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CFOSAT

Understanding of Ku-band backscattered signal properties using combined multi-instrumental CFOSAT measurements

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IFREMER Wind and Wave Operational Center

- The **Ifremer Wind and Wave Operation Center** (IWWOC) is the downstream French CFOSAT processing center, cofunded by Ifremer and CNES, operated by CERSAT (Ifremer Satellite Data Processing and Dissemination Center) and supported by experts from the Laboratory of Space and Physical Oceanography (LOPS)

- IWWOC focus is on advanced research product :
  - Delayed mode, **long and consistent time series** to complete climate data series from other missions
  - **Higher level products** : L2S to L3/L4 (global fields of wind and wave parameters)
  - **Synergy** between SWIM and SCAT, alternative processing method and testing
  - Ultimately combination with other missions such as **Sentinel-1**
  - **Resources** for **cal/val** and **algorithm development** : cross-overs with altimeters/scatterometers/SAR, match-ups with in-situ data, dedicated wave hindcast over SCAT & SWIM measurement locations (WW3)

The first IWWOC products were **released to public early 2022**, through **ODATIS** (French federated access to national ocean data) / **CERSAT** portal :

- https://www.odatis-ocean.fr
- https://cersat.ifremer.fr/Data/Catalogue#/search?from=1&to=30

Access

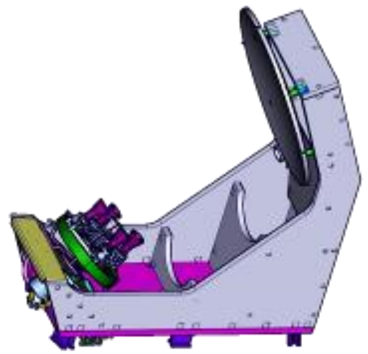
- HTTP: https://data-cersat.ifremer.fr/projects/iwwoc/swisca_l2s___/

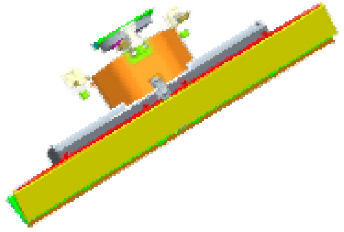
- FTP: ftp://ftp.ifremer.fr/ifremer/cersat/projects/iwwoc/swisca_l2s___/

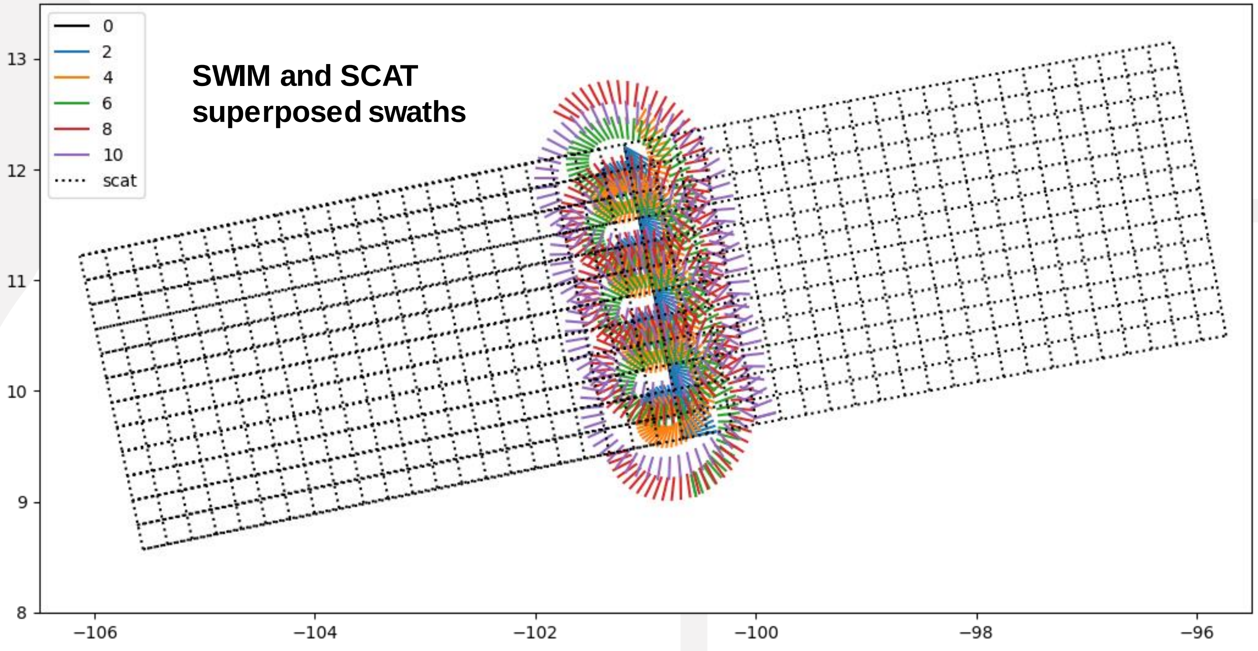
SWIM and SCAT synergetic products

IWWOC is working on two SWIM/SCAT combined products:

- **SWISCA L2S** – collocated SWIM and SCAT data in a common geometrical reference grid (25 km). Together with background model information: wave spectrum, wind, sea surface currents, precipitations, sea ice concentration etc.
- **SCA L2S –** SWIM and SCAT combined wind vector product







Moderate angle and near-nadir radar observations

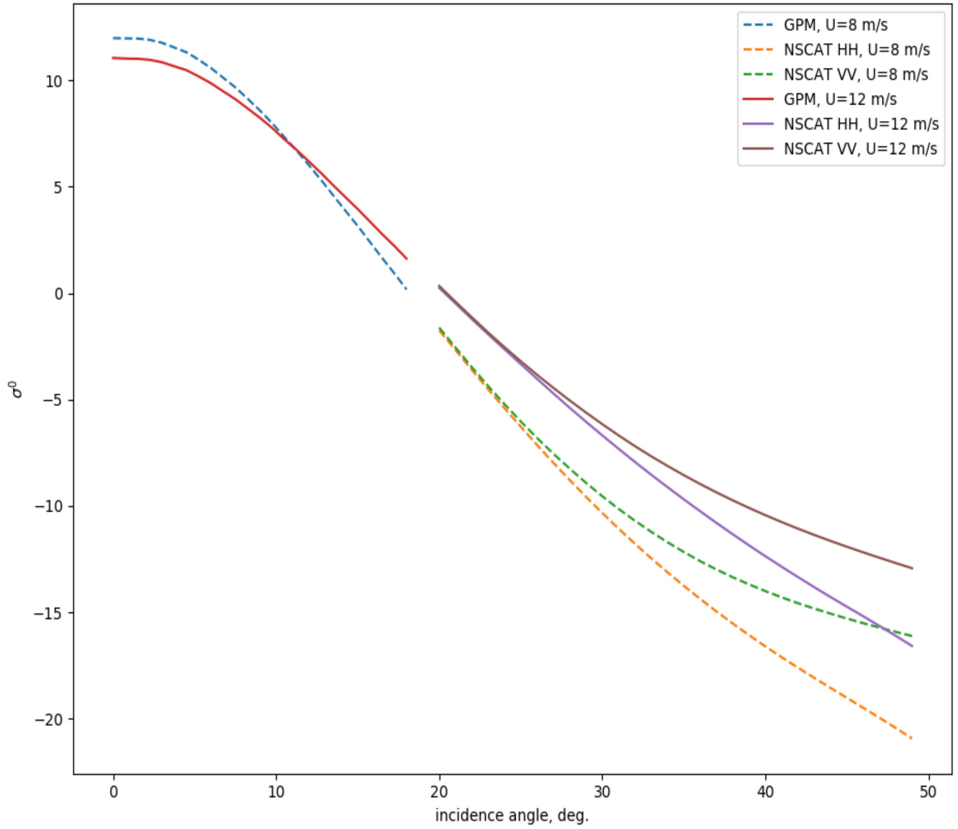
Radar backscattered signal sensitivity and noise properties are different for different incidence angles:

