Institut de Ciències del Mar

BEC Barcelona Expert Center

World Ocean Circulation

esa

Development of the ERA* high resolution ocean forcing product

Ana Trindade (ICM-CSIC & UPC)

Giuseppe Grieco (ISMAR-CNR)

Evgeniia Makarova (ICM-CSIC)

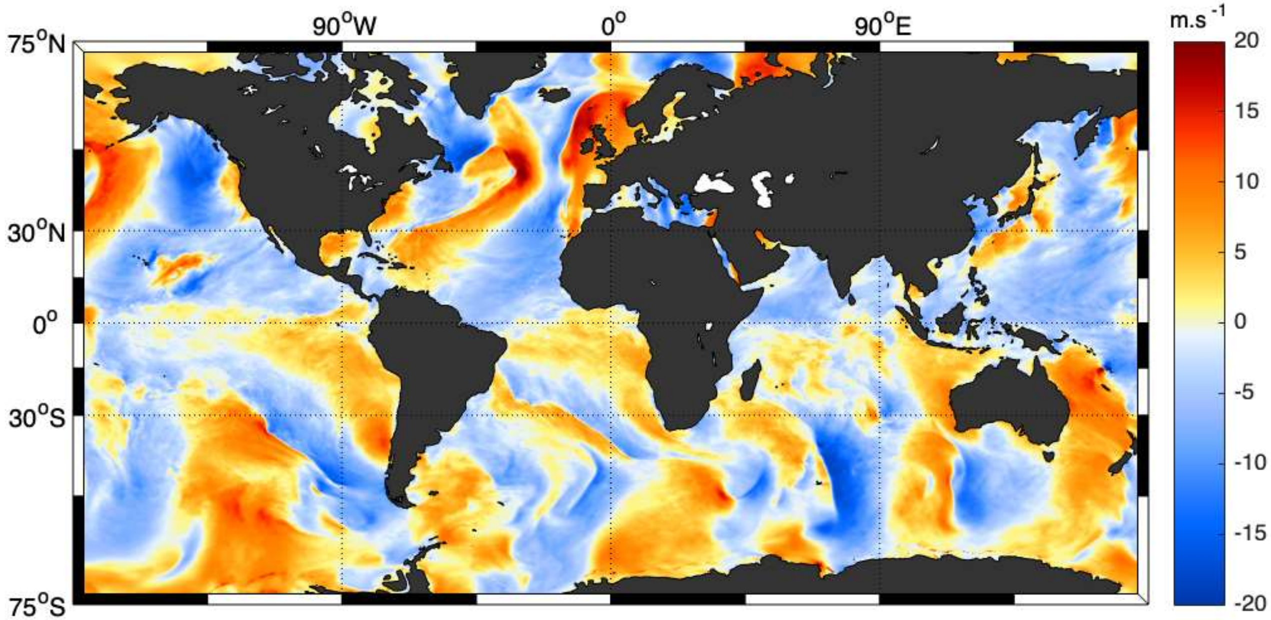
Marcos Portabella (ICM-CSIC)

Rianne Giesen (KNMI)

Anton Verhoef (KNMI)

Ad Stoffelen (KNMI)

portabella@icm.csic.es



ISMAR ISTITUTO DI SCIENZE MARINE

Koninklijk Nederlands Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

WOC User Consultation Meeting, October 10-12, 2022

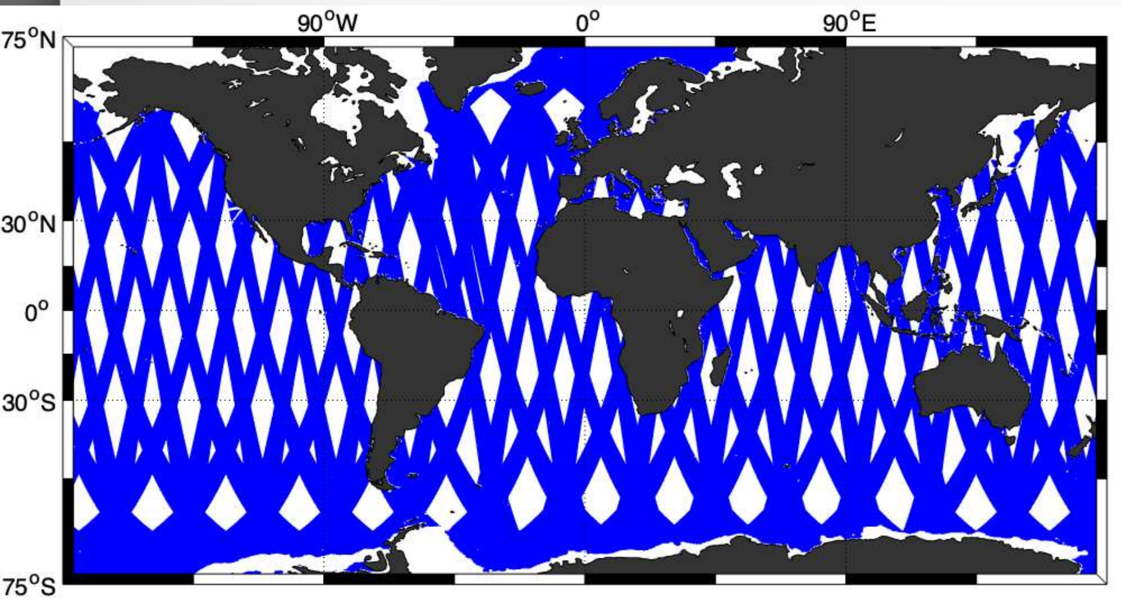
Ocean wind forcing

- NWP wind output is generally used as ocean forcing since it’s ubiquitous.
- NWP winds resolve up to 100-150 km scales in open ocean, and miss small scale processes like moist convection, wind stress-SST coupling, coastal effects, etc.
- Scatterometers provide high-resolution (25-km), accurate sea surface wind field information up to 15-20 km off the coast
- Active microwave sensors, operating at C- & Ku-band, i.e., almost all-weather capabilities
- They are used in a wide variety of applications, e.g., assimilation into global and regional NWP, nowcasting, hurricane advisories, climate trend analyses, air-sea fluxes, etc.
- They measure the sea surface roughness, which is a good proxy for wind stress

