Model bias correction in NWP data assimilation

Ad.Stoffelen@knmi.nl

Zhixiong Wang, NUIST

Rianne Giesen, KNMI

Isabel Monteiro, KNMI/IPMA

Giovanna De Chiara, ECMWF

Sean Healy, ECMWF

EUMETSAT
NWP SAF
NUMERICAL WEATHER PREDICTION

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Wind Bias Correction Guide

Ad Stoffelen and Jur Vogelzang

KNMI, the Netherlands

Scatterometer missions overview (WMO OSCAR)

Instrument	NRT?	Relevance	Satellite	Orbit	DLR	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
WindRAD		1 - primary	FY-3E	05:40 desc		X	X	X	X	X	X								
WindRAD		1 - primary	FY-3J	05:00 desc							X	X	X	X	X	X	X	X	X
ASCAT	Yes	2 - very high	Metop-B	09:31 desc	50	X	X	X											
ASCAT	Yes	2 - very high	Metop-C	09:31 desc	85	X	X	X	X	X	X								
SCA (Scatterometer)		2 - very high	Metop-SG-B1	09:30 desc					X	X	X	X	X	X	X	X			
SCA (Scatterometer)		2 - very high	Metop-SG-B2	09:30 desc												X	X	X	X
CSCAT		2 - very high	CFOSAT	07:00 desc		X	X												
HSCAT		2 - very high	HY-2B	06:00 desc	273	X	X												
HSCAT		2 - very high	HY-2D	66 °		X	X	X	X	X									
HSCAT		2 - very high	HY-2E	06:00 desc				X	X	X	X	X							
HSCAT		2 - very high	HY-2C	66 °		X	X	X	X										
HSCAT		2 - very high	HY-2F	66 °					X	X	X	X	X						
OSCAT-3		2 - very high	OceanSat-3 (EOS-06	12:00 desc		X	X	X	X	X	X	X	X	X					

Source: https://space.oscar.wmo.int/gapanalyses?mission=12

Past C-band missions :

ERS-1,2/ESCAT	10:30 desc.	1992-1996, 1995-2000
MetOp-A/ASCAT	9:30 desc.	2007-2021

Past Ku-band missions :

SeaWinds/QuikScat	6:00 desc.	1999-2009
RapidScat/ISS	52 *	2014-2016
OceanSat-2/OSCAT-1	0:00 desc.	2009-2014
ScatSat-1/OSCAT-2	8:45 desc.	2016-2021

- ➢ Prepare yourselves for many scatterometers ☺

Quintuple collocation analysis

Table 2. Observation error standard deviations and their accuracies.

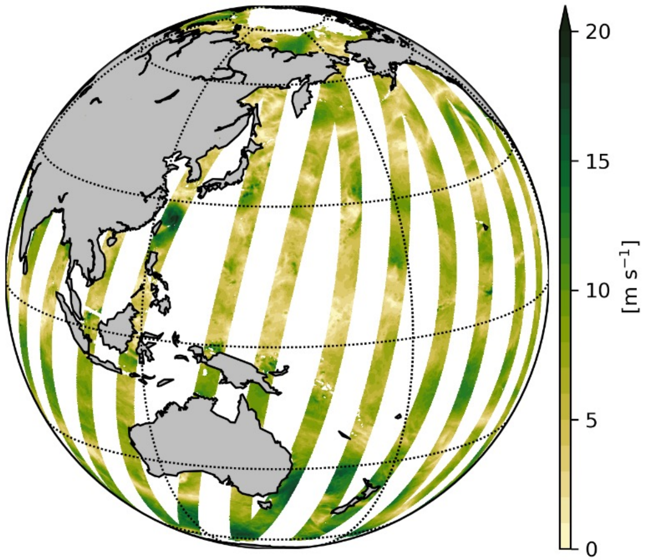
Observing System		σ_u (m/s)	std(σ_u) (m/s)	σ_v (m/s)	std(σ_v) (m/s)
buoys		0.914	0.017	1.063	0.020
ASCAT-A	(C-band)	0.372	0.022	0.505	0.029
ASCAT-B	(C-band)	0.390	0.025	0.444	0.020
ScatSat	(Ku-band)	0.683	0.018	0.594	0.021
ECMWF		0.845	0.017	1.006	0.021

- Beyond triple and quadruple collocation for global calibration and random error assessment
- Consolidated several methodologies to solve collocation error equations
- Added better ability to approximate the errors of the errors
- Confirms the excellent accuracy of scatterometer winds
- Stress-equivalent 10-m winds

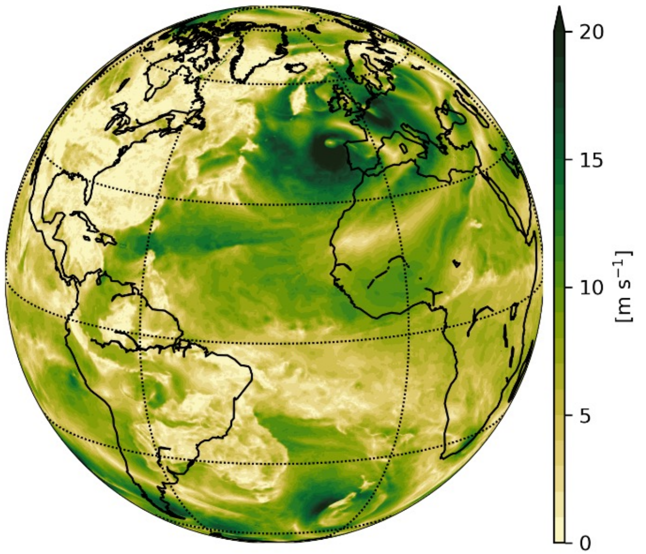
Jur Vogelzang and Ad Stoffelen, 2022a, 2022b, 2021

Rationale

- ✓ See SCA SAG science plan (drafted 2016)
- ✓ U10 Model biases are locally rather high compared to innovation, violating Best Linear Unbiased Estimate paradigm in data assimilation
- ✓ A few decades of model improvement have not solved this problem, though one is still trying actively; it is a problem for ocean forcing too
- ✓ The EU Copernicus Marine Service L4 OPS and ERA5 corrections can be inversely applied to the scatterometer winds to adjust them to be geographically unbiased with respect to the model
- ✓ ECMWF provided a reference run without scatterometers for which NUIST and KNMI computed model biases, averaging over 20 days (like for Copernicus L4 product)
- ✓ NUIST applied these biases to obtain adjusted SCAT BUFR products
- ✓ ECMWF will run a SCAT* OSE and compare it to reference OSEs with (SCAT OSE) and without (noSCAT OSE) scatterometer data assimilation
- ✓ EUMETSAT MIDAS project result on scatterometer OSEs with the HARMONIE model also points to a bias problem



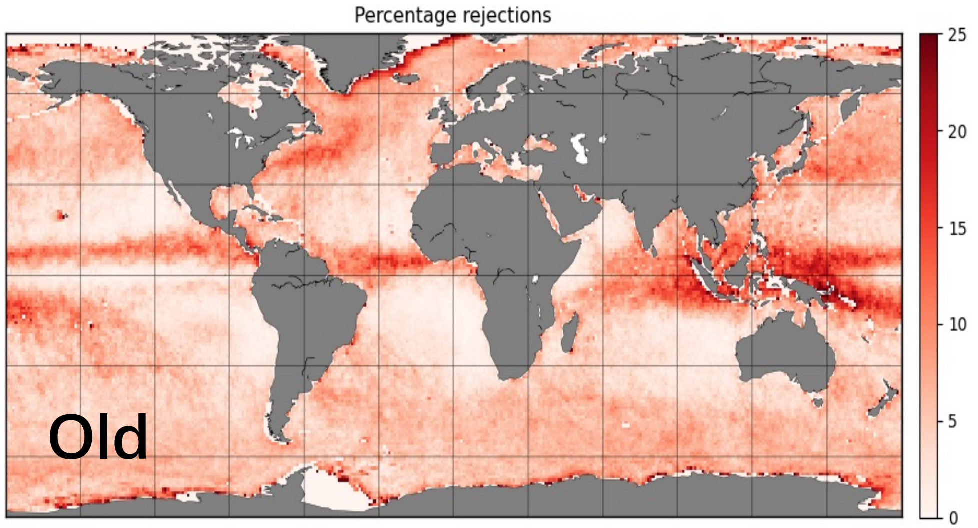
L3 daily Copernicus Marine Service

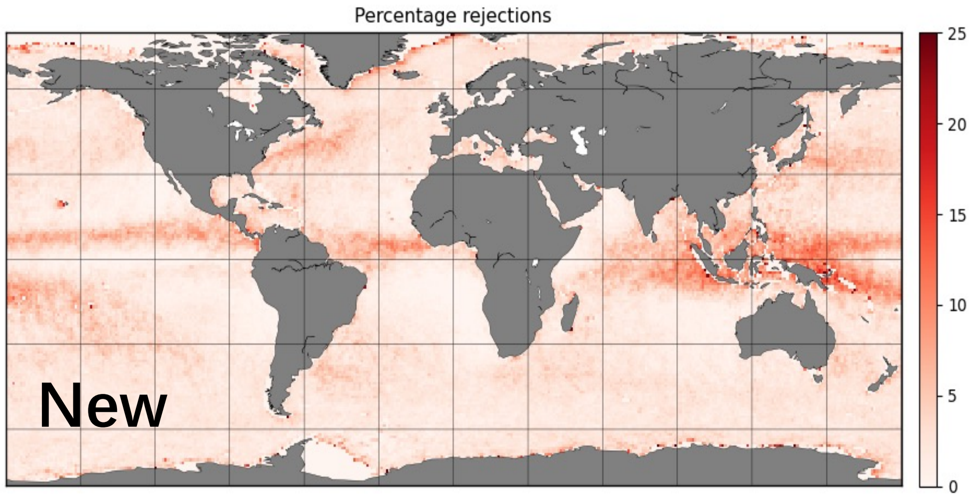


L4 hourly Copernicus Marine Service

Quality Control and ocean winds

- EUMETSAT OSI SAF continuously improves quality control (QC)
- For Ku-band scatterometers we need to control rain events (=>)
- Develop algorithms to correct for remaining observational sampling biases
- Downbursts in moist convection have a large and systematic impact on air-sea interaction
- These fast (30 min) and mesoscale (few km) processes are not well tracked in global NWP
- Scatterometers help correct climatological biases due to missing processes in models





Zhao et al., 2023

King et al., 2022

Xu and Stoffelen, 2021, 2019

Trindade et al., 2020, 2023

Belmonte and Stoffelen, 2019

The EUMETSAT Network of Satellite Application Facilities

OSI SAF Ocean and Sea Ice

Copernicus Marine Service

SCAT* : Making ASCAT and HY2 consistent

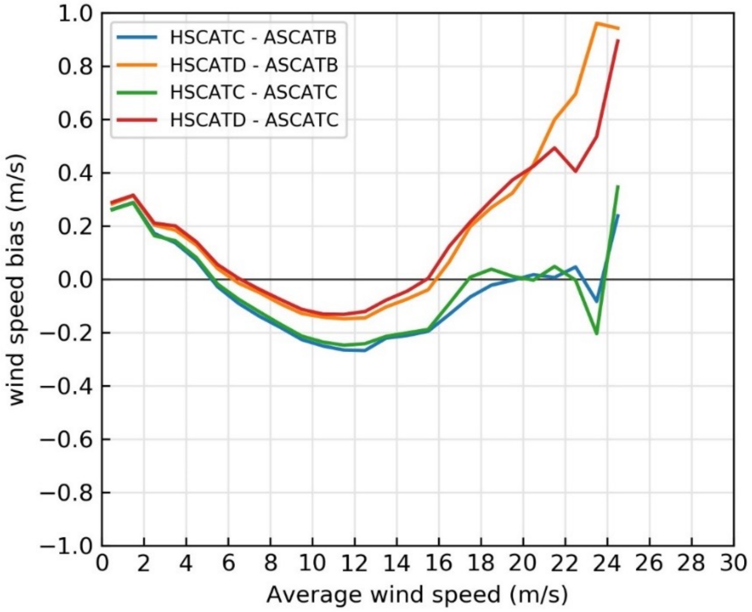
- ✓ Significant inconsistencies of wind speed are found between ASCAT and HSCAT NRT products; Zhixiong Wang confirmed that this is NOT caused by resolution differences (25/50km)
- ✓ Rep01: By using more accurate σ^0 NWP Ocean Calibration (NOC) after improved rain QC, winds among HSCAT-B, C, and D become more consistent, but NOT close enough to ASCAT
- ✓ Rep02: By making and using the new NSCAT-4ds.hy2 GMF and compute corresponding NOC, winds from HSCAT and ASCAT show good agreements. However, wind speeds below 2 m/s or above 20 m/s still need further calibration after running over longer periods
- ✓ **The products of ASCAT NRT and HSCAT Rep02 are the best version choices as sea surface wind vector inputs to the ECMWF ASCAT* OSE**
- ✓ **The residual biases (i.e., depending on instrument or WVCs) are acceptable, and we can move on to the next step**

More details are given on following slides . . .

