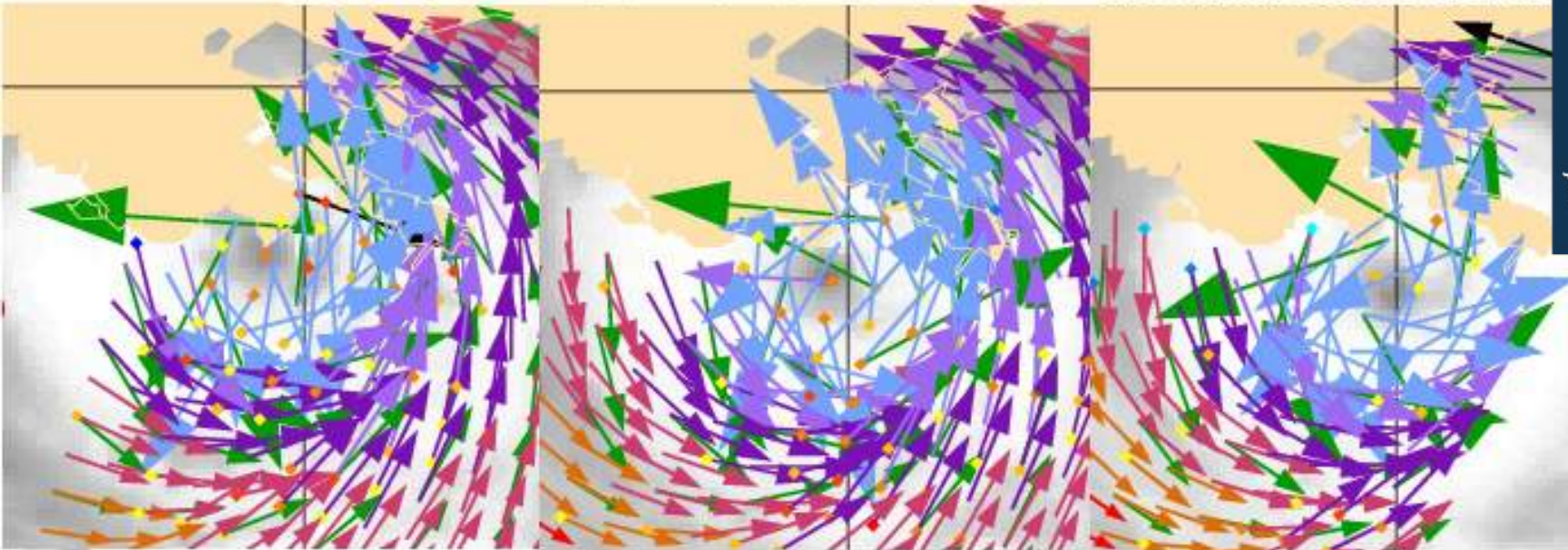


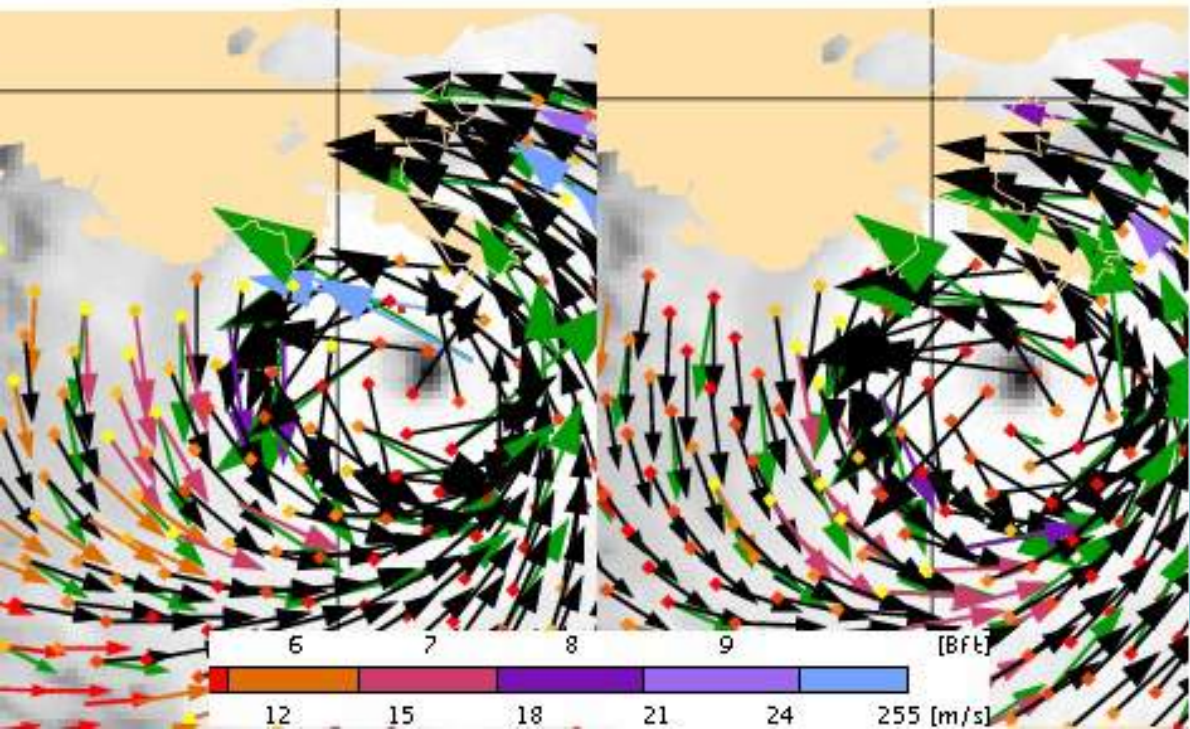
ASCAT-B: 20210829 16:30Z ASCAT-C: 20210829 15:30Z ASCAT-A: 20210829 14:30Z



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HY-2B: 20210829 11:30Z

HY-2C: 20210829 11:30Z



Hurricane Ida

# Exploiting many scatterometers

EUMETSAT OSI SAF,  
[Ida land-fall news story](#)

[Ad.Stoffelen@knmi.nl](mailto:Ad.Stoffelen@knmi.nl), fellow [IEEE](#)

Leader active sensing  
R&D satellites (RDSW), KNMI,  
the Netherlands





# Today's status of KNMI wind processing

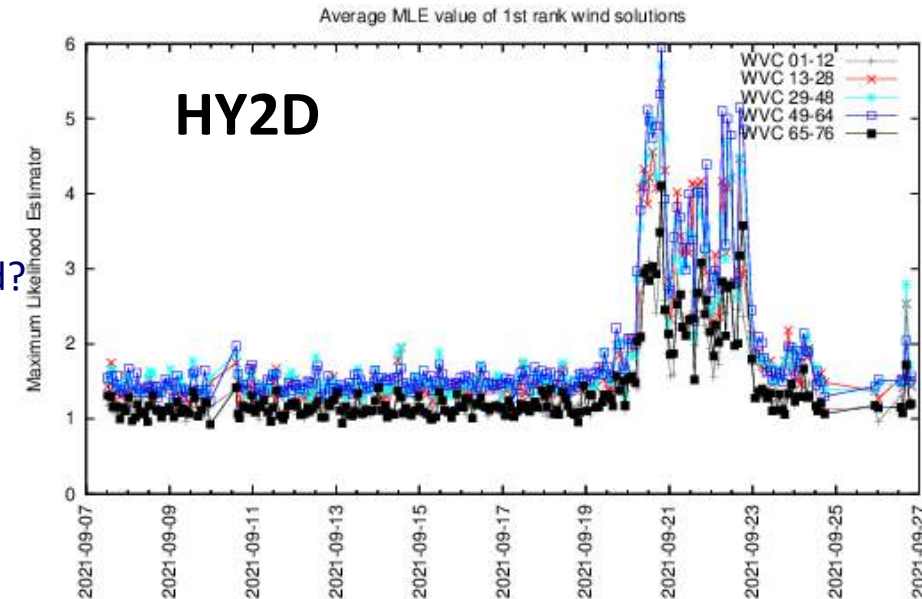
- ASCAT-A, MetOp-A : 2007- Nov 2021 9:30 LST
- ASCAT-B, MetOp-B : 2012- healthy 9:30 LST
- ASCAT-C, MetOp-C : 2018- healthy 9:30 LST, Excellent for wind changes in convection
- OSCAT-2, ScatSat-1 : 2017- Feb 2021 8:45 LST, Excellent for Ku/C intercalibration
- OSCAT-3, OceanSat3 : Q2 2022 12:00 LST, Good quality, high NRCS
- HSCAT-B, HY2B : 2018- healthy 6:00 LST
- HSCAT-C, HY2C : 2020- healthy Not sun-synchronous, regresses
- HSCAT-D, HY2D : 2021- healthy Regresses, commissioning
- CSCAT, CFOSAT : 2019- 2022 Stability issues
- WindRad, FY3E : 5/7/'21- now 5:30 LST, commissioning, C-band?

