C-band High and Extreme-Force Speeds
-- CHEFS --

Full project report here

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• **VH GMF**: The understanding of the future C-band VH information contribution to high and extreme wind retrievals from C-band scatterometer missions;

• **Spatial scaling** of extremes: The definition of spatial scaling issues and related consequences for product sample resolutions and validation approaches;

• **Understanding** of extremes: To further understanding of satellite remote sensing of high and extreme wind conditions over the ocean.

• In-situ wind speed reference needed for all extreme wind products, from satellites, reanalyses to NWP models
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- **EUMETSAT ITT 16/166**
  - Extreme winds calibration
  - VH test data

- **KNMI**
  - EPS-SG design and VH
  - GMF and retrieval
  - Calibration strategy

- **ICM**
  - Scatterometer science

- **IFREMER**
  - SAR wind retrieval
  - Data lab, L-band, GMF
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- 12 -> 29 months parallel efforts at KNMI, ICM and IFREMER
- Select and collect satellite observations at VH, VV and HH
- Select and collect in-situ reference wind speed data and ancillary geophysical information
- Collocate radar parameters from satellite with geophysical parameters from reference data
- Assess Sentinel-1 VH beam response to extreme winds
- Revisit the VH GMF; compare to passive L-band
- Assess wind variability effects, notably on the SAR signal (VV and VH)
- Cal/Val of SFMR with dropsonde wind data
- Define day-1 SCA processing method
- Generate SCA test data and validation

In-situ wind speed reference?
Are dropsondes too high, or moored buoys and ECMWF too low at 20-25 m/s? In-situ wind speed reference?
Dropsondes

- Dropsondes form the basis for further assessments dedicated to the high and extreme winds conditions.
- Dropsondes are compared against SFMR and SAR on the local scale and with ASCAT and ERA5 on larger scales.
- Direct comparison of moored buoys and dropsondes is unlikely.
- Dropsondes will be segregated in different vertical sampling, in different profile (shear) conditions and in different drift conditions.
- The scatter in dropsonde winds at 20 ms\(^{-1}\) versus ASCAT winds is relatively large and the dropsonde profile fits to compute 10-m winds from dropsondes will be evaluated and used for QC.
- Since ASCAT retrievals have good relative accuracy around 20 ms\(^{-1}\), they will be used as a (relative) reference to understand biases and scatter in both moored buoys and dropsondes.
- Collocations of SFMR with moored buoys exist occasionally to explore biases and scatter, but this remains pending.
WL150

- Used in operational practice to estimate maximum 1-minute sustained 10-m winds, $U_{10M1mS}$
- Dropsonde lowest reading at 10-15 m altitude
- WL150 mean altitude 80-90 m
- Linear fit consistent with WL150: 0.85 from Uhlhorn et al. (2007)
- Vertical averaging in WL150 enhances cyclone representation
- Measured $U_{10S}$ however best for instrument calibration
- $U_{10S}$ needs position, speed and acceleration
- Deceleration high near surface
Logarithmic profile

• In a log profile $z_0 = 5\text{ mm}, u^* = 1.58\text{ m s}^{-1}$ and $z_0 = 1\text{ mm}, u^* = 1.3\text{ m s}^{-1}$ lead to $U_{10LR} = 30\text{ m s}^{-1}$

• Corresponding $U_{10LR}/W_{150N}$ is 0.81 and 0.84 resp. (plot)

• Corresponding $U_{15LR}/W_{150N}$ is 0.85 and 0.87 respectively

• A shift in the 10m value may be due to
  ➢ No log profile (e.g., due to waves)
  ➢ GPS position lag, hence speed and acceleration error and 10-m wind measurement error

• Such errors are speed dependent
• The thinner the averaging layer, the lower variance
• Little variance in the lowest 25m, hence little sign of variability due to waves
• Note that due to the log profile and strong deceleration close to the surface, the dropsonde is integrating in the vertical
Averaging / Distance

