Analysis of the scatterometer ocean surface measurement dependency on sea state

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Motivation

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- Recent Synthetic Aperture Radar (SAR) work confirms the different ocean surface scattering mechanisms for vertically (VV) and horizontally (HH) co-polarized measurements of the Normalized Radar Cross section (NRCS).
- VV modulation is well described by the so-called Bragg scattering of electromagnetic waves on wind-generated gravity-capillary ocean waves.
- It is of interest to also investigate the other ocean surface electromagnetic wave scattering mechanisms, associated with horizontally-polarized microwaves (wave breaking statistics).
- The HH NRCS depends both on the local wind and the non-locally generated waves that propagate through the scatterometer Wind Vector Cell (WVC).
- The aim of this study is to thoroughly analyze sea state conditions in association with HH (and VV) NRCS.

Conceptual model

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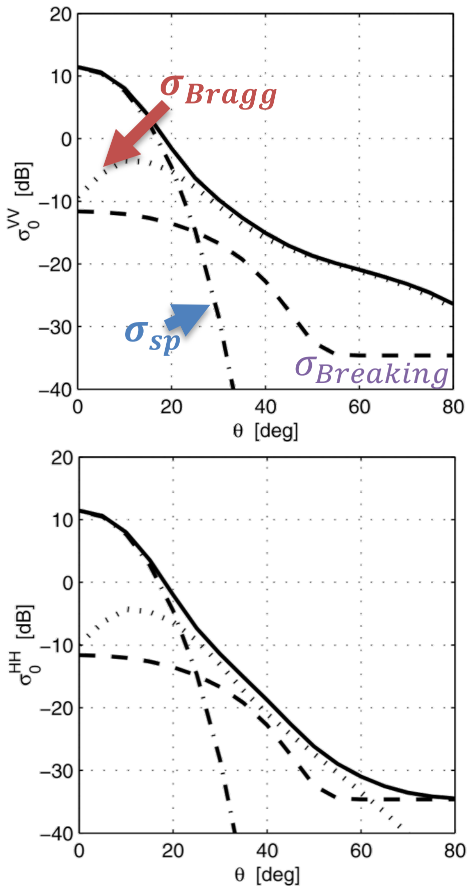
$$\sigma_{0,PP} = \sigma_{Bragg,PP} + \sigma_{sp} + \sigma_{Breaking}$$

Non-polarized
σ_s



(slide courtesy of Paco López-Dekker)

Data

- Collocations between:
  - Ku-band dual-polarized scatterometer HSCAT-C (onboard the HY-2C satellite) 25 km product
  - ECMWF WAM sea state parameters
  - SST from ERA5

- Period analyzed: Dec 2021 – Mar 2022 (3 months, 1240 orbits)

- Scatterometer inversion residual is analyzed

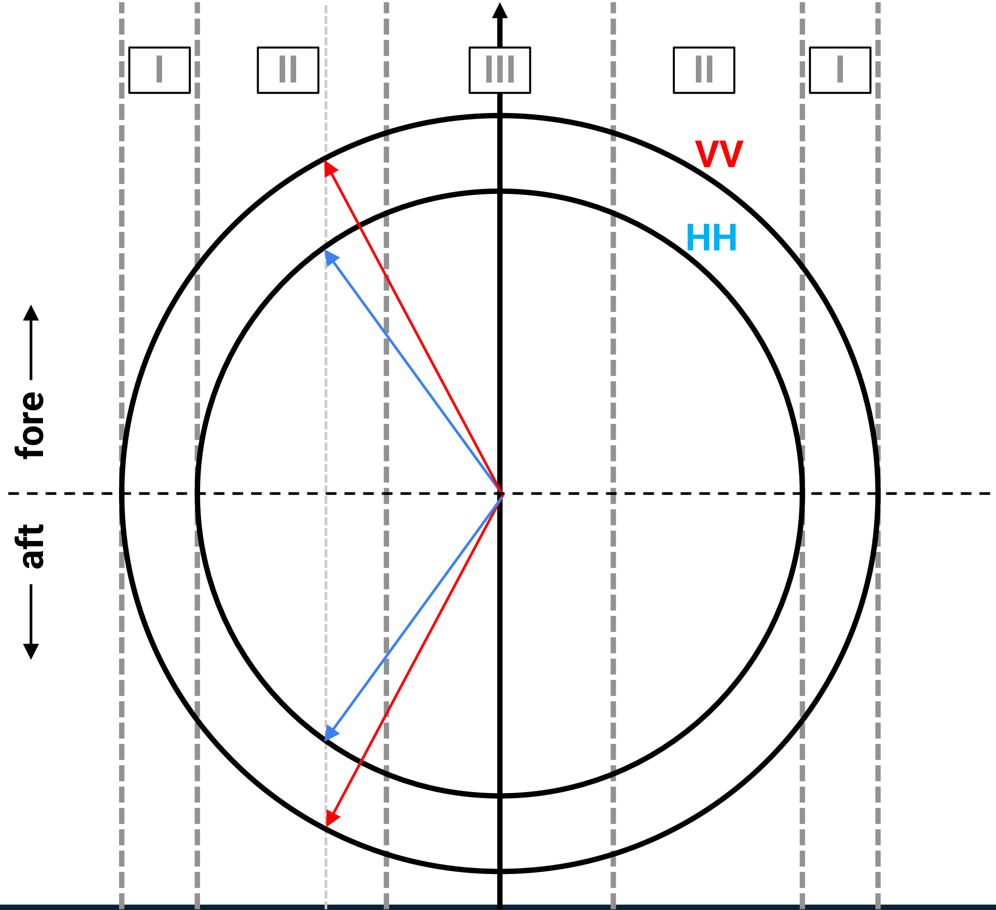
- Quality flags used for wind filtering: unfiltered (all points) and KNMI QC passed

