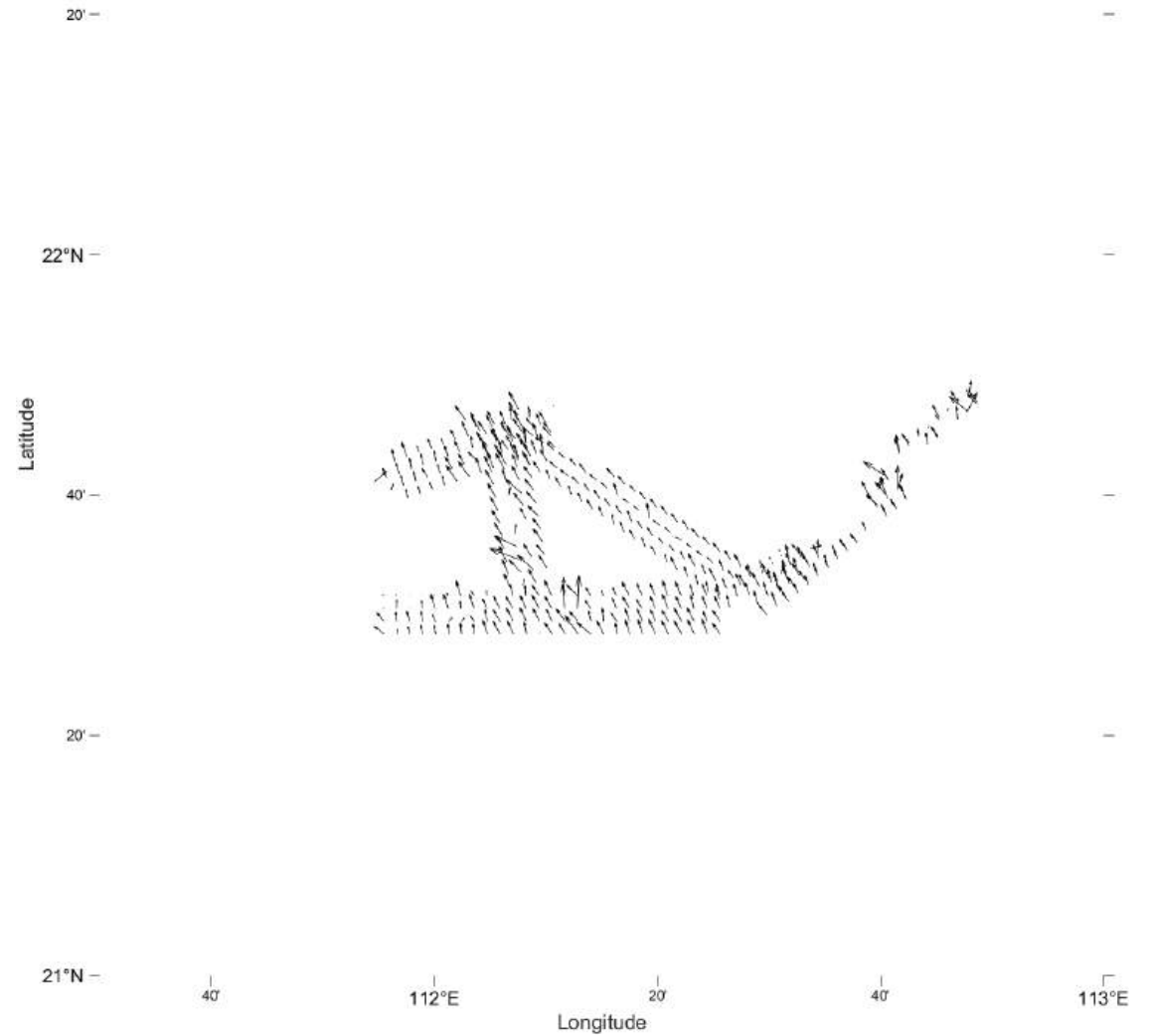
1. Simulate σ_0 using collocated ECMWF winds and KaDPMoD GMF.
2. Calculate the shift of azimuth angle, which is the 'true' wind direction.
3. For each leg, reproduce simulated σ_0 using the 'true' wind direction and ECMWF wind speed.
4. Calibrate measurement using NOC method.
5. Modify KaDPMoD GMF using mean σ_0 of new simulation and calibration.
6. Inverse wind field with calibrated σ_0 and modified GMF.



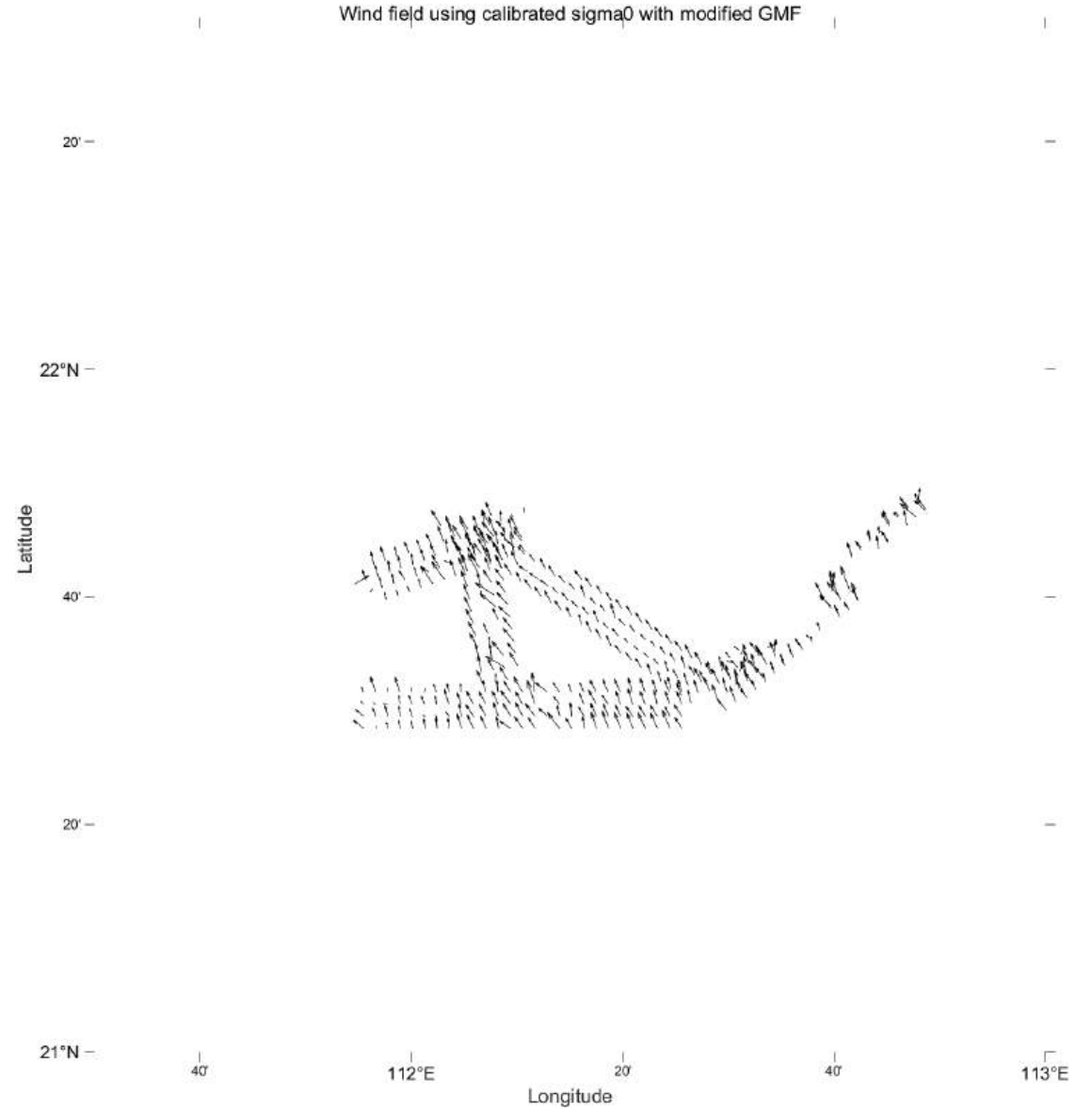
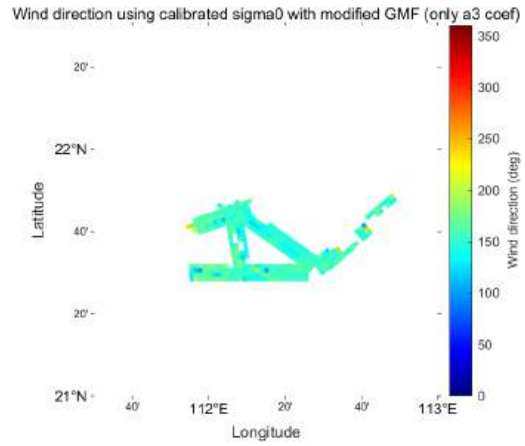
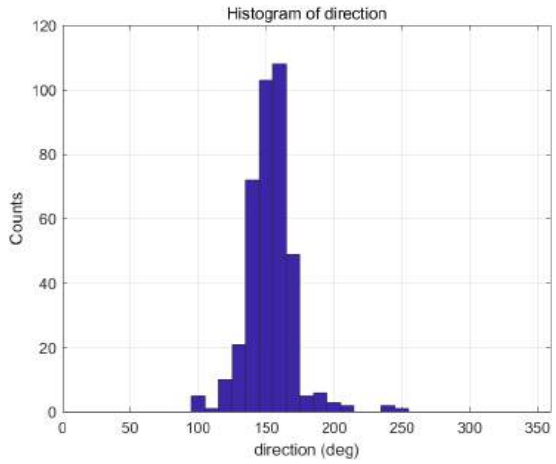
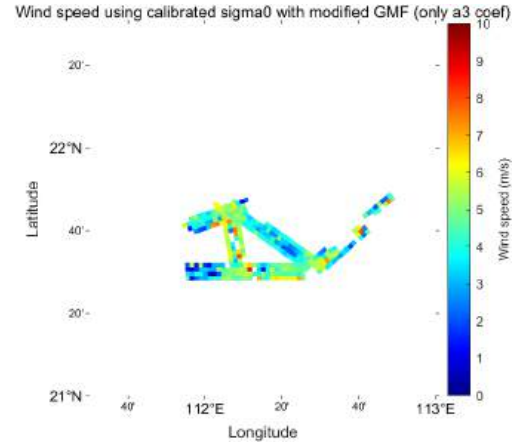
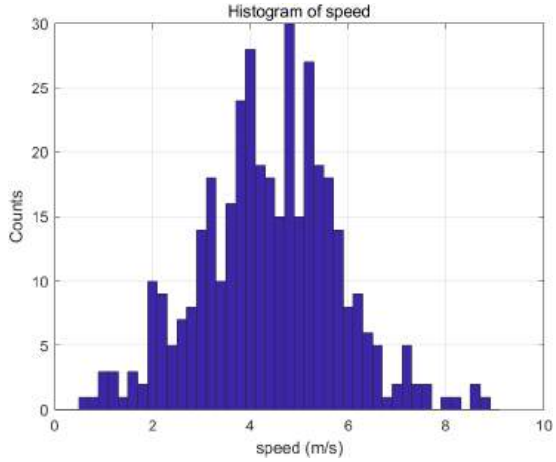
2.5 Wind Inversion: with modified GMF