➤ [scatterometer.knmi.nl/proc\\_status/](https://scatterometer.knmi.nl/proc_status/)

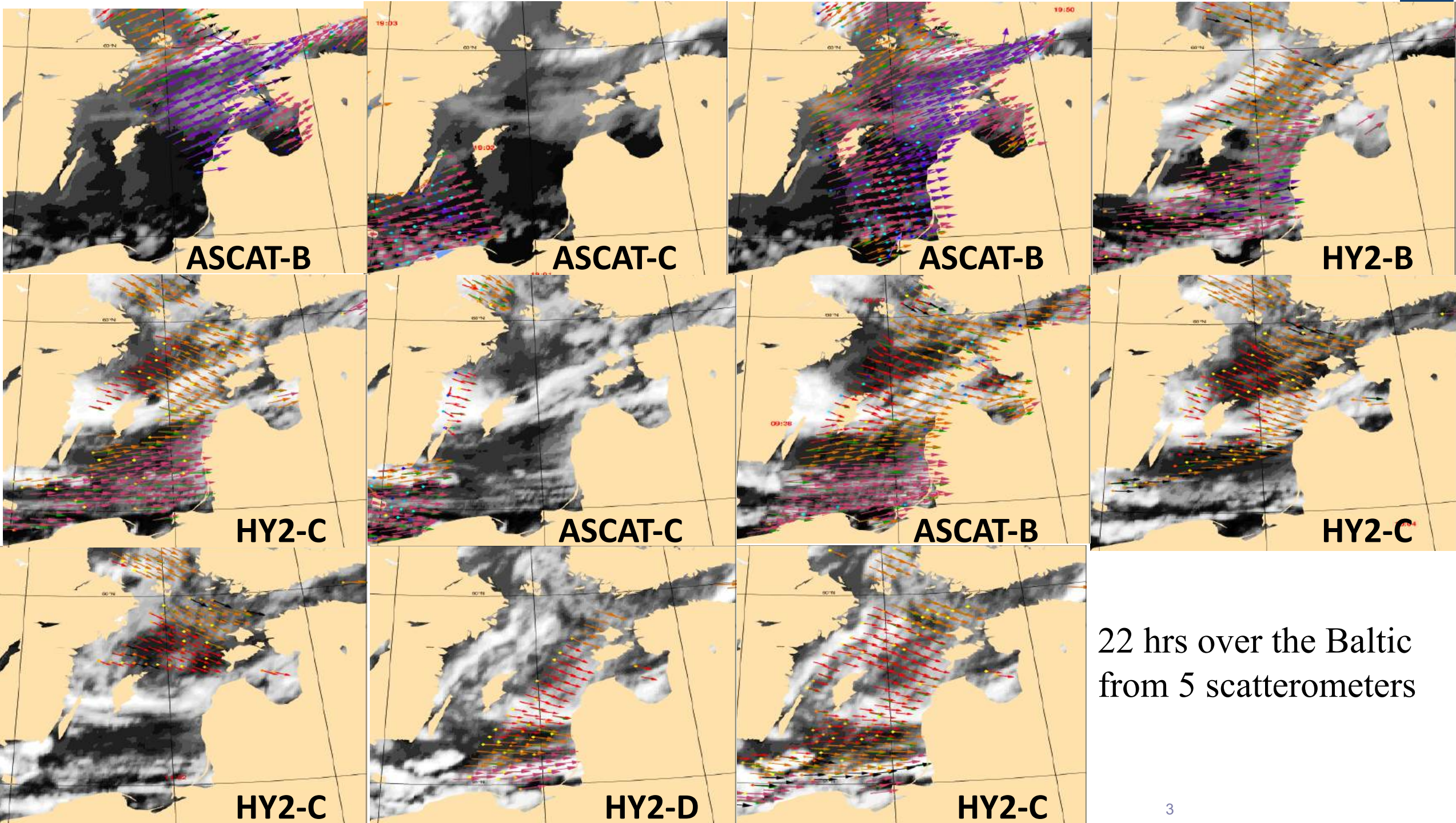
- Vector wind CDRs for ERS (1991-1999), QuikScat (1999-2009), ASCAT (2007-), OSCAT (2014+), needed to monitor re-analyses
- Reanalyses are subject to changing inputs

➤ [scatterometer.knmi.nl/archived\\_prod/](https://scatterometer.knmi.nl/archived_prod/)

➤ [EU Copernicus Marine Service Wind TAC](#)



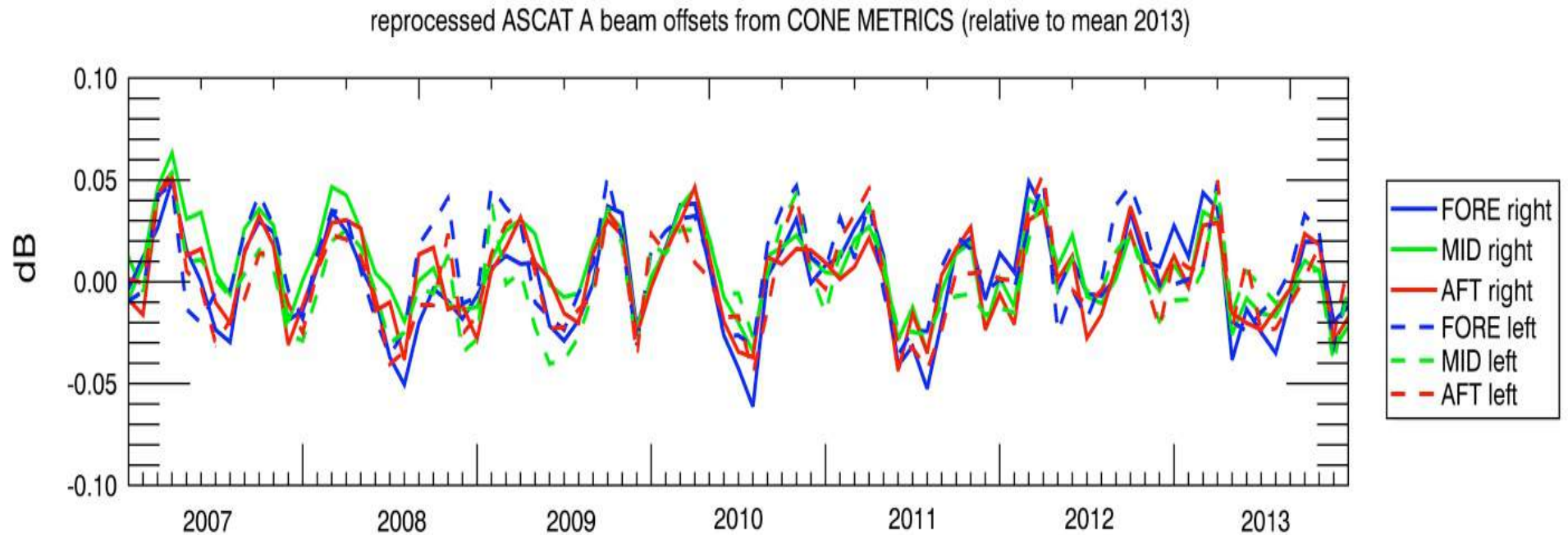
[https://scatterometer.knmi.nl/hy2d\\_25\\_prod/index.php?cmd=monitoring&period=week&day=0&flag=yes](https://scatterometer.knmi.nl/hy2d_25_prod/index.php?cmd=monitoring&period=week&day=0&flag=yes)



22 hrs over the Baltic  
from 5 scatterometers

# Scatterometers are very stable

- ASCAT-A beams stay within a few hundreds of a dB (eq. to m/s)
- Measurement space cone position variation due to seasonal wind variability
- Reference for climate research (to check reanalyses)