- **nadir:** determined by specular sea surface reflections; sensitive to significant wave height, wind speed

- **near-nadir:** impacted by long wave sea surface modulation; sensitive to the gravitational wave directional spectrum, wind direction (sigma0 goes down with wind speed)

- **moderate angles:** determined mostly by resonant scattering and linked tightly to short capillary wave spectrum, pronounced difference between vertical and horizontal polarizations, sensitive wind vector (sigma0 goes up with wind speed), SST, sea surface currents …

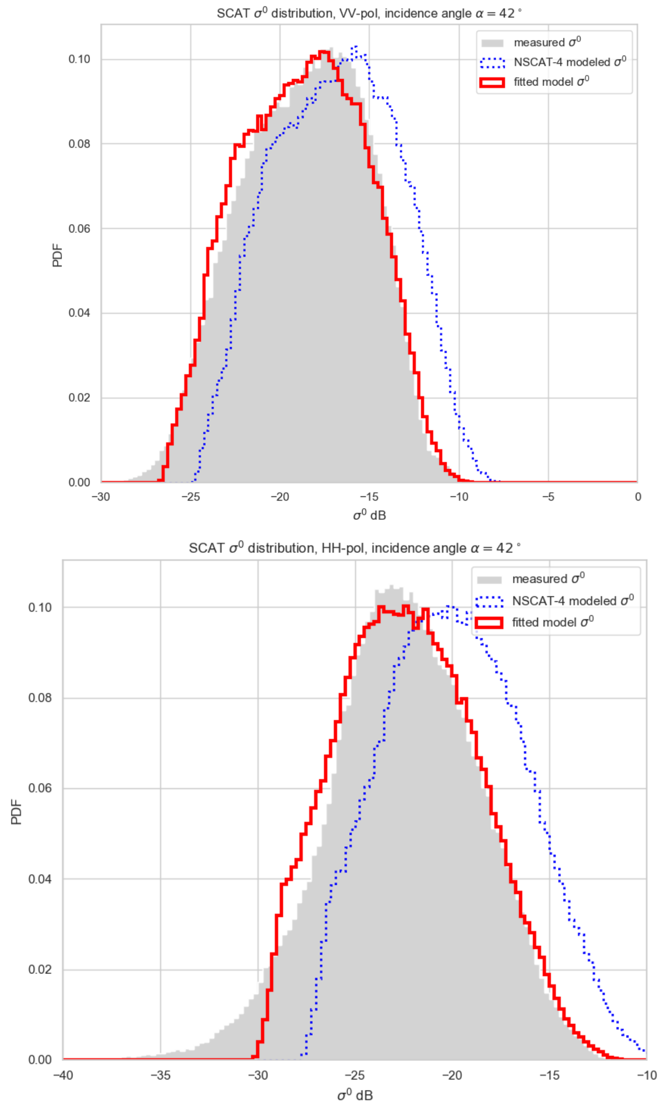
All angle Ku-band GMF



SWISCA L2S SWIM and SCAT collocation and signal inter calibration. Calibration approach

- The SCAT/SWIM calibration procedure is based on equalization of measured and Ku-band GMF simulated histograms.
- The data withing wind speed range 7-8 m/s selected for each incidence angle and every polarization
- Then, the daily calibration coefficient could be calculated for each incidence angle and polarization.

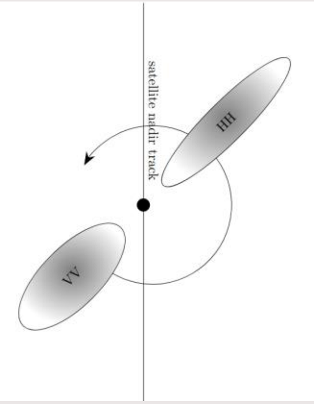
SCAT signal histograms example

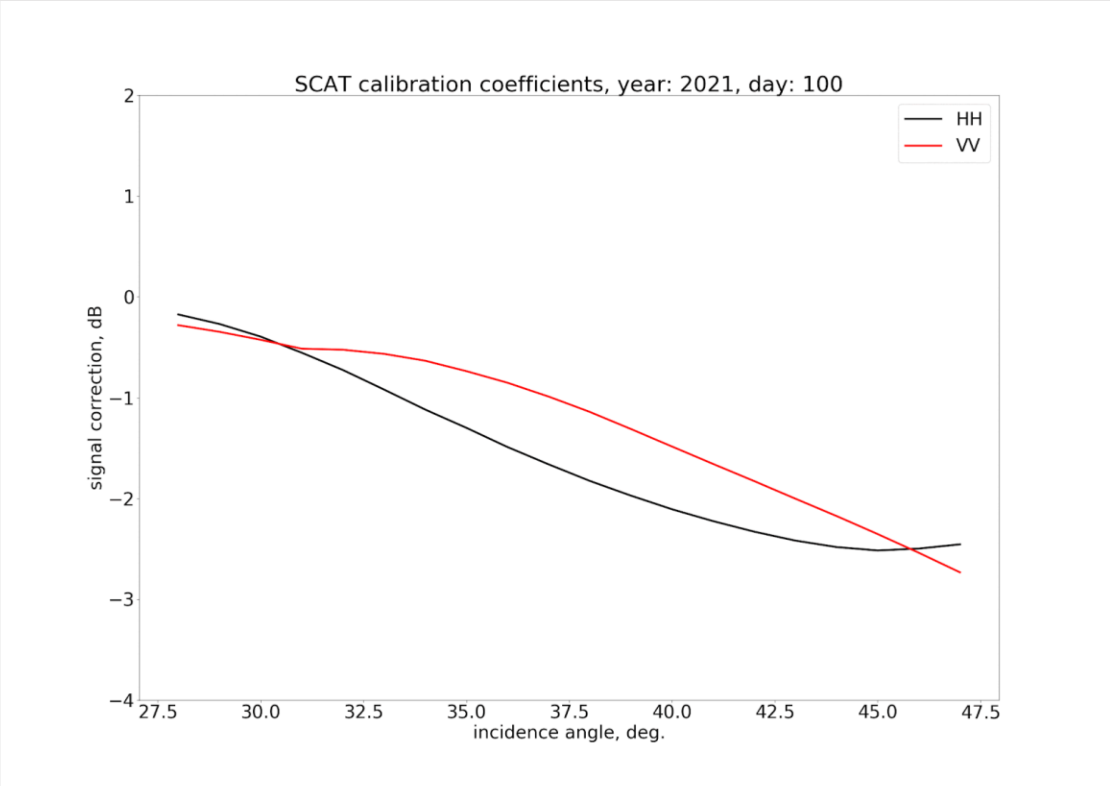


Calibration issues: signal temporal instabilities

- Histogram matching calibration approach allows creating daily calibrations.
- SCAT calibration for both polarizations has constant slope and constantly fluctuating level
- HH and VV fluctuations are strongly correlated!

Possible explanation =>
Not compensated tilting of the CFOSAT platform.





