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HURRICANE OCEAN WIND SPEEDS

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ABSTRACT

How strong does the wind blow in a hurricane? This proves a question that is difficult to answer, but has far-reaching consequences for satellite meteorology, weather forecasting and hurricane advisories. In the EUMETSAT CHEFS project, KNMI, ICM and IFREMER worked with international colleagues to address this question to prepare for the EPS-SG SCA scatterometer, which introduces C-band cross-polarization measurements to improve the detection of hurricane-force winds. To calibrate the diverse available satellite, airplane and model winds, in-situ wind speed references are needed. Unfortunately, these prove rather inconsistent in the wind speed range of 15 to 25 m/s, casting doubt on the higher winds too. Should we trust dropsondes at high and extreme winds or perhaps put more confidence in the moored buoy references? This dilemma will be presented to initiate a discussion with the international community gathered at IGARSS '21.

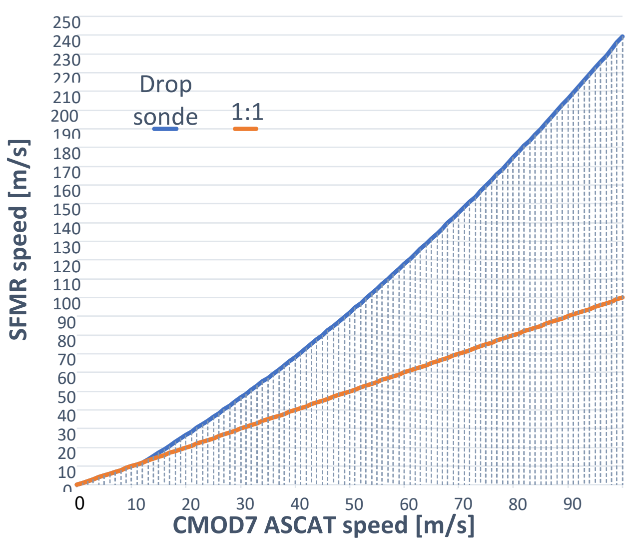

Fig. 1. SFMR wind speed, based on dropsonde calibration, versus CMOD7 scatterometer speeds based on moored buoys, showing substantial deviation from the 1:1 line [2].

Index Terms— Hurricane winds, dropsondes, moored buoys, atmospheric modelling, scatterometer, ocean vector winds, atmospheric dynamics, climate change, weather, clouds and aerosol.

1. INTRODUCTION

Hurricanes are among the deadliest of the existing natural disasters, moreover causing formidable economic losses [1]. The most deadly winds are mainly measured by dropsondes, airplanes and several diverse satellite instruments, whereby these are all essentially calibrated by dropsonde winds. Operational hurricane advisories hence depend on dropsonde winds, either directly or indirectly. A constellation of satellite scatterometer winds monitors the initiation, development and evolution of the earth's hurricanes, exploiting their all-weather capability. Scatterometer winds show sensitivity to high winds, but lack good Geophysical Model Function (GMF) calibration, due to, inter alia, the lack of a consolidated in-situ wind reference [2]. Significant progress has been achieved in CHEFS [2] on the evaluation of moored buoys, dropsondes and aircraft and satellite hurricane measurements. In particular, an evaluation of the different spatio-temporal averaging procedures of both dropsonde and airplane passive microwave (SFMR) winds was performed to address the representativeness issues of both data sources and further improve the SFMR calibration, with the following results:

– It is suggested that additional analysis are performed using logarithmic wind profiles in order to further investigate the observed dropsonde 10-m winds, which are a more direct calibration resource for the 10-m. The topic also included an assessment of the position processing of the sonde near the surface, where its deceleration is maximum.