Sea state parameters

The sea state parameters from the European Centre for Medium-range Weather Forecasts (ECMWF) wave model (WAM) are:

- **swh**: significant height of combined wind waves and swell.
  This parameter represents the average height of the highest third of surface ocean/sea waves generated by wind and swell. It represents the vertical distance between the wave crest and the wave trough.
- **shts**: significant height of total swell.
  This parameter represents the average height of the highest third of surface ocean/sea waves associated with swell.
- **pp1d**: peak wave period.
  This parameter represents the period of the most energetic ocean waves generated by local winds and associated with swell.
- **mpts**: mean period of total swell.
  This parameter represents the mean period of the waves associated with swell.
- **dwps**: wave spectral directional width for swell.
  This parameter indicates whether waves associated with swell are coming from similar directions or from a wide range of directions.
- **mwd / rwd**: mean wave direction / relative wave direction.
  This parameter is the mean direction of ocean/sea surface waves. It is a mean over all frequencies and directions of the two-dimensional wave spectrum. From this parameter, we compute the relative wave direction between the direction of the waves and the direction of the wind vector.

Rotating scatterometer geometry (HSCAT-C)



- Category I: outer regions (VV views only, poor azimuth diversity)
- Category II: sweet regions (HH+VV views, good azimuth diversity)
- Category III: nadir region (HH+VV views, poor azimuth diversity)

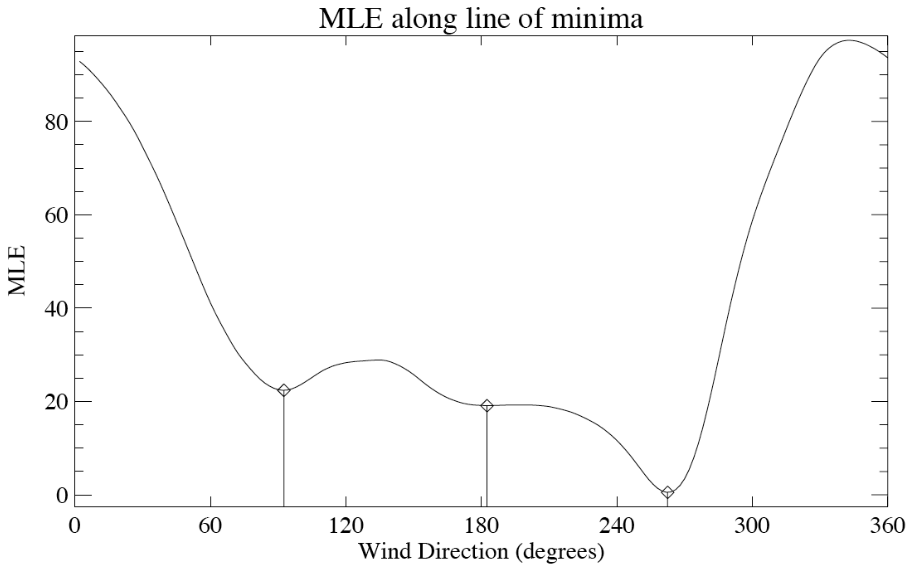
HH+VV views only available in the inner region (sweet + nadir region)

Relation between MLE and NRCS

In scatterometry, the true wind solution is given by minimizing the cost function of the Maximum Likelihood Estimator (MLE), which depends on the NRCS (σ^0):

$$MLE = \sum_{i=1}^{4} \frac{\left(\sigma^0_{i,GMF} - \sigma^0_{i,meas}\right)^2}{Kp\left(\sigma^0_{i,meas}\right)}$$

- *i*=1,2,3,4 (the four possible views/measurements)
- $\sigma^0_{i,GMF}$: NRCS simulated through the Geophysical Model Function (GMF), it depends on wind speed and SST
- $\sigma^0_{i,meas}$: measured NRCS
- Kp: measurement error variance (noise)



MLE is normalized by Kp, but it is not uniform across the swath (node number).