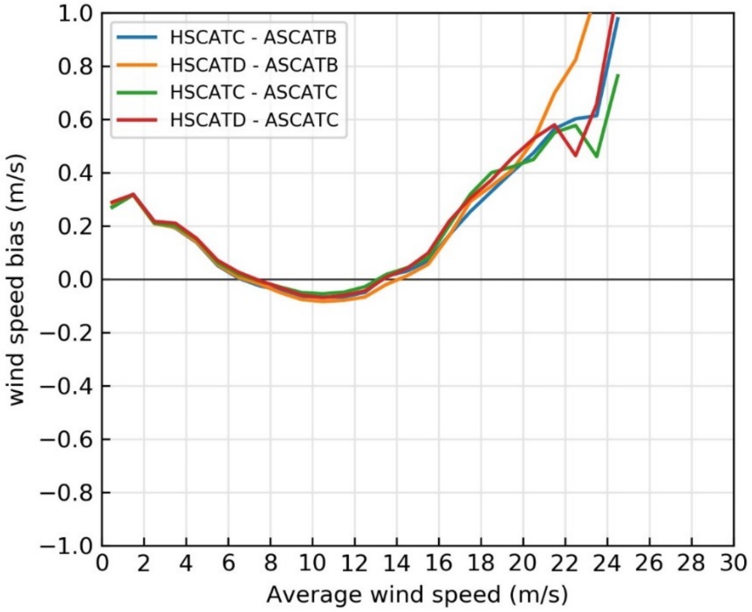
Collocated ASCAT and HSCAT winds

- ◆ Time diff. ≤ 45min
- ◆ Spatial distance ≤ 50*0.7071km

HSCAT NRT

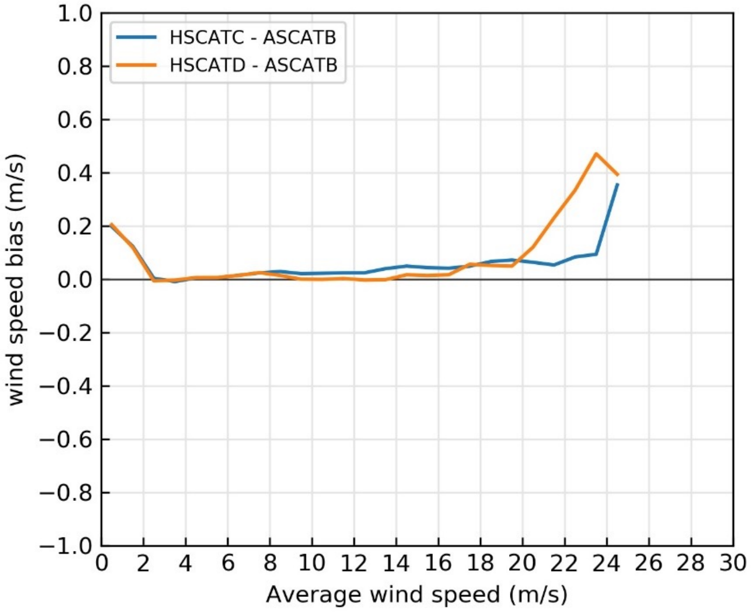


HSCAT Rep01



- NWP Ocean Calibration (NOC)

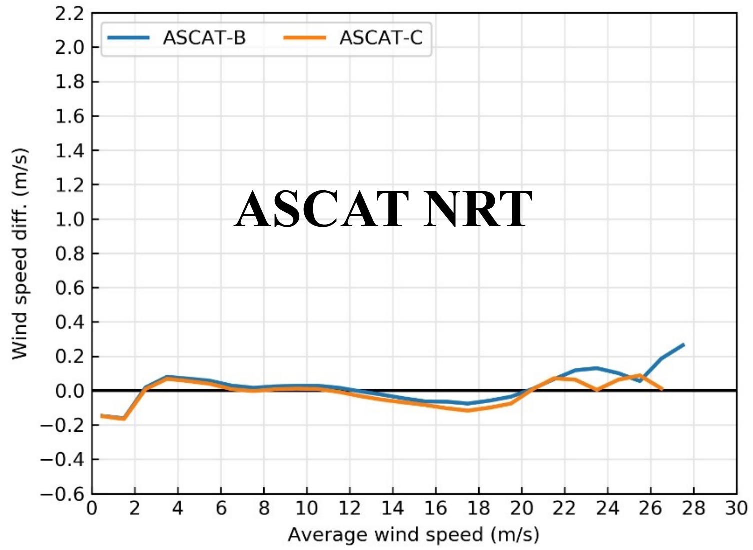
HSCAT Rep02

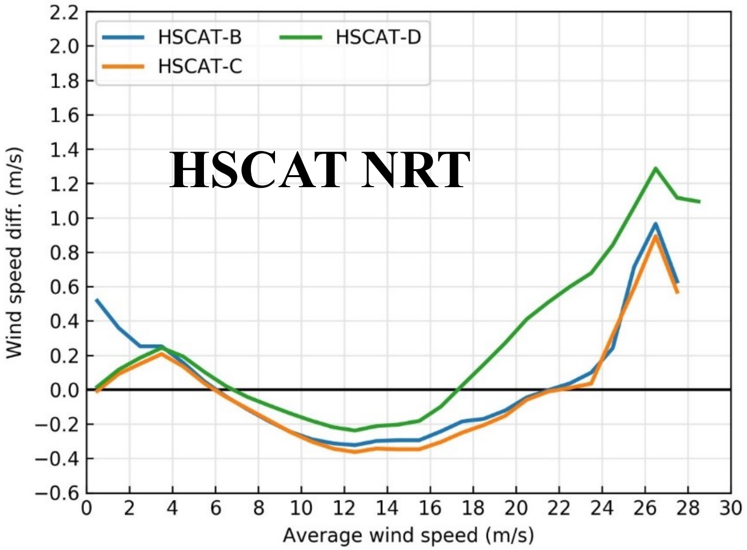


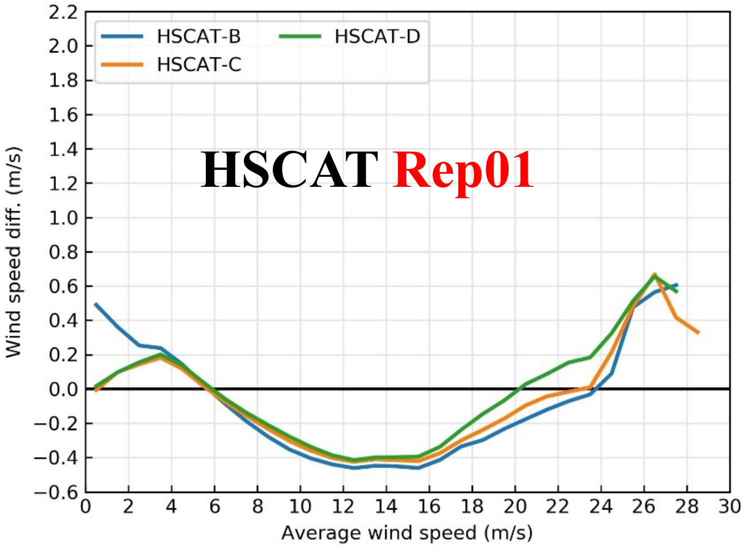
- Improve rain QC
- NOC
- Improve Geophysical Model Functions

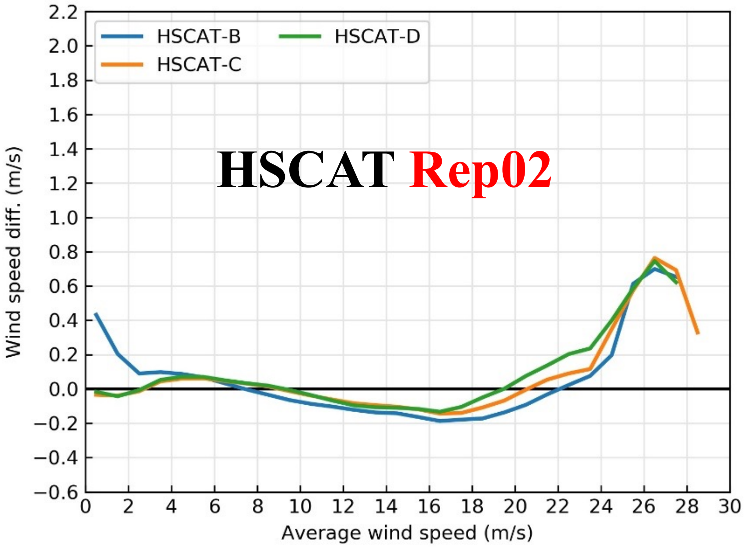
Verifying with ECMWF winds

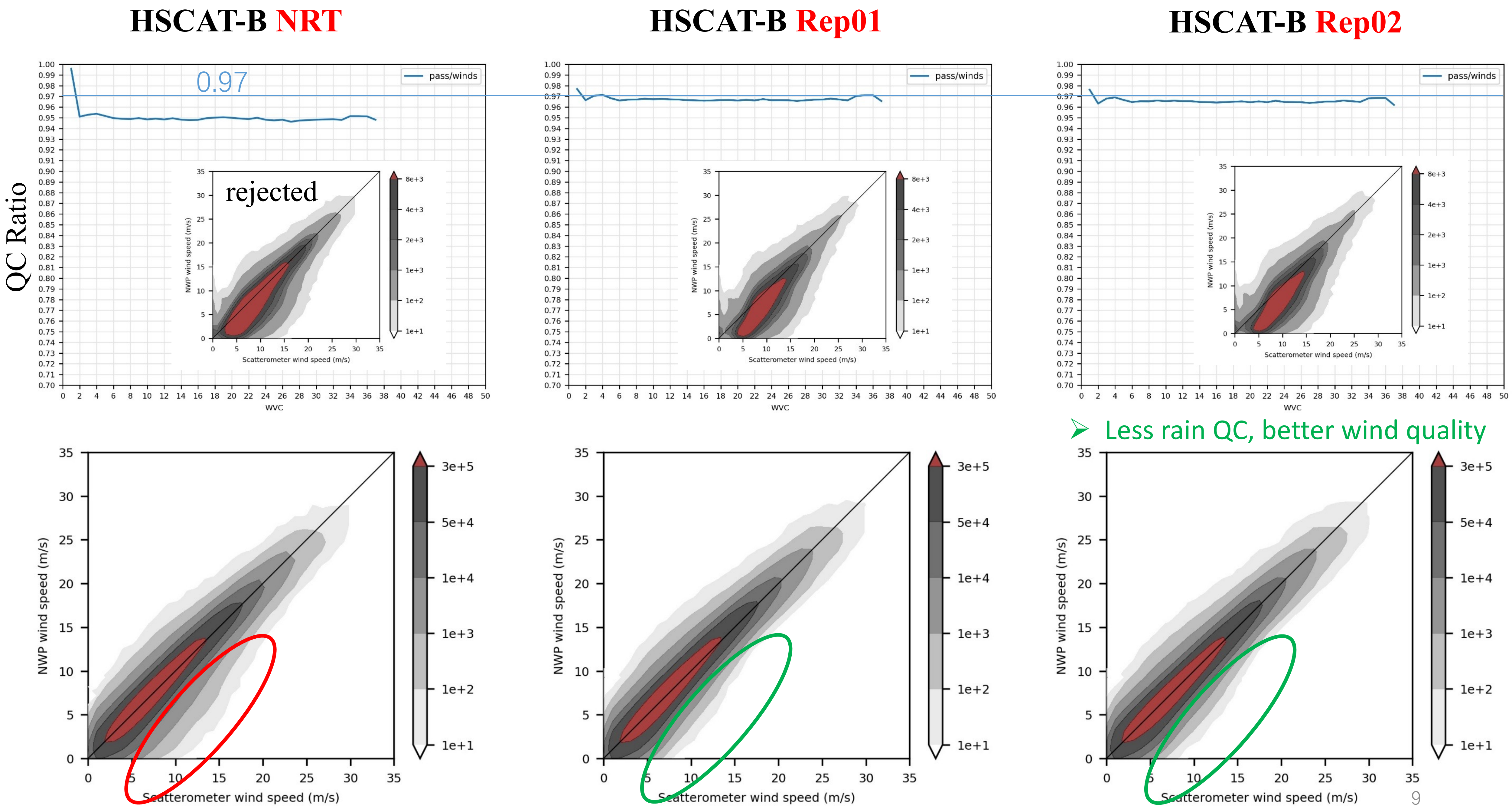
- ☑ It is clear that: HSCAT Rep02 is better.
- ☑ Wind speed dependent wind seed biases are reduced, and the curves of HSCAT become more similar to ASCAT curves.