Wind field using calibrated sigma0 with modified GMF



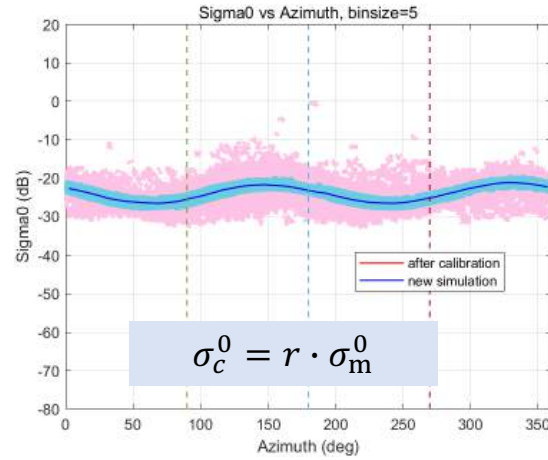
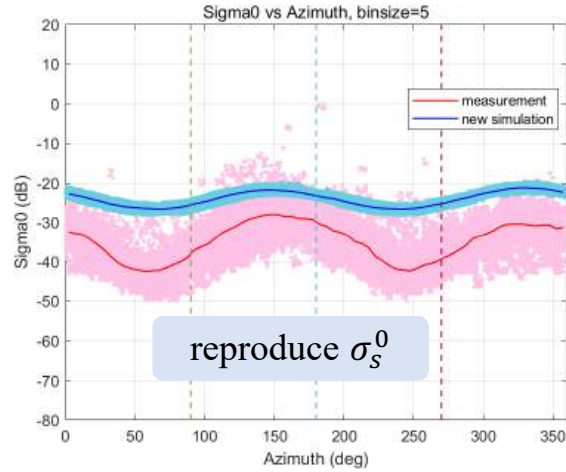
2.5 Wind Inversion: with modified GMF (only a3_coef)



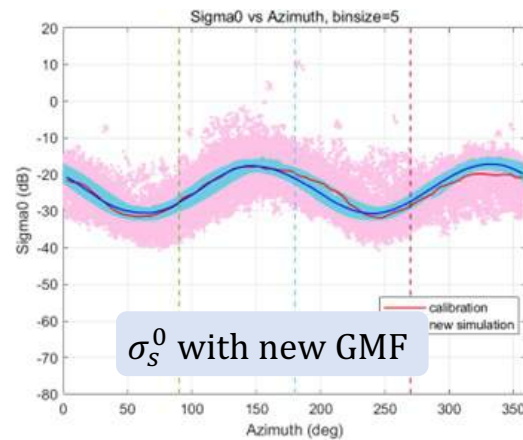
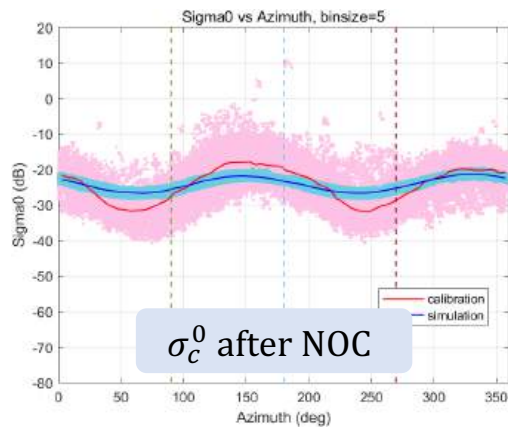
2.6 Comparison

3) Sigma0 as a function of azimuth

- Method 1: using azimuth-calibrated sigma0



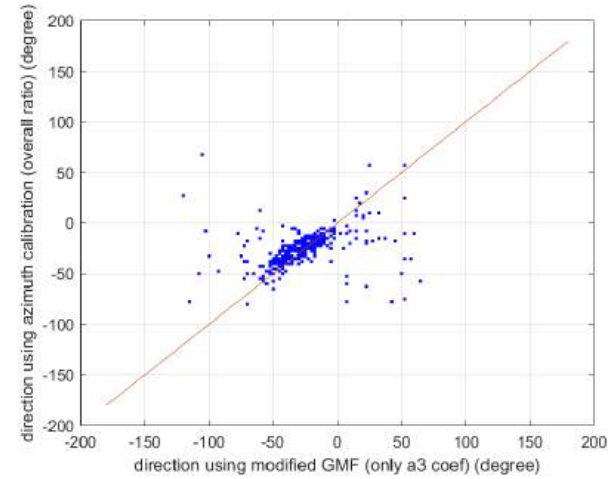
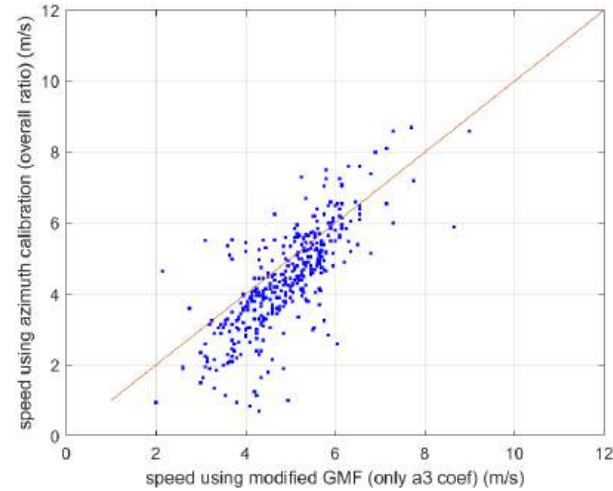
- Method 2: using modified GMF



2.6 Comparison

1) Retrieved winds

- Comparison between winds using 2 methods

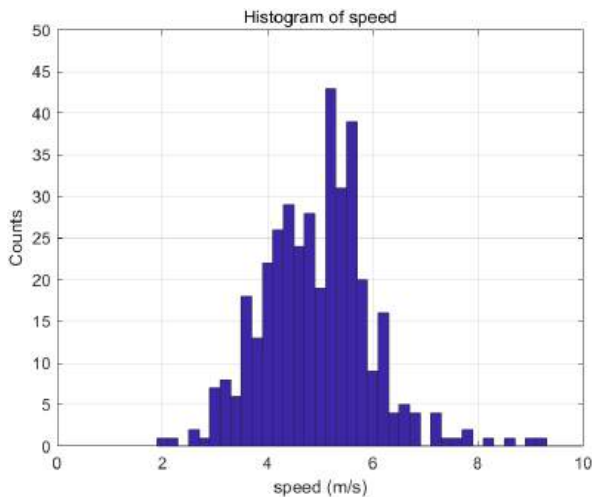


2) Comparison against ECMWF:

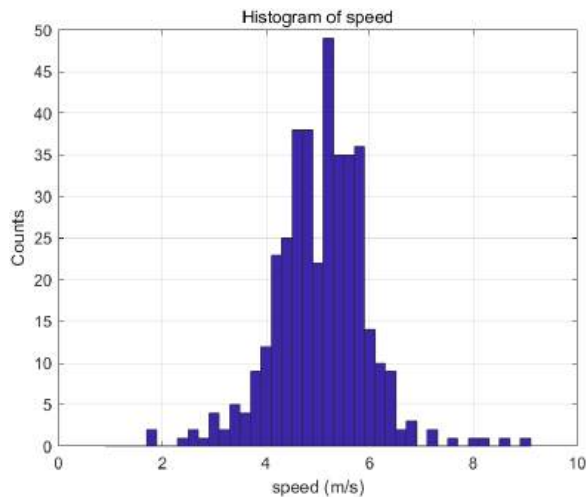
	cells	speed bias (m/s)	speed SD (m/s)	direction SD (deg)	U SD (m/s)	V SD (m/s)
with modified GMF	429	-0.92	1.65	17.18	1.40	1.47
with modified GMF (only a3_coef)	429	-0.97	1.38	17.24	1.14	1.33
with azimuth calibration (overall ratio)	429	-0.42	1.02	25.91	1.82	1.39
with azimuth calibration (each leg's ratio)	429	-0.31	0.84	25.72	1.71	1.50

- Comparison between winds using 4 different methods

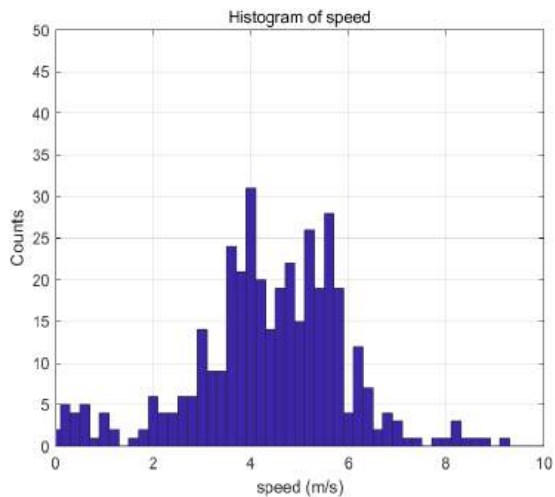
with azimuth calibration
(overall ratio)



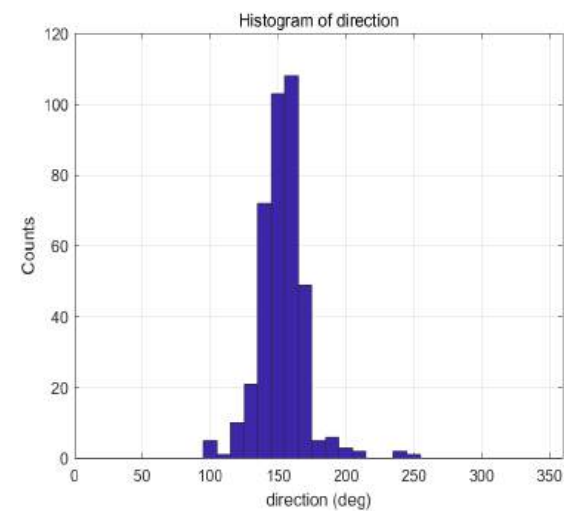
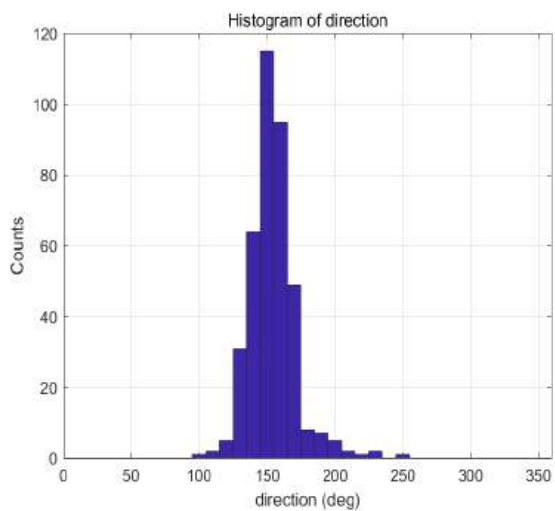
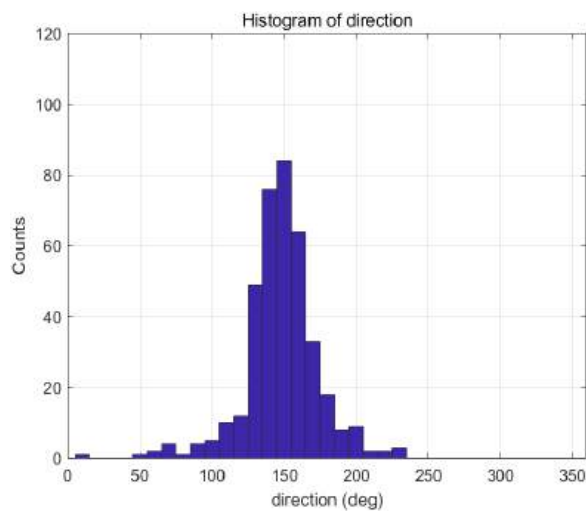
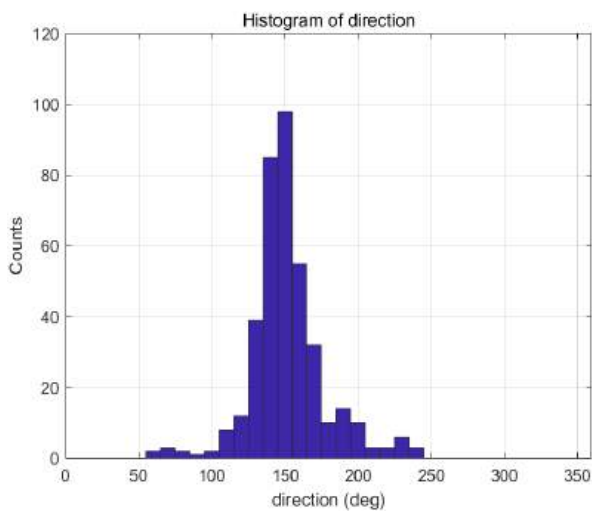
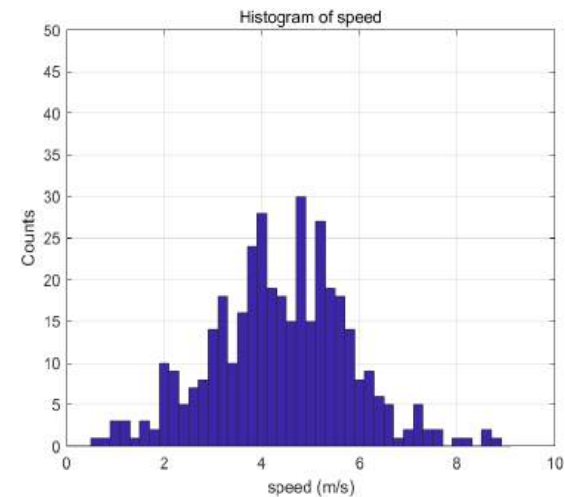
with azimuth calibration
(each leg's ratio)



with modified GMF



with modified GMF
(only a3_coef)



3. Ongoing work

Simultaneous wind and current retrievals from Doppler scatterometer data:

Principal:

- Winds and currents are retrieved **separately**. Winds are inversed using the backscatter, and currents are retrieved using the doppler shift.

$$y_U = F(x_{dp}, p) + \varepsilon_{0-dp}$$

$$y_{\sigma_0} = F(x_{\sigma_0}, p) + \varepsilon_{0-\sigma_0}$$

$$U_D = U_{geo} + U_{nwd} + U_{wd}$$

U_{geo} : non-geophysical component

U_{nwd} : **C**urrents that are not driven by the instantaneous local wind.

U_{wd} : **w**ind-driven component

- Backscatter and doppler observations are **combined** in the cost function. Thus winds and currents are inversed at the same time.

$$\mathbf{y} = F(\mathbf{x}, p) + \varepsilon_0$$

\mathbf{x} : wind and current vector

\mathbf{y} : NRCS (σ_0) and doppler shift (dp)

p : model parameters

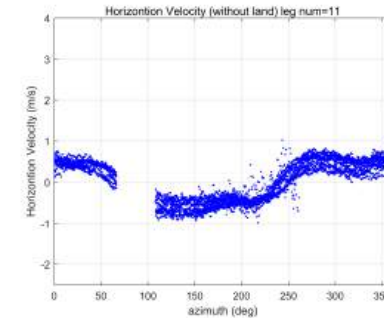
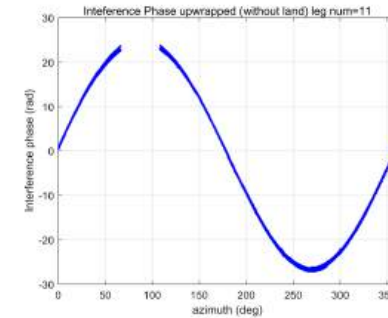
ε_0 : errors

Work:

- Ocean current retrieval**

Inteference Phase $\Delta\varphi \rightarrow$ Horizontion Velocity $v = \frac{\Delta\varphi \cdot \lambda}{4\pi m T_S} \rightarrow$ Surface_Velocity $\rightarrow \dots$

(λ : wave length, mT_S : interference phase interval)



Surface_Velocity

- Joint wind & current cost function**
- Use Metop-SG scatterometer simulation study to analyze performance of other DoppScatt potential configurations**
- New campaign upcoming (July 2024)!**
- OSCOM to be launched in 2026**
- But... CFOSAT follow-on to be launched by the end of 2024 will have DOPSCA capabilities**

Thank you!