Normalized MLE

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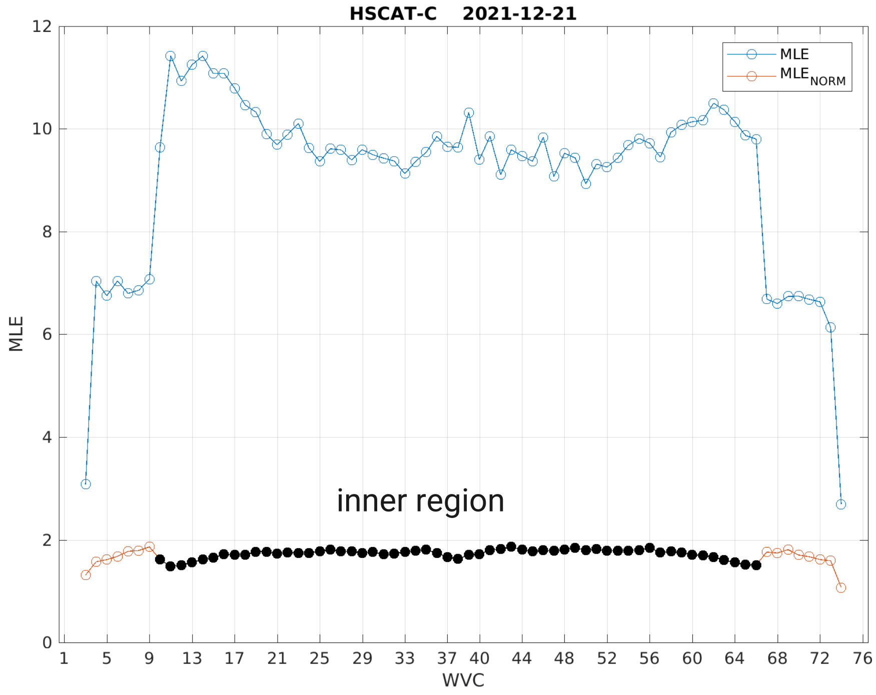
To normalize MLE across the swath, MLE is divided by an expected MLE value ($\langle MLE \rangle$), which depends on the wind speed and node number.

$$MLE_{NORM} = \frac{MLE}{\langle MLE \rangle}$$

Only the WVC numbers from 10 to 66 (inner region with HH and VV views) are selected for the HH/VV decomposition.