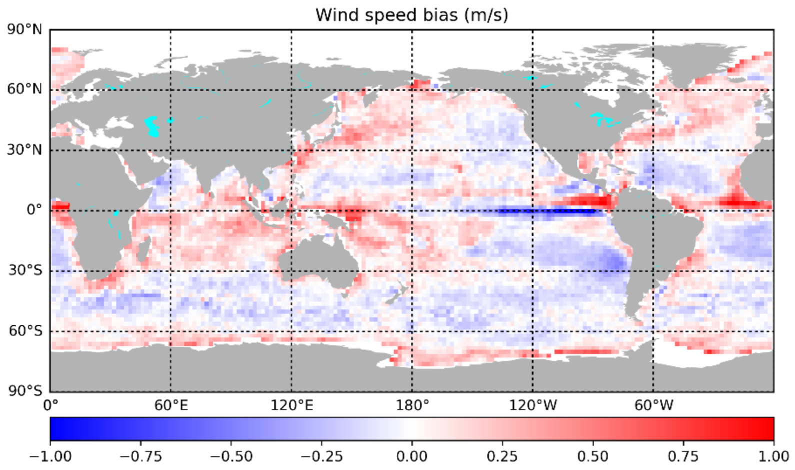




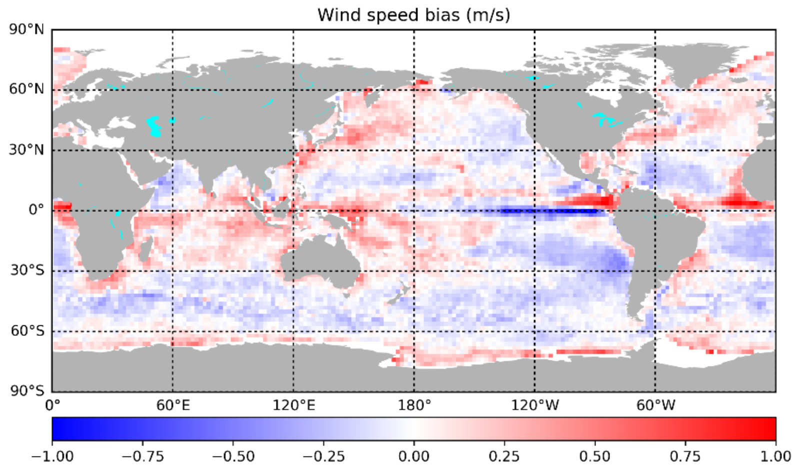
HSCAT-B NRT
HSCAT-B Rep01
HSCAT-B Rep02
QC Ratio
pass/winds
0.97
rejected
WVC
NWP wind speed (m/s)
Scatterometer wind speed (m/s)
Less rain QC, better wind quality