- Best correspondence over 10 km
- 10 km is the typical distance between SFMR measurement location and dropsonde 10-m wind
ASCAT-VV SFMR comparisons

- Storm centered
- SFMR relatively high
- SFMR and ASCAT VV correlate well
- SFMR outlier tracks

\[ y = 0.57x + 5.16 \]
ASCAT-VV calibrated to SFMR

- Storm centered
- SFMR relatively high
- SFMR is based on dropsondes
- ASCAT VV is based on buoys

\[ V'(ASCAT) = 0.0095x^2 + 1.52x - 7.6 \]

- Better cc, bias, SD and rmse for the same sample
- Good match up to 40 m/s

Recalibrated
Stress-equivalent winds in TCs

• Only near tropical cyclones (TC)
• Pressure and humidity affect air mass density
• Particularly near TC centres
• At extreme winds up to a few m/s (5%)

➢ Needs to be accounted for
Moored buoys

- Best controlled resource for in-situ wind speed calibration at moderate and high winds
- Work well up to 25 m/s as verified with wind tower
- Dynamically corrected platform winds
- Claims of ocean wave shielding lead to non-substantiated sources (WP2)

![Graph showing Hurricane Lana at buoy 51002](image)
Other references?

- +ve and –ve wind flow distortion around platforms
- Verification shows differences to platforms 2x as high as to buoys; what is this scatter? Does it cause bias? Useful as calibration reference?
- Platform motion (ships)
- Errors are not well controlled, larger than for moored buoys and tend to be environmentally dependent

Hasager et al., 2013
Compare NRT to archive

- GTS: last 10 minutes of hour
- [icoads.noaa.gov](http://icoads.noaa.gov/) 10-minute values “super-obbed” into hourly values
- GTS is best resolved data
- Averaging causes asymmetric scatter, small (negligible) bias
- Stress-equivalent wind causes small bias
- Triple collocation analysis of the wind characteristics of different types of moored buoys in terms of height and mooring against ECMWF and/or ASCAT wind references
- Sea state?
Number of extremes

Wind speed PDF of archived buoy winds collected from NDBC, TAO, PIRATA and RAMA (Cwind), as collocated with the same data received by GTS at ECMWF (called MARS; purple), vice versa (red), Cwind PDF if no GTS found (blue) and vice versa (black). Red and purple correspond to 3.2 million collocations, black to 3.3 million points and blue to 1.7 million. Collocation is considered successful when location, hour and heights match.

- MARS data base is largest and has most extremes in PDF
Typical citation-support for the high wind buoy wind error issue/disclaimer (Peterson et al., 2017): “The wind speed, wind gust and wind direction were measured at 4 m height with a Gill WindSonic wind sensor (Fugro OCEANOR AS, 2007). It has been shown that during rough seas, due to sheltering effects and elevation changes, wind measurement by buoys can be negatively biased (e.g. Large et al., 1995; Zeng and Brown, 1998). Here, no attempt is made to compensate for a potential bias in the data set; that is left to the user.”
Results: 10 m neutral winds compared

Orthogonal (TLS) fits

All winds
\[ y = 0.97x + 0.27 \; ; \; R = 0.92 \]

Winds > 10
\[ y = 0.99x + 0.14 \; ; \; R = 0.81 \]

Filtering applied on dU/dt per Gilhousen, 1987, due to distance (24 km)
ASCAT versus buoys

- ASCAT $U_{10S}$ low with respect to buoy $U_{10N}$
- PMSL = 980 mb implies $\sim1$ m/s error
- Stress-equivalent wind computation needs to be done

<table>
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<th>Triple collocation</th>
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<th>ECMWF</th>
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Synthetic Aperture Radar