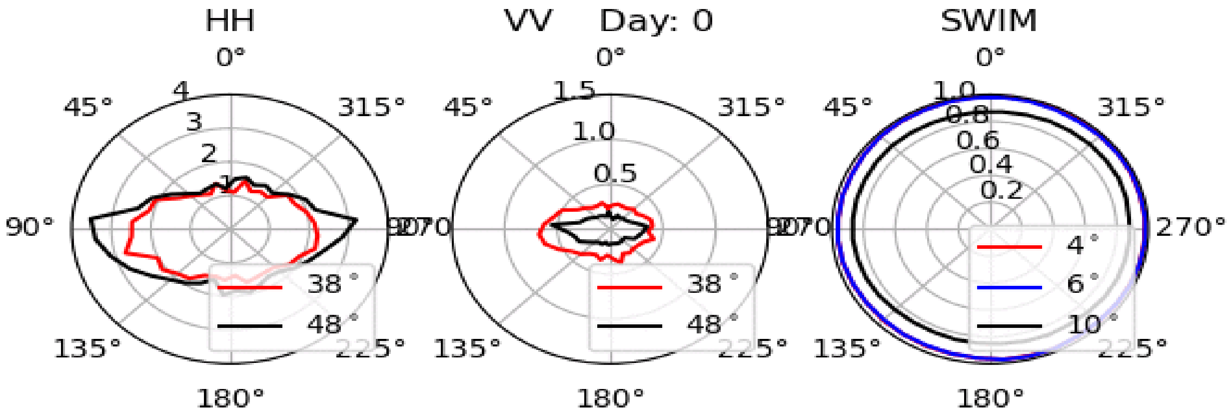
Calibration issues: azimuthal radar response asymmetry

The same calibration procedure was applied for each direction of the radar antenna for both CFOSAT instruments.

Some constant asymmetry is observed for SCAT and SWIM azimuthal calibrations. As well, SCAT HH, VV and SWIM changes are strongly correlated. This can be explained by the residual non-compensated orientation (roll/pitch) of CFOSAT platform.

Worth to repeat CFOSAT pointing calibration?

Azimuthal CFOSAT calibration for the year 2021



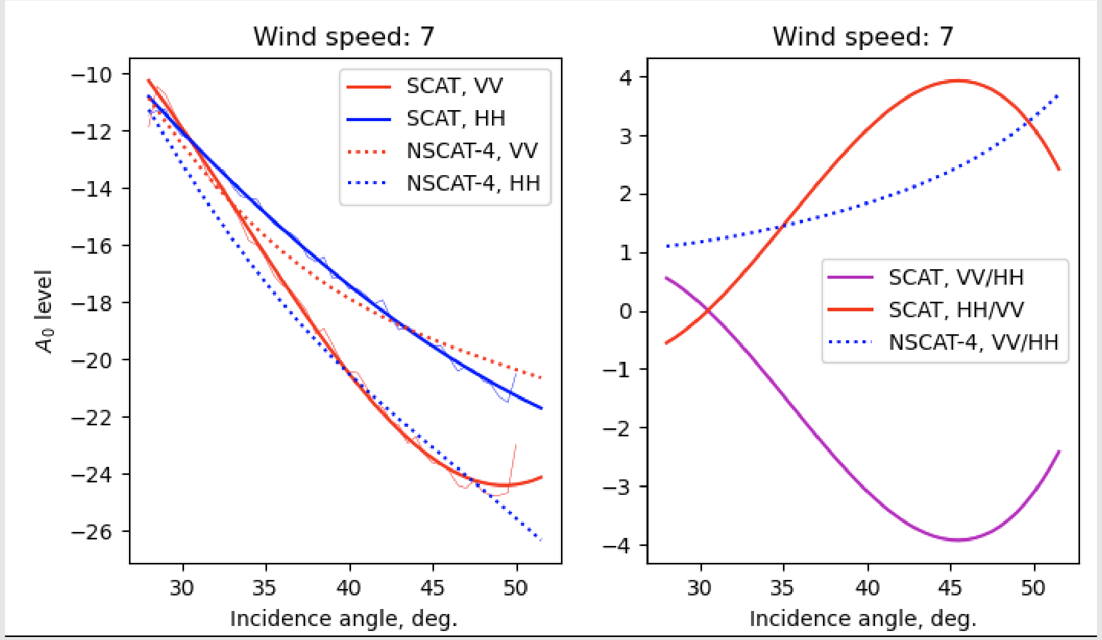
SCAT polarization verification

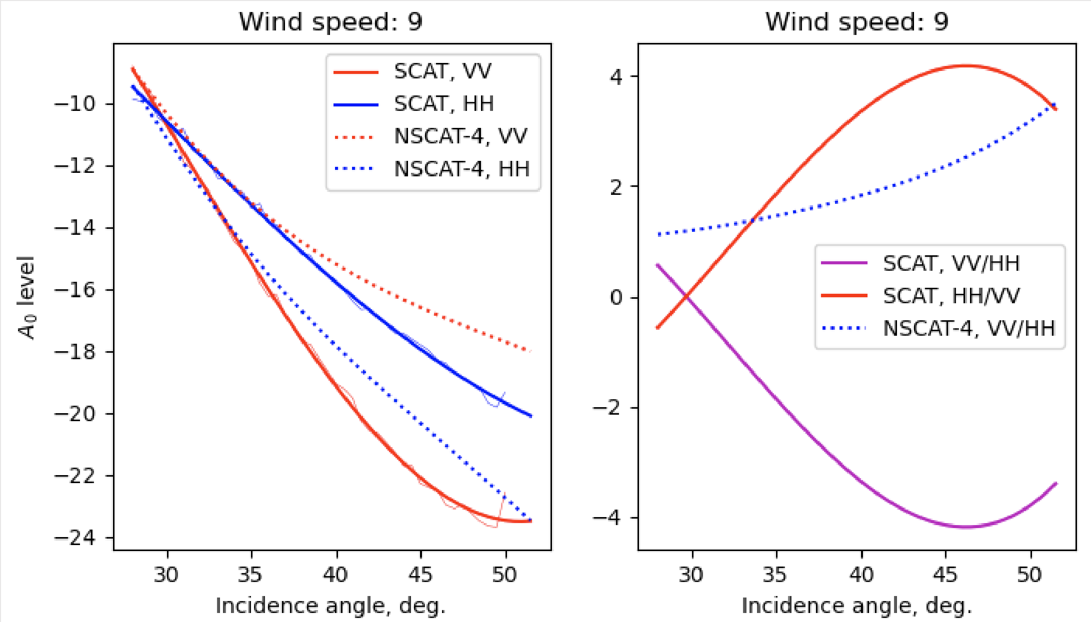
For moderate incidence angles, radar backscatter vertically-polarized signal (VV) should be always higher when horizontally-polarized (HH) one. The level decay with incidence angle of VV signal is slower with respect to HH.