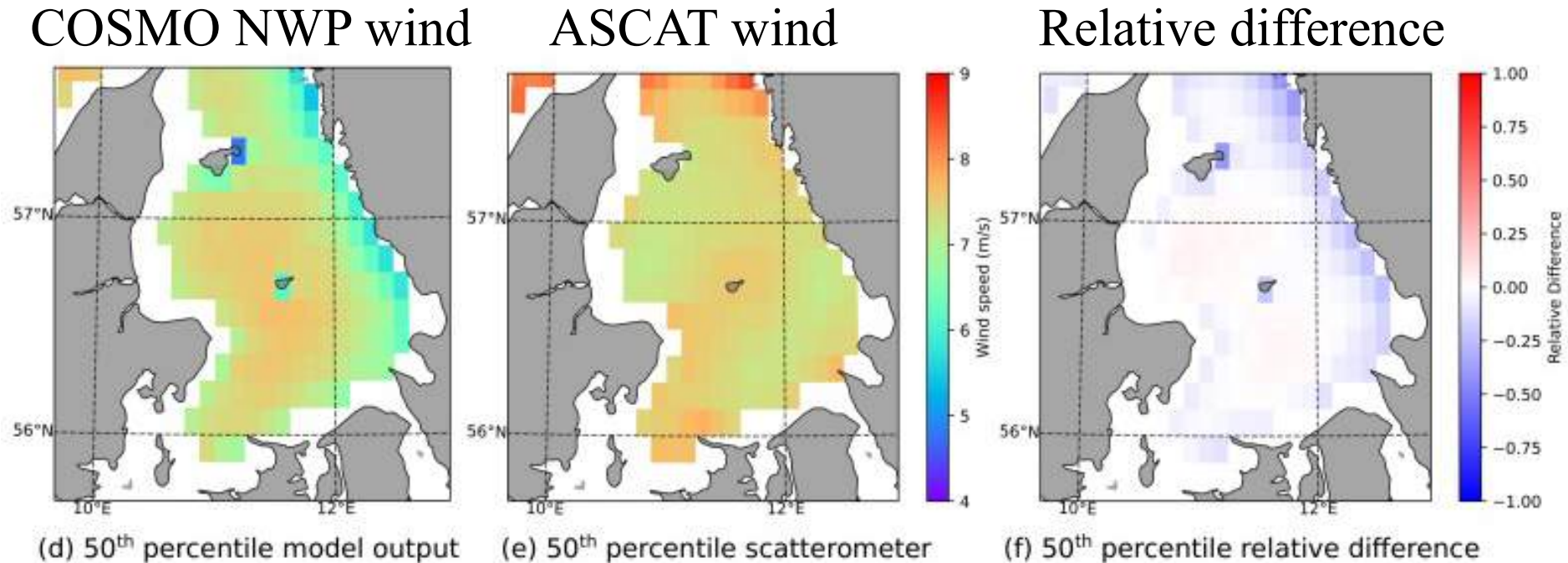
# Scatterometer winds are excellent quality

Subset	Buoys		ASCAT-A		ScatSat		ECMWF	
	$\sigma_u$	$\sigma_v$	$\sigma_u$	$\sigma_v$	$\sigma_u$	$\sigma_v$	$\sigma_u$	$\sigma_v$
bAS	1.03	1.12	0.41	0.49	0.78	0.65	--	--
bAE	1.06	1.15	0.34	0.41	--	--	0.94	1.03
bSE	1.09	1.21	--	--	0.72	0.59	0.92	1.03
ASE	--	--	0.43	0.49	0.76	0.65	0.90	0.98
range	0.06	0.09	0.09	0.08	0.06	0.06	0.04	0.05

- Scatterometers winds and stresses are unbiased with respect to moored buoys and have the smallest random error among in-situ and NWP winds
- Consolidated several methodologies to solve multiple collocation error equations
- Added better ability to approximate the errors of the errors
- Confirms the excellent accuracy of scatterometer winds
- Stress-equivalent 10-m buoy and ECMWF winds



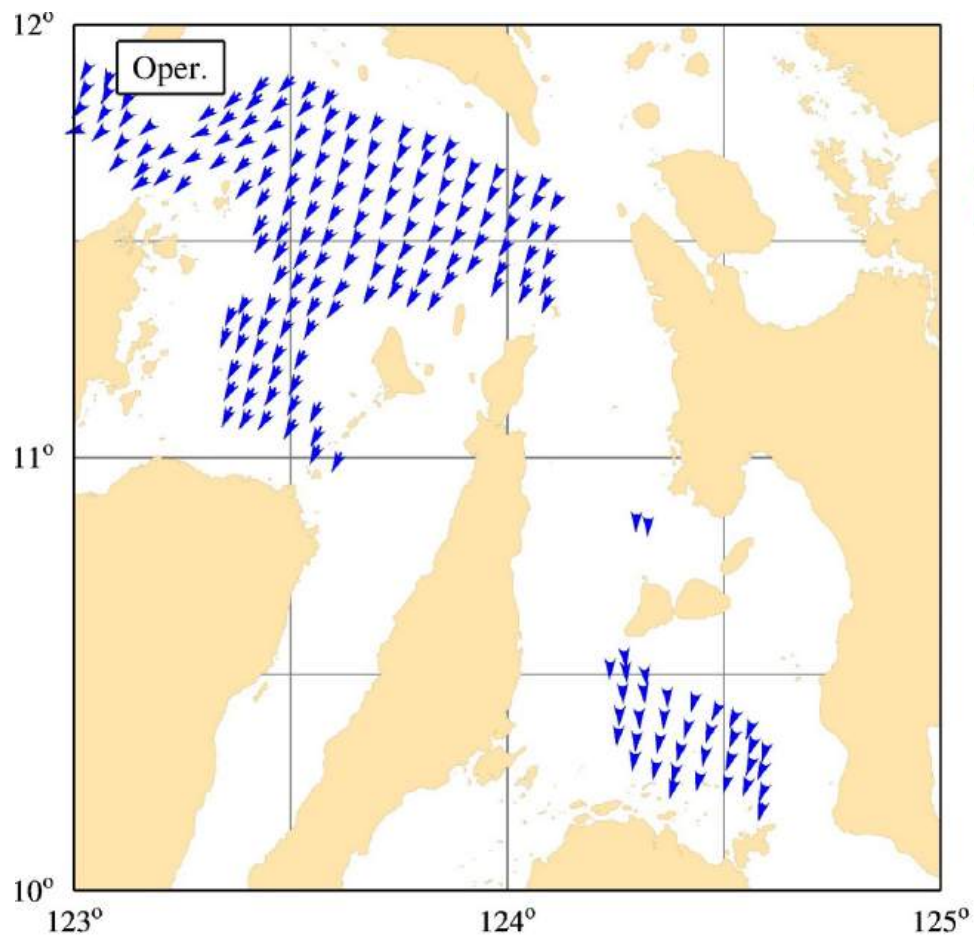
# Coastal winds from ASCAT and NWP



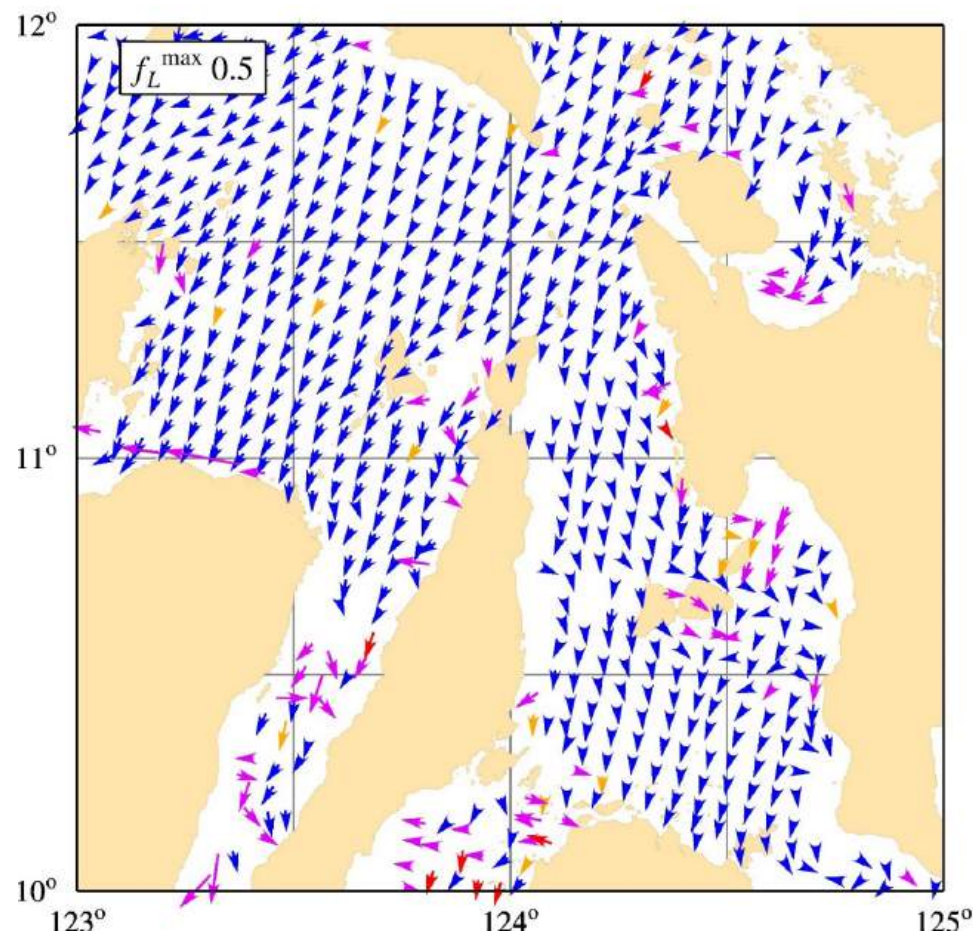
- New ASCAT land contribution flag to get 50% closer to the coast (~5 km)
- Also in development for other scatterometers for coastal wind monitoring
- Use more sporadic SAR for local variability studies, e.g., S-1, RadarSat
- Mesoscale and global NWP models are degraded in coastal regions