Wind speed biases of SCA - NWP

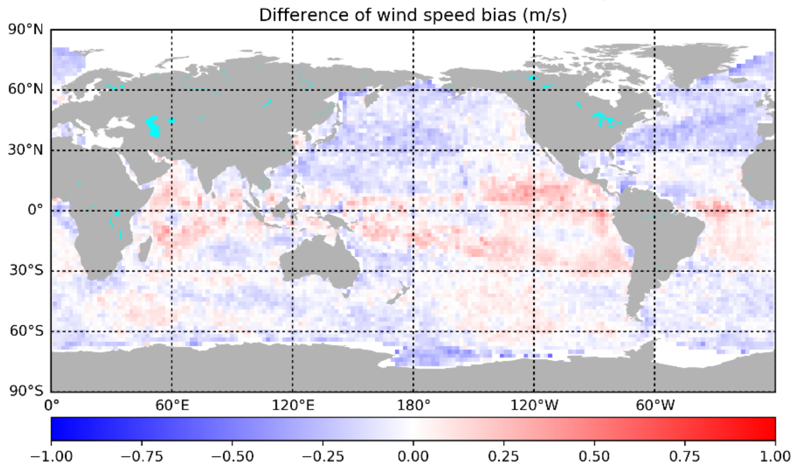
- Pattern could be diurnal cycle error



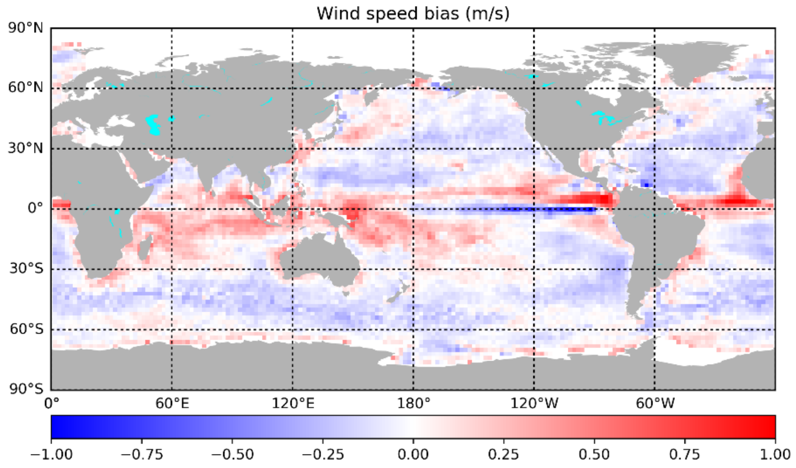
ASCAT-B NRT



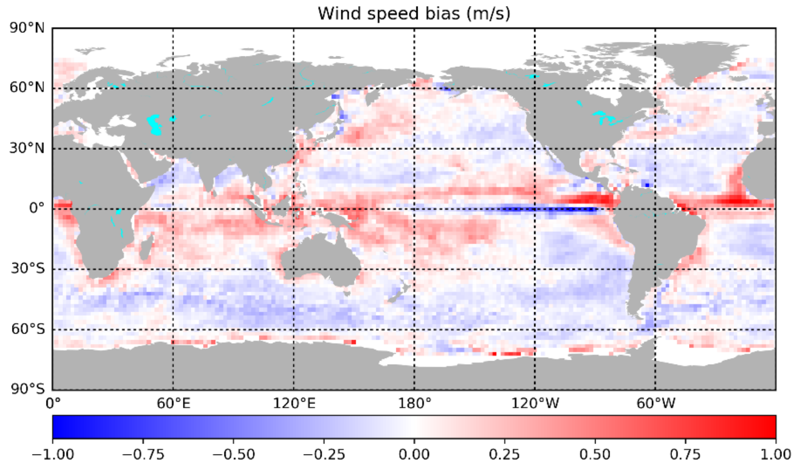
ASCAT-C NRT



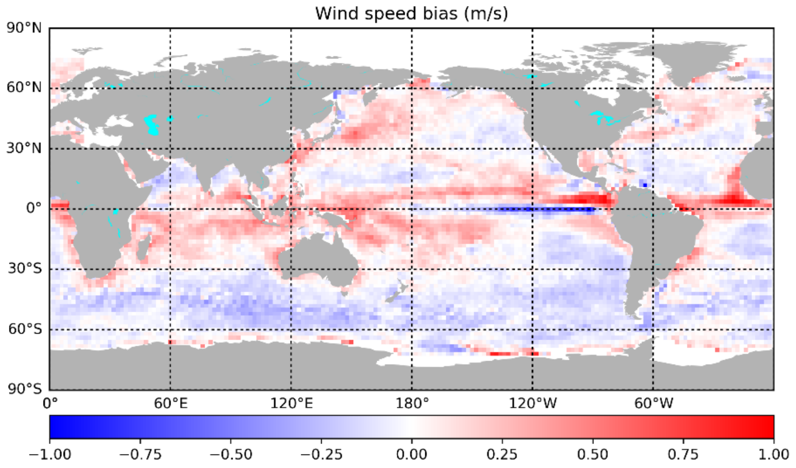
ASCAT-B/NRT – HSCAT-B/Rep02



HSCAT-B Rep02



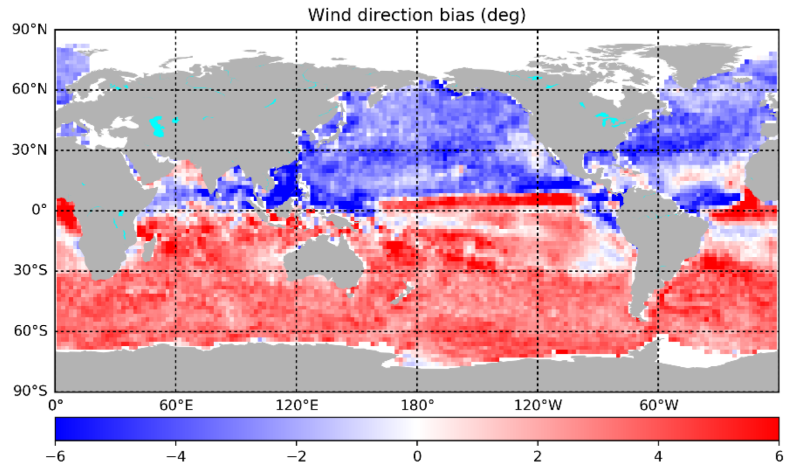
HSCAT-C Rep02



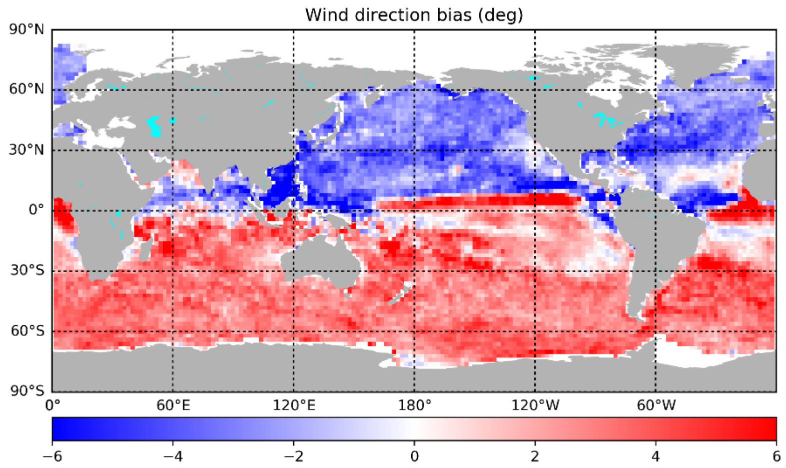
HSCAT-D Rep02

Wind direction biases of SCA - NWP

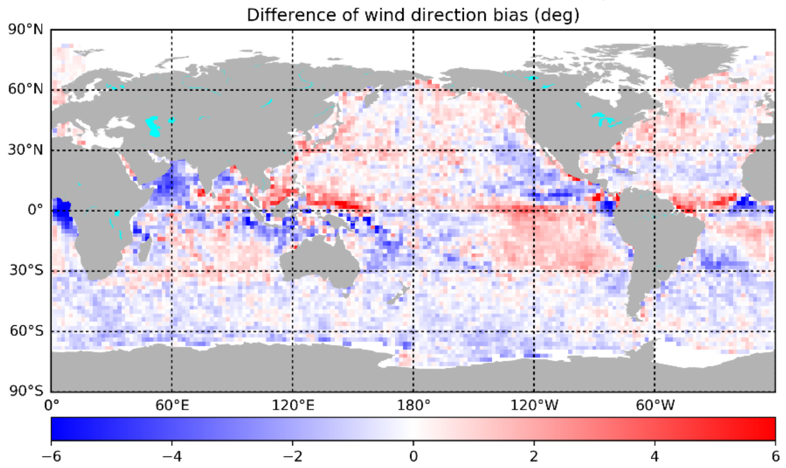
➢ Pattern could be diurnal cycle error



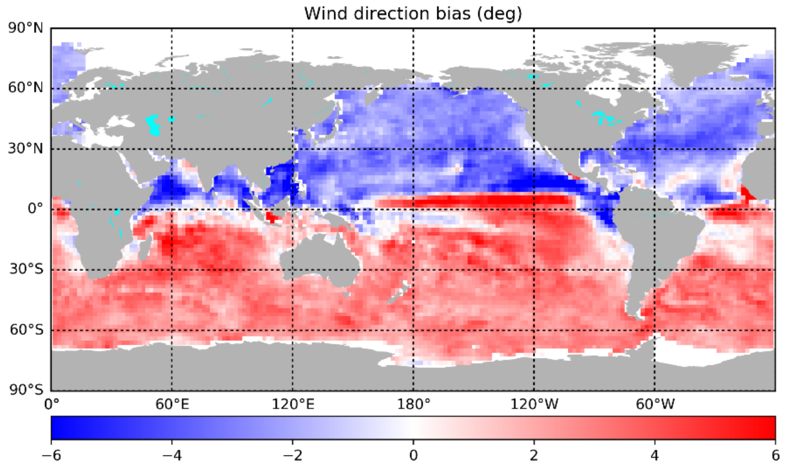
ASCAT-B NRT



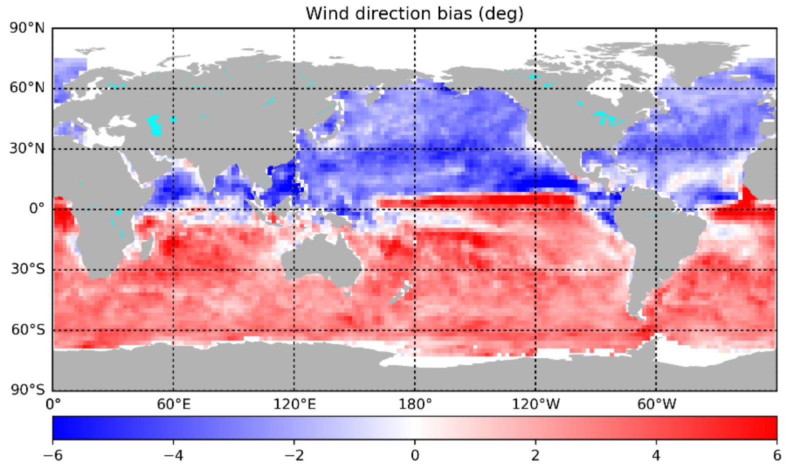
ASCAT-C NRT



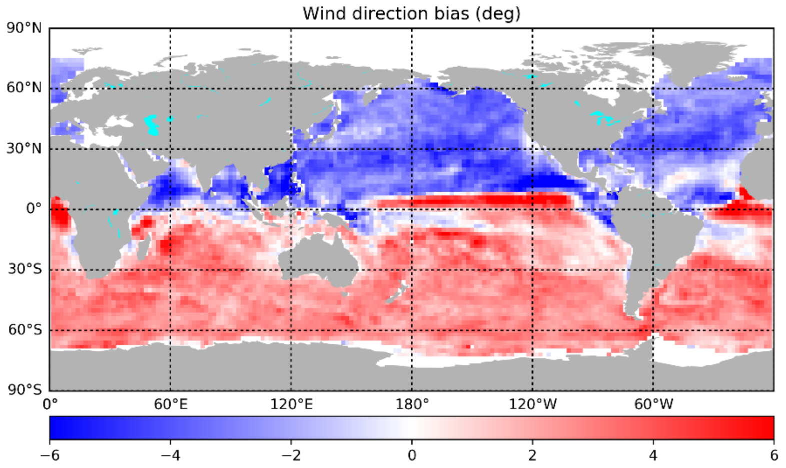
ASCAT-B/NRT – HSCAT-B/Rep02



HSCAT-B Rep02



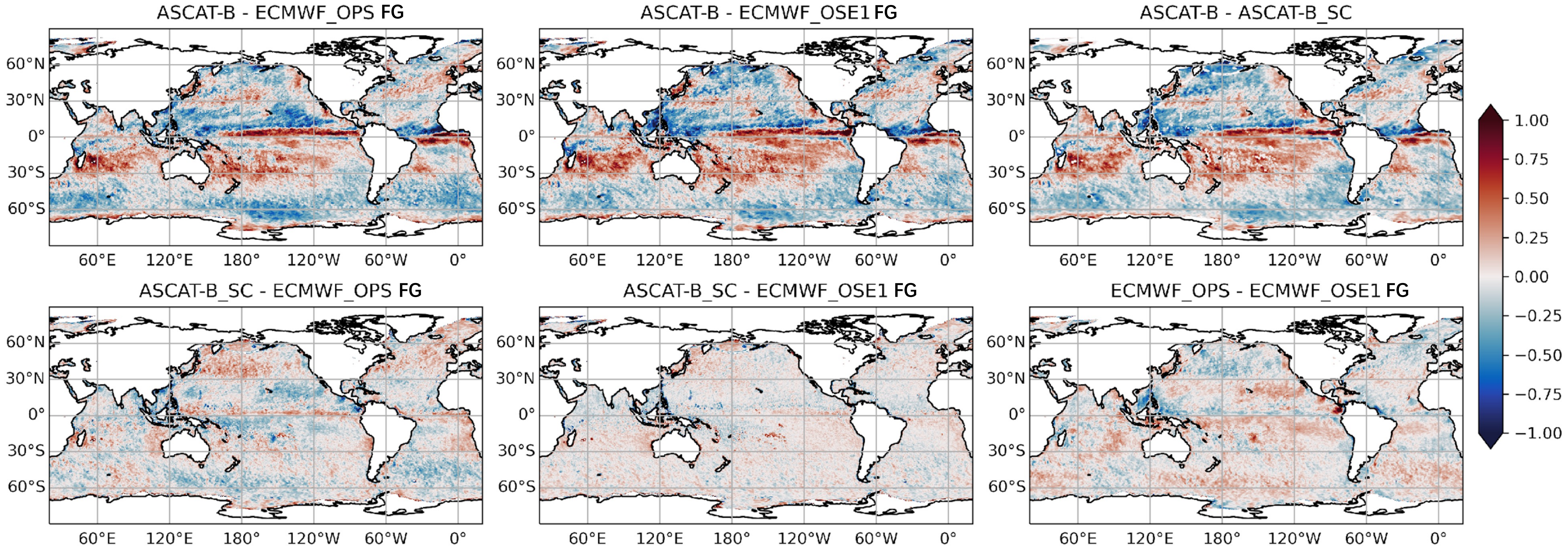
HSCAT-C Rep02



HSCAT-D Rep02

Meridional (v) model bias adjustment

SCATs assimilated | No SCAT assimilated | SCAT and FG differences



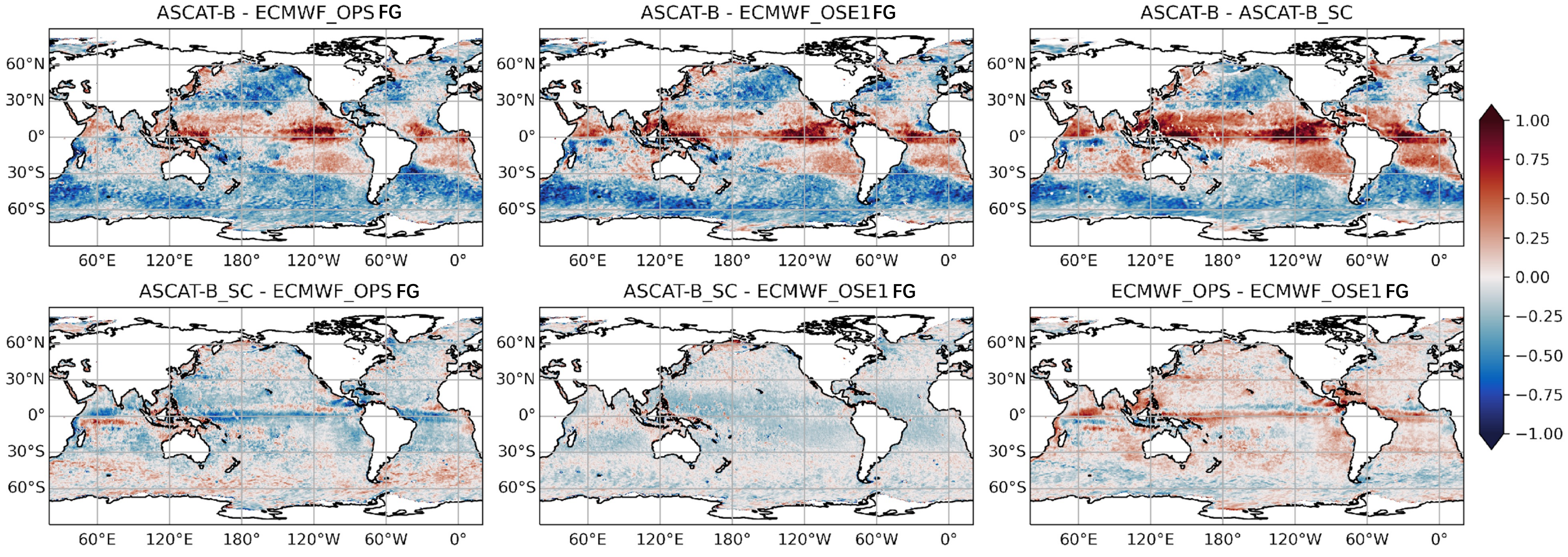
- Top: large v first guess biases, both in runs with (OPS) / without (OSE1) ASCATs and HY2B used
- Bottom: ASCATB_SC is adjusted to OSE1 and not to ECMWF_OPS, while with small biases

- Top: large v first guess biases, both in runs with/without ASCATs and HYB assimilated
- Bottom: ASCATB_SC is well adjusted to OSE1

- Top: large v biases in ASCAT-B_SC as expected
- Bottom: ECMWF_OPS minus OSE1 is complement of ASCAT-B_SC minus OPS (on left)
- OPS FG biases adjust only a little to the scatterometers

Zonal (u) model bias adjustment

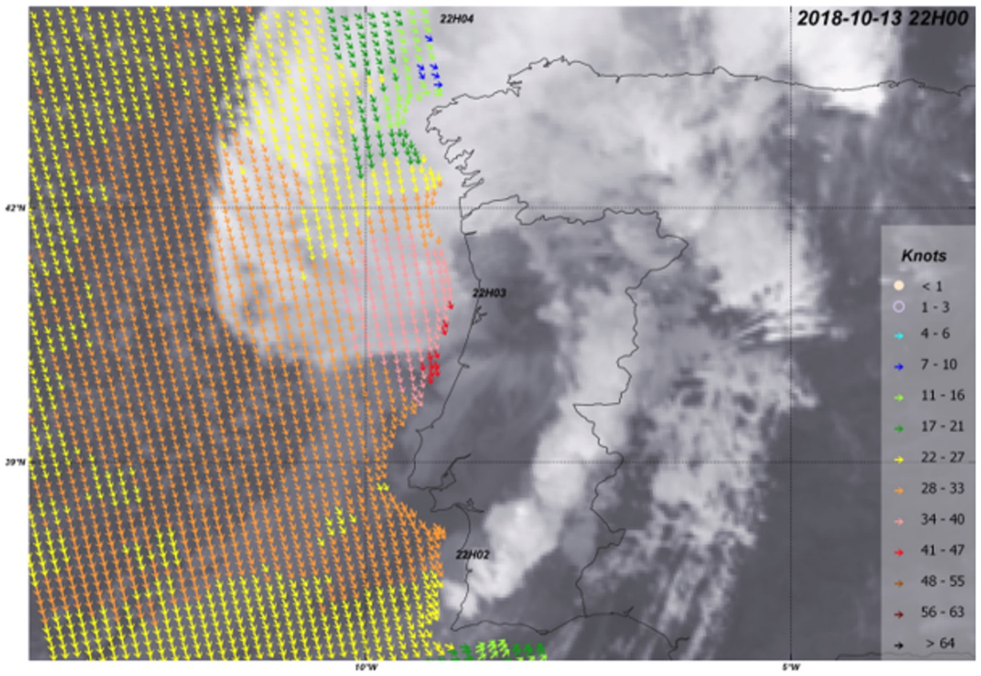
SCATs assimilated | No SCAT assimilated | SCAT and FG differences



- Top: large u first guess biases, both in runs with (OPS) / without (OSE1) ASCATs and HY2B
- Bottom: ASCATB_SC is adjusted to OSE1 and not to ECMWF_OPS, while with small biases

- Top: large u first guess biases, both in model runs with/without ASCATs and HYB
- Bottom: ASCATB_SC is well adjusted to OSE1

- Top: large u biases in ASCAT-B_SC as expected
- Bottom: ECMWF_OPS minus OSE1 is complement of ASCAT-B_SC minus OPS (on left)
- OPS FG biases adjust only a little to the scatterometers



Mesoscale Improved Data Assimilation of Scatterometer winds (MIDAS)

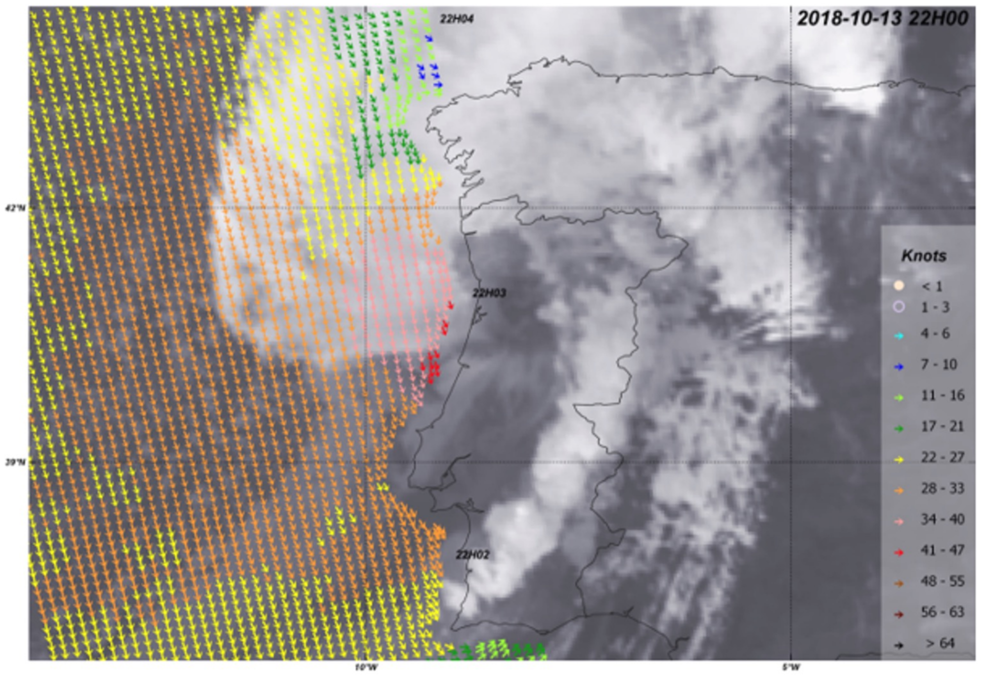
Draft version prepared by:
Isabel Monteiro, Gert-Jan Marseille, Fabíola Silva, Jan Barkmeijer and Ad Stoffelen

MIDAS conclusions

- HARMONIE 3-hour 4D-Var better than the widely used 3D-Var
- ASCAT improves the forecast skill both in 3D- and 4D-Var
- Tested data thinning distances, superobbing and observation error inflation
- Particular effects on the v component
- Error inflation at full density similar to superobbing statistically (as expected in Stoffelen et al., 2020)
- Local model biases are substantial with respect to the innovations and violate the data assimilation BLUE paradigm
- Scatterometer winds are not effective to initialise dynamical weather features and model biases need to be accounted for to better exploit scatterometer winds in HARMONIE