Simultaneous wind and current retrievals from Doppler scatterometer data: calibration of OSCOM backscatter measurements

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Marcos Portabella (portabella@icm.csic.es)

Xiaolong Dong (dongxiaolong@mirslab.cn)

Wenming Lin (002853@nuist.edu.cn)

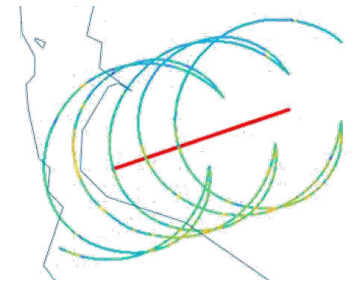
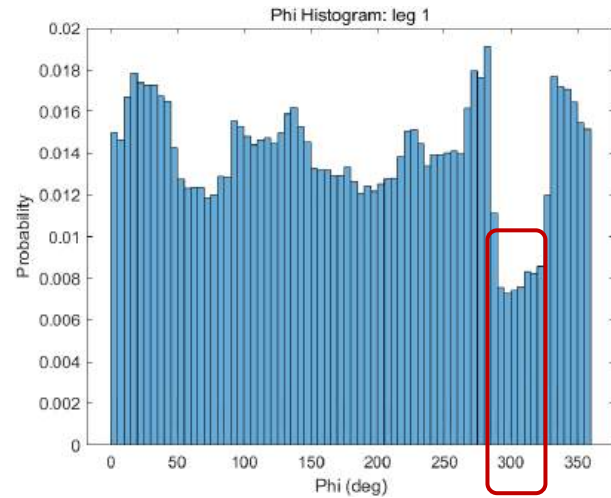
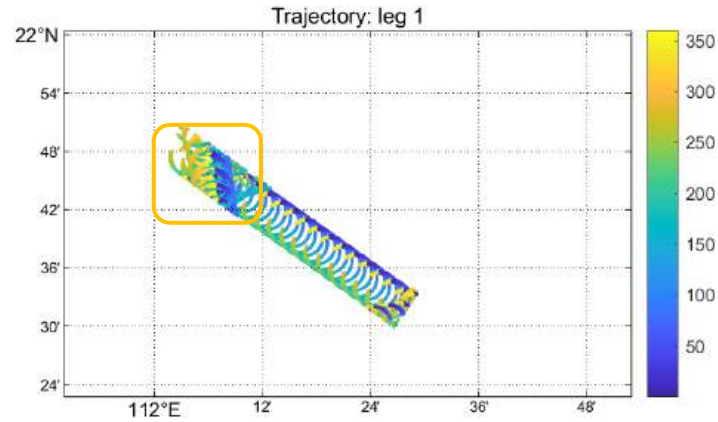
Qingliu Bao (baoqingliu@piesat.cn)

The reason why **there is no 'azimuth gap'** in each of the curves (legs) of the top left plot in slide 10:

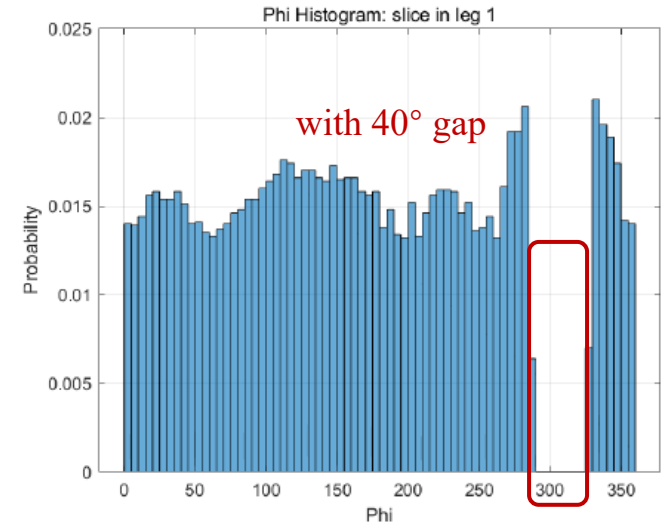
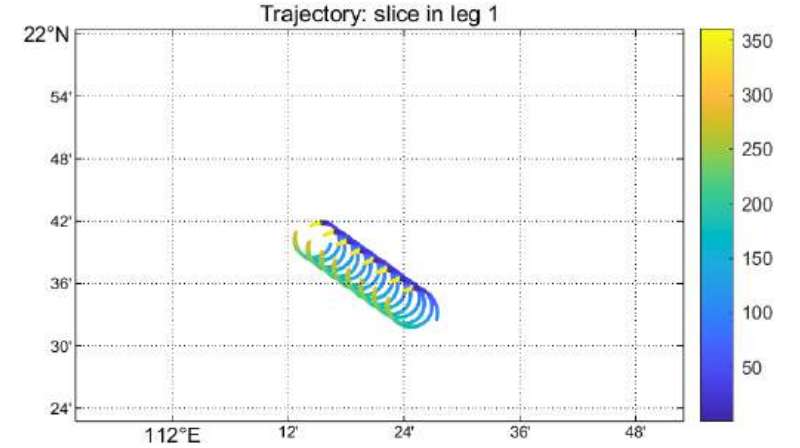
When legs are divided, the turning parts are also included.

Take leg 1 as an example:

- Leg 1:
straight-line section
turning section

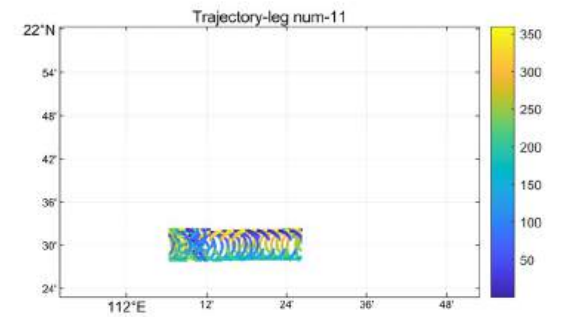
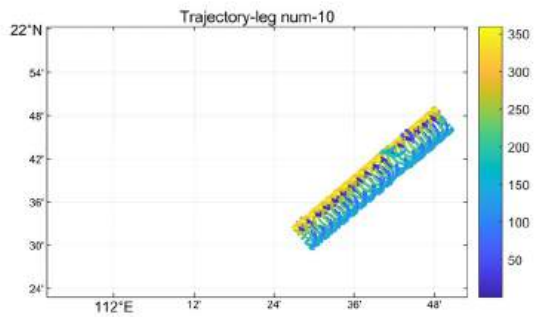
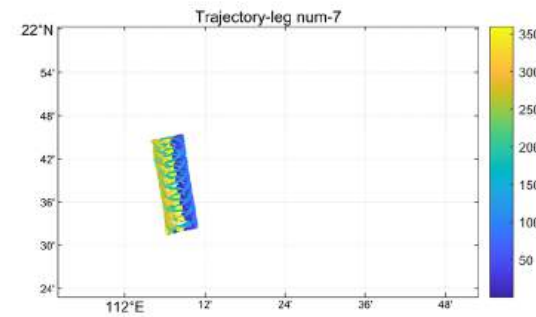
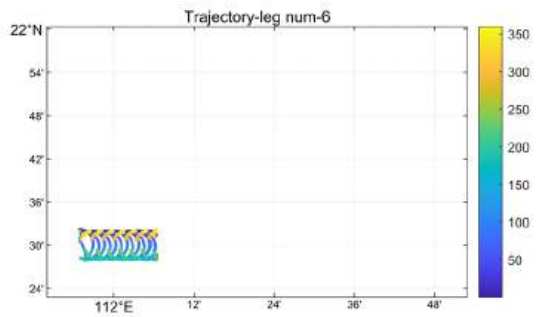
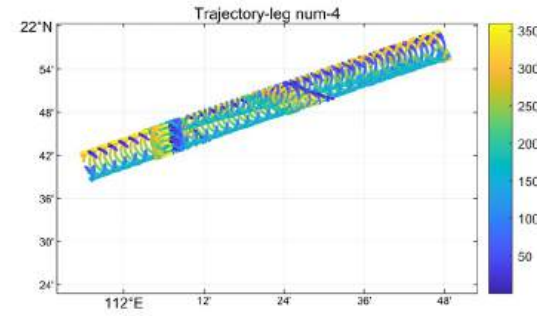
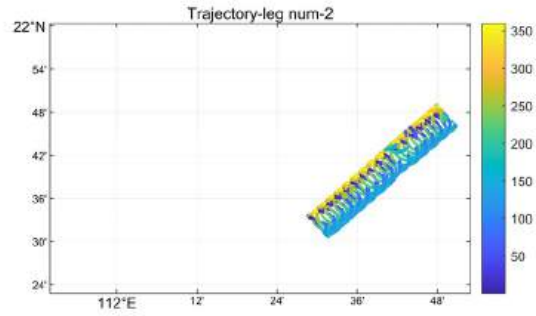
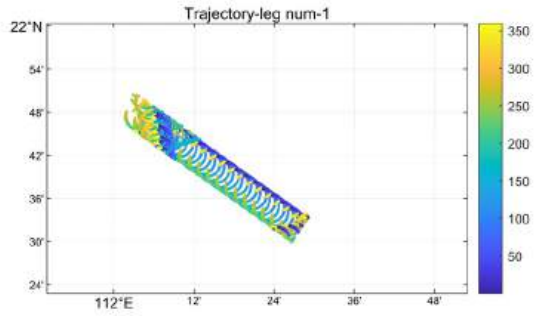