The proper polarization of a radar backscatter could be verified by comparing of first coefficients of truncated Fourier series, which can be estimated directly from SCAT observations and compared with NSCAT-4 model.

$$A_0 = (\Delta\sigma^{up} + 2\Delta\sigma^{cross} + \Delta\sigma^{down})/4$$

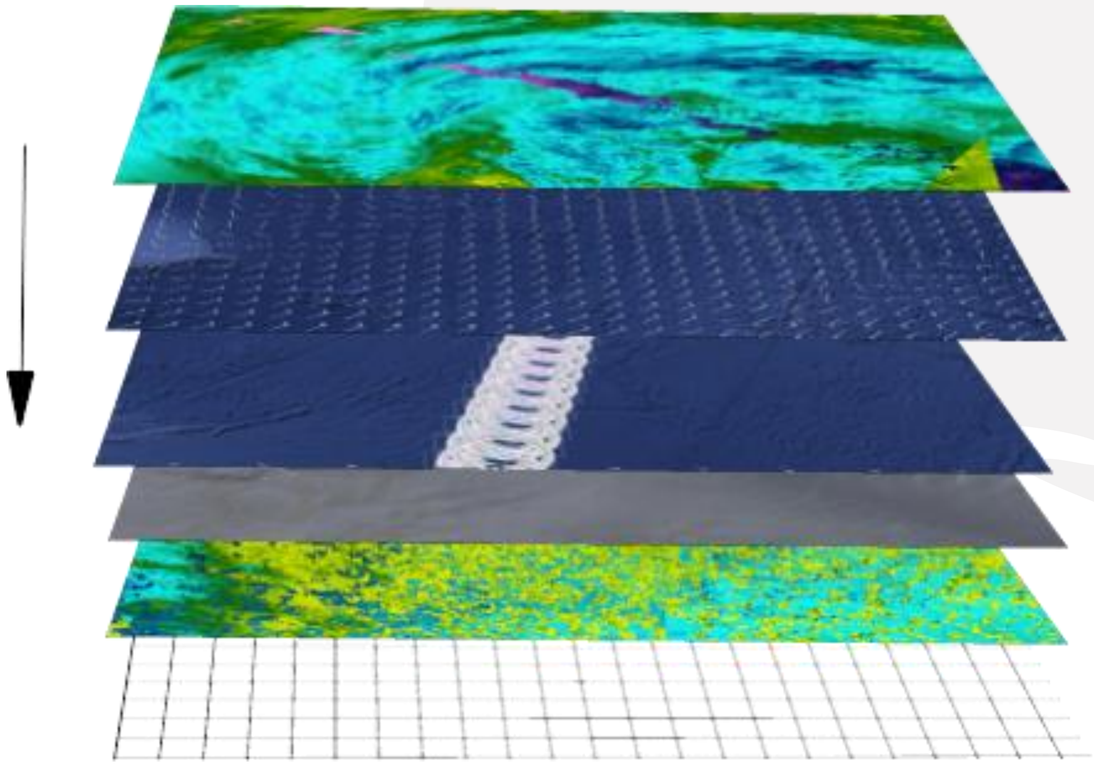
The SCAT VV and HH flags should be inversed to conform NSCAT-4 model !





SWIM and SCAT combined products and processing methods

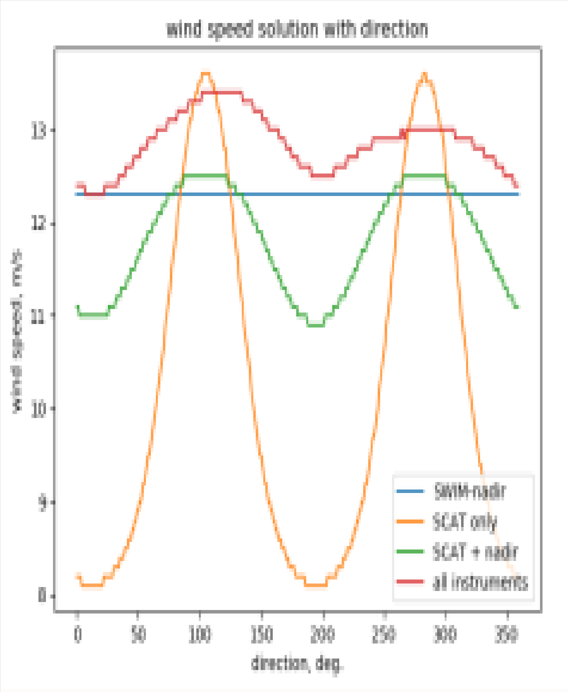
SWIM and SCAT combined products

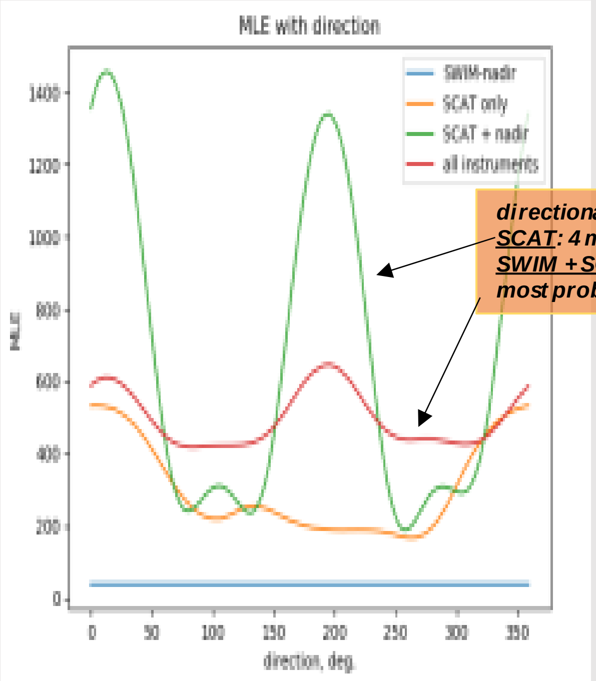


The advantage of collocated measurements:

- Different sensitivity of radar measurements at different incidence on various geophysical parameters potentially allows to reduce ambiguities and errors.
- Improved quality and resolution of retrieved geophysical fields due to higher observational diversity and spatial resolution
- More geophysical variables could be involved to the analysis

Wind vector inversion from CFOSAT observations



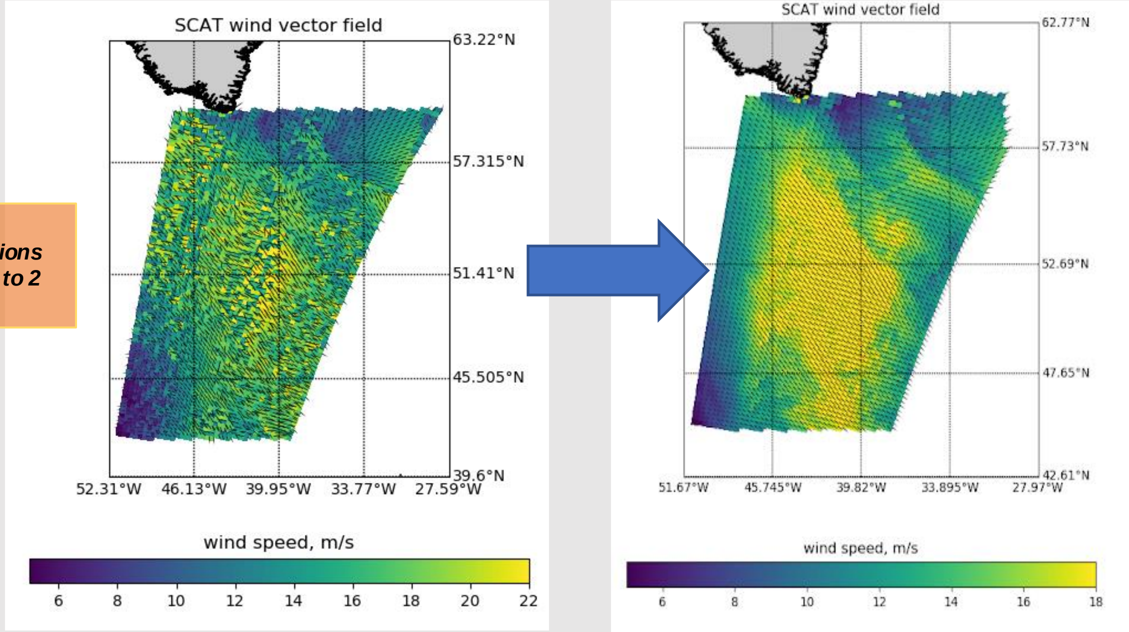


directional MLE:
<u>SCAT</u>: 4 most probable solutions
<u>SWIM + SCAT</u> : MLE reduced to 2 most probable solutions