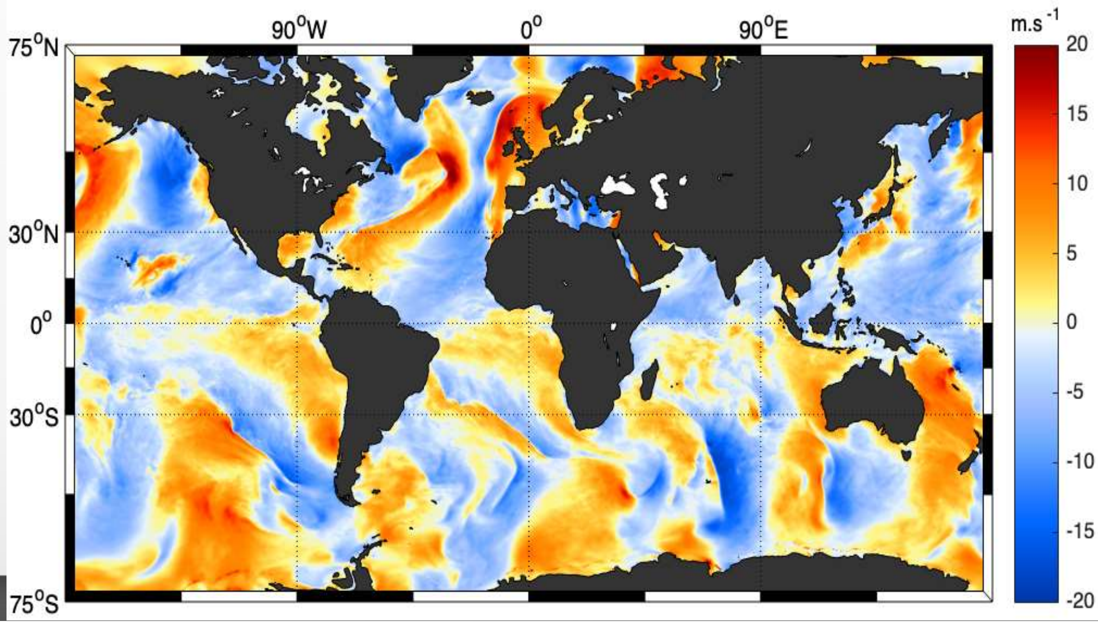
Level 4 wind forcing

- Can scatterometers be used to improve current NWP ocean forcing products?
- Can they bring higher resolution & more accurate forcing?
- An optimal combination of NWP output and scatterometers winds is needed to overcome sampling issues

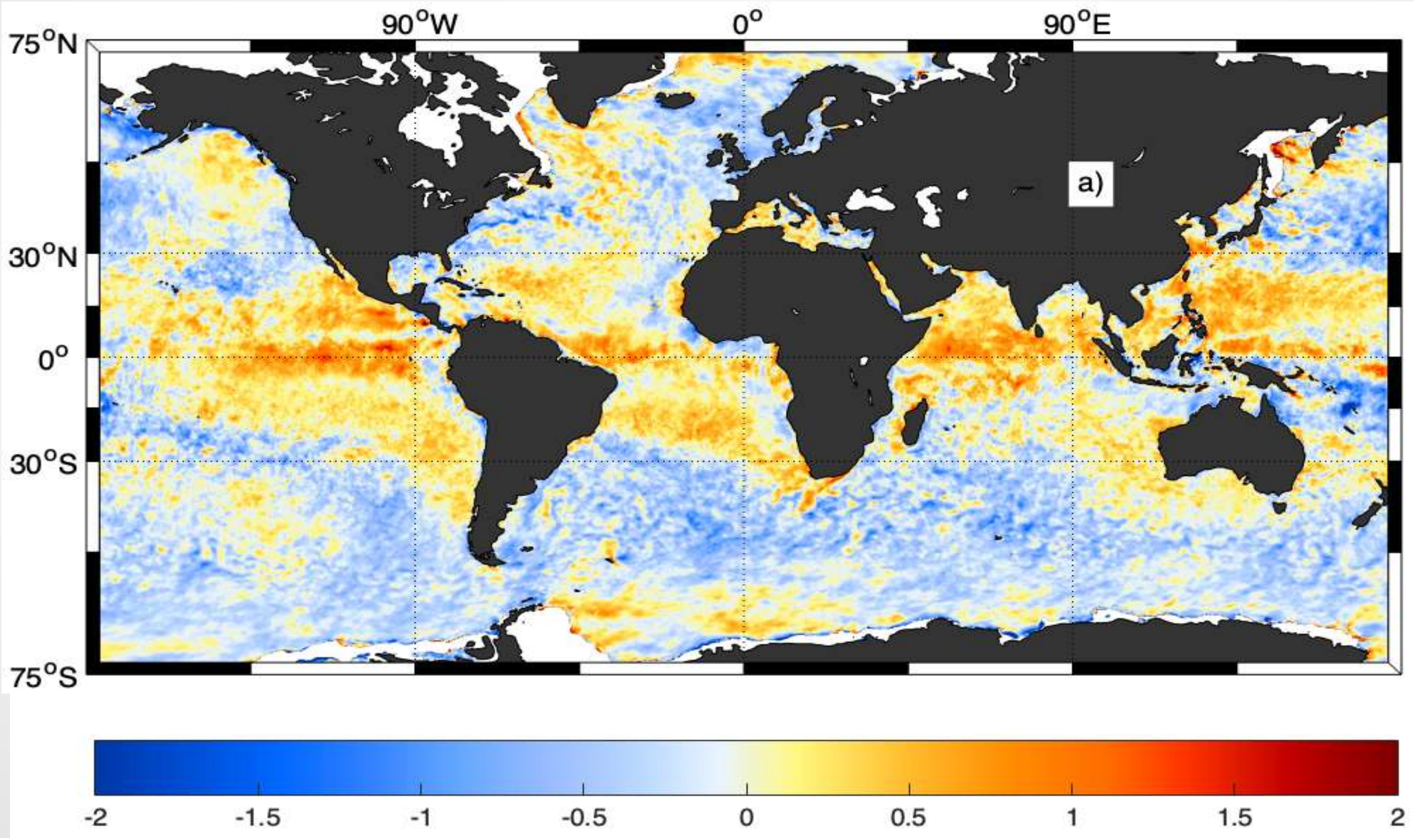
DAILY COVERAGE FROM A SINGLE SCATTEROMETER (over ocean)



ERA* HOURLY L4 WIND PRODUCT



SYSTEMATIC DIFFERENCES BETWEEN NWP AND SCATTEROMETER



COLLOCATIONS
- ASCAT-A/B/C – ERA5 u10S
- 30-d Temporal Window

Zonal component (v10S)