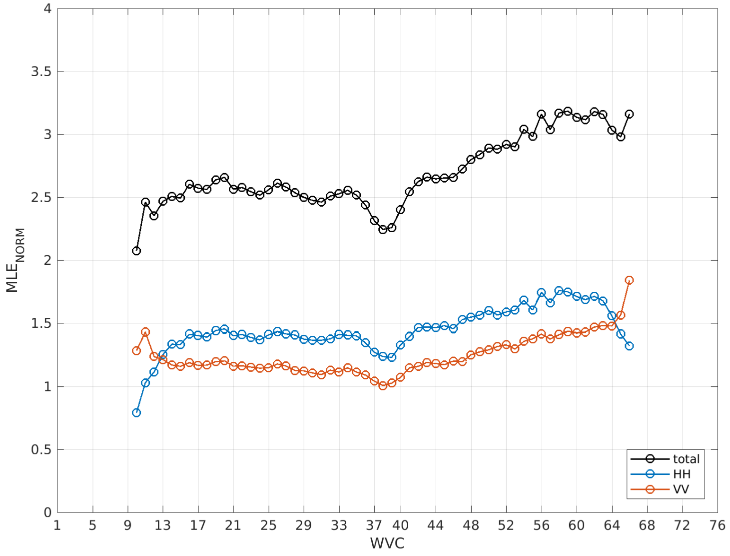


MLE decomposition: HH and VV

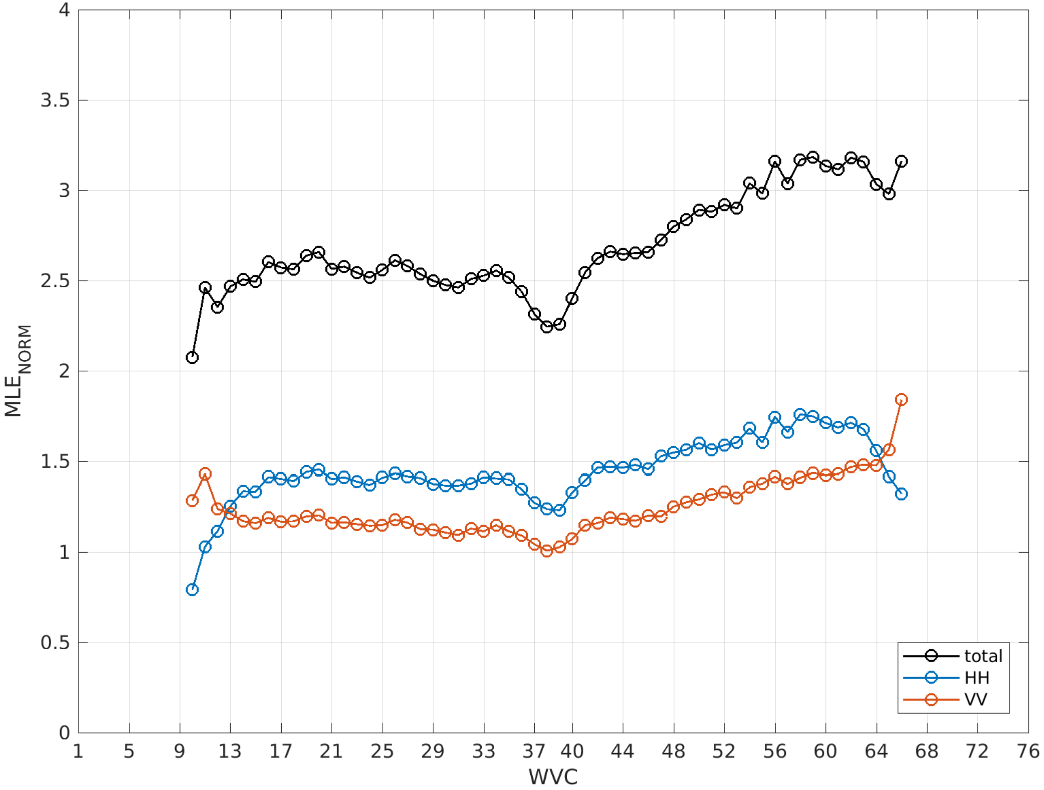
$$MLE = \sum_{i=1}^{4} \frac{\left(\sigma^0_{i,GMF} - \sigma^0_{i,meas}\right)^2}{Kp\left(\sigma^0_{i,meas}\right)} \longrightarrow MLE_{NORM} = \frac{MLE}{\langle MLE \rangle}$$

$$MLE_{HH} = \sum_{i=1,3} \frac{\left(\sigma^0_{i,GMF} - \sigma^0_{i,meas}\right)^2}{Kp\left(\sigma^0_{i,meas}\right)} \longrightarrow MLE_{NORM,HH} = \frac{MLE_{HH}}{\langle MLE \rangle}$$

$$MLE_{VV} = \sum_{i=2,4} \frac{\left(\sigma^0_{i,GMF} - \sigma^0_{i,meas}\right)^2}{Kp\left(\sigma^0_{i,meas}\right)} \longrightarrow MLE_{NORM,VV} = \frac{MLE_{VV}}{\langle MLE \rangle}$$



Normalized MLE (inner region)