This was a EUMETSAT study

MIDAS conclusions



Mesoscale Improved Data Assimilation of Scatterometer winds (MIDAS)

Draft version prepared by:
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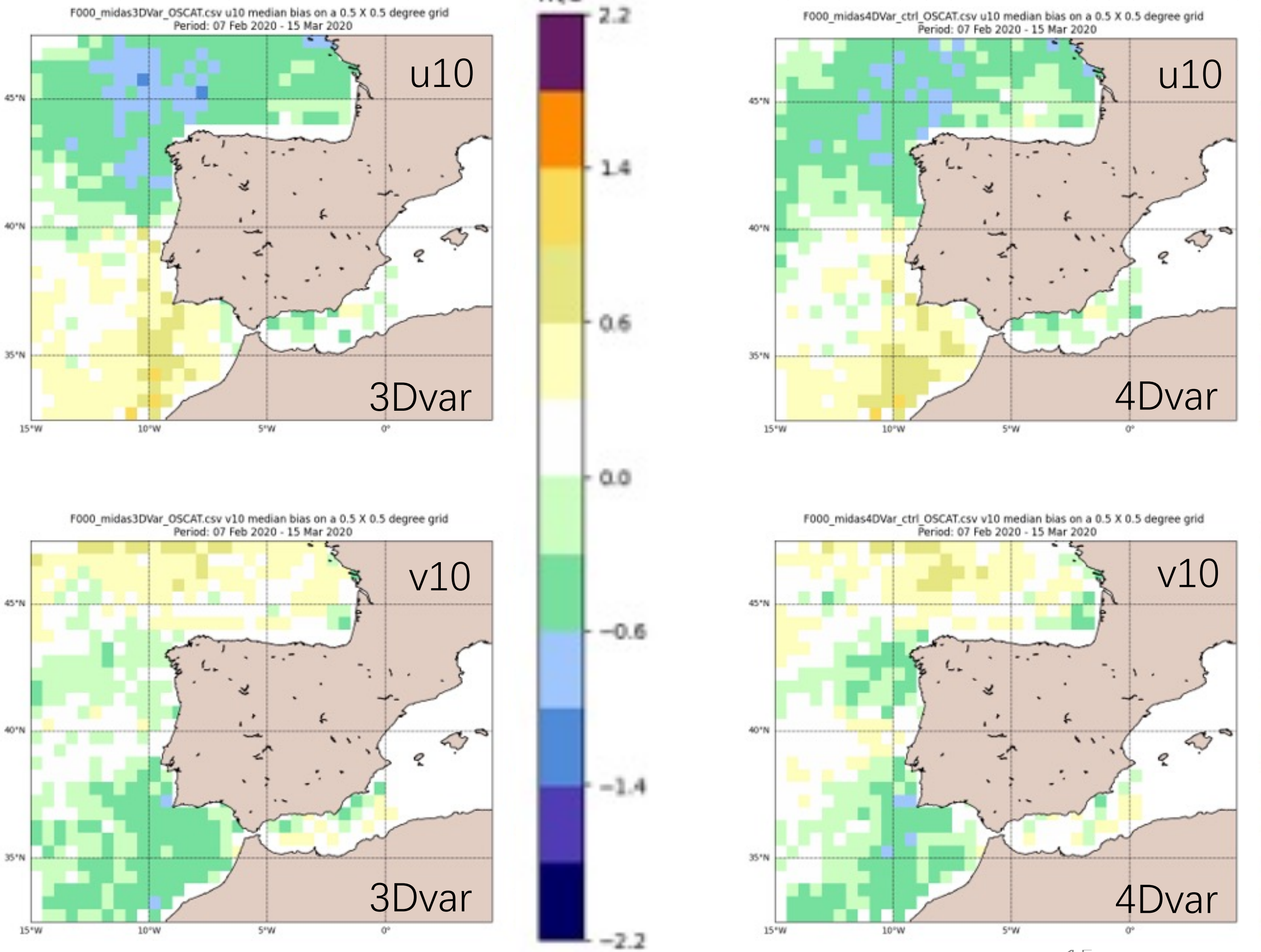
7 Feb – 15 Mar 2020

Median OSCAT – noSCAT FG



Conclusions

- Model biases of 10-m stress-equivalent wind (U10s) are substantial with respect to observations
- Scatterometers can map out the rather stable spatial biases well
- Biases prevent effective data assimilation (BLUE paradigm)
- Experiment with ECMWF o-b bias correction in progress by adjusting scatterometer BUFR data
- Biases also prevent effective scatterometer data assimilation in HARMONIE
- U10s biases affect ocean forcing and hence air-sea coupling and earth system dynamics (ocean is 70% of the surface)
- EUMETSAT awarded a fellow position at KNMI/ICM/ECMWF to address data assimilation, ocean forcing and physical causation of biases
- EUMETSAT OSI SAF visiting scientist Evgenia Makarova at ICM employs Machine Learning based on model parameters to predict the biases (MOS)
- Each scatterometer may contribute a few % in the reduction of the forecast errors and with 6 complementary scatterometers it may be a worthwhile investment to improve their assimilation by addressing remaining problems, of which model biases is a prominent one
- Furthermore, scatterometers can be well exploited to (much?) improve the coupled model dynamics at the air-sea interface

Brief Introduction of Datasets

☑ ASCAT-B 25km NRT
☑ ASCAT-C 25km NRT

☑ HSCAT-B 50km NRT (NOC: +0.62(HH), -0.63(VV))
☑ HSCAT-C 50km NRT (NOC: -1.17(HH), -1.32(VV))
☑ HSCAT-D 50km NRT (NOC: -0.34(HH), -0.12(VV))

☑ HSCAT-B 50km Rep01 (new NOC: +0.71(HH), -0.41(VV))
☑ HSCAT-C 50km Rep01 (new NOC: -1.01(HH), -1.11(VV))
☑ HSCAT-D 50km Rep01 (new NOC: -0.26(HH), -0.14(VV))

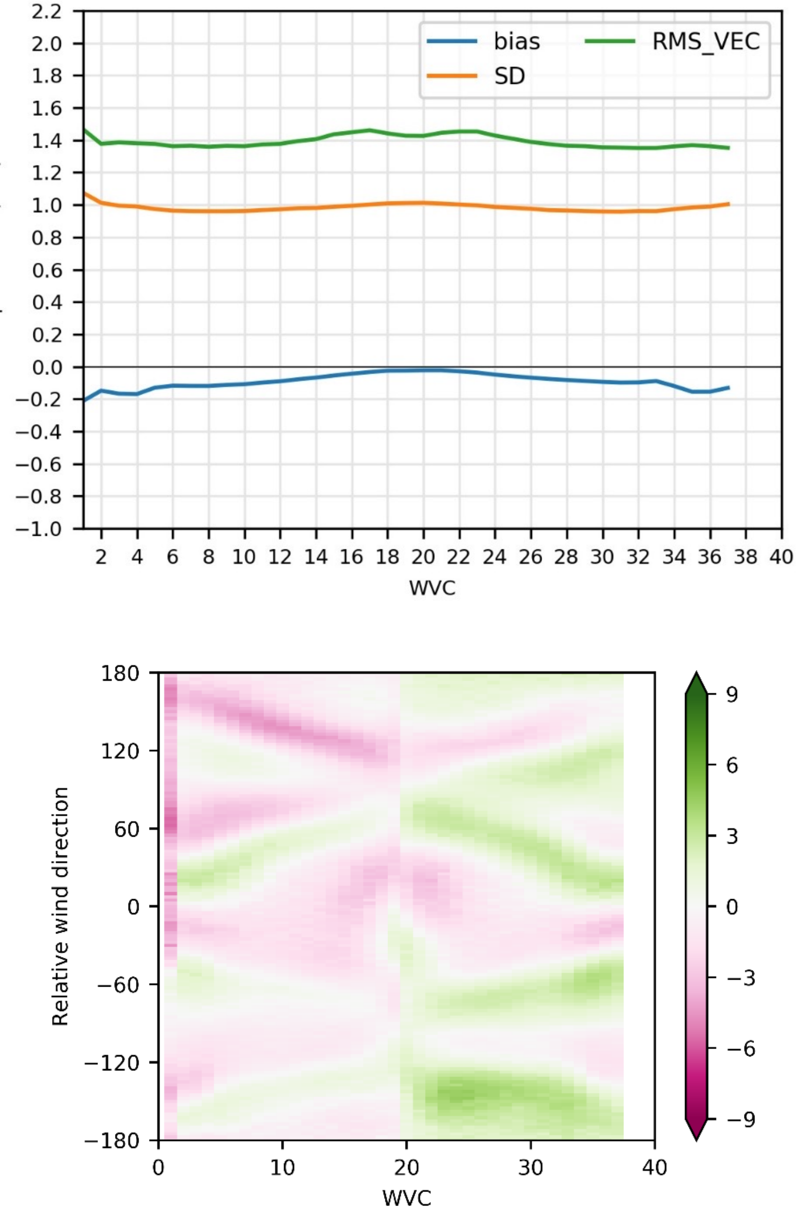
- NSCAT-4ds GMF
- SST Corr.
- **-mixqc (new rain QC)**

☑ HSCAT-B 50km Rep02 (new NOC: +0.52(HH), -0.56(VV))
☑ HSCAT-C 50km Rep02 (new NOC: -1.19(HH), -1.26(VV))
☑ HSCAT-D 50km Rep02 (new NOC: -0.45(HH), -0.30(VV))

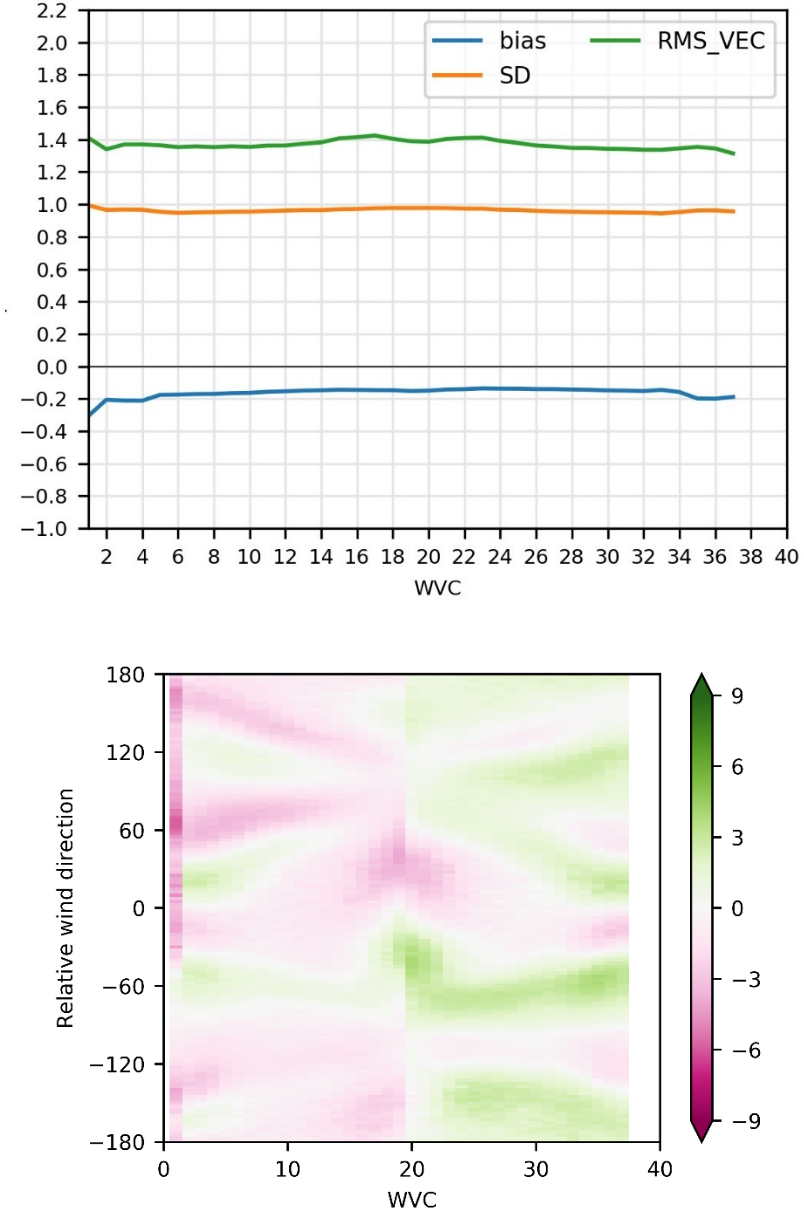
- NSCAT-**4ds.hy2** GMF
- SST Corr.
- **-mixqc**

- NWP data are taken from BUFR files, i.e., the same as NRT processing used!
- Time period: Dec. 01, 2021 ~ April 30, 2022
- SST data are taken from ERA5 at analysis time.
- NSCAT-4ds.hy2 GMF was made using CDF matching tech. based on collocated ascatb and hscatc+d winds
- New NOC was calculated using NSCAT-4ds.hy2 GMF and NWP winds contained in BUFR files.