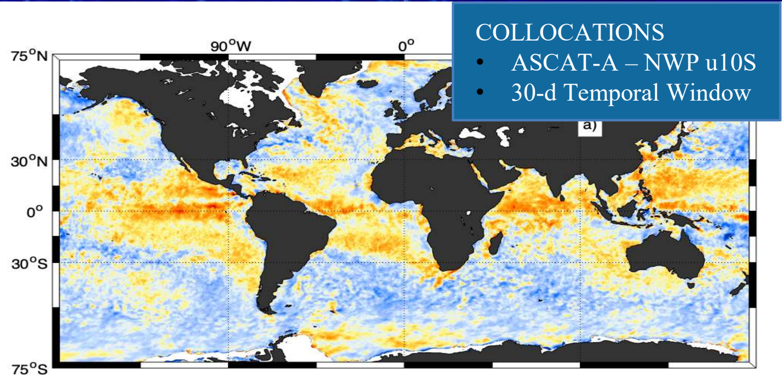
ERA* wind & stress product

Development of ERA*:

1. Scatterometer-based corrections:

$$SC(i,j,t_f) = \frac{1}{M}\sum_{t=1}^{M}\left(u_{10s}^{SCAT_k}(i,j,t) - u_{10s}^{ERA}\ (i,j,t)\right)$$

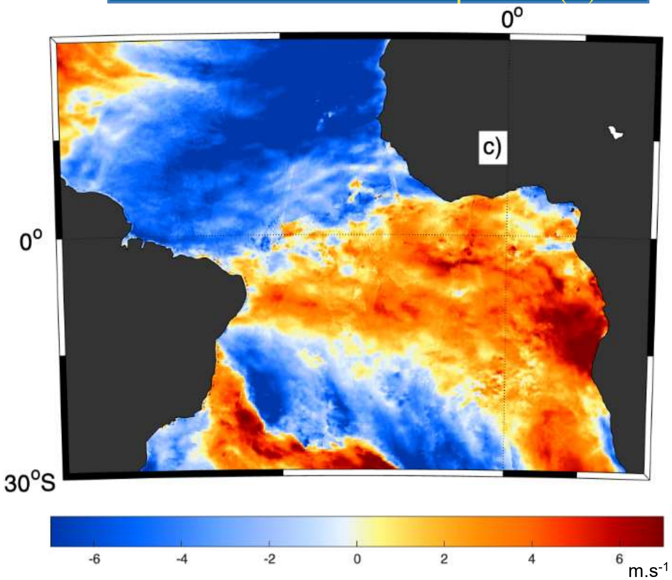
N length of the temporal window (d);
k Scatterometer combinations
M is the number of scatt. and ERA collocations
Applied at every forecast time

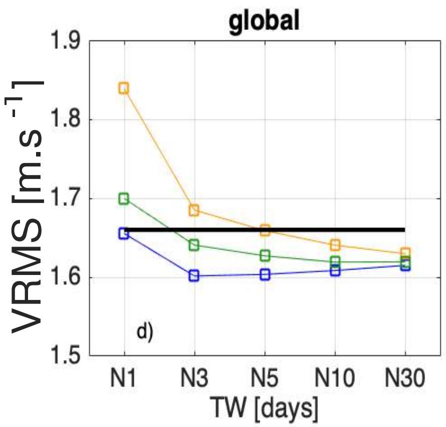


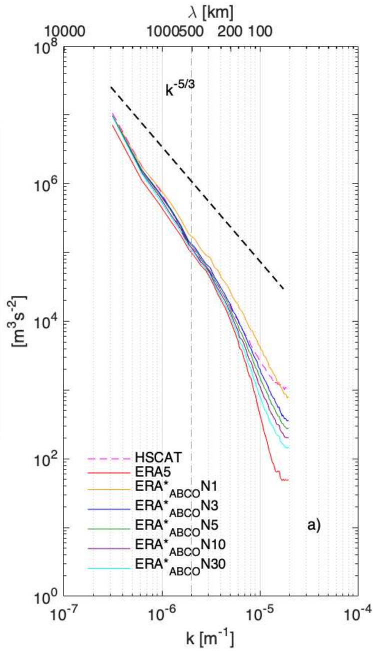
2. ERA5-corrected stress-equivalent winds (ERA5*):

$$u_{10s}^{ERA5^*}(i,j,t_f) = u_{10s}^{ERA}\ (i,j,t_f) + SC(i,j,t_f)$$

Meridional wind component (v)







ERA* corrects for large-scale circulation errors and adds small-scale true wind variability, due to oceanic features such as wind changes over SST gradients and ocean currents.

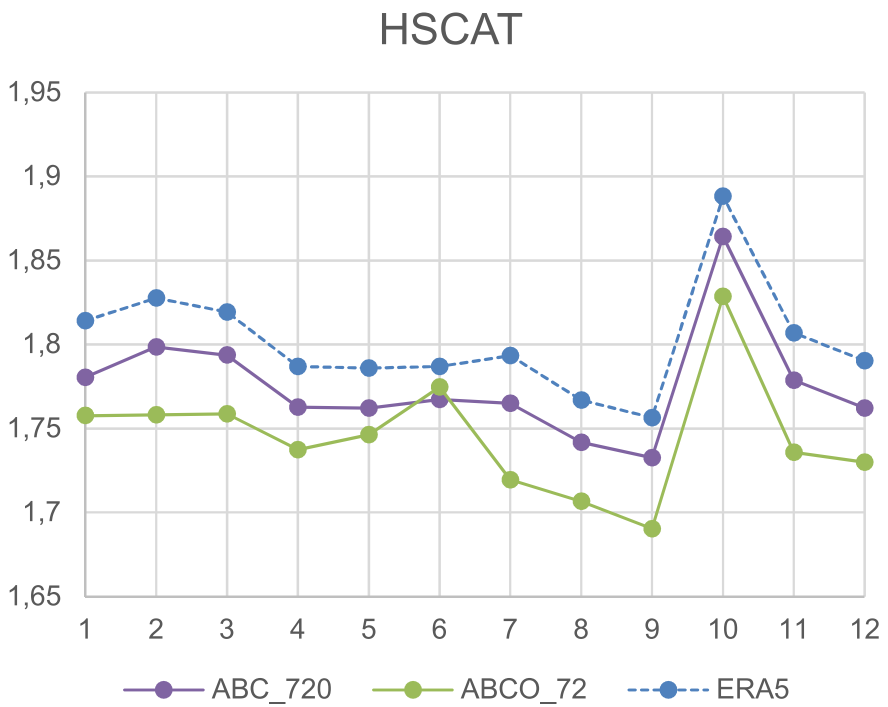
ERA* error variance (w.r.t. HSCAT-B) is 9% lower than that of ERA5