WVC: 10−66

Fore-aft views azimuth separation

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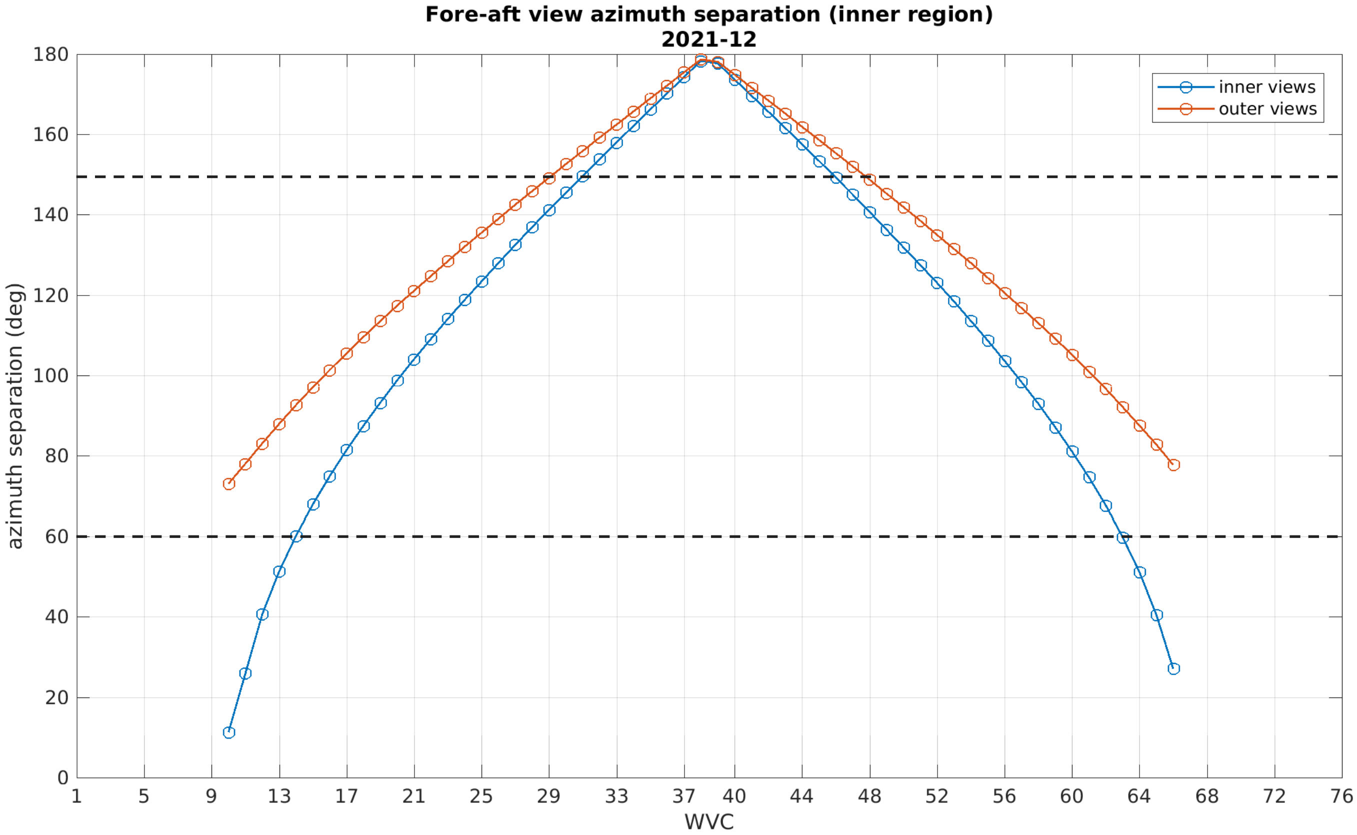
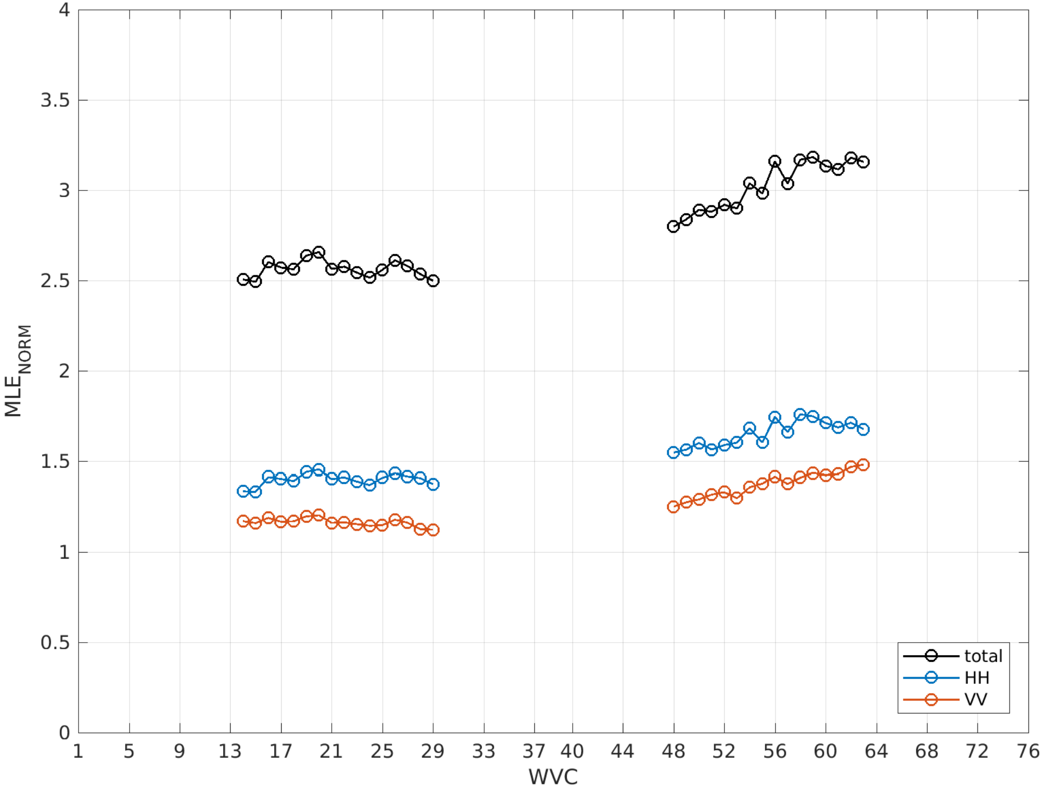


optimal range

Normalized MLE (sweet region)



Azimuth separation: 60°–150°

WVC: 14–29 & 48–63

Sea state categories

Sea state categories identified with the method from Grieco et al., 2016.

$$H_S^{FD} = 0.22 \frac{U^2}{g}$$

$$\text{growing sea :} \quad H_S - H_S^{FD} \leqslant -0.44 \frac{U}{g} \Delta U$$

$$\text{fully developed sea :} \quad |H_S - H_S^{FD}| < 0.44 \frac{U}{g} \Delta U$$