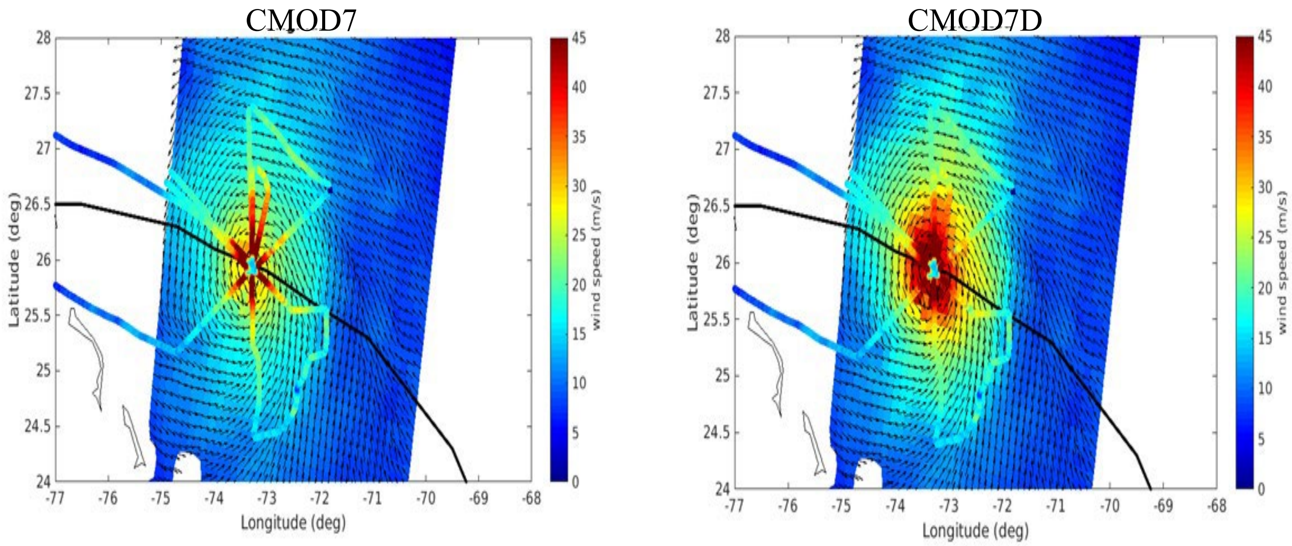

Fig. 2. SFMR wind speeds (colored lines), based on dropsonde calibration, and (original) CMOD7-based ASCAT scatterometer speeds, showing substantial deviation (left). The right panel is identical, but now ASCAT is calibrated (corrected) against SFMR according to *V'*(ASCAT)=0.0095x^2+1.52x-7.6, with x=V(ASCAT), above 12 m/s (Figure 1) [2], called CMOD7D here.

– wind reports showed great consistency, but also revealed many high wind reports that are not available in the archives, an issue that has been communicated to the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM).
– So-called stress-equivalent winds, U10S, need to be used for all satellite ocean surface wind comparisons, particularly at high and extreme winds, as these mainly occur at low pressures and hence low air mass density. Typical ocean surface roughness impacts of air mass density are 5% in tropical hurricanes.
– As more Sentinel-1 (S1) Synthetic Aperture Radar (SAR) campaign data are collected, improved cross-polarization (VH) GMFs are obtained in extreme winds. It was found that VH GMFs are closely related to L-band (SMAP) brightness temperatures (Tb) and wind relationships, and due to its expected accuracy and stability, SCA VH measurements appear excellent to retrieve extreme winds at scatterometer resolution. Moreover, collocated SAR, scatterometer and radiometer data are useful to further investigate geophysical effects (e.g. rain, SST, SSS) in both VH and L-band winds by using, for example, S1 and SMAP.

Furthermore, the high calibration stability of the ASCAT instrument somehow compensates the saturation of the C-band vertical co-polarization (VV) GMF at extreme winds. As a result, further backscatter calibration refinements will support the retrieval of good-quality scatterometer winds in extreme conditions. In addition, GMF development and wind retrieval studies will prove useful to improve high and extreme winds, in particular after a consolidated in-situ wind reference has been established.

This paper briefly presents the dropsonde winds and moored buoy winds in section 2. Moored buoy extremes are discussed in section 3. Conclusions are provided in section 4.

2. DROPSONDE WINDS

Dropsondes are used as basis for wind speed calibration of the Stepped Frequency Microwave Radiometer (SFMR) and SFMR in turn is used for calibration of the broad spectrum of surface winds from satellites. This calibration should take the spatio-temporal scale of the verification sources into account, and it was found that calibration uncertainties are not dominated by local gradient effects [2]. However, the following aspects of dropsondes do cause concern:

– Dropsondes cannot follow the wind near the surface, due to the strong deceleration as function of the drag;
– The correction for this leads to an integration effect in the vertical, depending on the deceleration, hence wind speed;
– The integration effect causes bias due to the logarithmic wind profile;
– 10-m SFMR winds in hurricanes are inconsistent with a log profile [2];
– The accuracy of the position computation by the dropsonde GPS chip has not (yet) been investigated, in particular for the derivation of speed and acceleration needed for 10-m wind derivation, with may cause further bias in strong deceleration (drag);
– Most passive satellite winds, SFMR, best track, etc. are all calibrated with respect to dropsondes and show the same inconsistency with respect to moored buoy winds from 15-25 m/s, where moored buoys are shown to be accurate [2];

These results call for further investigation of the true in-situ wind speed reference in hurricane conditions. Due to the above-mentioned inconsistency, calibration of satellite winds (above 15 m/s) is uncertain, as well as their assimilation in NWP and the associated drag formulation in Earth System Models.