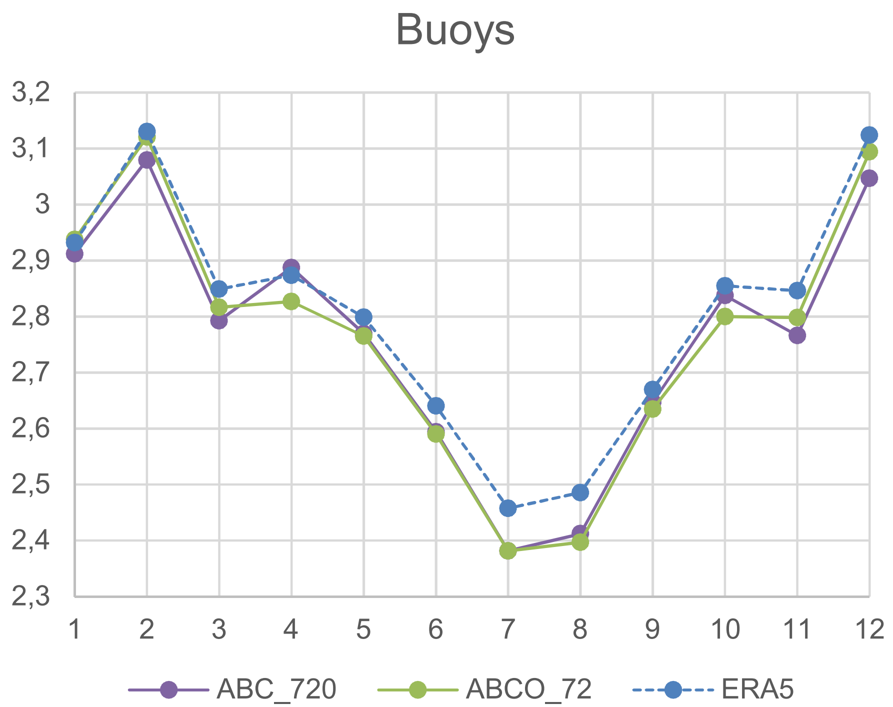
ERA* wind & stress product

- Scatterometer constellation in 2010-2020 (only C-band & Ku-band with global, continuous coverage)
  - 2010-2012: ASCAT-A & OSCAT
  - 2013: ASCAT-A, ASCAT-B & OSCAT
  - 2014-2016: ASCAT-A, ASCAT-B
  - 2017-2018: ASCAT-A, ASCAT-B & OSCAT2
  - 2019-2020: ASCAT-A, ASCAT-B, ASCAT-C & OSCAT2, HSCAT-B
- HSCAT-A and RapidSCAT don't have full coverage and/or continuous coverage, therefore used for verification purposes only
- The 2019 period is used as testbed for ERA* optimization over the entire period since it contains all the possible combinations of C-band and Ku-band scatterometer sampling
- Validation against buoys is added to independent scatterometer verification

ERA* wind & stress product

Global





$$VRMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\left(u_{i,REF} - u_{i,NWP}\right)^2 + \left(v_{i,REF} - v_{i,NWP}\right)^2\right)}$$