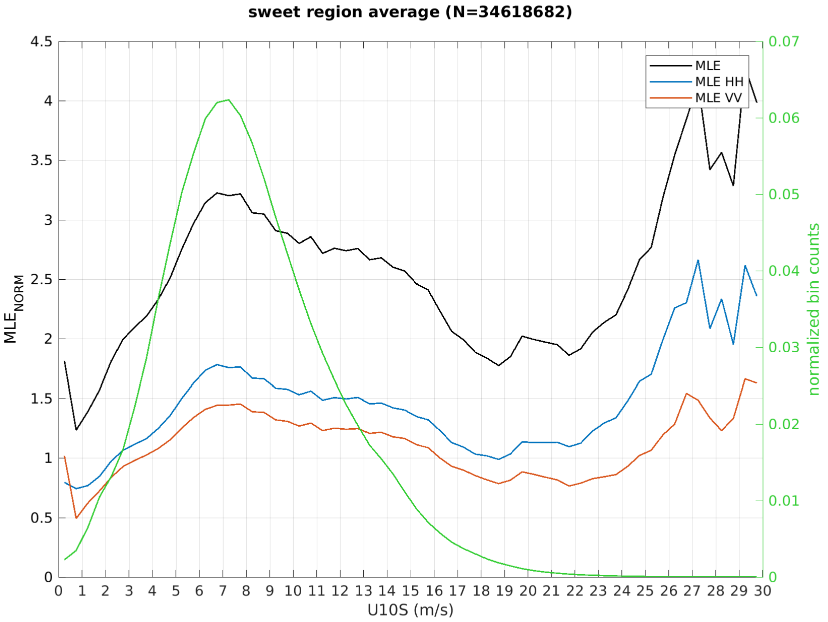
$$\text{decaying sea :} \quad H_S - H_S^{FD} \geqslant 0.44 \frac{U}{g} \Delta U$$

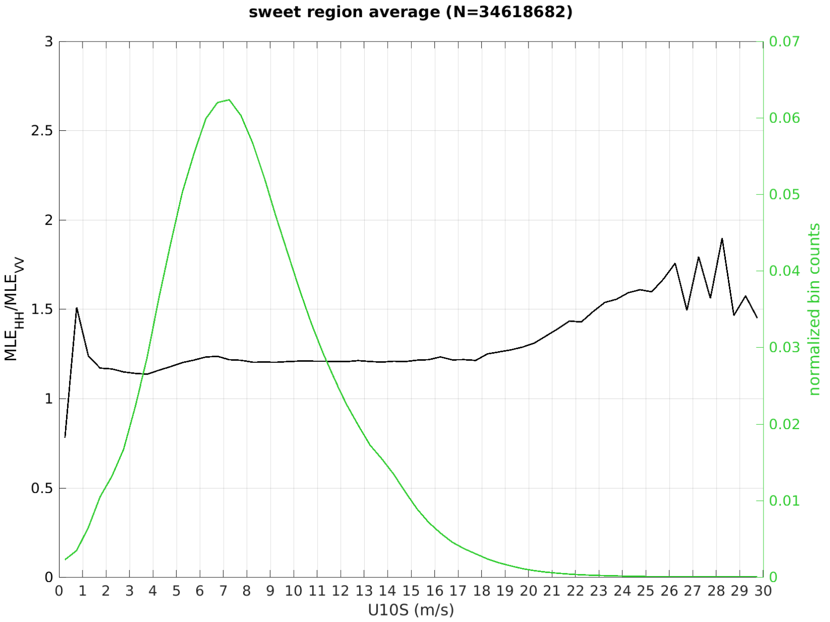
where:

- U: HSCAT-C wind speed (U10S)
- ΔU: 1.3 m/s
- g: gravitational acceleration

We found 4.1% samples for growing sea, 21.1% for fully developed sea and 74.8% for decaying sea.

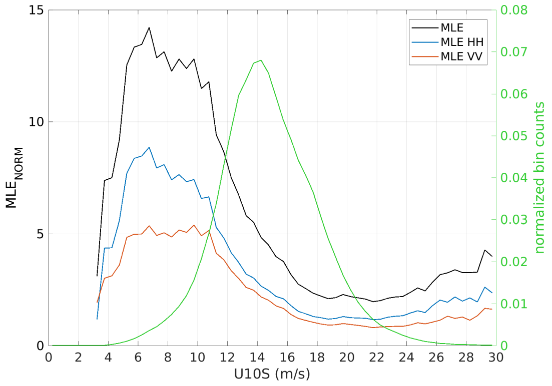
Results: sweet region average (unfiltered winds)



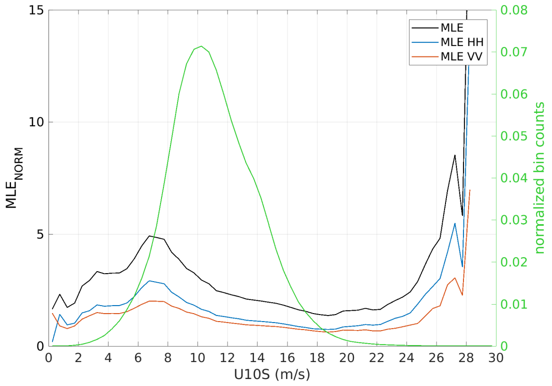


Results: sea state categories (unfiltered winds)