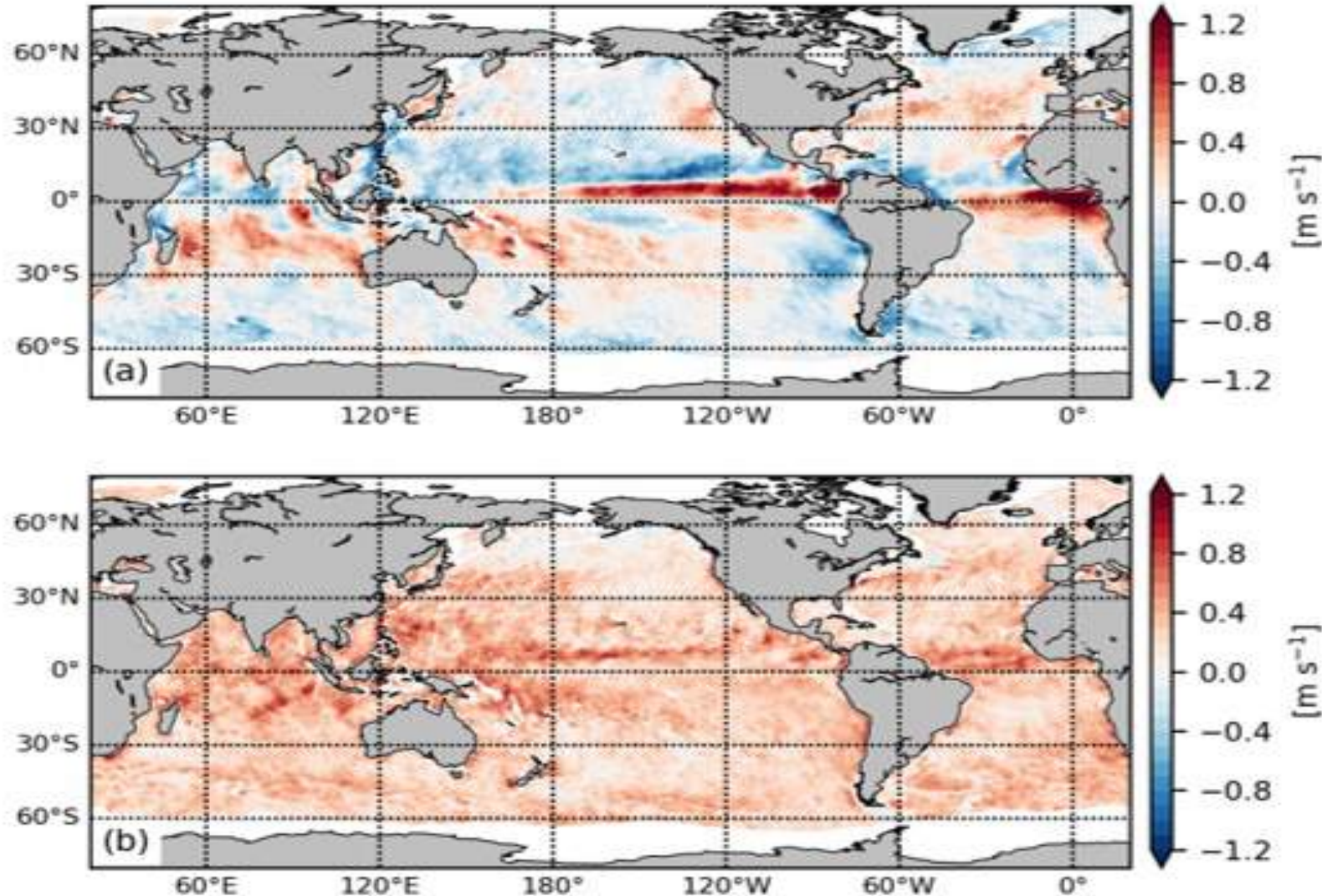
# First result at 6.25 km grid size



- ▲ 10 m/s
- ▲ MLE flag
- ▲ VarQC flag
- ▲ Both flags



# Higher level ocean vector wind services



Air-sea interaction has major errors in forcing and fluxes, affecting NWP and climate research using models

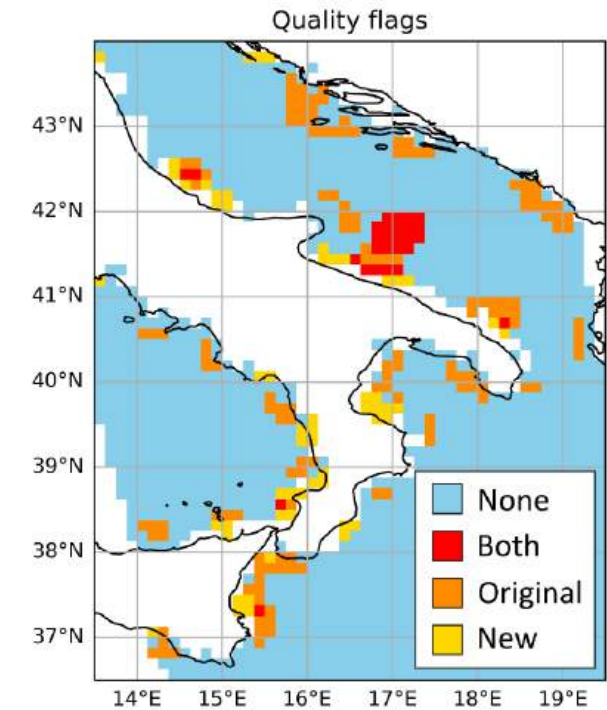
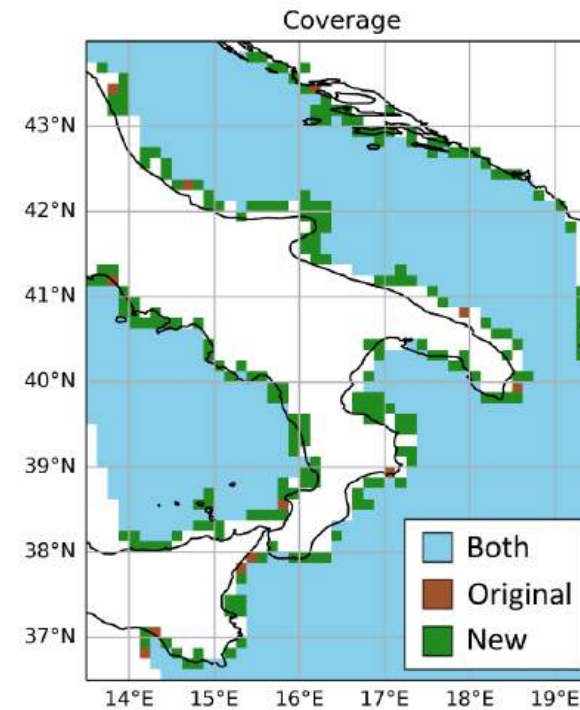
Correct NWP model wind biases by exploiting the virtual scatterometer constellation:

- Vector wind / variability
- Stress vector / variability
- Divergence
- Curl
- Fluxes



Figure 2: Annual mean meridional (a) wind speed difference and (b) transient wind speed difference between scatterometer (Metop-A ASCAT) and collocated ECMWF ERA5 for 2018.

- Service Evolution continues L3/L4 winds
- A (new) SAR winds project has just started
- Snapshots of higher resolution winds by SAR
  - Use for coastal scatterometer product validation and enhancement
  - Besides ASCAT and SCA, extend to Ku-band scatterometers
  - Improve SAR stress-equivalent wind vectors in coastal regions (complement with scatterometer wind direction information)
- Exploit quality-controlled in-situ TAC wind, stress and air stability information
  - Needed for coastal wind and stress validation



- SAR services are being developed in the Copernicus Marine Service to add value to scatterometer wind products, in particular for extremes and coastal winds assessment
- Satellite B of MetOp-SG (2025) has SCA and will provide
  - 10% more swath than ASCAT
  - Double spatial resolution w.r.t. ASCAT
  - Better extremes, due to a VH channel
  - Continuous calibration by transponders
- Satellite B of MetOp-SG (2025) has a microwave radiometer MWI complementing SCA
  - “Day-2” SCA-intercalibrated MWI stress-equivalent winds
  - “Day-3” synergetic SCA and MWI stress-equivalent winds
- Copernicus Imaging Microwave Radiometer, CIMR (2025+), will provide ice and sea products, among which stress-equivalent wind speed/vector
  - Intercalibrate with virtual scatterometer constellation (cf. [Dinnat et al., 2023](#))



# Extreme Wind Trends in Climate Data Records

Ad Stoffelen, Alexandre Payez, Rianne Giessen



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Environment



- Wind trends in extremes are difficult to measure due to irregular sampling by in-situ observations
  - Re-analyses sample regularly and in a fixed model setting, but suffer from varying observational data set inputs over time, probably affecting trends
- We have stable scatterometer instruments over several decades to detect trends in extremes
  - Analyzing trends by scatterometer instrument is reliable due to its constant sampling characteristics over time (see example plots)
  - Combining several overlapping instruments in a row may produce long-term reliable trends
  - PDF interpolation could further reduce sampling errors and allow determination of 99.9 wind speed percentiles over larger areas, e.g., basin
  - This is being shown in the ESA MAXSS project