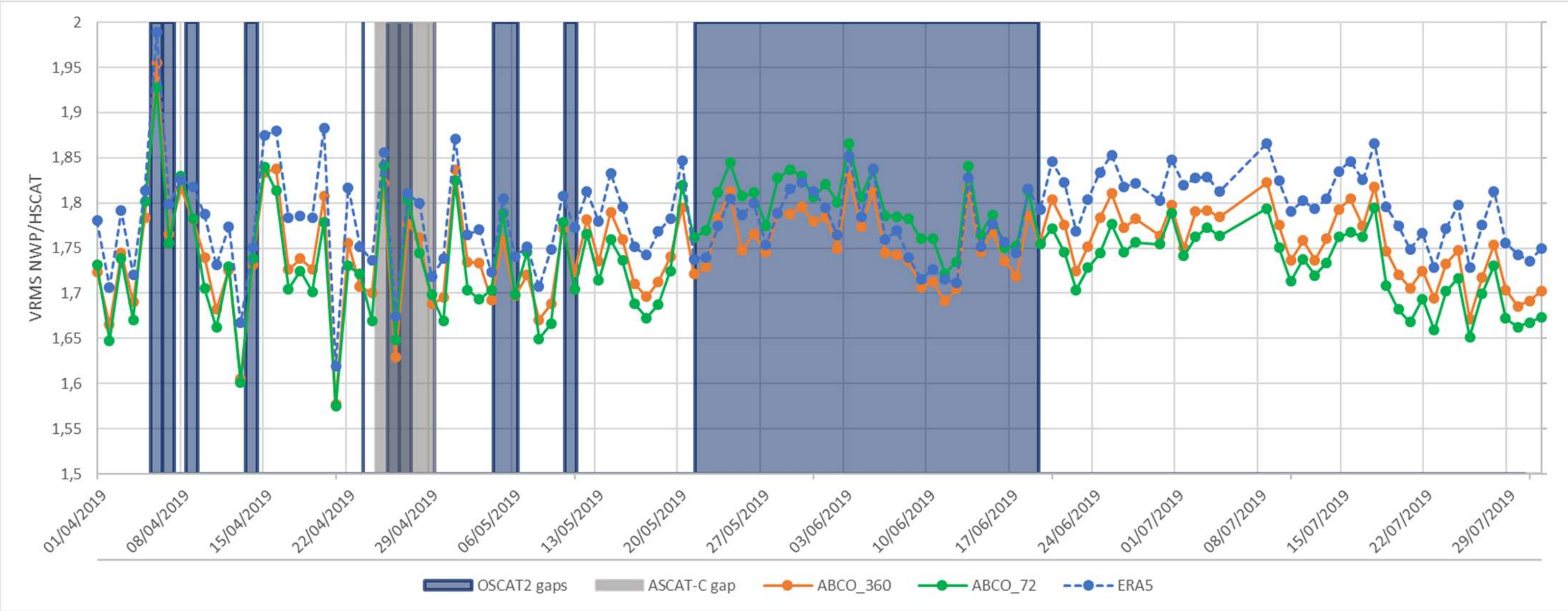
REF: HSCAT, buoys
NWP: ERA5, ERA*

72: 3-day window
720: 30-day window

A: ASCAT-A
ABC: ASCAT-A, -B & -C
ABCO: ASCAT-A, -B, -C & OSCAT2

ERA* wind & stress product

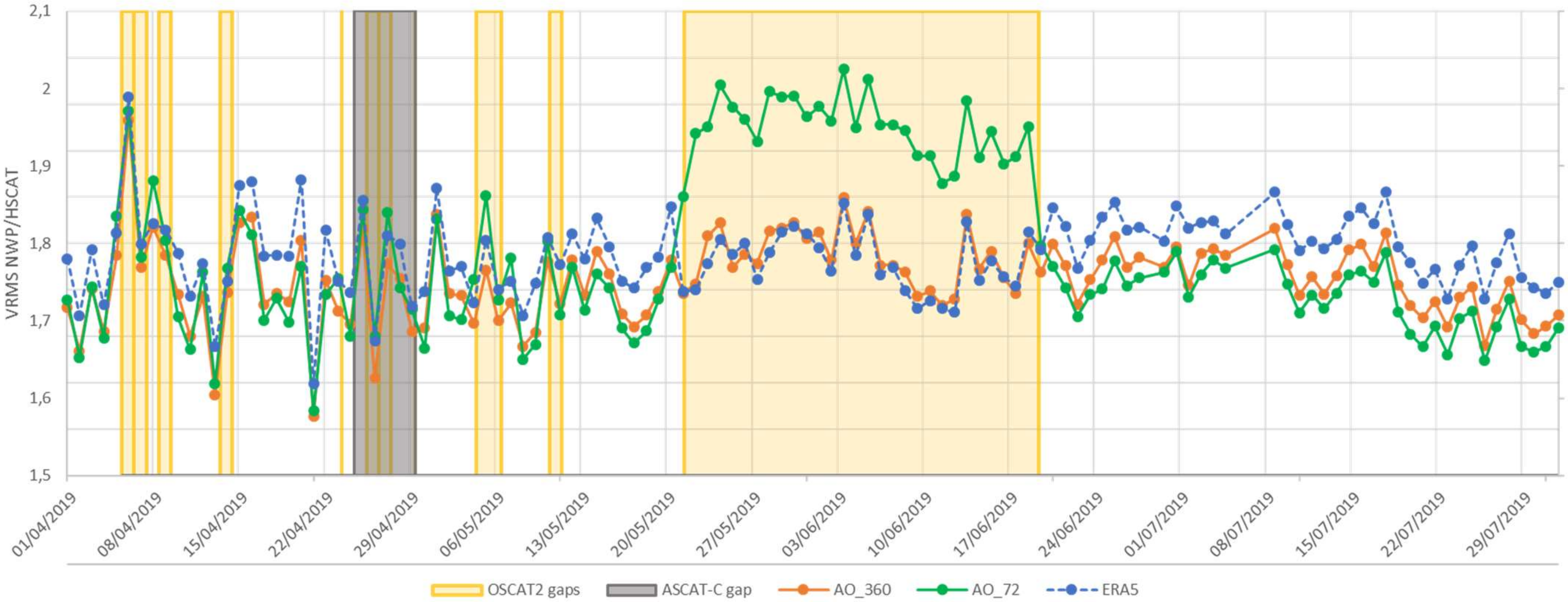
ERA5* ABCO daily metrics vs HSCAT and gaps in scatterometer sampling (2019)