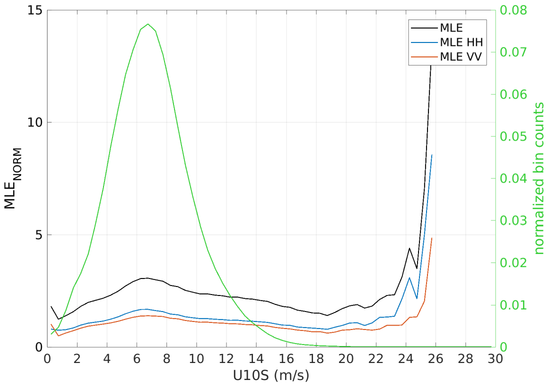
growing sea (N=1393606)

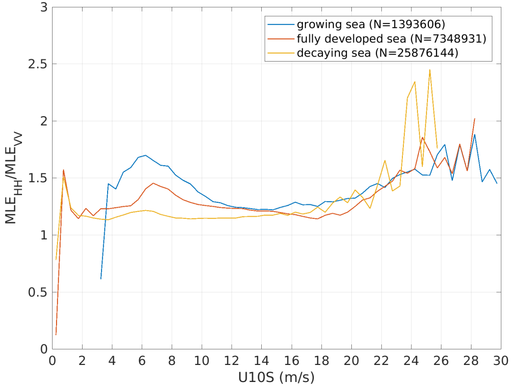


fully developed sea (N=7348931)

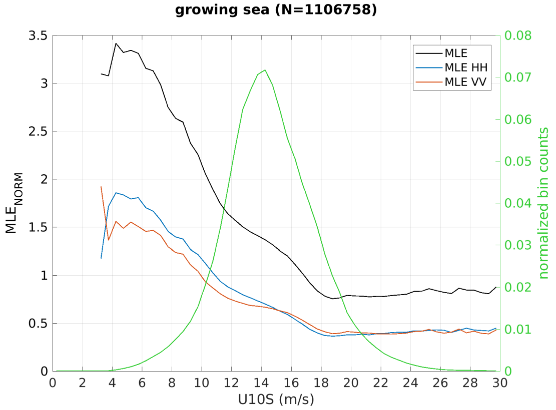


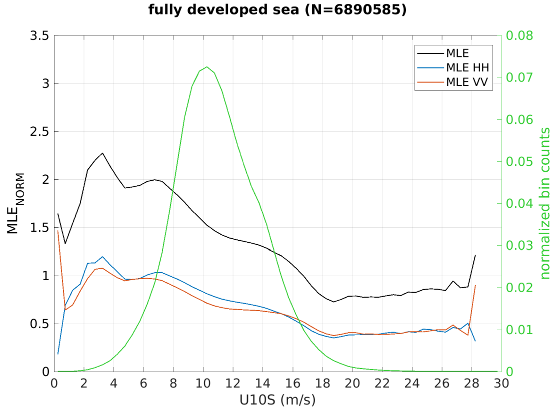
decaying sea (N=25876145)

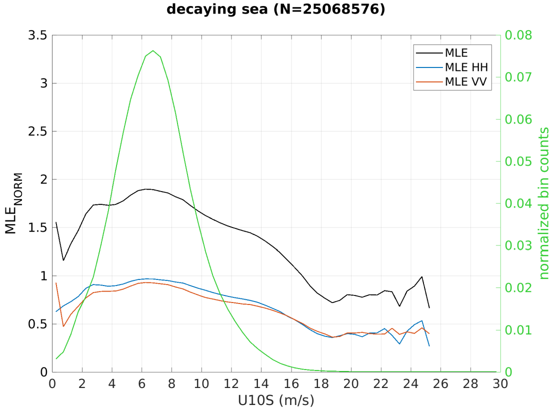


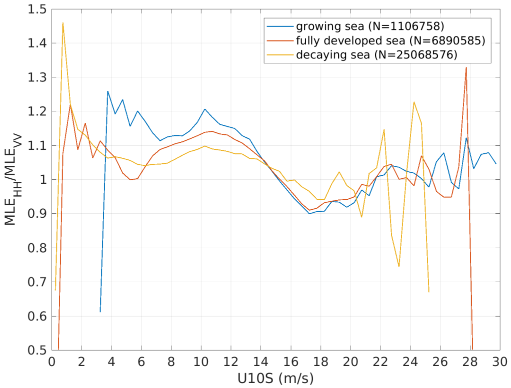


Results: sea state categories (KNMIQC-passed winds)