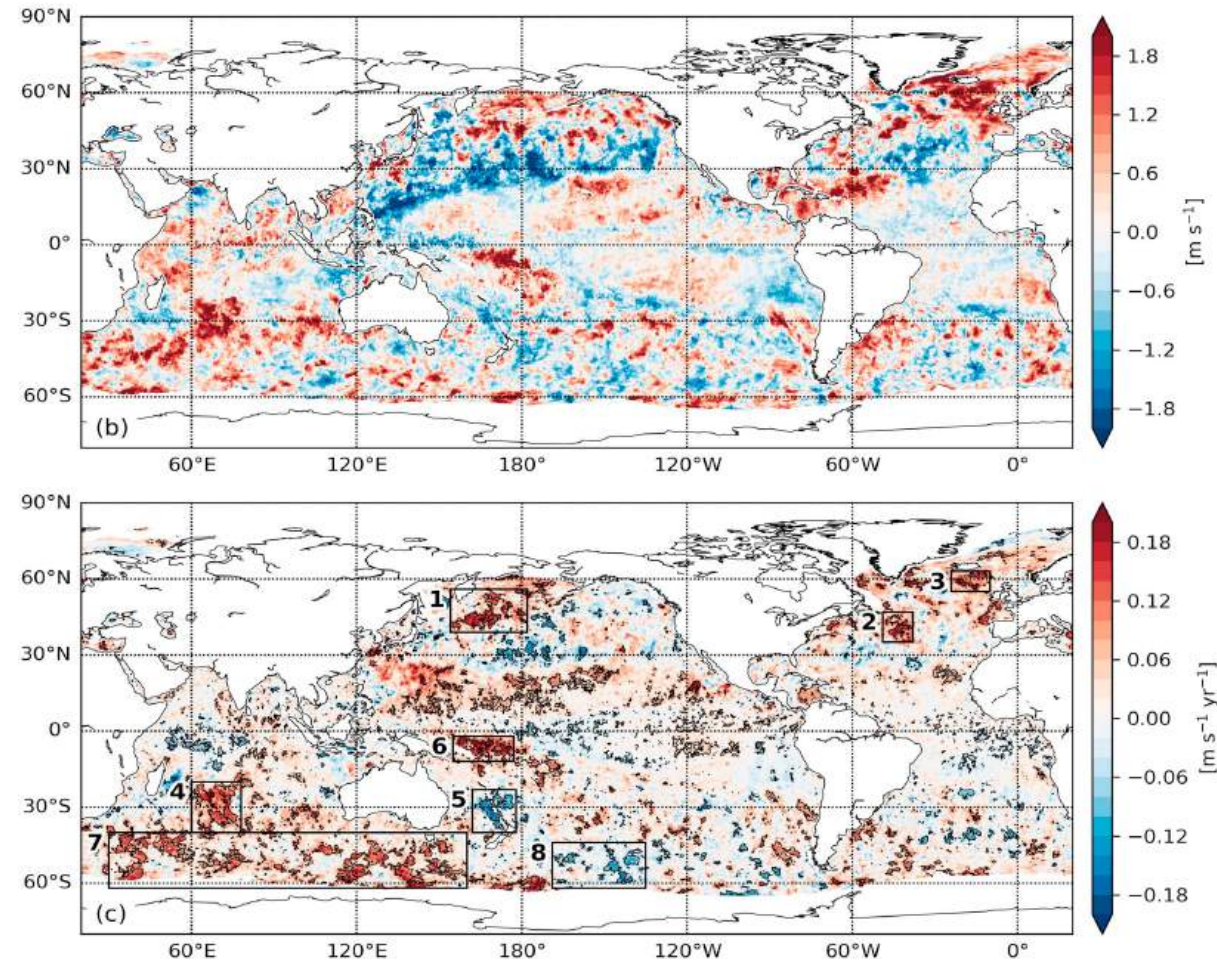


Figure 2.1.2. ASCAT-A 99th wind speed percentile (a) annual anomaly for 2020 and (b) annual trend (2007–2020). Areas with trends significant above the 90% confidence level are outlined in black.



# Summary

- Winds determine weather, hurricanes, ocean waves and surges, electricity, ocean forcing, motion, heat and carbon budget, sea ice decline, climate change, ...
- Are used by marine forecasters, in NWP, by oceanographers, wind engineers, off-shore industry, safety authorities, climate scientists, . . .
- Golden age of scatterometry to benefit these applications
- Scatterometer winds are generally stable and accurate, even in the most extreme conditions
- Opportunities for multiple collocations, NRCS intercalibration, QC improvements, GMF estimation, improved wind retrieval, rain correction, coastal winds development, ...
- Allows standardized user products, which are easy to use for the global user communities
- Model biases in mean wind vector, variability and wind derivatives should be corrected for data assimilation, coupled modelling or forecasting applications (ML) to the benefit of more realistic earth system dynamics
- In-situ wind references need consolidation for satellite instrument calibration and model applications, in particular at the extremes
- New missions measuring ocean motion will complement scatterometry and can exploit the high SRL in wind scatterometry



# Further information . .

Services:

[scatterometer.knmi.nl](https://scatterometer.knmi.nl)

[training material](#)

[osi-saf.eumetsat.int](https://osi-saf.eumetsat.int)

[marine.copernicus.eu](https://marine.copernicus.eu)



Ad Stoffelen

[FOLLOW](#)

Active Instruments group leader, Satellite Division, [KNMI](#)

Verified email at knmi.nl - [Homepage](#)

Wind satellite NWP data assimilation

TITLE	CITED BY	YEAR
<a href="#">Coastal wind retrievals from corrected QuikSCAT Normalized Radar Cross Sections</a> G Grieco, M Portabella, A Stoffelen, A Verhoef, J Vogelzang, A Zanchetta, ... Remote Sensing of Environment 308, 114179		2024
<a href="#">The contribution of Aeolus wind observations to ECMWF sea surface wind forecasts</a> H Zuo, A Stoffelen, M Rennie, CB Hasager Journal of Geophysical Research: Atmospheres 129 (6), e2023JD039555		2024
<a href="#">Mesoscale modelling of North Sea wind resources with COSMO-CLM: model evaluation and impact assessment of future wind farm characteristics on cluster-scale wake losses</a> R Borgers, M Dirksen, IL Wijnant, A Stepek, A Stoffelen, N Akhtar, ... Wind Energy Science 9 (3), 697-719		2024
<a href="#">Multi-decadal surface wind forcing products for the Copernicus Marine Service</a> R Giesen, A Stoffelen EGU24		2024
<a href="#">Presenting lidar surface returns as Aeolus product with the outlook on future spaceborne lidar missions including EarthCARE and Aeolus-2</a> LD Labzovskii, GJ van Zadelhoff, DP Donovan, J de Kloe, LG Tilstra, ... EGU24		2024
<a href="#">Emerging Opportunities for Air-Sea Fluxes from Space</a> MF Cronin, ST Gille, N Reul, CA Clayson, PL Dekker, C Gommenginger, ... 2024 Ocean Sciences Meeting		2024
<a href="#">High resolution observations of surface stress and current vectors and ocean wave spectra with the upcoming Harmony mission.</a> PL Dekker, M Kleinherenbrink, A Theodosiou, F Collard, L Gaultier, ... 2024 Ocean Sciences Meeting		2024
<a href="#">Vientos—A New Satellite Mission Concept for 3D Wind Measurements by Combining Passive Water Vapor Sounders with Doppler Wind Lidar</a> X Zeng, H Su, S Hristova-Veleva, DJ Posselt, R Atlas, ST Brown, ... Bulletin of the American Meteorological Society 105 (2), E357-E369		2024
<a href="#">Uncertainty of atmospheric winds in three widely used global reanalysis datasets</a> L Wu, H Su, X Zeng, DJ Posselt, S Wong, S Chen, A Stoffelen Journal of Applied Meteorology and Climatology 63 (2), 165-180	3	2024
<a href="#">Remote sensing and analysis of tropical cyclones: Current and emerging satellite sensors</a> I Ricciardulli, B Howell, CR Jackson, J Hawkins, J Courtney, A Stoffelen	2	2023



**Our host did really everything to make this meeting a success 😊**

**Many thanks to all organizers and staff !**



# Quality Control and ocean winds

- We continuously collaborate to improve quality control (QC)
- For Ku-band scatterometers we need to control rain ( $\Rightarrow$ )
- Develop algorithms to correct for remaining observational sampling biases
- We compare geographical biases between rain-insentitive (ASCAT) and rain-sensitive (Ku-band) scatterometers and collocated ECMWF winds
- Using ECMWF allows correction of satellite sampling biases
- It allows to estimate the bias due to the systematic removal of at maximum  $\sim 10\%$  of the Ku-band winds in moist convection
- We work on Ku-band rain correction methods using Bayesian estimation

[Zhao et al., 2023 \(2x\)](#)

[King et al., 2022](#)