3. MOORED BUOY WINDS

The best controlled resource for in-situ ocean wind speed calibration are moored buoys for low, moderate and high winds. This is the main reason why the ASCAT and ECMWF follow the moored buoy scale (up to recently). When compared to other wind data sources, buoys show the lowest dispersion and error attribution is well advanced. However, buoys have only rare encounters with hurricanes, e.g., as shown in Figure 3. Buoy winds are not frequent in hurricanes, but are validated by masts to be unbiased up to 25 m/s (within ~10%) [4], while at 25 m/s the conversion bias from Figure 1 is 45%.

The cup anemometers used by moored buoys are calibrated in wind tunnels up to 80 m/s and it is known that biases at extreme winds may be a few % (only). The largest challenge of moored buoys and other moving platforms at sea, may be in the potentially large inertial motions, initiated by the waves, particularly at extreme speeds. Much research has gone into the dynamical correction of the platform motion and the correction for the anemometer motions. Earlier claims in literature of ocean wave shielding of moored buoy anemometers lead to non-substantiated sources [4] and theoretical assessments suggest such notable effects up to a height of 10% of the wave height, i.e., generally well below the buoy anemometer height [2].

Not many other in-situ winds will be available in hurricanes either, due to the adverse conditions. Moreover, these other in-situ (incl. land-based) wind sources suffer from wind flow distortion biases, positive and negative, or from height down-conversion biases to 10 m [3]. Platform winds are made at elevated heights and most often distorted by constructions, in both upwind and downwind directions and leading to both enhanced and decreased winds. Furthermore, downscaling is needed to 10-m height, which results in large uncertainties and biases [5].

4. DISCUSSION AND CONCLUSIONS

How strong does the wind blows in a hurricane proves a question that is difficult to answer, but has far-reaching consequences for satellite meteorology, weather forecasting and hurricane advisories. Moreover, huge year-to-year variability in extremes challenges evidence for changing hurricane climatology in a changing climate. Tropical circulation conditions, such as El Nino and the Madden Julian Oscillation, are associated with the large year-to-year variability and their link to climate change is poorly understood, though of great societal interest. Since hurricanes are sparsely sampled, satellite instruments are in principle very useful to monitor climate change. However, their stability over time in quality and quantity (sampling) needs to be guaranteed. Moreover, to use the longest possible satellite record, satellite instrument intercalibration of the extremes is needed [6]. This implies for a single instrument using a single processor version (calibration, QC, GMF, retrieval) for change detection over a decade typically and the use of overlapping single-instrument/single-processor series for climate analyses, cf. Figure 4. Figure 4 shows systematic inconsistencies in the extremes, as obtained within the European Union (EU) Copernicus Climate Change Windstorm Information Service (C3S WISC) [7]. Besides for the scatterometers ERS, QuikScat, HSCAT and OSCAT, these instrument series may be extended to passive microwave wind instruments from 1979, if proven reliable at the extremes?

In the EUMETSAT CHEFS project, KNMI, ICM and IFREMER worked with international colleagues to improve the detection of hurricane-force winds. To calibrate the diverse available satellite, airplane and model winds, in-situ wind speed references are needed. Unfortunately, these prove rather inconsistent in the wind speed range of 15 to 25 m/s, casting doubt on the higher winds too. However, dropsondes are used as reference operationally at high and extreme winds in nowcasting and in the European Space Agency project MAXSS satellite intercalibration is further investigated based on dropsondes to serve this community. However, from a scientific point of view, we should perhaps put more confidence in the moored buoy references? This would favor accuracy in drag parameterizations and physical modelling

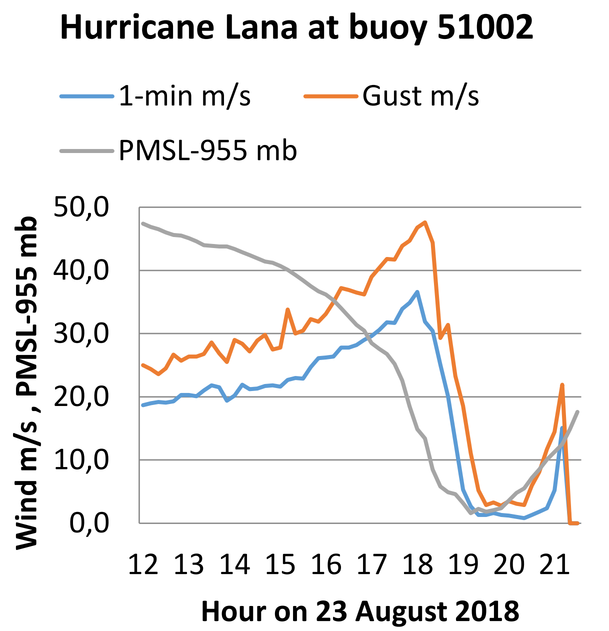

Fig. 3. Moored buoy 10-m wind speeds for hurricane Lana on 23 August 2018 [2].