Modified MLE:

$$MLE_{SWIM/SCAT} = \frac{1}{N+1}\left(\sum_{i=1}^{N}\frac{\left(\sigma^0_{obs}(i)-\sigma^0_{GMF}(i)\right)^2}{K_{p,obs}(i)}+\frac{\left(\sigma^0_{SWIM}-\sigma^0_{GMF}\right)^2}{K_{SWIM}}\right).$$

Event-adaptive wind direction ambiguity removal



In special cases, i.e. extreme winds, tropical cyclones, rain, wind vector ambiguities could be effectively reduced using specific characteristic scales and modified GMFs

Building all-angle multiparametric Ku-band backascattering model

IWWOC CFOSAT SWIM/SCAT L2S, available collocated variables:

- 25x25 km common grid geometry for SCAT and SWIM sigma0 observations
- Common cross-instrumental calibration based on NSCAT-4 GMF
- Background wind field based on interpolated 1-hour 0.12° ECMWF data
- Sea surface current (CMEMS)
- Sea surface temperature
- Directional wave spectrum (Wave Watch III)
- Background precipitation (IMERG)
- Sea ice concentration (CERSAT)
- Observation period 05/2019 - now

This data set could be used for the developing of multi-parameter all-angle dual polarization Ku-band GMF

However, traditional look-up table or empirical parametrization approaches are not efficient or cannot be used.

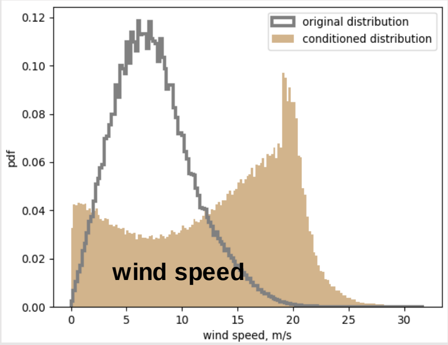
<u>The possible solution is to build new GMF using a neural network approach.</u>

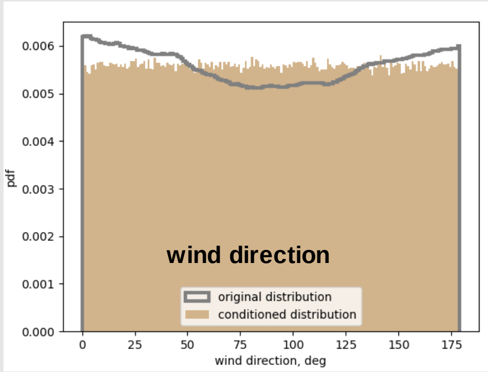
Building neural network: input data quality analysis, uniformization and normalization of observation dataset

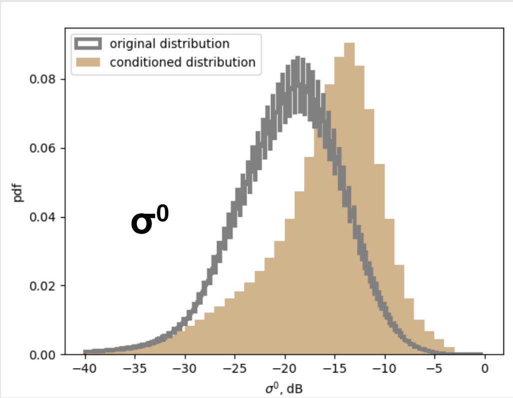
Geophysical variables are distributed unevenly. This means that we will most likely learn values that belong to a narrow interval.

The original dataset was conditioned according to the following scheme:

1. The appearance frequency of variable value estimated through the PDF of distribution P(x)
2. The values from original dataset selected randomly with the probability 1/P(x)*μ (μ is the condition variable)
3. This approach reduces the learning dataset by 100. Eg. for 30 days observation period we have only ~10M sigma0



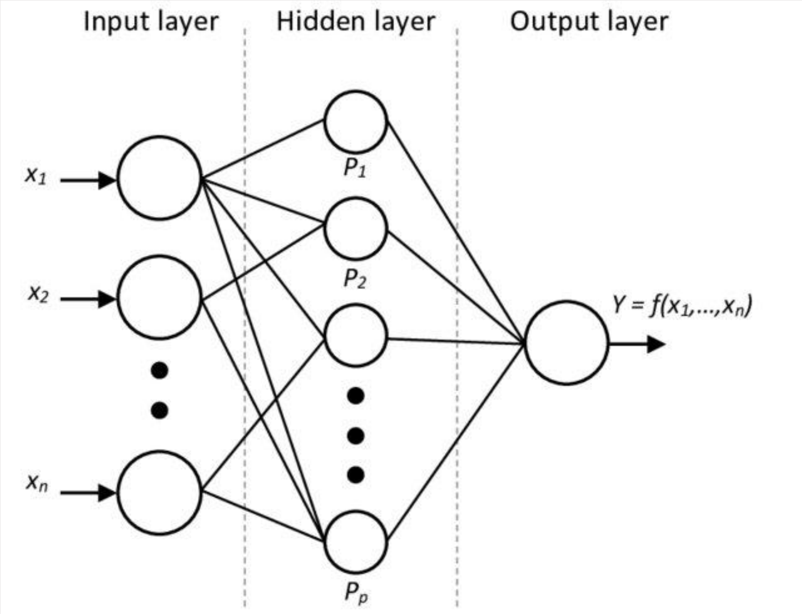




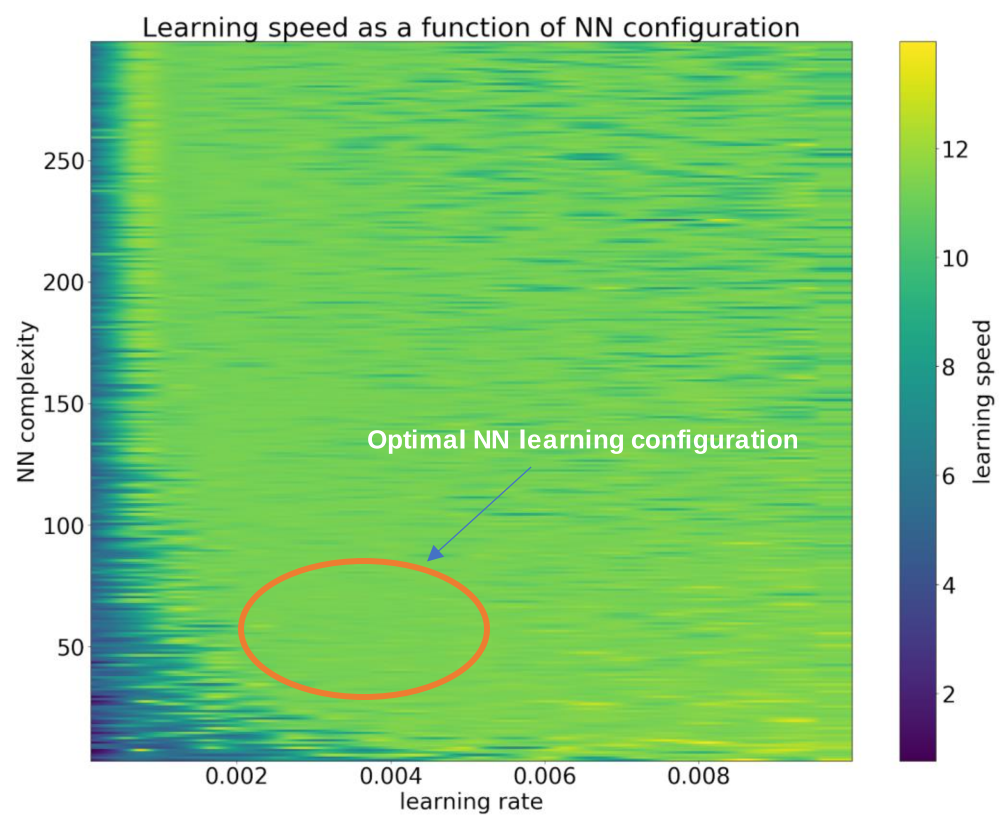
Selecting an optimal neural network configuration

Iterative approach for optimal neural network configuration.