HSCAT-B NRT



HSCAT-B Rep01



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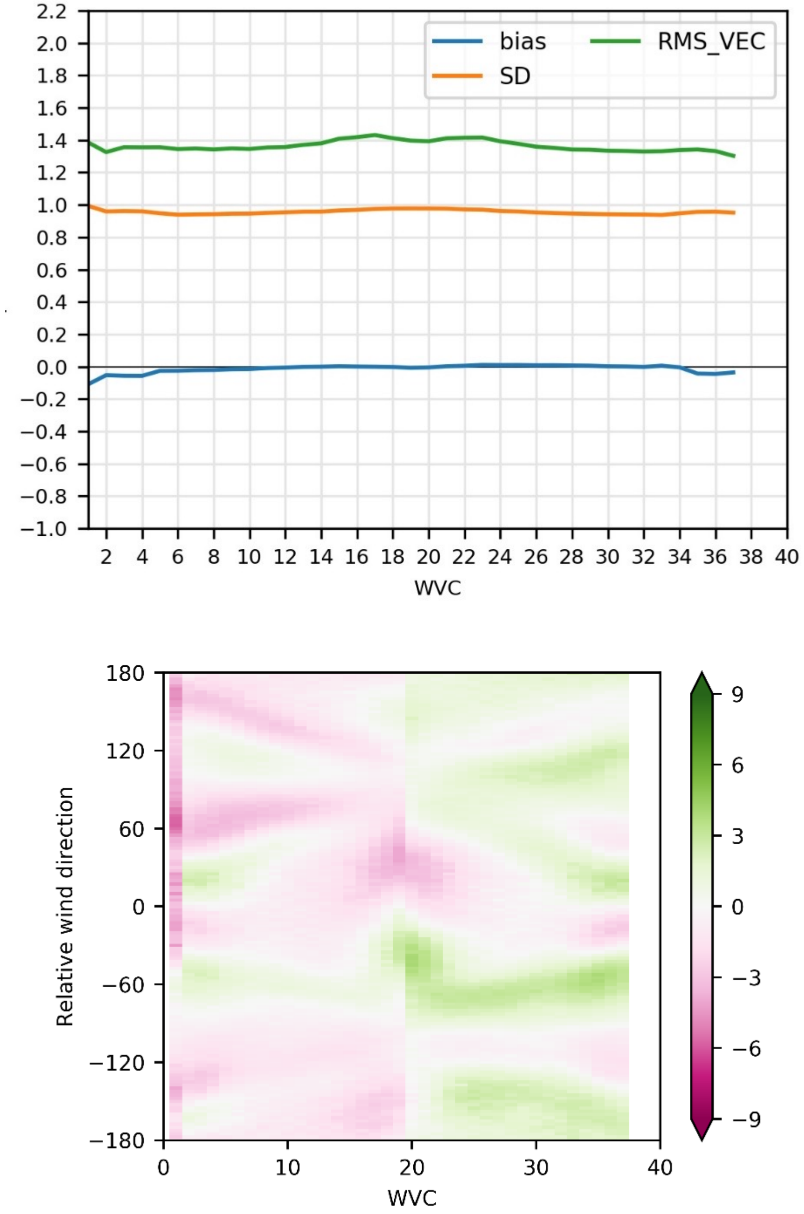
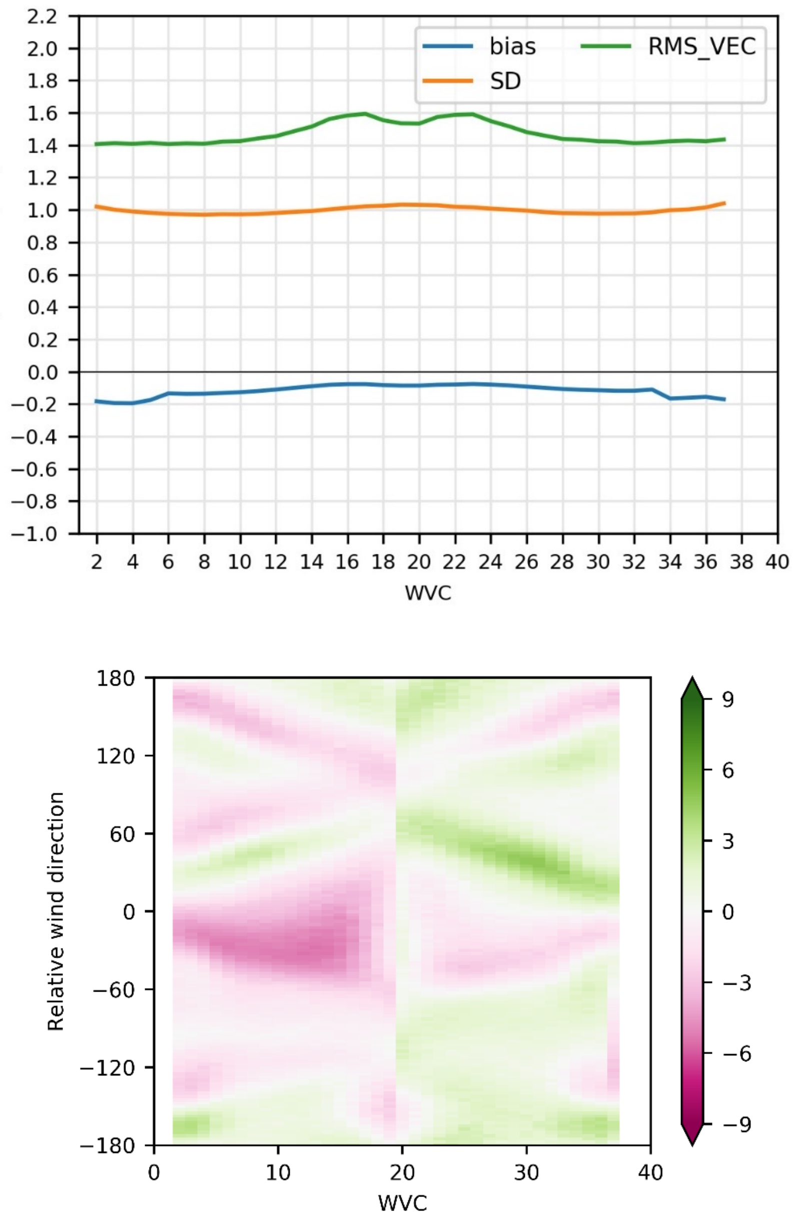
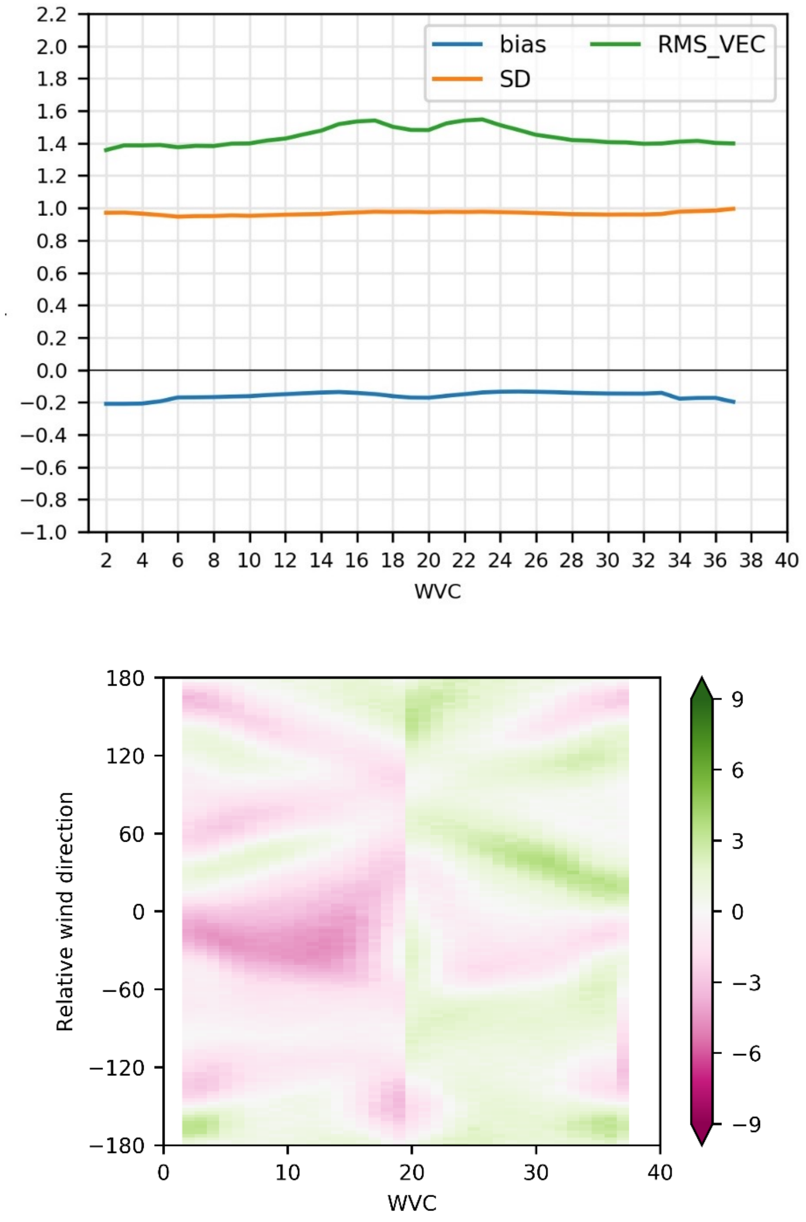