Short temporal windows sensitive to data gaps

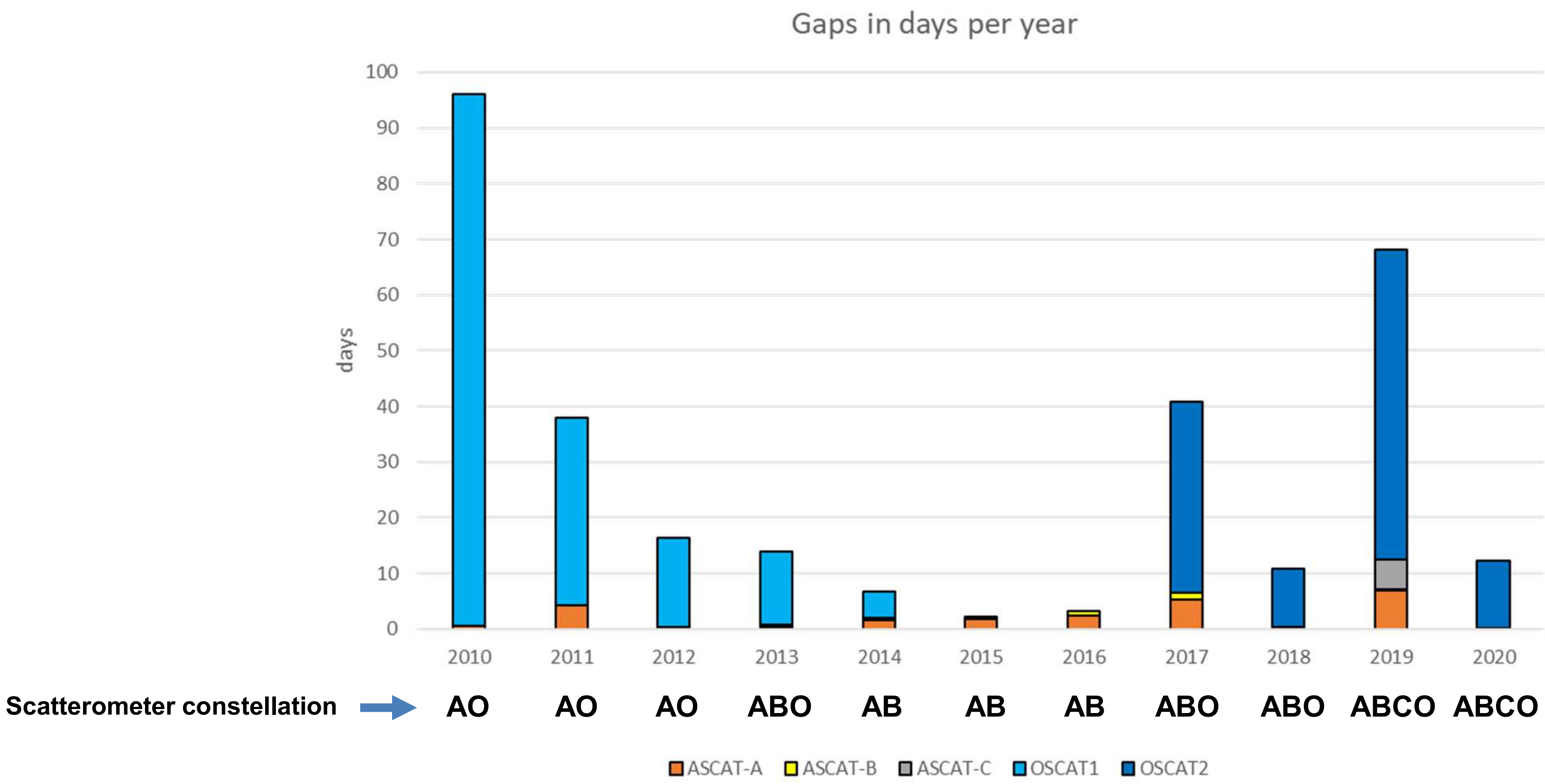
ERA* wind & stress product

ERA5* AO daily metrics vs HSCAT and gaps in scatterometer sampling (2019)



Few scatterometers & short temporal windows very sensitive to data gaps

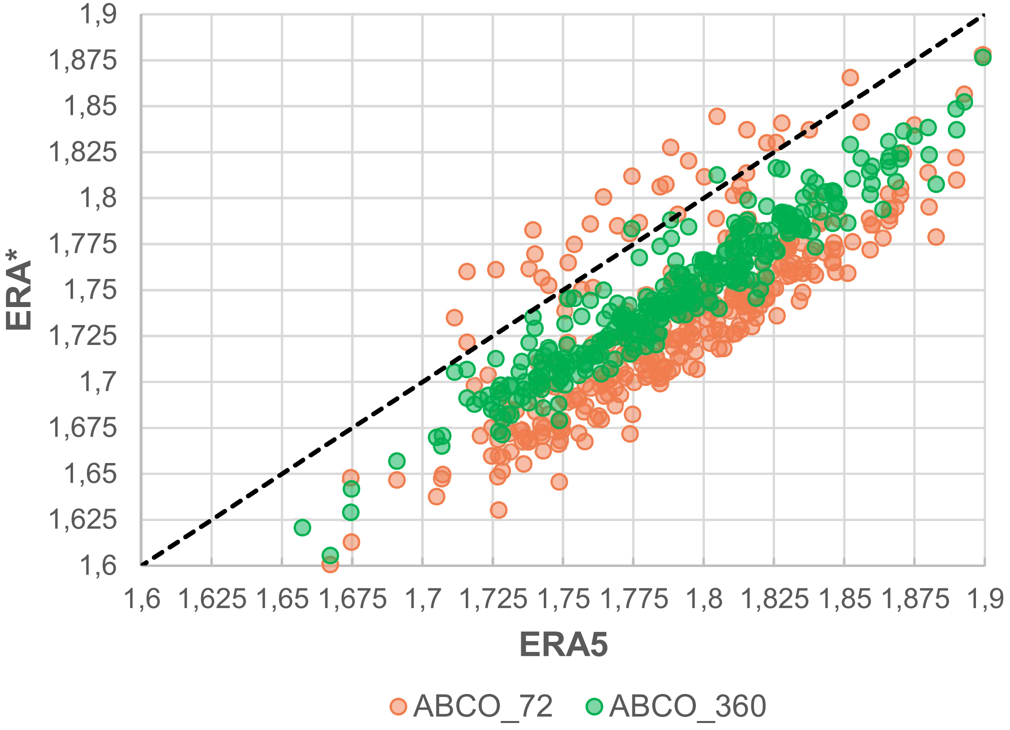
ERA* wind & stress product

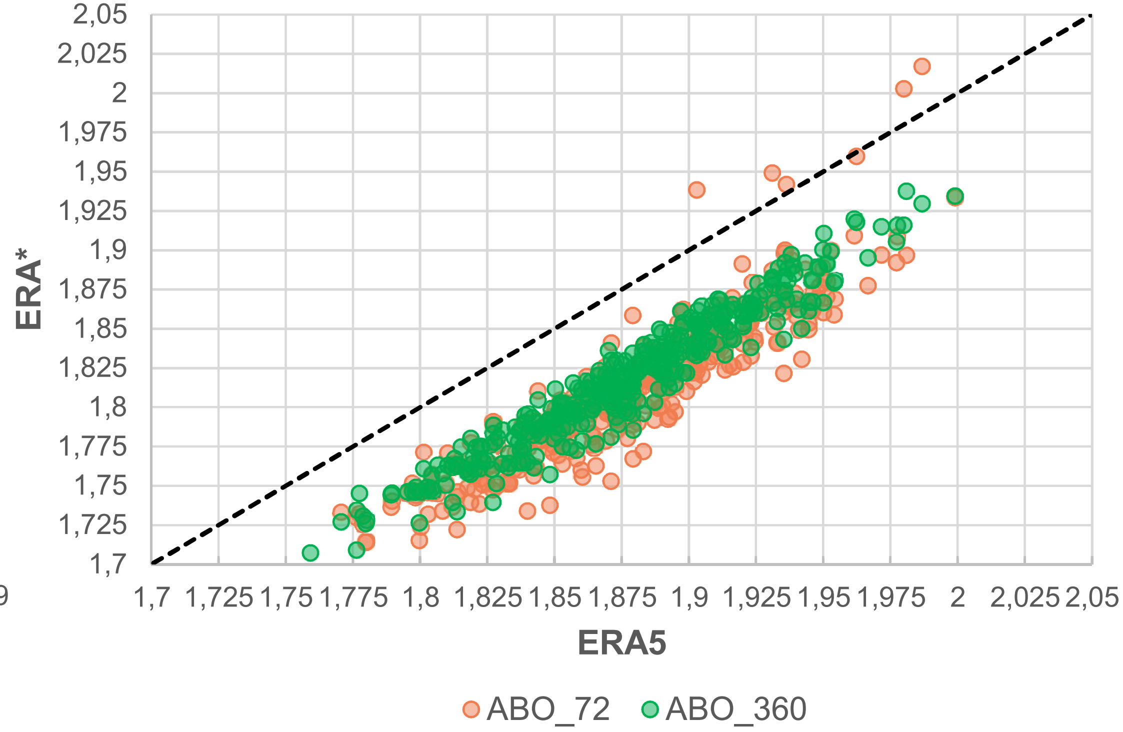


Large data gaps in Ku-band systems!