- Slice of Leg 1:
only straight-line section



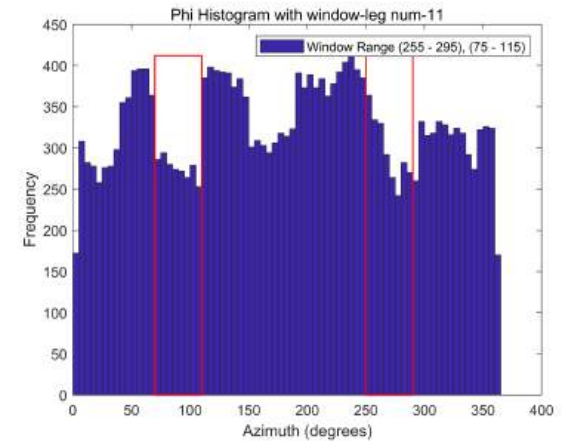
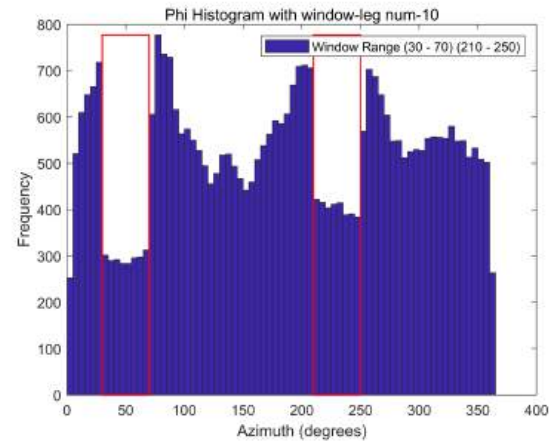
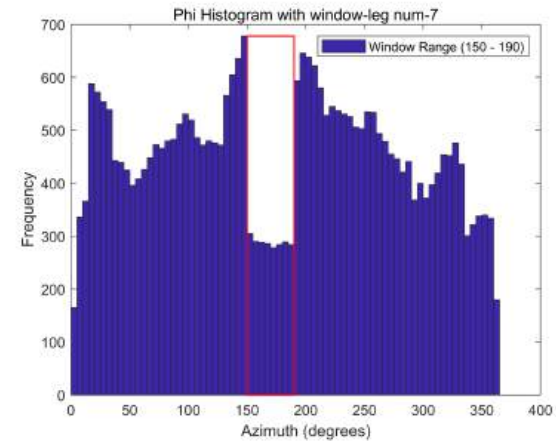
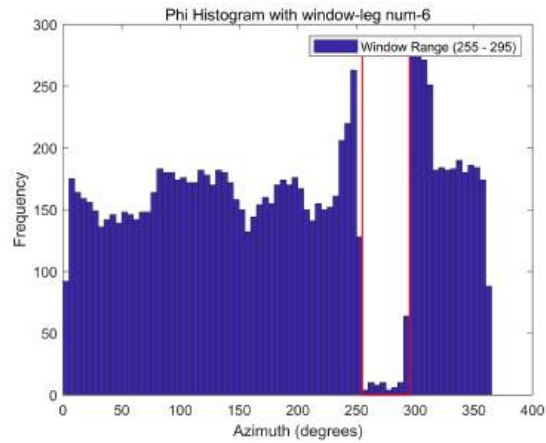
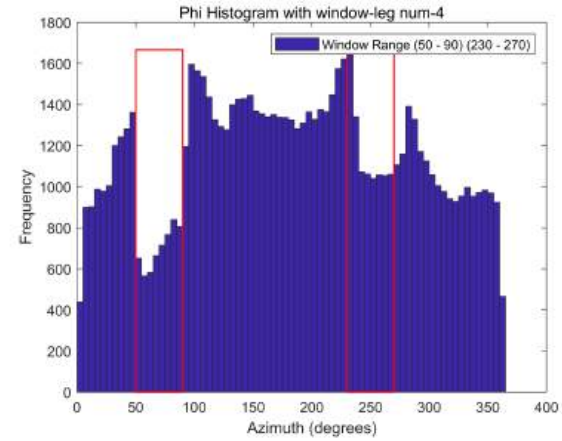
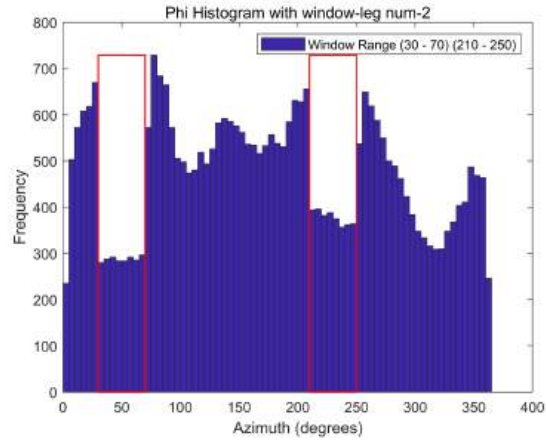
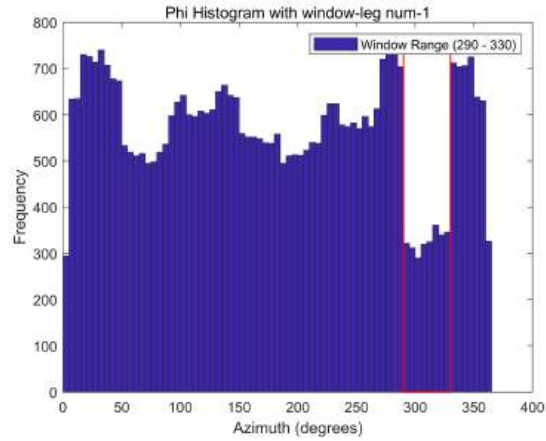
The impact of the 'gap' of azimuth