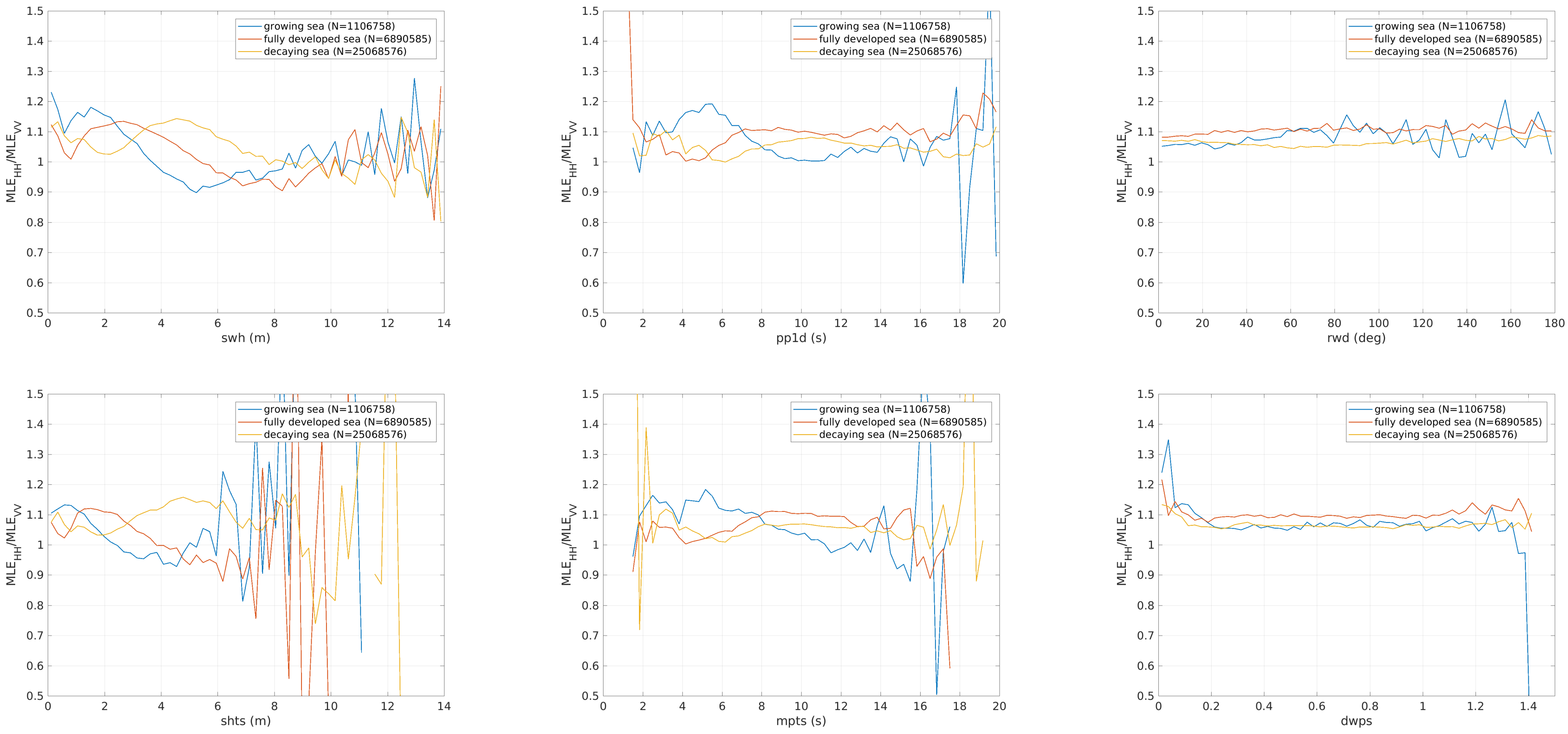








HH/VV ratio (KNMIQC-passed)



Conclusions and outlook

- Ku-band dual-polarization scatterometer measurements have the potential to highlight the non-polarized contribution due to the sea state, thanks to the different sensitivity of HH and VV NRCS to the Bragg scattering.
- MLE (wind inversion residual) is analyzed and compared to 6 sea state parameters + U10S
- The unfiltered winds show of a distinct HH (compared to VV) sensitivity to wind speed and sea state category, although such result is most probably due to rain effects.
- For the KNMI_QC-passed winds the HH/VV ratio is smaller compared to the unfiltered winds, proving the effectiveness of the QC on rain contamination removal.
- The sea state parameters related to wave height and wave period show a more complex behaviour of the HH/VV ratio (compared to U10S).
- The sea state parameters related to the directional properties show a rather uniform response across their range of values.

<u>Outlook:</u>

- Apply a new QC which removes rain more efficiently and keeps more good-quality high winds.
- Extend the analysis period and test $MLE/\langle MLE_{U10S}\rangle$
- Extend the analysis to other Ku-band (ScatSat, HY-2 series) and C-band (ASCAT) scatterometers.

Thank you!

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