ERA* wind & stress product

Global





$$VRMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\left(u_{i,REF} - u_{i,NWP}\right)^2 + \left(v_{i,REF} - v_{i,NWP}\right)^2\right)}$$

REF: HSCAT
NWP: ERA5, ERA*

72: 3-day window
360: 15-day window

A: ASCAT-A
ABC: ASCAT-A, -B & -C
ABCO: ASCAT-A, -B, -C & OSCAT2

ERA* wind & stress product

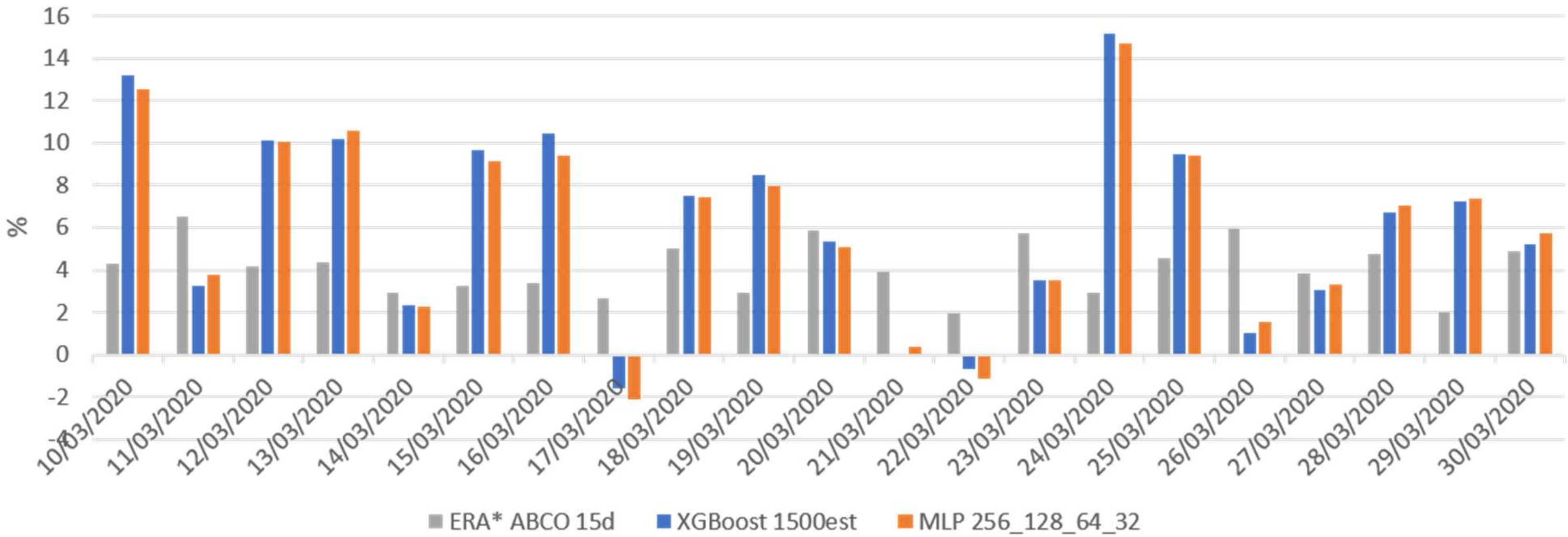
- ERA* baseline configuration (overall **6%** error variance reduction w.r.t. ERA5):
  - **2010**: 30-day time window (since 25% of the time only ASCAT-A available)
  - **2011-2013 & 2017-2020**: 15-day time window for combined C- & Ku-band
  - **2014-2016**: 15-day time window for C-band only

- ERA* optimized configuration (overall **9%** error variance reduction w.r.t. ERA5):
  - **2013, 2018 & 2020**: 3-day time window for combined C- & Ku-band

- Current activities
  - ERA* operational implementation in CMEMS (see poster from **A. Stoffelen**)
  - Machine learning approach to directly relate ECMWF forecast U10S & MBL parameter fields to NWP-scatterometer differences
  - ERA* being tested in several applications (NTA, surge) and in **WOC Themes 2 & 3**

Machine learning approach for ERA*: preliminary results

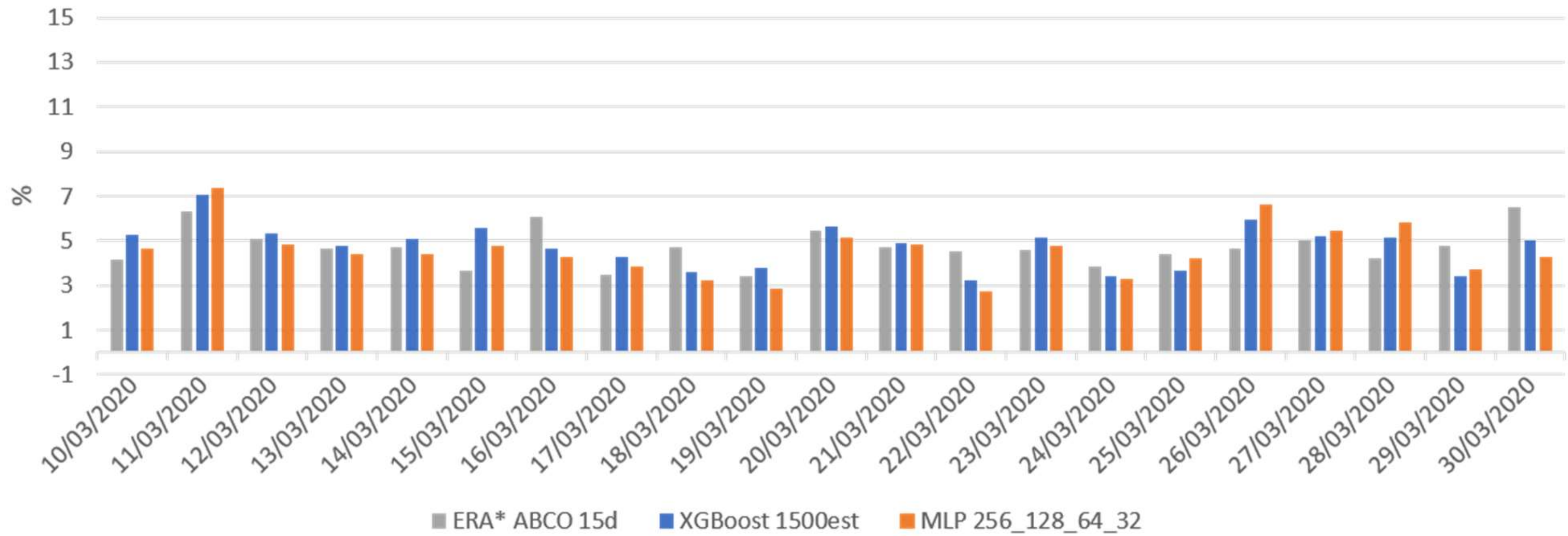
ERA* error variance reduction w.r.t. ERA5 error (middle latitudes)