- The trajectory of each leg



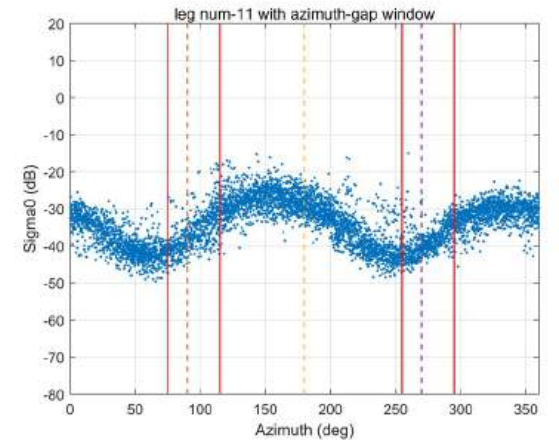
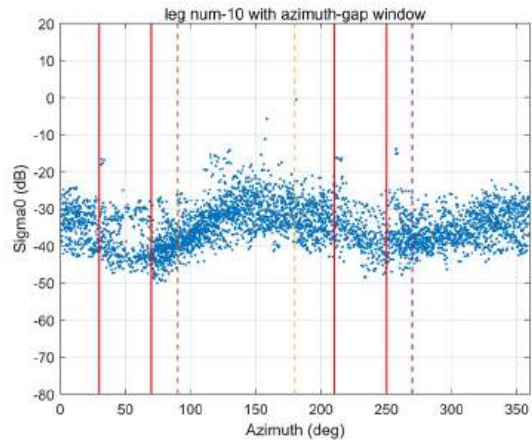
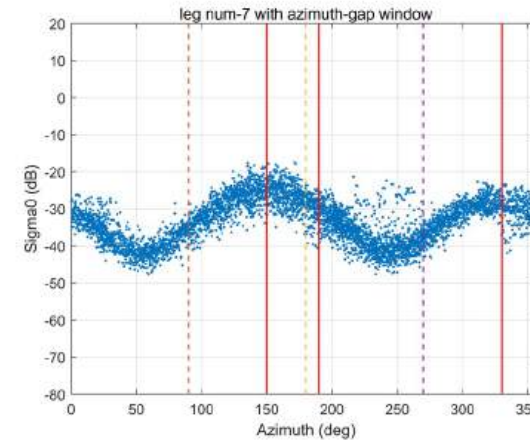
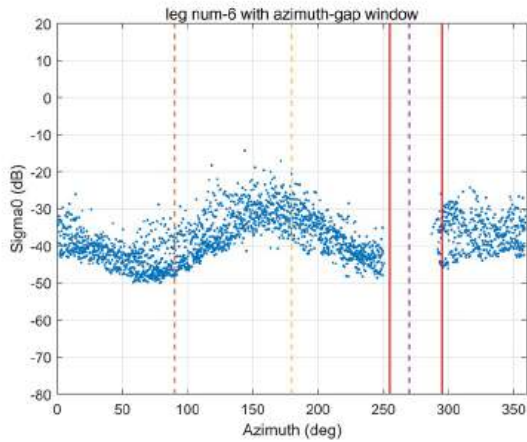
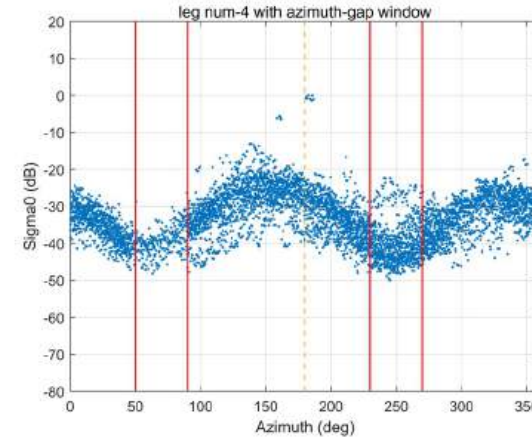
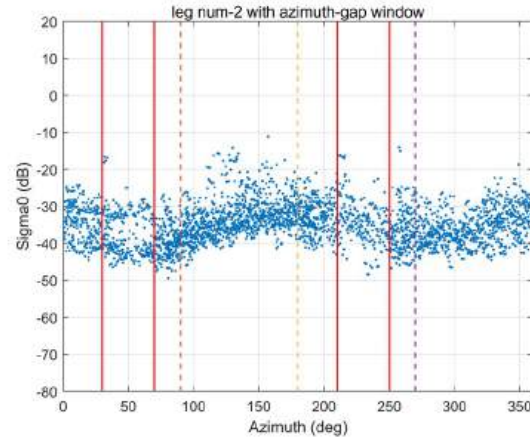
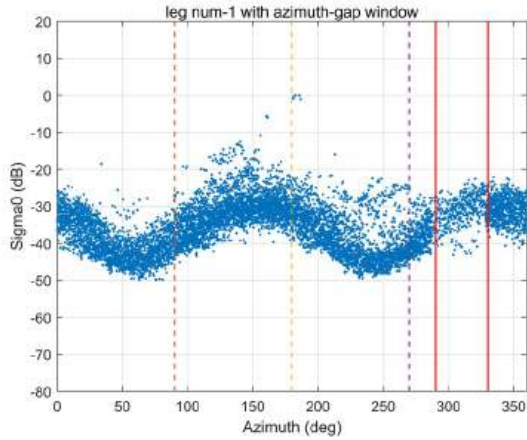
The impact of the 'gap' of azimuth

- Find the 'gap': use the histogram



The impact of the 'gap' of azimuth

- Point out the 'gap' in the scatter plot (within the red lines)



- the size of the 'gap' : 40°
- Sometimes there are 2 gaps: due to two flight directions in one leg. The azimuth difference between 2 gaps are 180° .
- The noise level of the "turning plane" data is **not** different from that of the "straight plane" data according to the figures.

According to calculation using L1B raw dataset,

the spatial resolution of L1B data is

In degree scale:

- Latitude: 1.0848×10^{-8} deg
- Longitude: 8.6062×10^{-10} deg

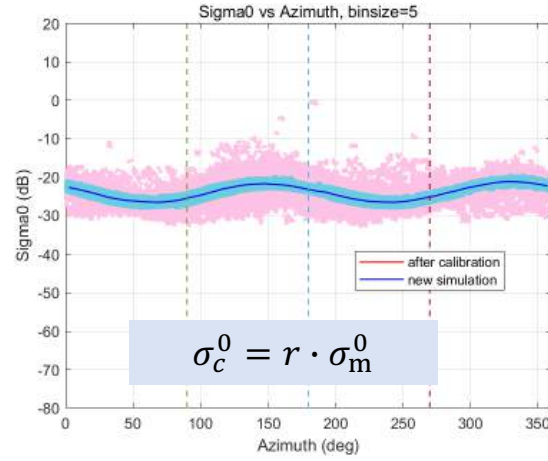
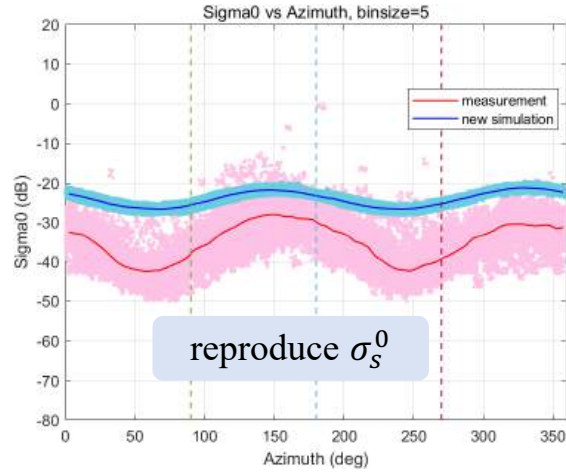
In meter scale:

- Latitude ~ 0.0012 m
- Longitude ~ 0.0001 m

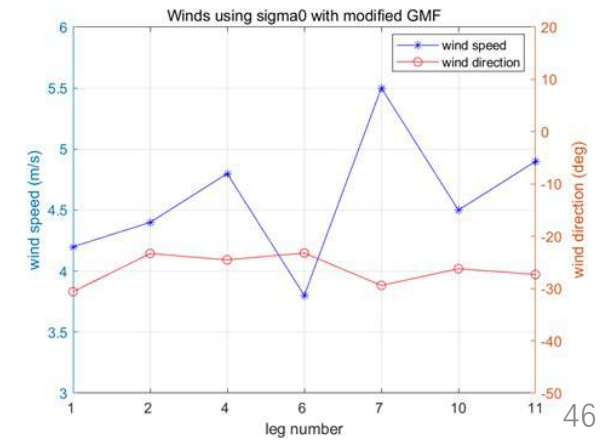
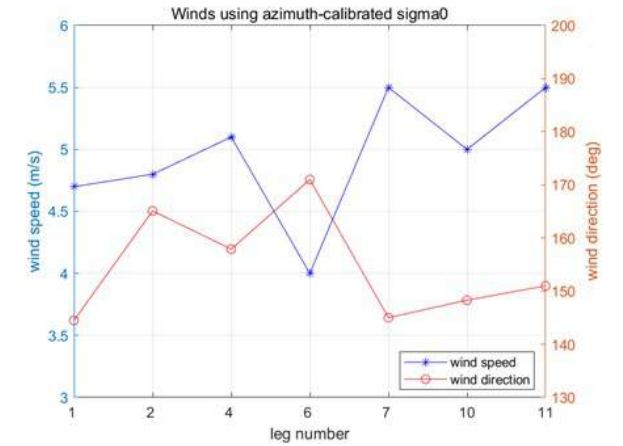
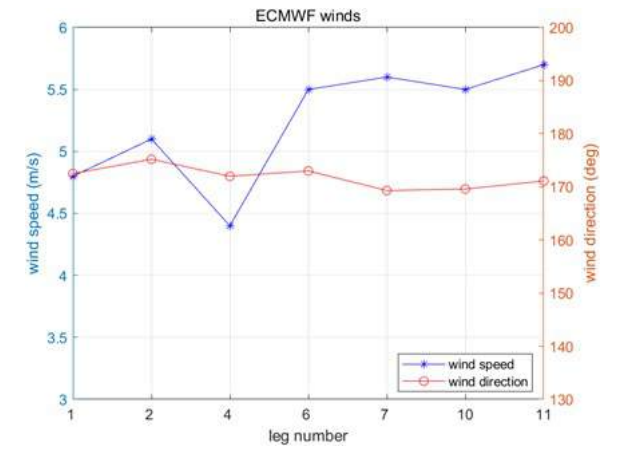
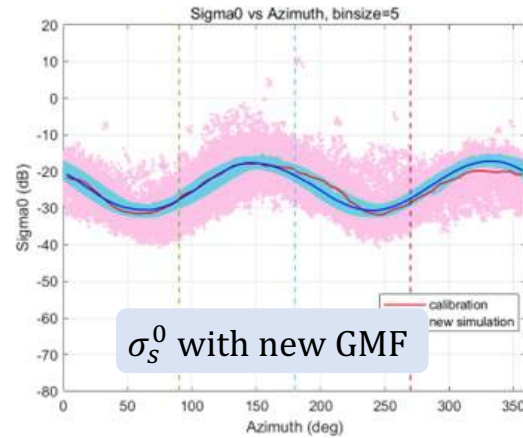
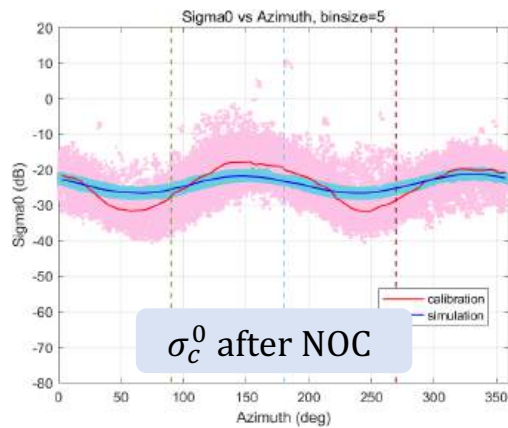
2.6 Comparison