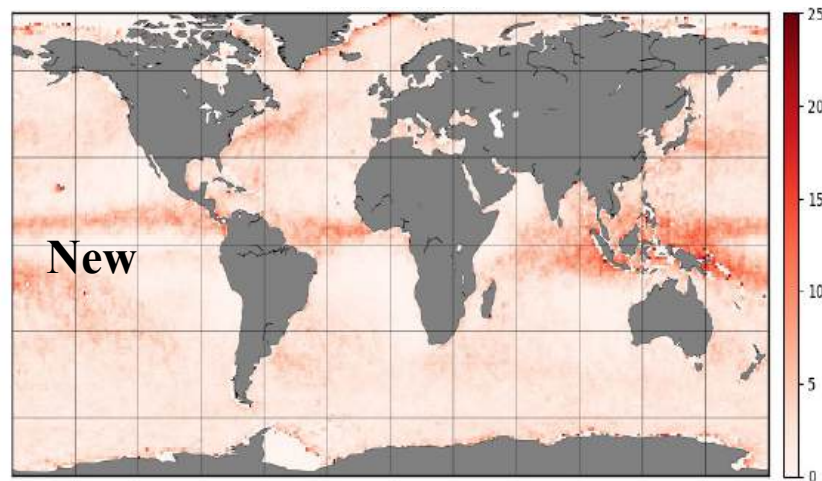
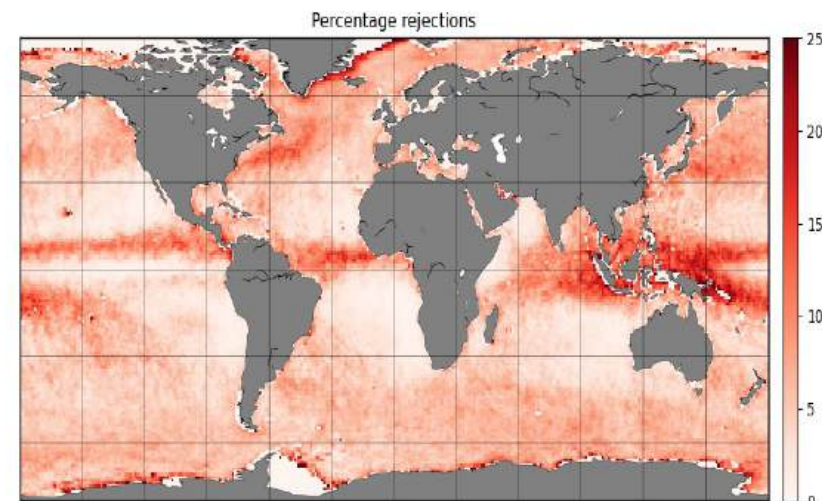
[Xu and Stoffelen, 2021, 2019](#)

[Trindade et al., 2020, 2023](#)

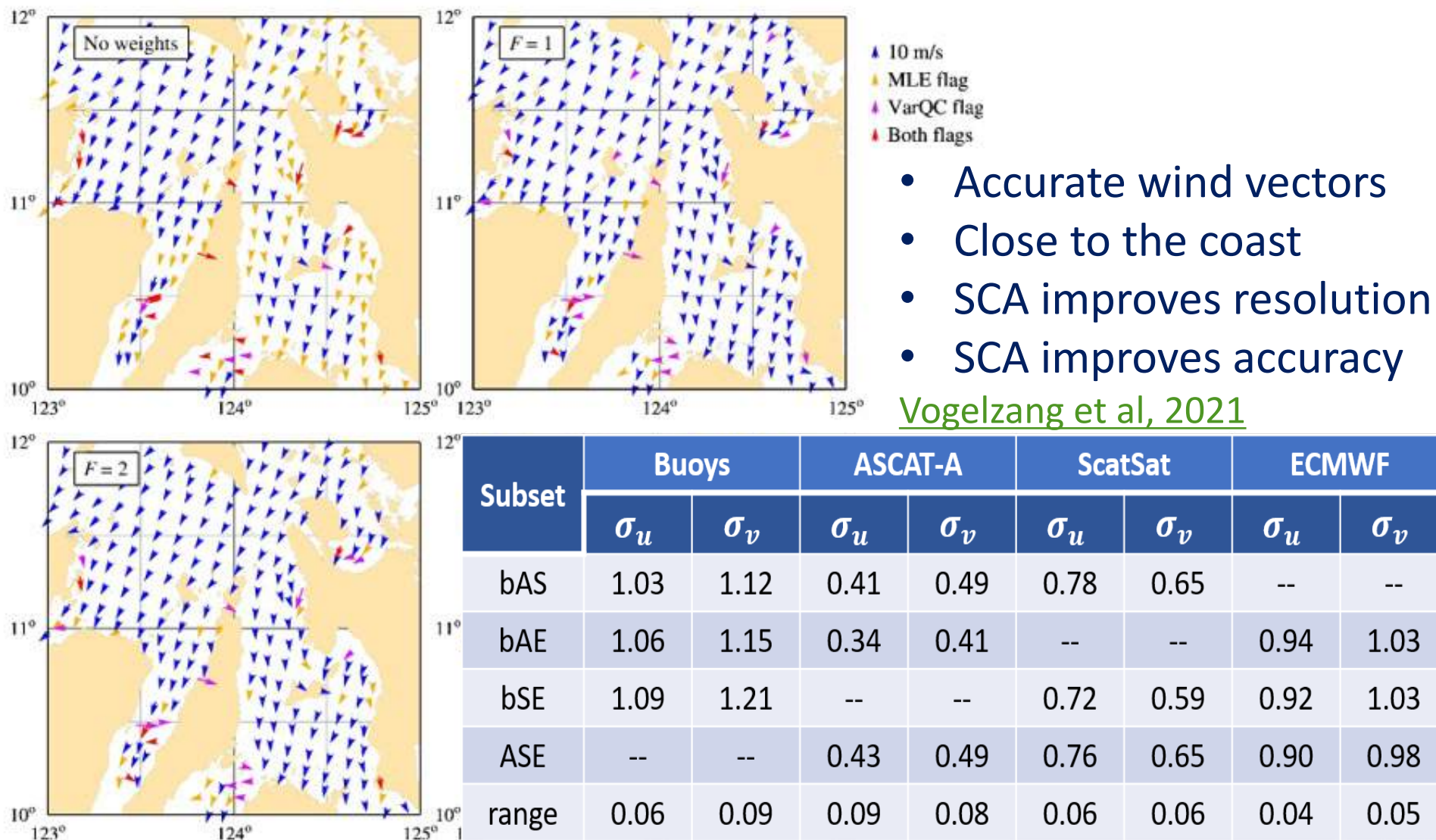
[Belmonte and Stoffelen, 2019](#)



% rejections Ku-band



# Coastal ASCAT and wind quality



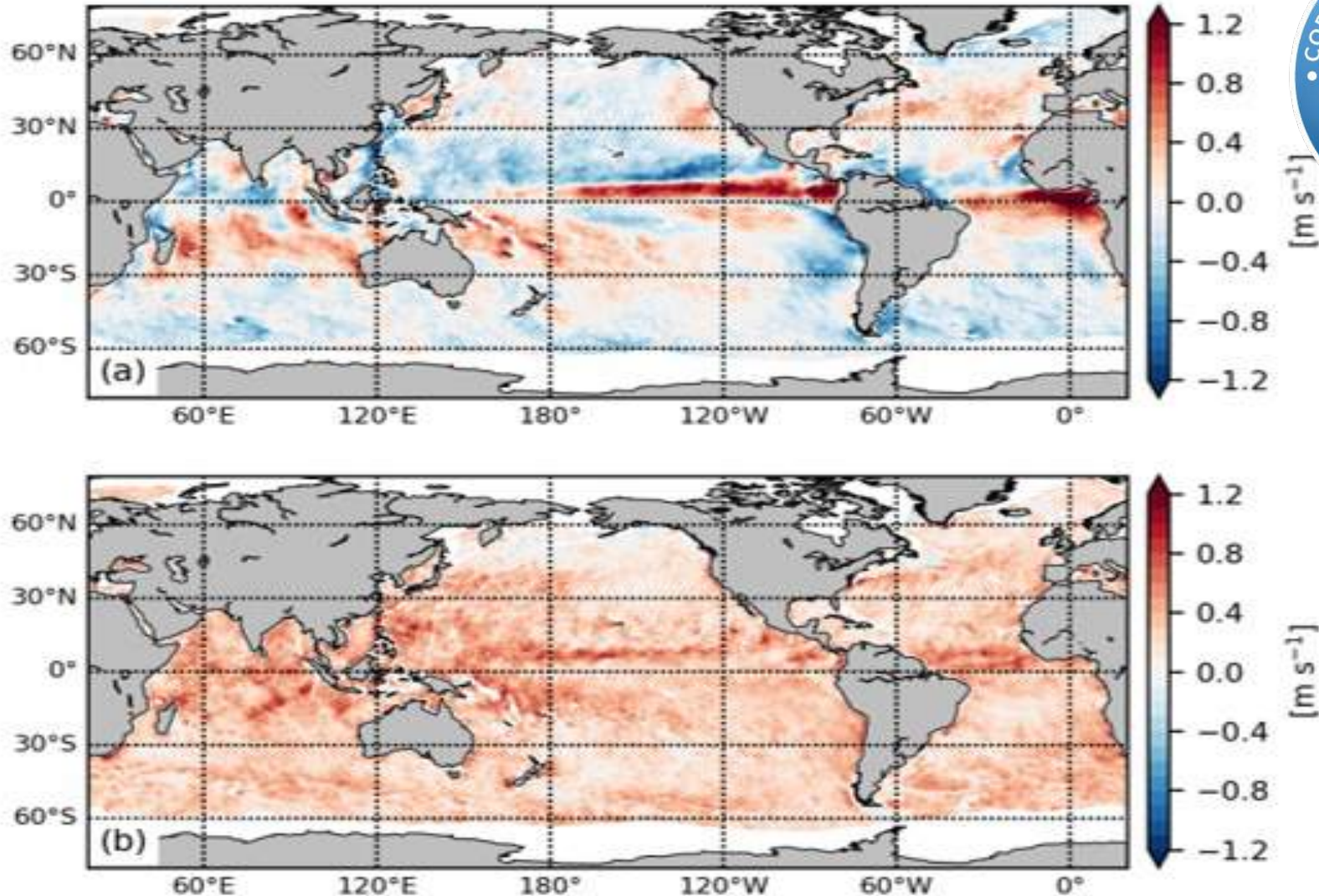
- Accurate wind vectors
- Close to the coast
- SCA improves resolution
- SCA improves accuracy