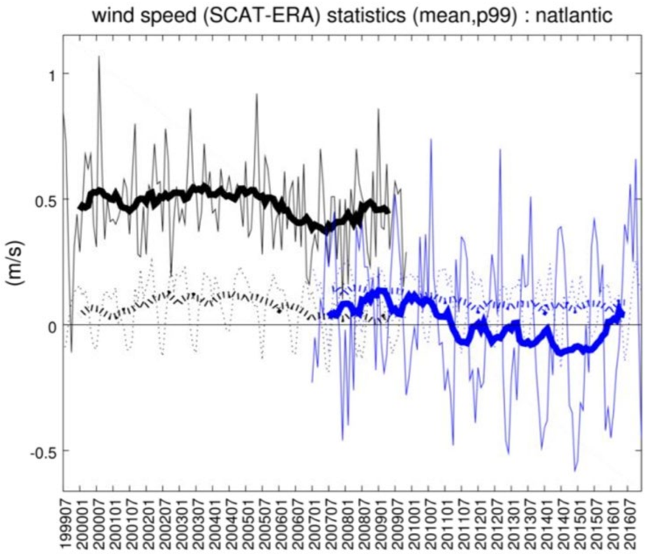

Fig. 4. Differences in monthly average mean (dashed) and 99-percentile (solid) statistics of ocean surface 10-m wind speed for scatterometer (black/blue for QuikScat/ASCAT respectively) and collocated ECMWF Reanalysis 10-m winds (ERA) over the North Atlantic [7].

and observation of the extremes. This dilemma will be presented to initiate a discussion with the international community gathered at IGARSS ‘21

5. REFERENCES

[1] Lucia Bevere, Irina Fan, Thomas Holzheu, Swiss Re Institute estimates USD 83 billion global insured catastrophe losses in 2020, the fifth-costliest on record, Swiss Re web article, accessed 27 Dec 2020, https://www.swissre.com/media/news-releases/nr-20201215-sigma-full-year-2020-preliminary-natcat-loss-estimates.html.

[2] Ad Stoffelen et al., 2020, C-band High and Extreme-Force Speeds (CHEFS), EUMETSAT project report, accessed 28 Dec. 2020 https://www.eumetsat.int/CHEFS.

[3] Manaster, A., Ricciardulli, L., & Meissner, T. (2019). Validation of High Ocean Surface Winds from Satellites Using Oil Platform Anemometers, Journal of Atmospheric and Oceanic Technology, 36(5), 803-818. Retrieved Dec 29, 2020, from https://journals.ametsoc.org/view/journals/atot/36/5/jtech-d-18-0116.1.xml.

[4] Ad Stoffelen et al., 2018, State of the art and user requirements, project C-band High and Extreme-force Speeds, EUMETSAT ITT 16/166 WP2 report, KNMI, de Bilt, The Netherlands, https://doi.org/10.13140/RG.2.2.10541.13281.

[5] Charlotte Bay Hasager 1,*, Detlef Stein 2, Michael Courtney 1, Alfredo Peña 1, Torben Mikkelsen 1, Matthew Stickland 3 and Andrew Oldroyd, 2013, Hub Height Ocean Winds over the North Sea Observed by the NORSEWInD Lidar Array: Measuring Techniques, Quality Control and Data Management, Remote Sens. 2013, 5, 4280-4303, https://doi.org/10.3390/rs5094280

[6] A. Verhoef, J. Vogelzang, J. Verspeek and A. Stoffelen, "Long-Term Scatterometer Wind Climate Data Records," in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 10, no. 5, pp. 2186-2194, May 2017, doi: 10.1109/JSTARS.2016.2615873.

[7] Marseille, G.-J., A. Stoffelen, H. van den Brink and A. Stepek, 2019: WISC Bias Derivation and Uncertainty Assessment, C3S Windstorm Information Service - Copernicus (WISC), Doc. C3S_441_Lot3_WISC_SC2-D3.3-CGI-RP-17-0071, KNMI, https://wisc.climate.copernicus.eu/wisc/documents/shared/(C3S_441_Lot3_WISC_SC2-D3.3-CGI-RP-17-0071)%20(Final%20Bias%20Derivation)%20(v1.0).pdf)