3) Sigma0 as a function of azimuth

- Method 1: using azimuth-calibrated sigma0

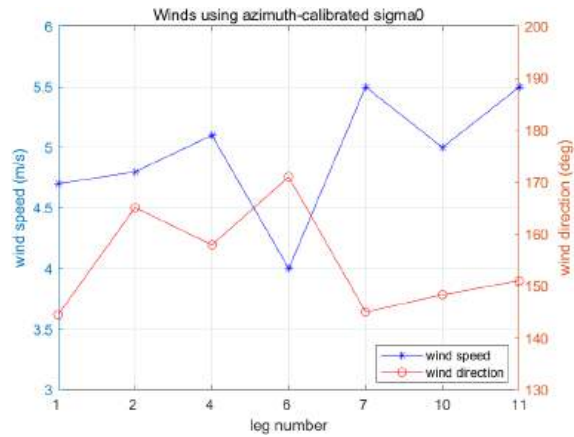


- Method 2: using modified GMF

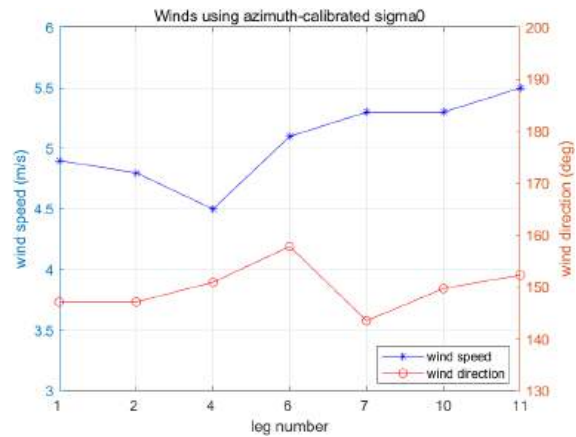


- Comparison between winds using 4 different methods

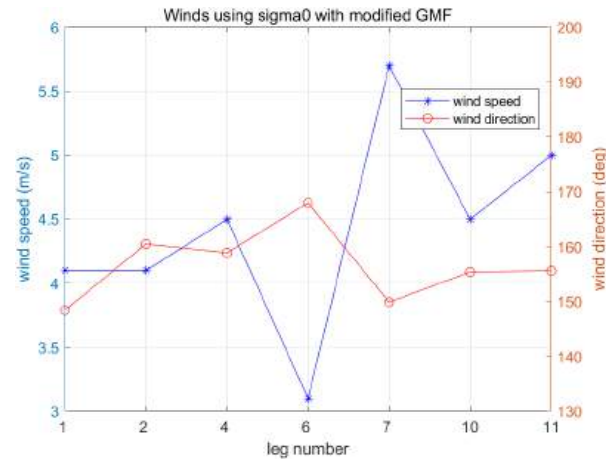
with azimuth calibration
(overall ratio)



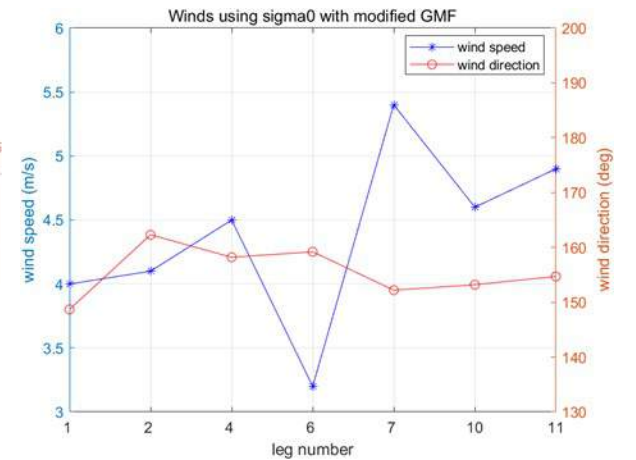
with azimuth calibration
(each leg's ratio)



with modified GMF



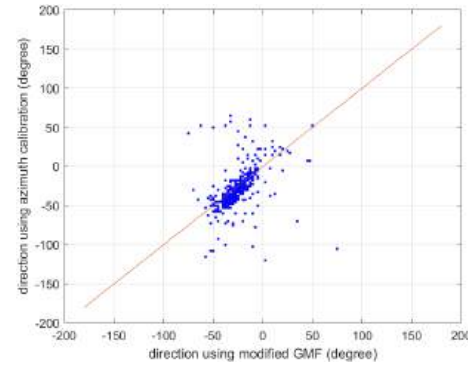
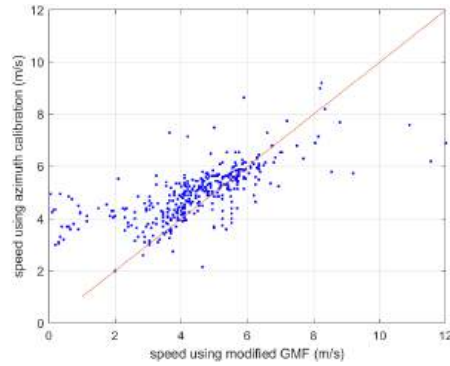
with modified GMF
(only a3_coef)



2.6 Comparison

1) Retrieved winds

- Comparison between winds using 2 methods



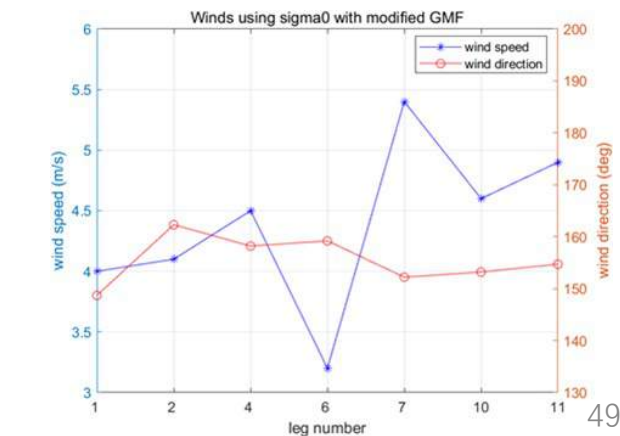
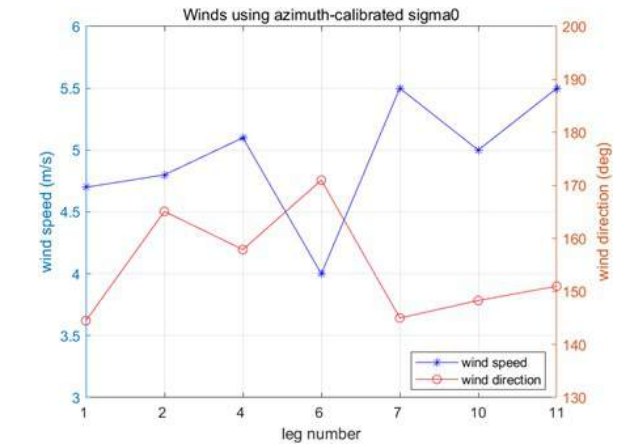
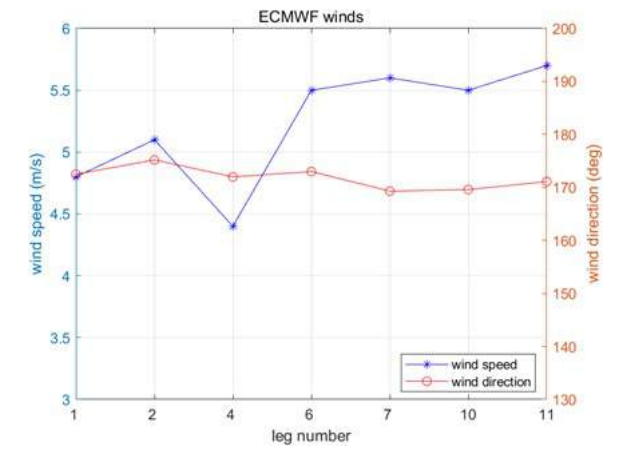
- Compare with ECMWF:

	cells	speed bias (m/s)	speed SD (m/s)	direction SD (deg)	U SD (m/s)	V SD (m/s)
with modified GMF	429	-0.92	1.65	17.18	1.40	1.47
with modified GMF (only a3_coef)	429	-0.97	1.38	17.24	1.14	1.33
with azimuth calibration (overall ratio)	429	-0.42	1.02	25.91	1.82	1.39
with azimuth calibration (each leg's ratio)	429	-0.31	0.84	25.72	1.71	1.50