- **XGBoost**: Decision tree based model with 1500 estimator
- **MLP**: Feed-forward Neural Network with 4 hidden layers, each containing 256, 128, 64, and 32 neurons.
- Training period: 2.5 months

Machine learning approach for ERA*: preliminary results

ERA* error variance reduction w.r.t. ERA5 error (global)



- **XGBoost**: Decision tree based model with 1500 estimator
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Case study: Warm 2017 North Tropical Atlantic event

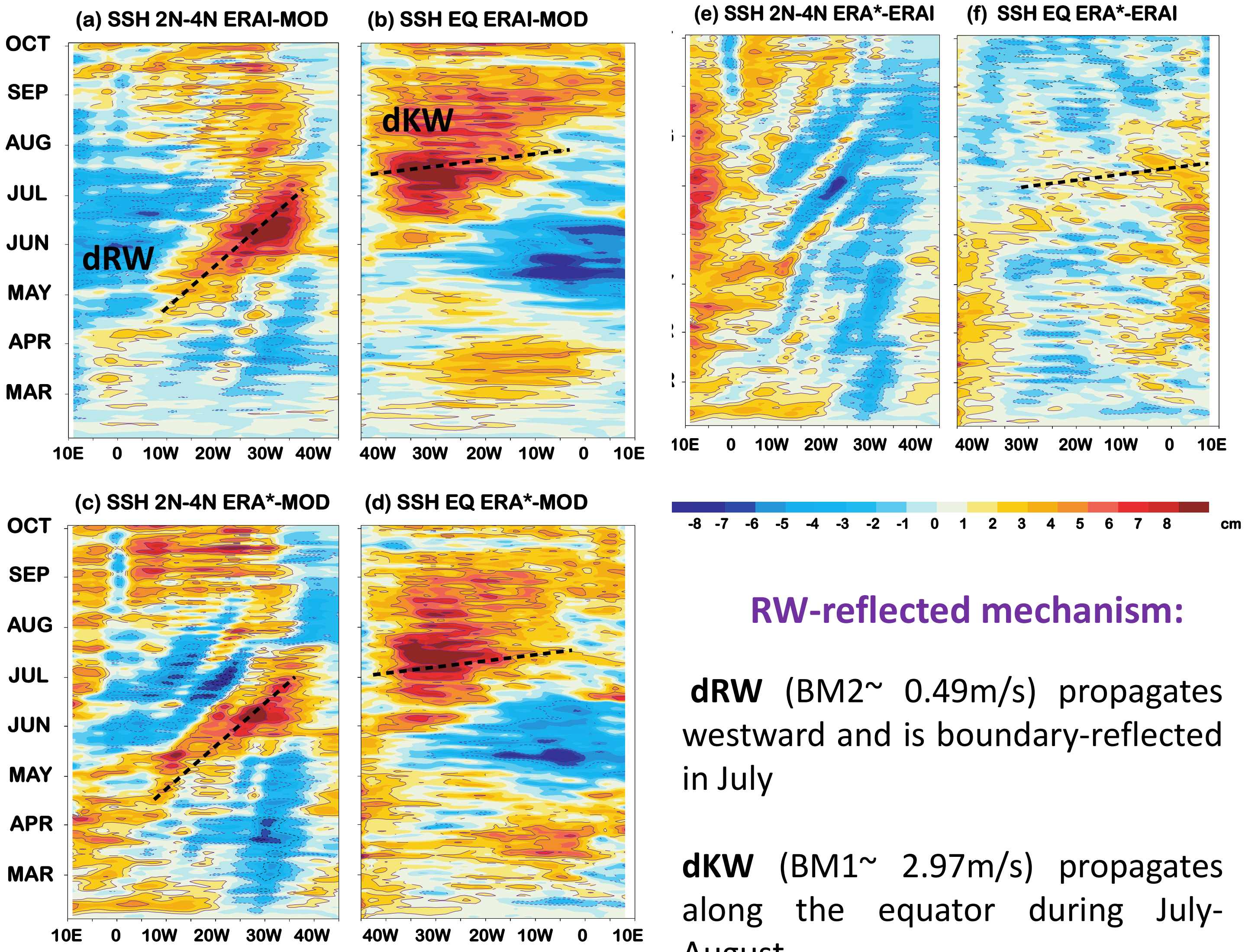
Sensitivity experiments with the EC-Earth3 model:

- **MOD:** 11-month initialized forecast simulation from February to December 2017, in which the model wind runs free in the tropical Atlantic region.
- **ERAI**: 11-month forecast simulation forced by wind stress from ERA-interim in the tropical Atlantic region from February to December 2017.
- **ERA*:** 11-month forecast simulation forced by wind stress from ERA* in the tropical Atlantic region from February to December 2017.

Technical specifications:

- ERA* consists of a scatterometer-based correction of ERA-interim, able to introduce true smaller scale signal that corresponds to physical processes absent or misrepresented in the ERA-interim output.
- Forced tropical Atlantic region [35°N-35°S, 70°W-20°E] with 4° buffering zone.
- Initial conditions on the 1st of February of 2017 from ORA-S4 and ERA-interim
- 10 members for each simulation perturbing atmospheric initial conditions

Case study: Warm 2017 North Tropical Atlantic event



Contours: significance at 95%

RW-reflected mechanism:

dRW (BM2~ 0.49m/s) propagates westward and is boundary-reflected in July

dKW (BM1~ 2.97m/s) propagates along the equator during July-August

- NTA-equatorial linkage in the 2017 event via wind-induced remote ocean waves
- RW-reflected mechanism arises when realistic surface stress is used
- Despite stronger ERA* wind curl, similar dRW w.r.t ERAi
- Enhanced dKW for ERA* experiment w.r.t. ERAi