- High resolution, multi-polarization backscatter, but at low temporal resolution and poor calibration relative to scatterometers
- Ideal for spatial scaling and VV, HH, VH and Doppler GMF studies
- 2018/19 has seen an active hurricane season and IFREMER informed that several S1 acquisitions of hurricanes have been made. Note that IFREMER collected all Sentinel-1 SAR data from the existing archive - to get everything acquired before and in addition of SHOC. Additional acquisitions over 2019/2020
- Some NOAA hurricane flights far out into the Caribbean and therefore suitable SFMR and dropsonde collocations
- NOAA 2019 winter campaign cancelled
- ESA S1 over typhoons in the South West Indian Ocean in 2017/18/19; China acquires 4-5 acquisition by GF3 SAR in the China Sea (cf. ESA Dragon). CHEFS linked SMOS-STORM
- Some RadarSat hurricane data through the French ordering system
- Allowed late acquisitions to enter the CHEFS results
- Use ERA5
Caution grid comparisons

- 0.25-degree box-car average of SAR. At the equator the 2-sigma value of the spatial resolution of a box-car window is 0.25/\sqrt{3} = 0.14 \text{ deg.} \text{ or } 16 \text{ km}

- 40-km resolution of SMAP comparable to a 60-km box-car averaging
SAR aggregated NRCS
NEXRAD/SFMR Rain on VH SAR

- Rain clouds difficult to quantitatively estimate
SFMR & SAR VH collocations

- Storm-relative and storm motion corrected
- Rain effects evident on SFMR wind and SAR VH
ECMWF, SFMR & SAR VH collocations

- Storm-relative and storm motion corrected
- Sentinel-1 SAR VH consistent with RadarSat
- Sentinel-1 SAR very useful addition with respect to RadarSat
- Upsloping until 75 m/s
Incidence angle and rain

- Some rain effect noticeable by incidence angle
- Incidence angle effect more pronounced (beyond calibration uncertainty)
1-min maximum sustained winds

- VH-GMF retrieved velocities between the 0.995 and 0.9995 %-iles (x bar)
- SD over 24 hr in y bar
- BEST track data set depends on available observations, which depends on basin
VV, VH and L-band $T_B$

- $L \ T_B$ is very close to $1000 * \sigma_{VH}^0$
- $\sigma_{VV}^0$ appears related to rain peaks, but $\sigma_{VH}^0$ not
- Wind direction effect?
VH and L-band $T_B$

- Linear dependency
- Theoretically not obvious to relate Bragg to L $T_B$
- Measurement accuracy will determine quality of L-band and VH extreme winds
- High rain enhances VH NRCS at 19-22 and 40-43 degrees
- High rain reduces VH NRCS at 22-25 and 31-34 degrees
- SCA VH is excellent choice for extremes
GMFs

- Select a VH GMF for SCA
- A first HH GMF based on RadarSat has recently been published: Biao Zhang et al., 2019, GRSL-01248-2018.R1
- Will be tested in OSI SAF
Recommendations

- Use dropsonde $U_{10S}$ rather than WL150
- Perform a log-profile analysis
- Investigate speed-dependent deceleration error dropsondes at 10 m
- Convert buoys, dropsondes and model winds to $U_{10S}$
- Investigate different buoy types and possible wave effects on buoy measurements
- Investigate direct buoy-dropsonde collocations > 15 m/s
- After in-situ wind speed calibration, SFMR needs adaptation, as well as all satellite sea surface winds
- It furthermore will allow NWP model drag parameterization tuning
- Closer collaboration with JCOMM, satellite wind producers and ECMWF will be very beneficial to consolidate the in situ, satellite winds and NWP community practices
- Refine ASCAT calibration, VV GMF (cone) and retrieval at high/extreme winds
- Extend SAR and NOAA campaigns for refined geophysical studies
Conclusion

- We still lack a consolidated in-situ wind speed reference
- Affects satellite & NWP products and hurricane advisories!
- Confidence in moored buoys up to 25 m/s
- U10S needed
- Questions drop sondes?
- ASCAT VV correlates well at high winds
- SCA VH excellent choice