[Vogelzang et al, 2021](#)

Figure 4.1 Part of the Philippines recorded January 1, 2017, with exponential radar cross section weights of various strength.



# Higher level ocean vector wind services

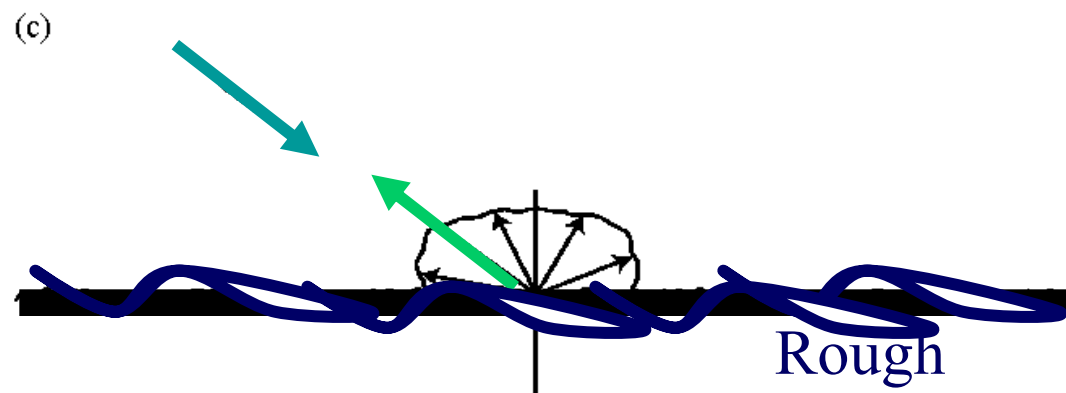
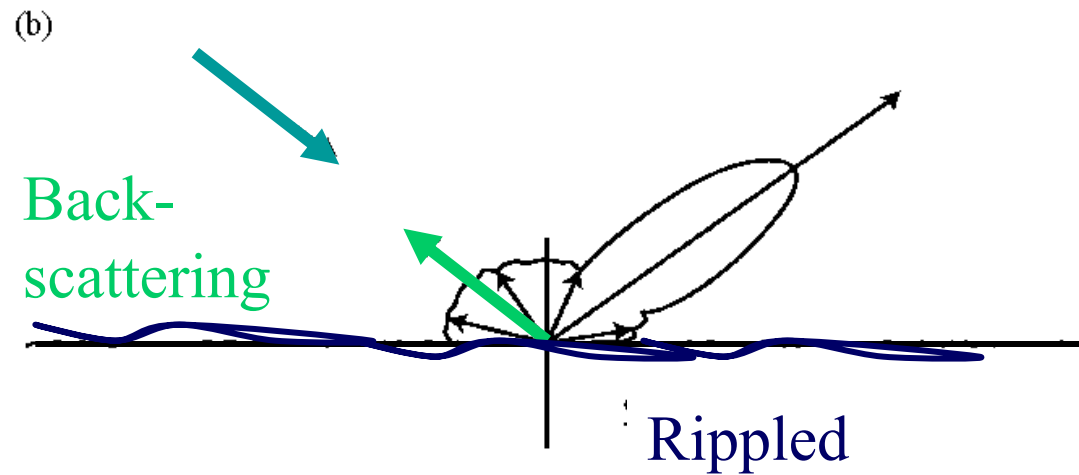
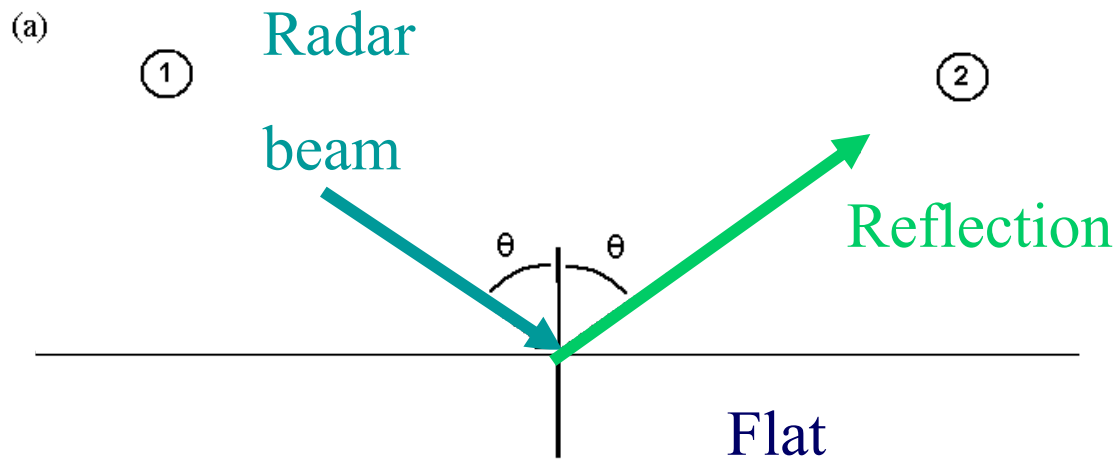


- Hourly gridded L3/L4 wind and stress
- Corrects NWP errors

Figure 2: Annual mean meridional (a) wind speed difference and (b) transient wind speed difference between scatterometer (Metop-A ASCAT) and collocated ECMWF ERA5 for 2018.



# Scatterometer?



- Interference with cm-waves (Bragg)
- The more wind, the more  $\mu$ golf scattering
- Also depending on wind direction



# Scatterometer research, partners KNMI abroad

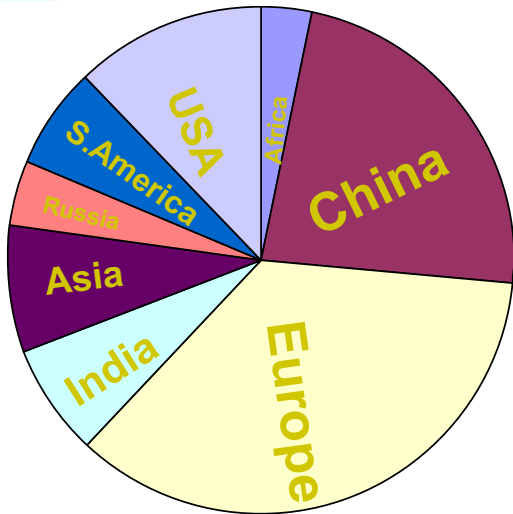
- Marcos Portabella, Ku-band scatterometry, 8 years at KNMI, now ICM in Barcelona, Spain
- Wenming Lin, 7 years at ICM, wind variability/rain; now at NUIST on CFOSAT, . . .
- 2023 PhD's: Weicheng Ni (NUDT) on hurricanes, Ke Zhoa (Qingdao) on rain, Haichen Zuo (DTU) on Aeolus and ASCAT, Ana Trindade (ICM) on ERA\*
- Giuseppe Grieco, 3 years at KNMI on GNSS-R, 1 year at ICM, now CNR in Italy on coastal PenWP
- Federico Cossu, EUMETSAT wind fellow at ICM, Spain
- Zhixiong Wang, Ku GMF with SST correction, product comparison Ku/C, now prepared data for ECMWF data assimilation experiments and WindRad, NUIST
- Xingou Xu at NSSC, Scatterometry, Machine Learning, Beijing, now at KNMI
- Paul Chang, NOAA hurricane hunters, USA
- Bertrand Chapron/Alexis Mouche, MAXSS, GlobCurrent, SAR winds, IFREMER
- Sean Healy, data assimilation, ECMWF
- Scatterometer Cal/Val: EUMETSAT, NASA, ESA, ISRO, NSOAS, CMA, CNES
- Paco Lopez Dekker, Doppler for EPS-SG SCA (2026), ESA EE Harmony PI, TU Delft, Netherlands
- CGMS Ocean Surface Winds Task Group, IOVWST, . . .
- ESA Earth Explorer MAG member for Harmony and SeaStar