This approach allows determining the minimal configuration of network with the sufficient approximation performance. This is important for high volumes of training data



NN performance map



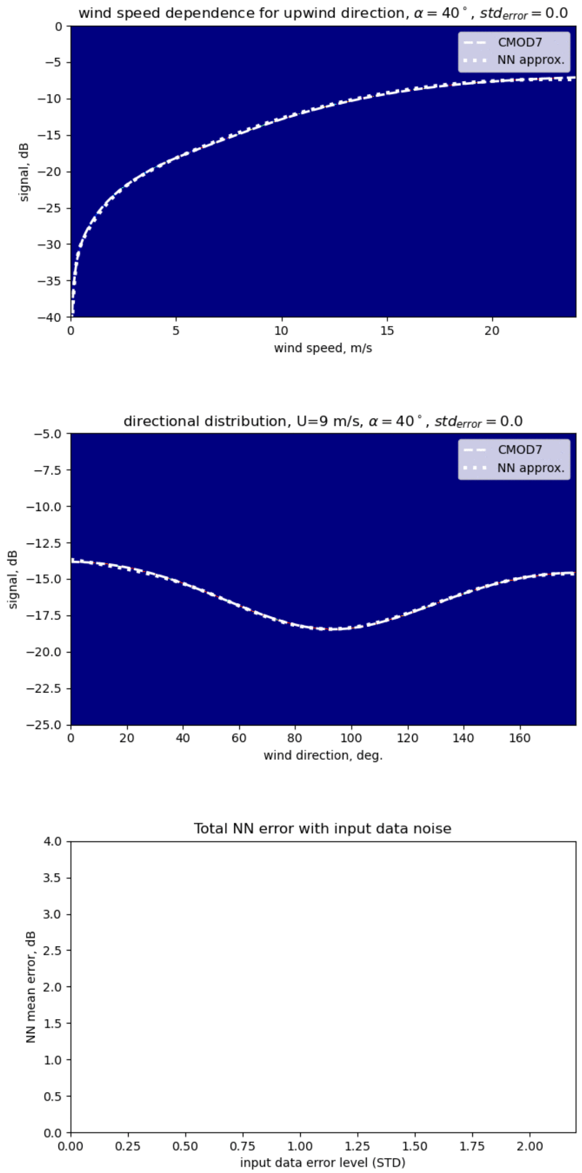
Effect of noise and model uncertainties on neural model approximation

- The required quality of GMF cannot be achieved even with "infinite" learning dataset at some level of noise, errors or data uncertainties

- Noise in the data leads to increase of sigma0 in up/down and cross wind dynamics. This effect makes derived GMF less directional and privilege wind vector aligned or perpendicular to an antenna direction

- Noise level in training dataset can be reduced by using "traditional" GMF obtained with Fourier series limited expansion

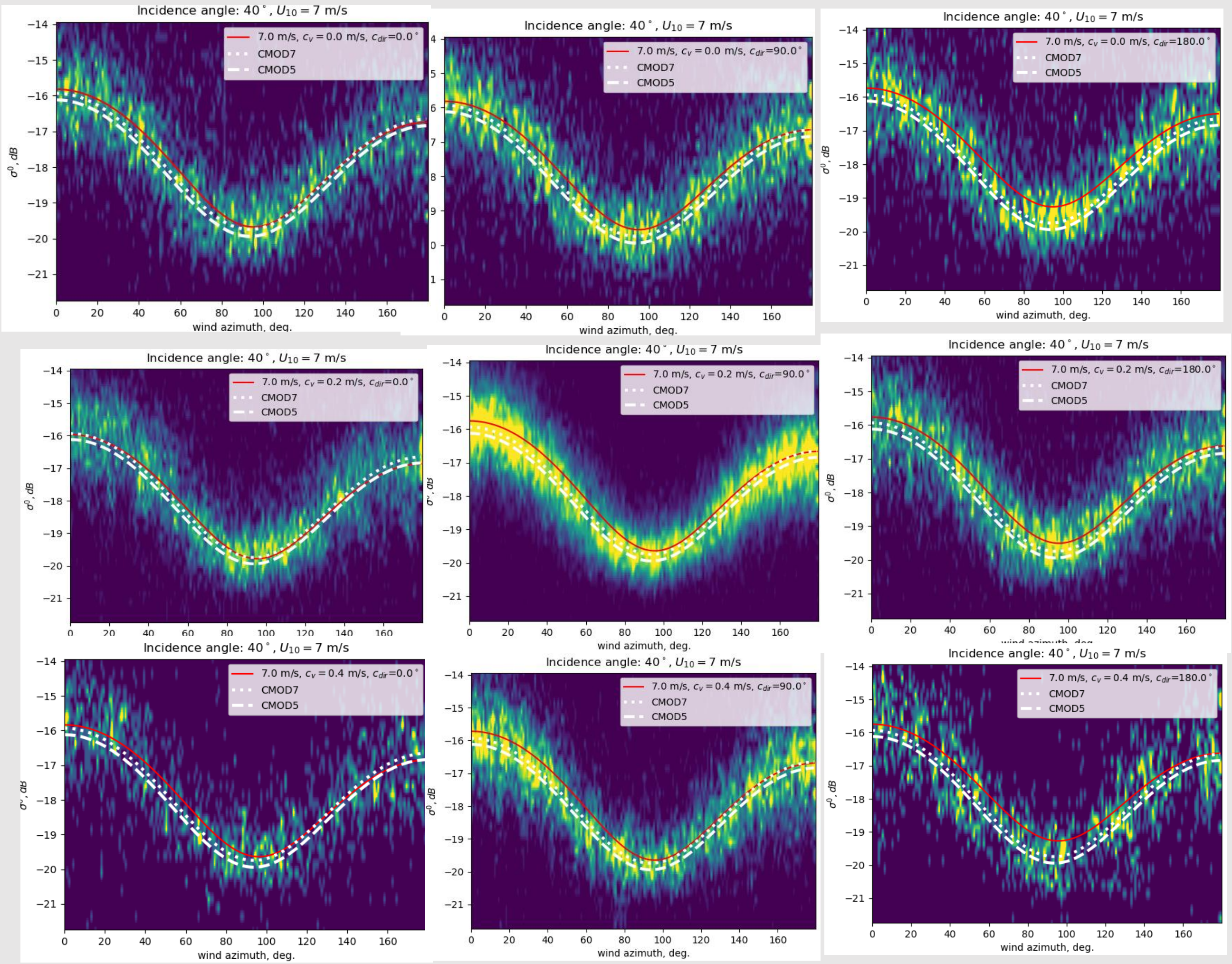
- Neural network attribute to strong sigma0 deviations more weight with respect to averaging techniques. This property allows to adjust approximation very quickly with a signal change. Bad for unstable signal, good for calibration purposes



Adding new variables: sea surface current vector

Involving using ASCAT reference dataset:

- New variables could be added to the backscattering model.
- Interpolated CMEMS sea surface total current vector was collocated with ASCAT data.
- The training dataset was significantly extended to describe rare geophysical situations (i.e. strong current directional distribution)
- Some gaps in the data could be completed with interpolation and extrapolation
- This analysis is fully compatible with CFOSAT data

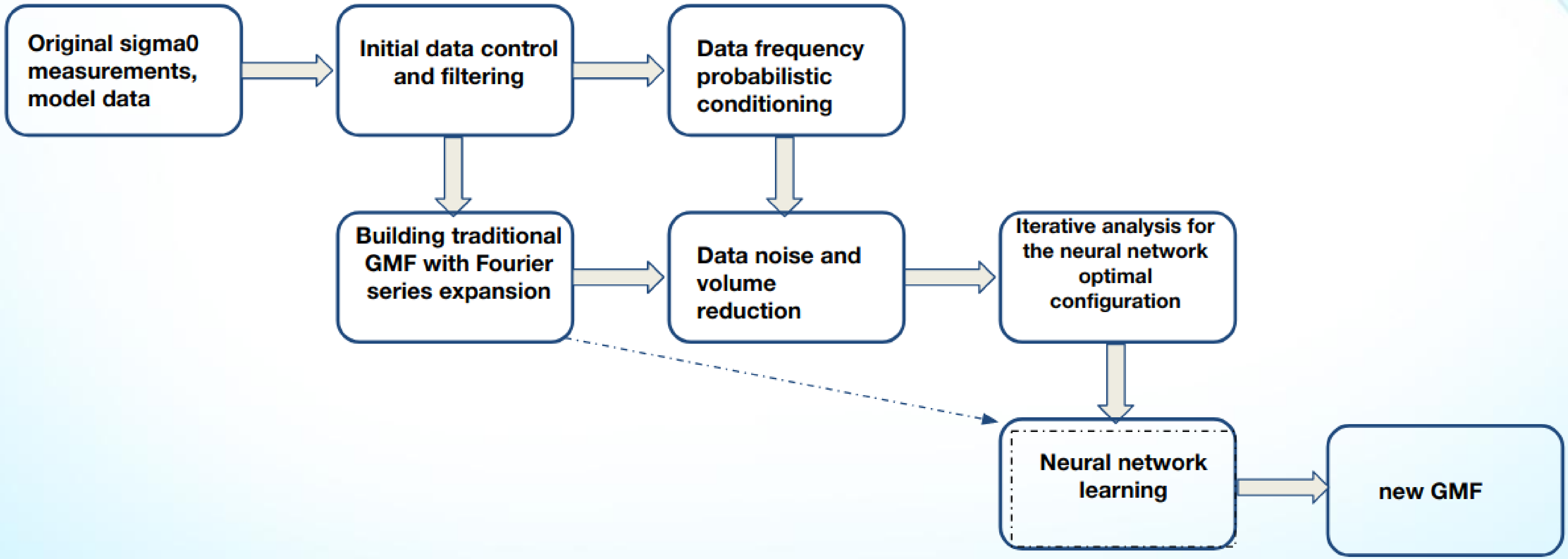


surface current speed ~ 0 m/s

surface current speed ~ 0.2 m/s

surface current speed ~ 0.4 m/s

Final processing workflow

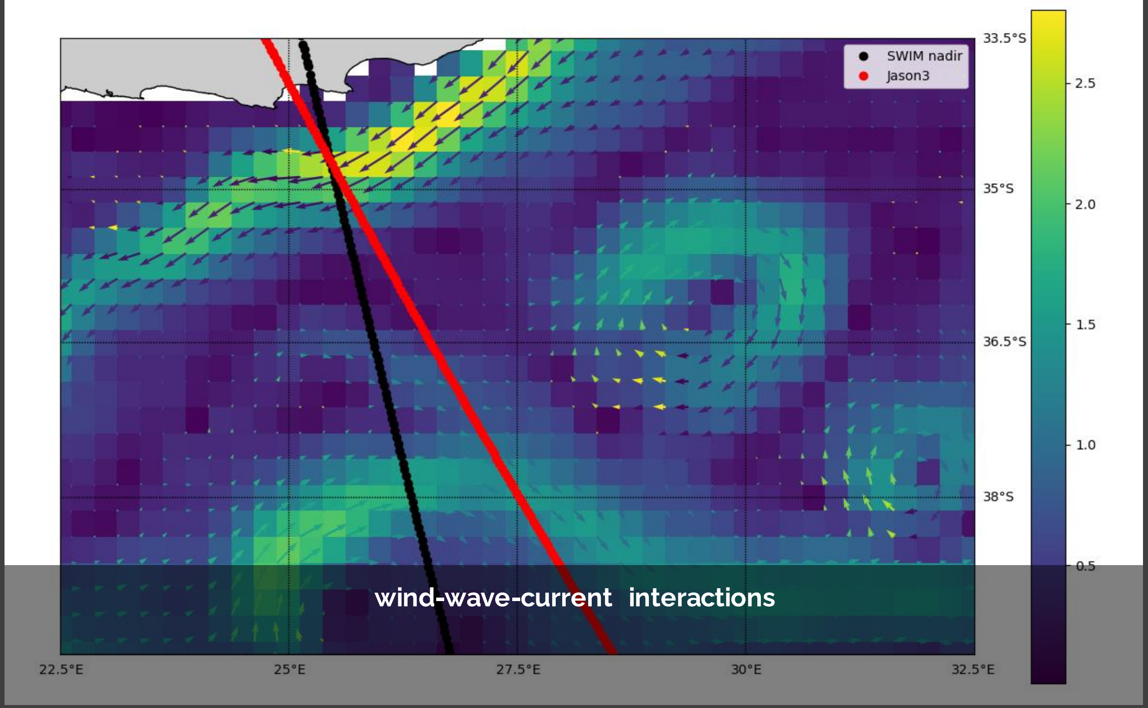


Problems to resolve, future works

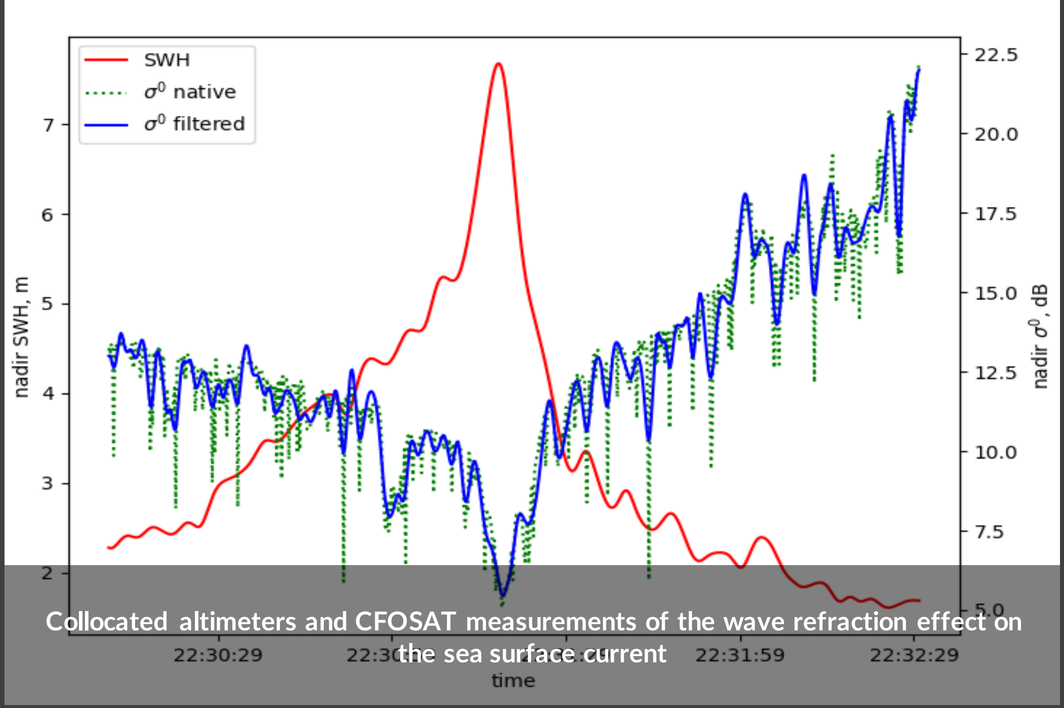
- ML methods requires stable and well calibrated data
- We need long observational series for large set of input parameters
- The method is very sensitive to the presence of noise of any kind
- All instruments should be calibrated in a common reference framework
- Need of physical driven approach for data interpolation and extrapolation to complete training datasets