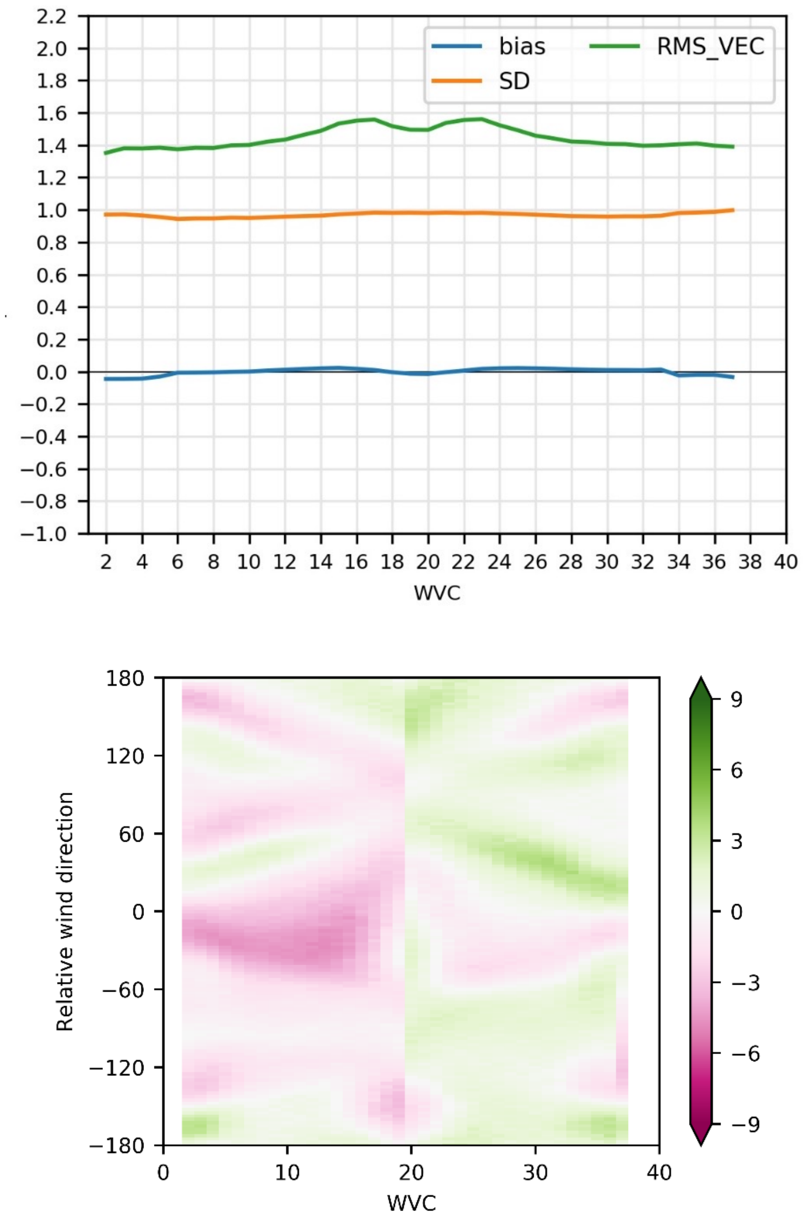
HSCAT-C NRT



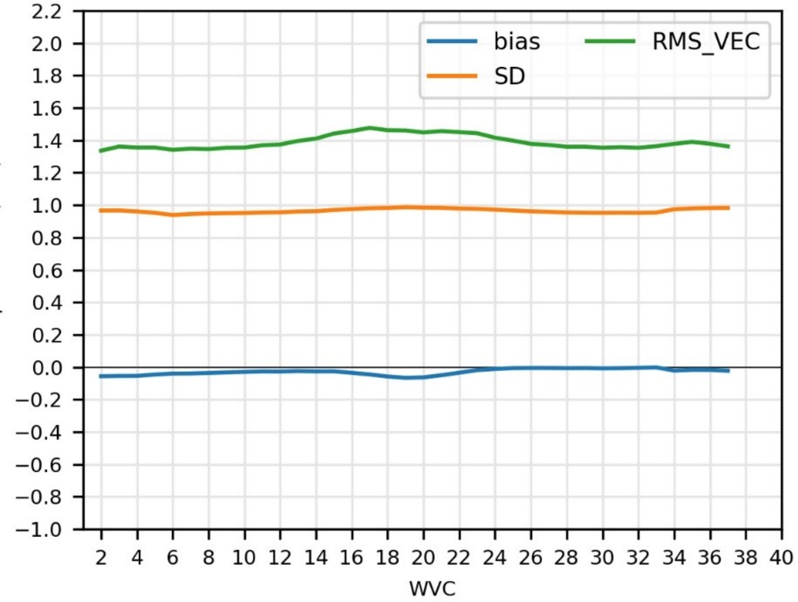
HSCAT-C Rep01

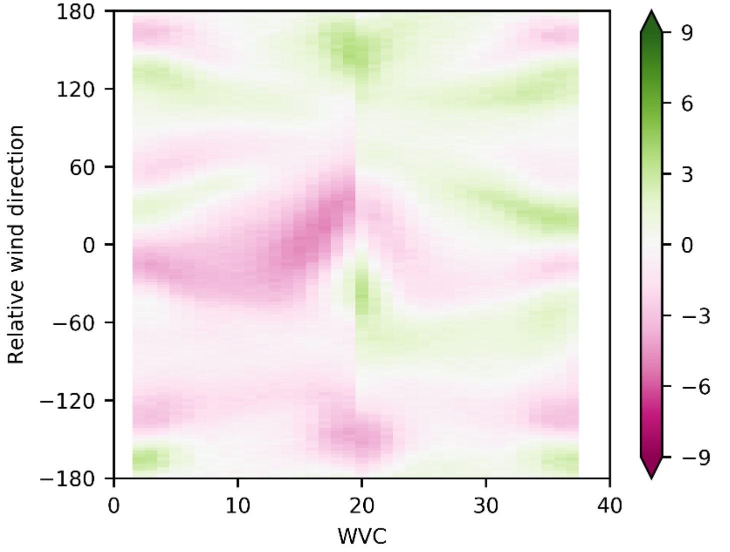


HSCAT-C Rep02

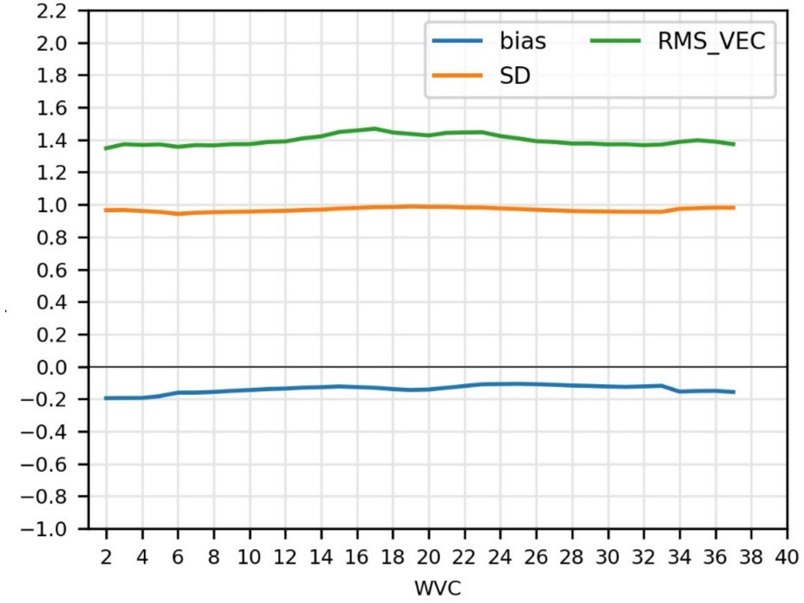


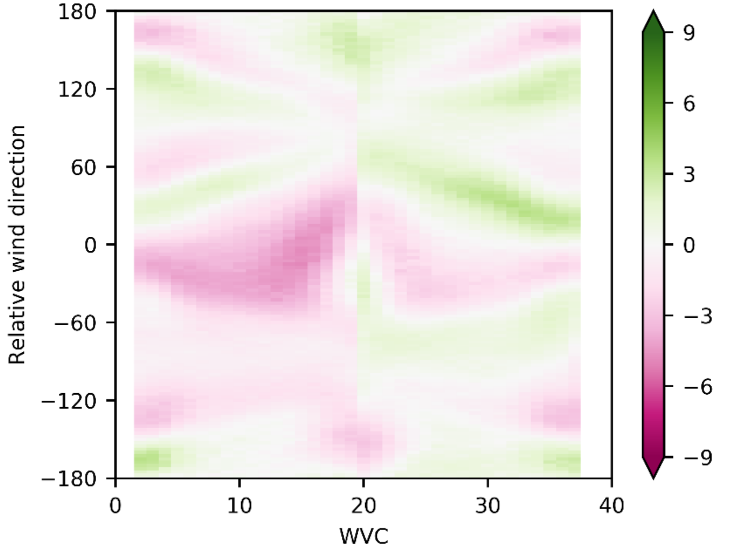
HSCAT-D NRT



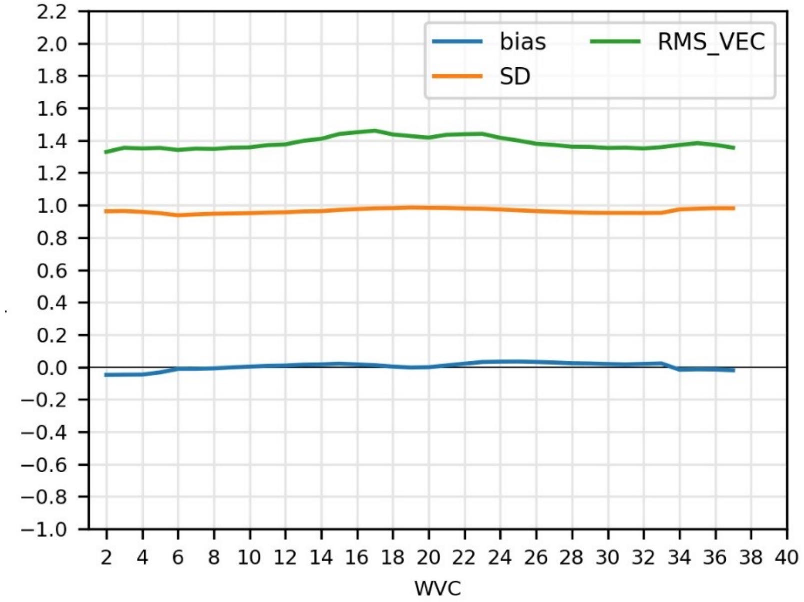


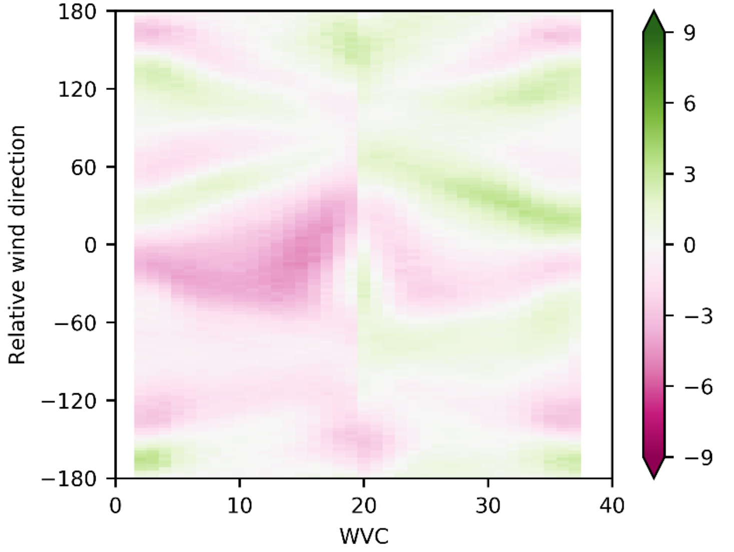
HSCAT-D Rep01

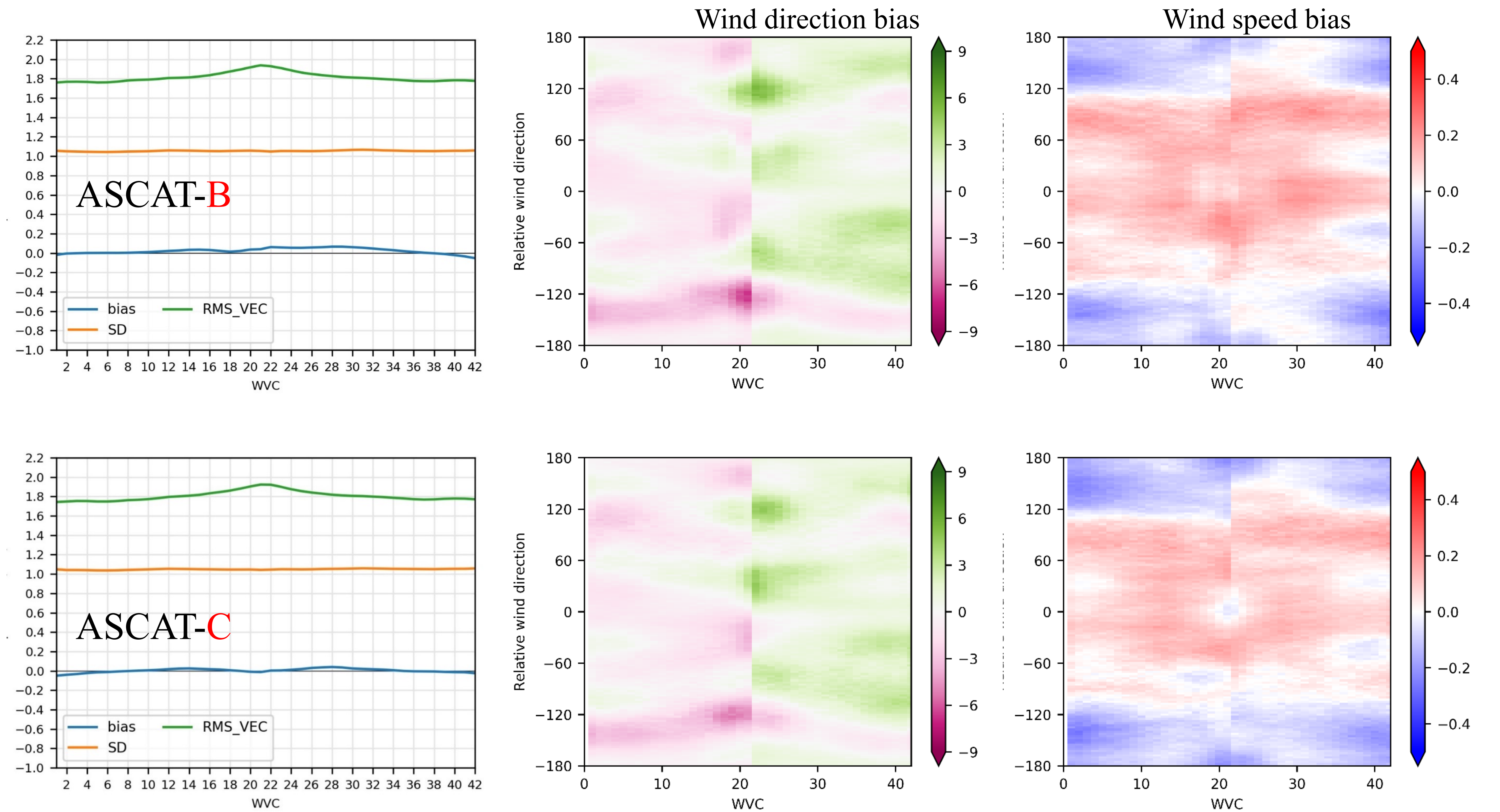




HSCAT-D Rep02



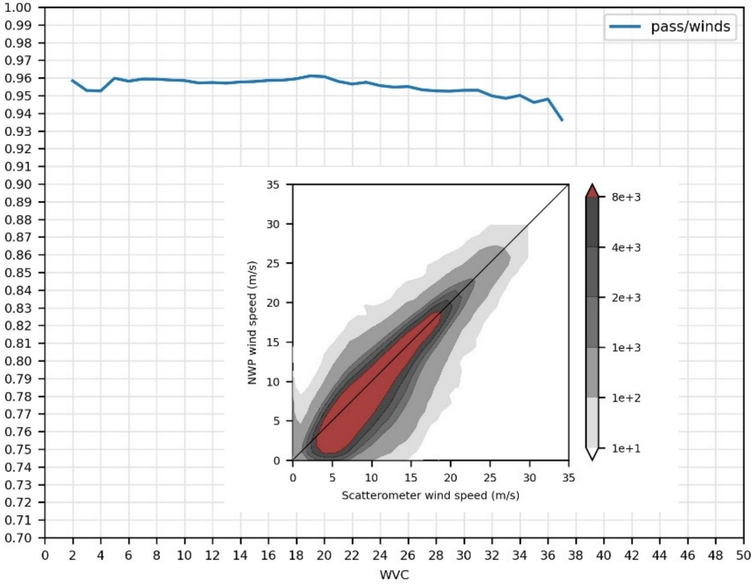


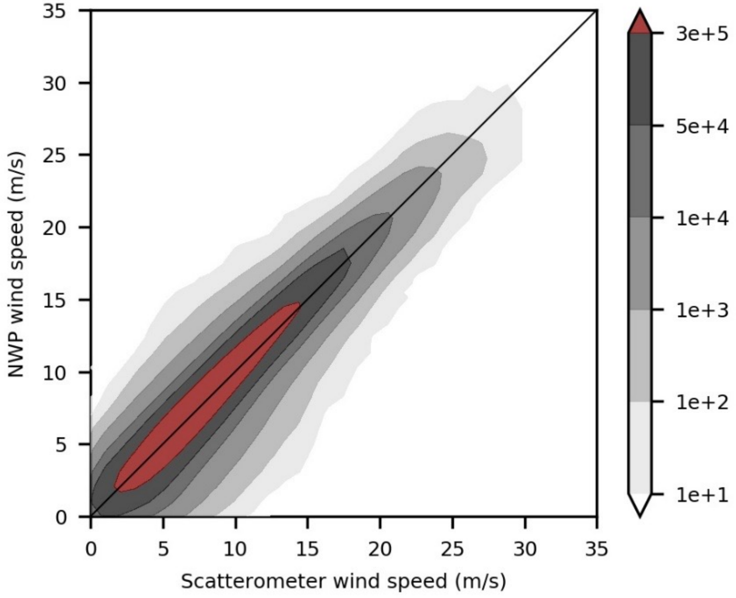


Wind direction bias
Wind speed bias
ASCAT-B
ASCAT-C
bias
SD
RMS_VEC
WVC
Relative wind direction