2) Mean winds for each leg

- Compare with ECMWF:

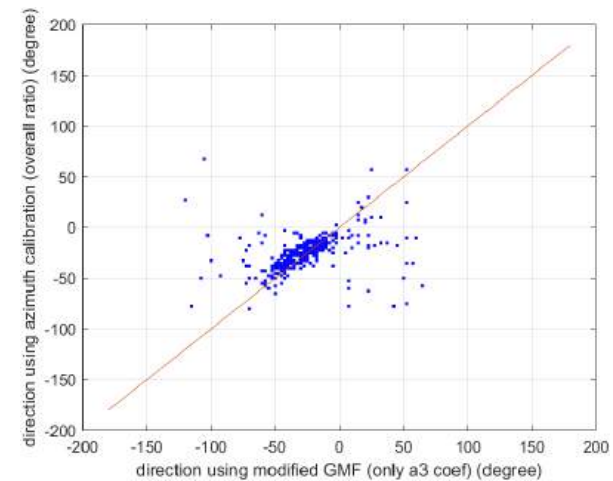
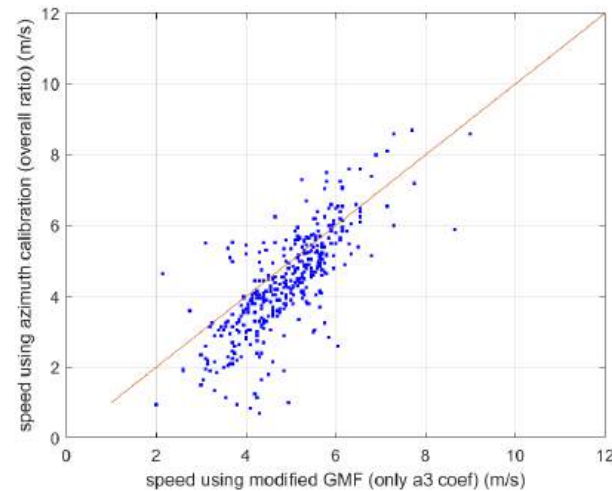
	legs	speed bias (m/s)	speed SD (m/s)	direction SD (deg)	U SD (m/s)	V SD (m/s)
with modified GMF	7	-0.80	0.84	5.86	0.58	0.70
with modified GMF (only a3_coef)	7	-0.84	0.76	3.67	0.36	0.70
with azimuth calibration (overall ratio)	7	-0.28	0.65	8.97	0.78	0.60
with azimuth calibration (each leg's ratio)	7	-0.17	0.20	4.56	0.33	0.27



- **Comparison between winds using azimuth calibration and modified GMF**

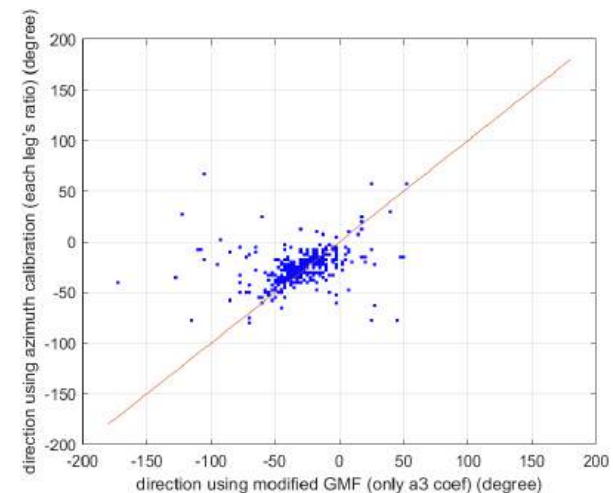
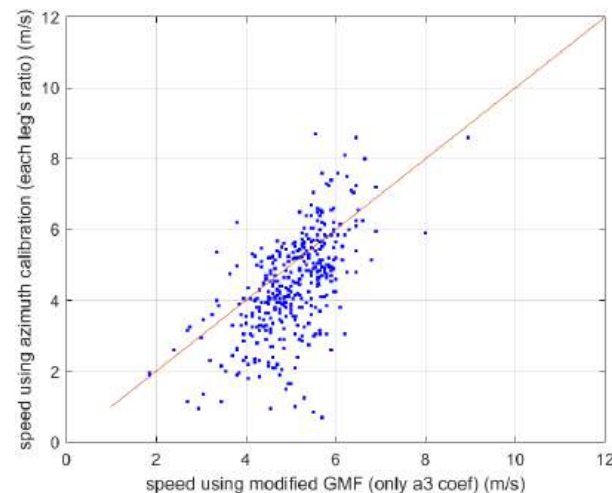
x axis: modified GMF with only a3_coef

y axis: azimuth calibration (overall ratio)



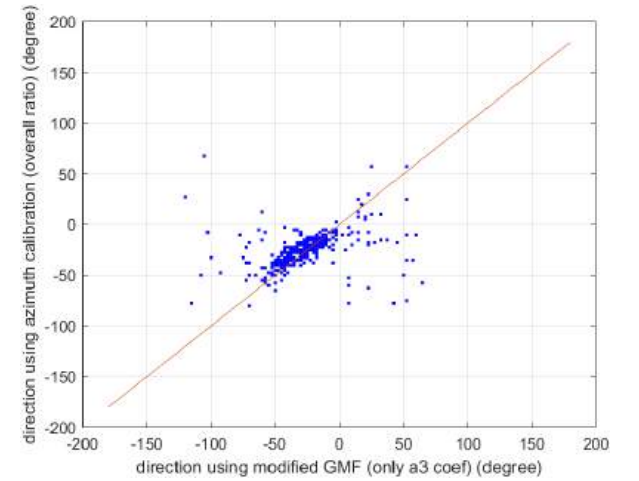
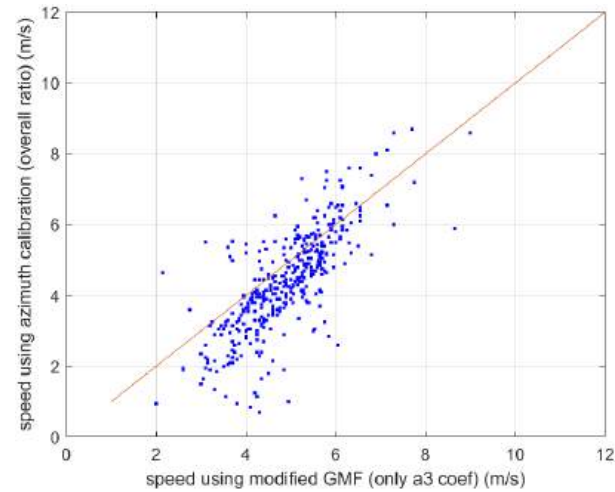
x axis: modified GMF with only a3_coef

y axis: azimuth calibration (each leg's ratio)

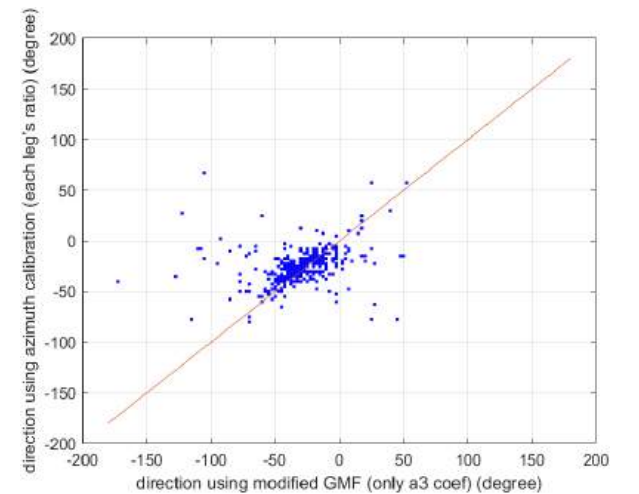
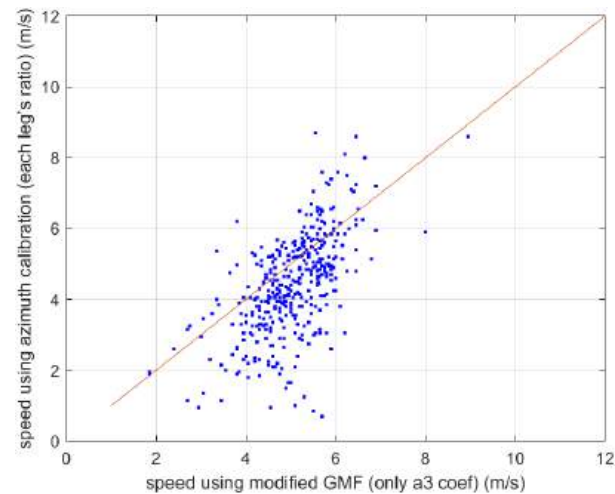


- **Comparison between winds using azimuth calibration and modified GMF**

x axis: modified GMF with only a3_coef
 y axis: azimuth calibration (overall ratio)



x axis: modified GMF with only a3_coef
 y axis: azimuth calibration (each leg's ratio)



- Comparison between winds using 2 modified GMF

x axis: only a3_coef

y axis: with a2_coef and a3_coef

low winds