## Motivation / Potential OSW TG

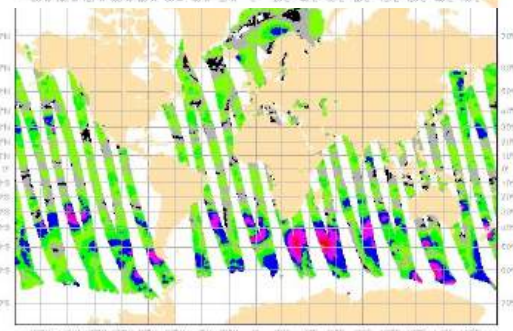
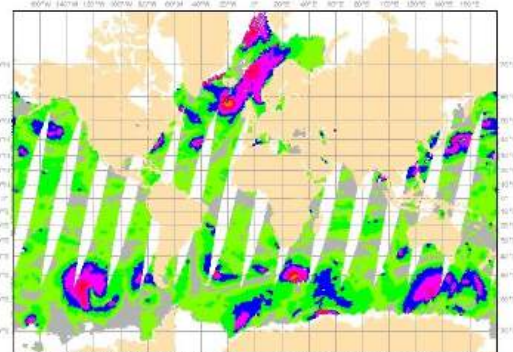
- Scatterometer winds were introduced and represented at the IWWG meetings since 1996 (Ascona meeting)
- OSW side meetings were held at several IWWG meetings with representatives of the NWP community
- Several topics need further attention beyond CEOS and IOVWST, such as:
  - **Intercalibration** of wind products for Climate Data Records and operational user convenience
  - An **in-situ wind speed reference** for high and extreme winds
  - Methods for the elimination of model biases in **NWP data assimilation** (local VARBC)
  - Improved spatial NWP wind assimilation methods; assimilate unique products
  - QC optimization for NWP, Ku-band rain
  - Open high-level wind services and both **local and global timeliness** of the virtual constellation
  - Open data comparisons and open software to share in the community
  - Exploit scatterometer wind stress measurements for improved **atmosphere-ocean coupling**
  - Development of **coastal winds** for all scatterometers
- The OSW TG facilitates an **open and shared environment** to address above points for the general benefit of the meteorological/ocean community



# KNMI Satellite Wind Services



- 24/7 Global Wind services (OSI SAF)
  - Constellation of satellites
  - High quality winds, QC
  - Timeliness 30 min. – 2 hours
  - Service messages
  - QA, monitoring
- Software services (NWP SAF)
  - Portable Wind Processors
  - Weather model comparison
- Organisations involved:  
KNMI, EUMETSAT, EU, ESA, NASA, NOAA, ISRO, SOA, WMO, CEOS, ..
- Users: NHC, JTWC, ECMWF, NOAA, NASA, NRL, BoM, UK MetO, M.France, DWD, CMA, JMA, CPTEC, NCAR, NL, . . .

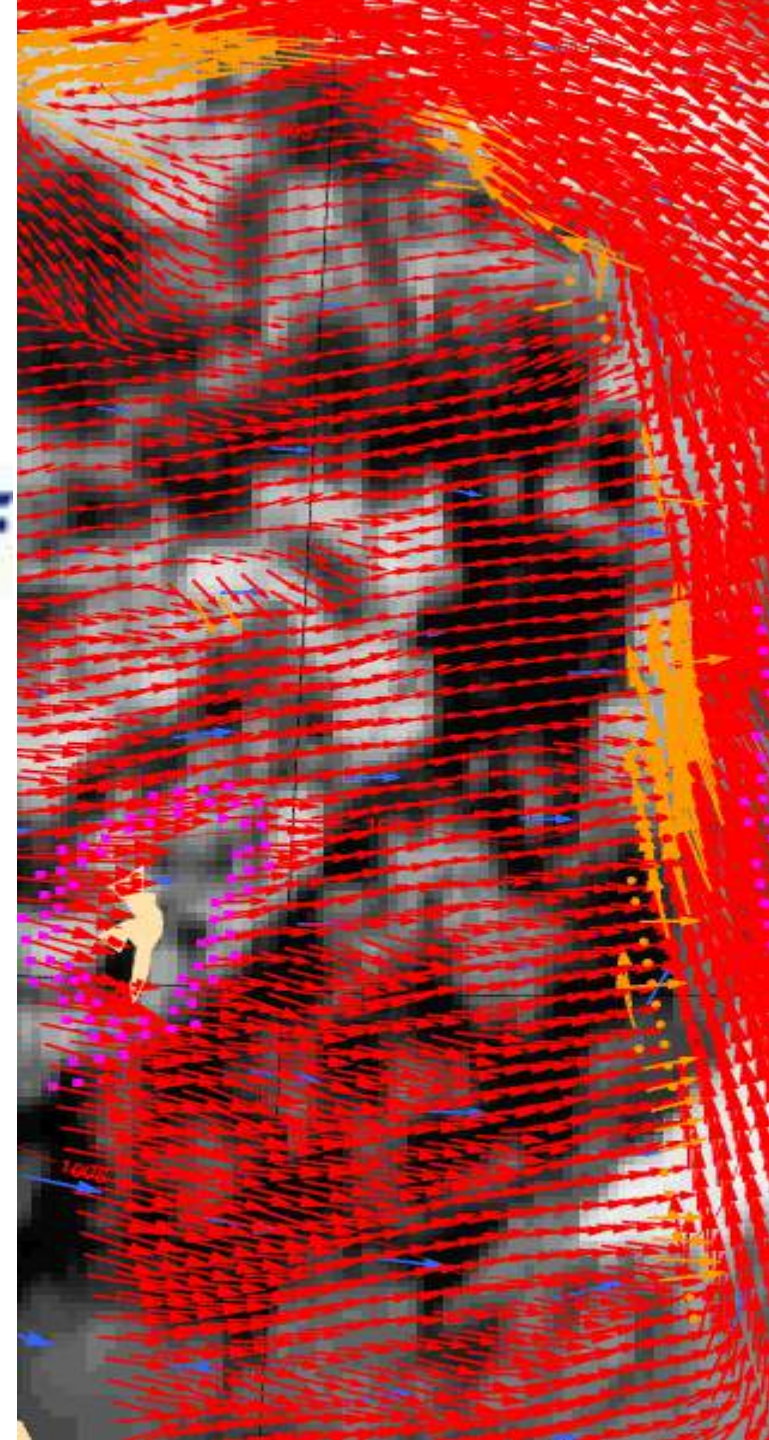


## More information:

[www.knmi.nl/scatterometer](http://www.knmi.nl/scatterometer)

Wind Scatterometer Help Desk

Email: [scat@knmi.nl](mailto:scat@knmi.nl)



# Golden age of Scatterometry (WMO OSCAR)



Instrument	NRT?	Relevance	Satellite	Orbit	DLR	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
<a href="#">WindRAD</a>		1 - primary	<a href="#">FY-3E</a>	05:40 desc		X	X	X	X	X	X								
<a href="#">WindRAD</a>		1 - primary	<a href="#">FY-3J</a>	05:00 desc							X	X	X	X	X	X	X	X	X
<a href="#">ASCAT</a>	Yes	2 - very high	<a href="#">Metop-B</a>	09:31 desc	50	X	X	X											
<a href="#">ASCAT</a>	Yes	2 - very high	<a href="#">Metop-C</a>	09:31 desc	85	X	X	X	X	X	X								
<a href="#">SCA (Scatterometer)</a>		2 - very high	<a href="#">Metop-SG-B1</a>	09:30 desc					X	X	X	X	X	X	X	X			
<a href="#">SCA (Scatterometer)</a>		2 - very high	<a href="#">Metop-SG-B2</a>	09:30 desc												X	X	X	X
<a href="#">C-SCAT</a> ⚠️		2 - very high	<a href="#">CFOSAT</a>	07:00 desc		X	X												
<a href="#">HSCAT</a>		2 - very high	<a href="#">HY-2B</a>	06:00 desc	273	X	X												
<a href="#">HSCAT</a>		2 - very high	<a href="#">HY-2D</a>	66 °		X	X	X	X	X									
<a href="#">HSCAT</a>		2 - very high	<a href="#">HY-2E</a>	06:00 desc				X	X	X	X	X							
<a href="#">HSCAT</a>		2 - very high	<a href="#">HY-2C</a>	66 °		X	X	X	X										
<a href="#">HSCAT</a>		2 - very high	<a href="#">HY-2F</a>	66 °					X	X	X	X	X						
<a href="#">OSCAT-3</a>		2 - very high	<a href="#">OceanSat-3 (EOS-06)</a>	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 ourselves for many scatterometers 😊
- Exploit for weather, ocean and climate applications