HSCAT-C **NRT** | HSCAT-C **Rep01** | HSCAT-C **Rep02**

HSCAT-C NRT





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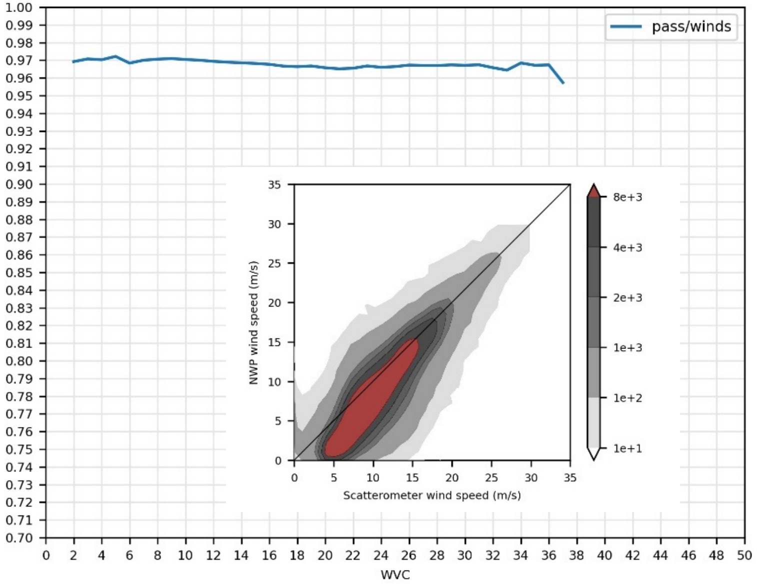
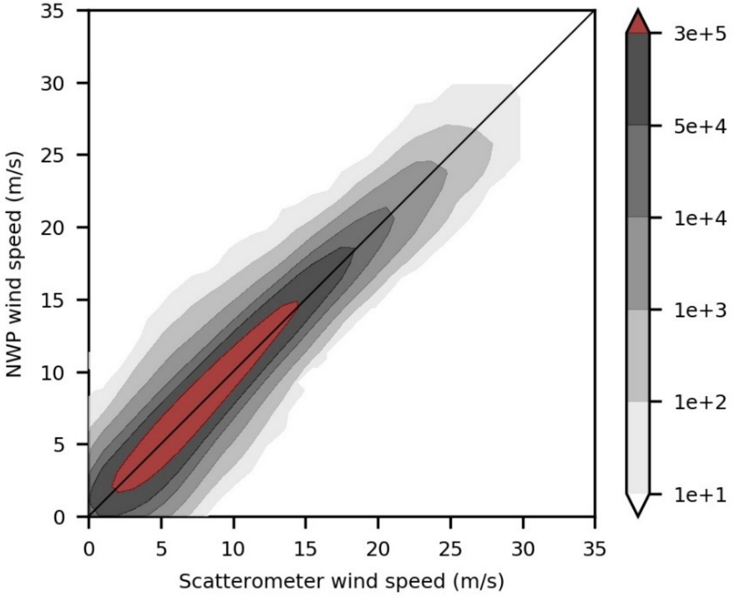
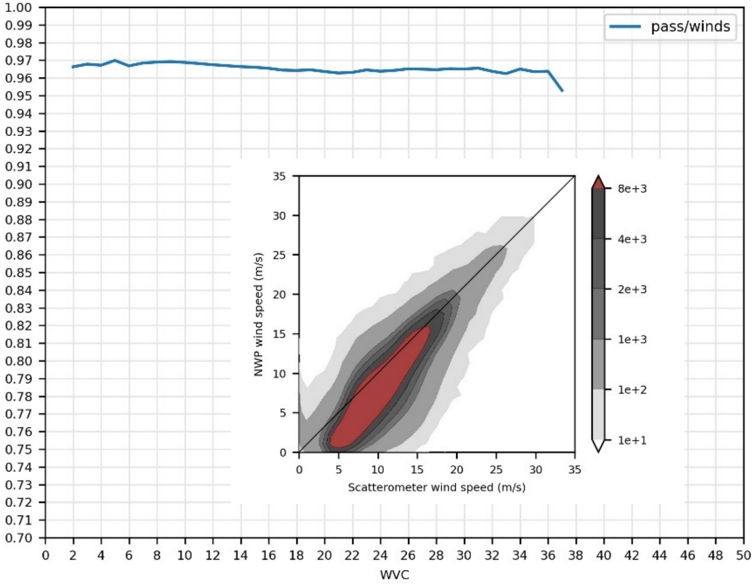
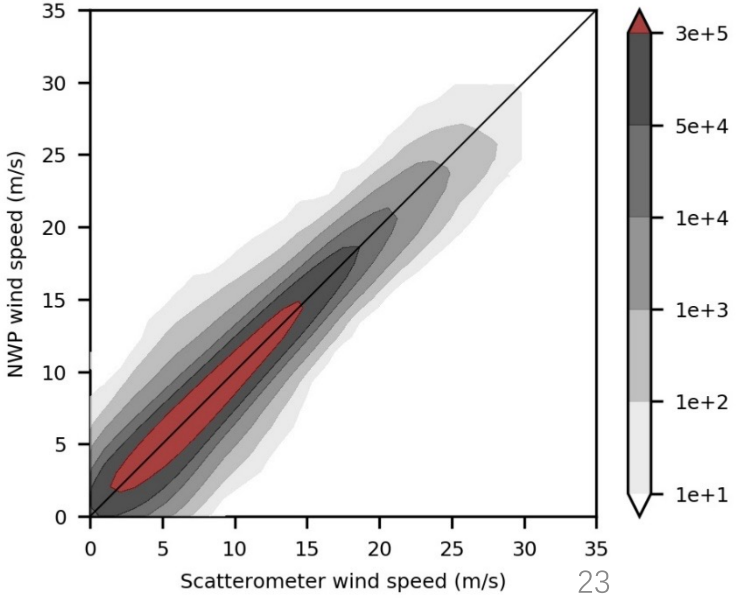


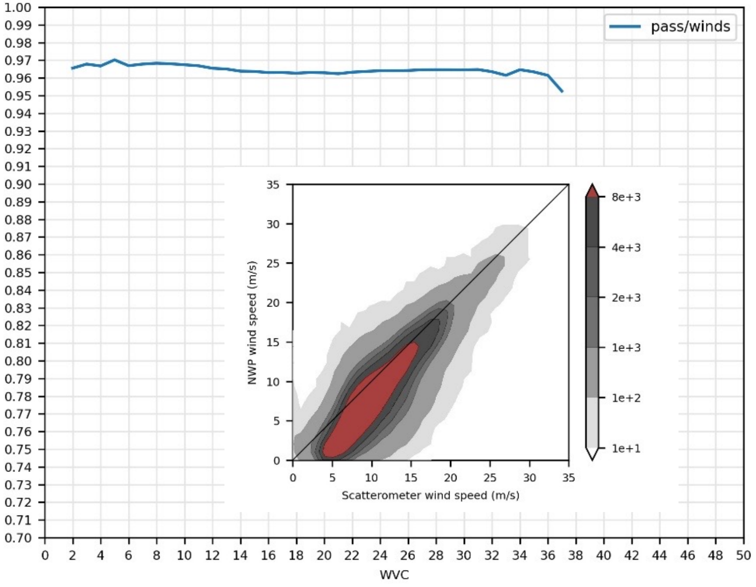


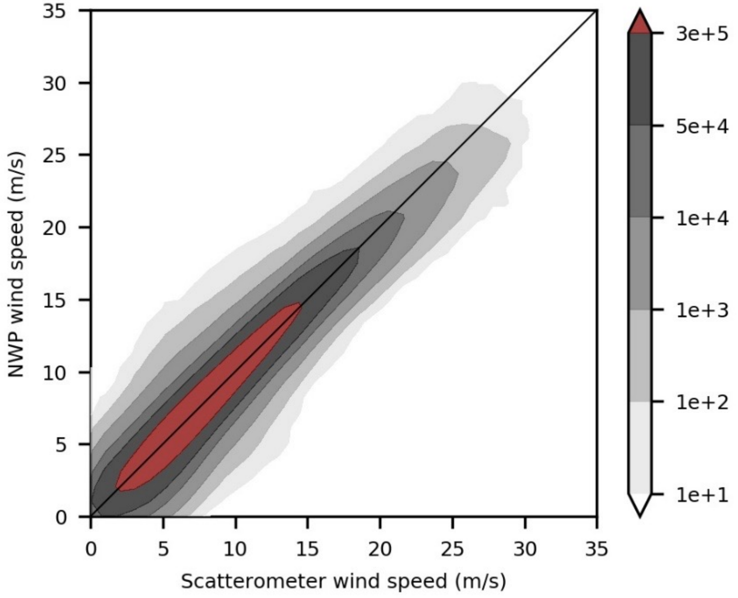
HSCAT-C Rep02



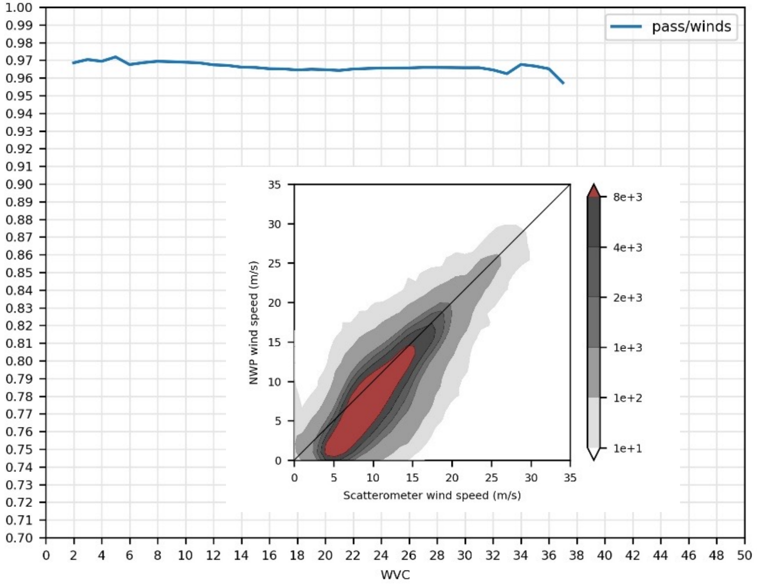


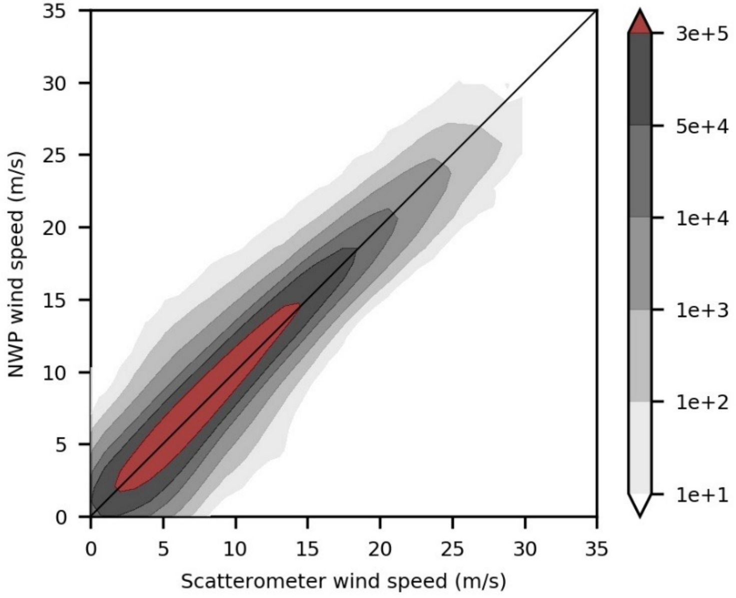
HSCAT-D NRT





HSCAT-D Rep01





HSCAT-D Rep02