SCAT/SWIM geophysical applications, multi-source collocation studies

SCAT/SWIM geophysical applications, multi-source collocation studies



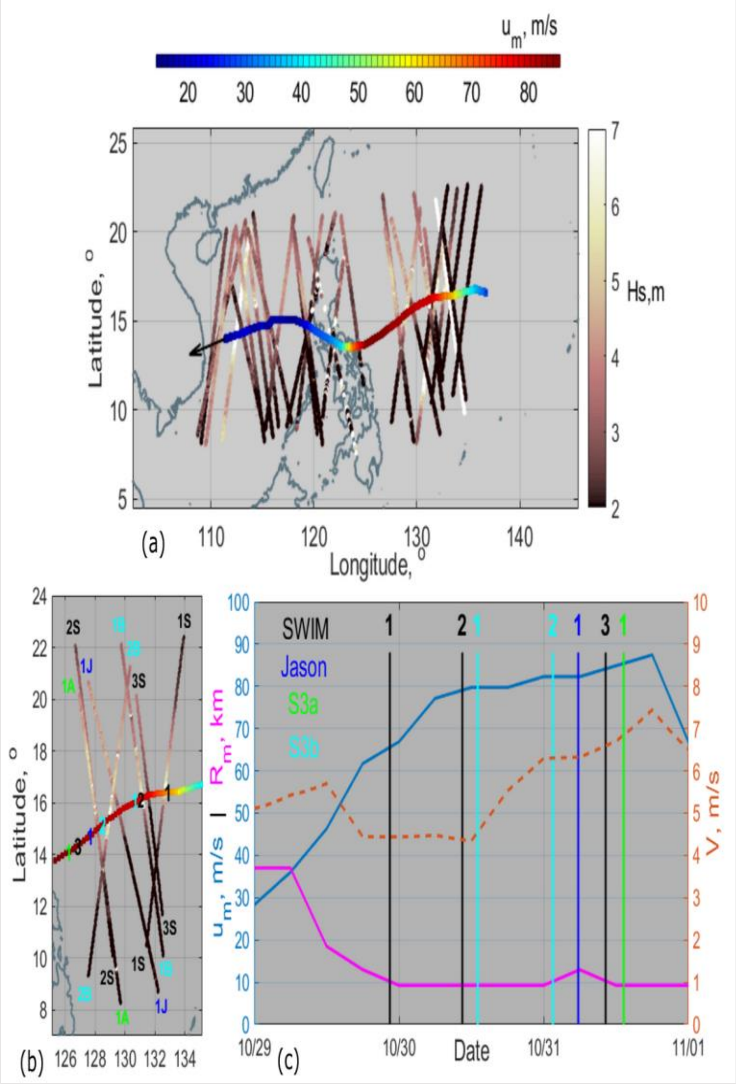
wind-wave-current interactions

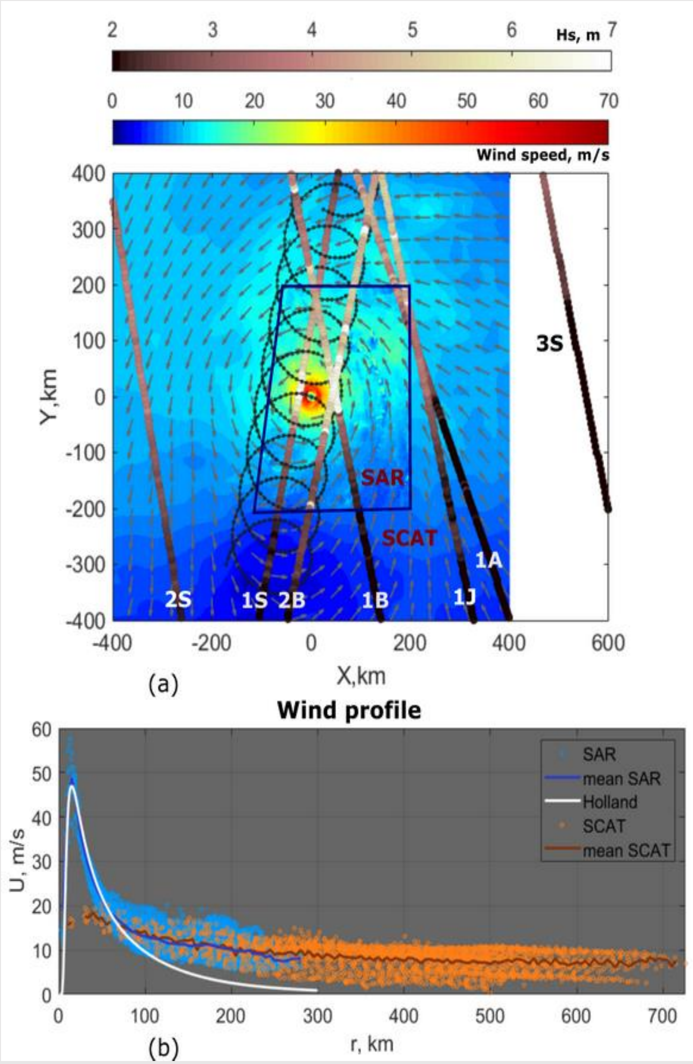


Collocated altimeters and CFOSAT measurements of the wave refraction effect on the sea surface current

SCAT/SWIM geophysical applications, multi-source collocation studies

Tropical cyclone wind and wave observations and modeling





Demonstration case: Goni tropical cyclone.
Example of study of tropical cyclone event using joint use of satellite collocations and numerical modelling

Paper: *Surface Wave Developments under Tropical Cyclone Goni (2020): Multi-satellite Observations and Parametric Model Comparisons. M. Yurovskaya, V. Kudryavtsev, A. Mironov, A. Mouche, F. Collard, B. Chapron // (submitted to Remote Sensing Journal)*

Summary

- CFSOAT is the promising mission which provides unique dataset of collocated dual-instruments radar measurements in Ku-band
- However, additional calibration/reprocessing work need to be done to ensure the quality of a resulting dataset.
- Multiple existing algorithms could be extended to improve wind vector and geophysical parameters retrieval using CFOSAT observations.
- Straightforward methodology could be proposed to build complex multi-parameter or dynamic GMFs for multi-instrumental and synergy analysis and geophysical variable retrieval
- In present work we propose the approach to define precise requirements for a measurement data and background numerical model data quality
- ML approach allows to include any number of additional variables to the model: sea surface currents, SST, sea wave spectrum, ascending/descending satellite passes, rain, ice, etc.
- Collocated radar measurements together with other space remote sensing missions and modeling allows to perform the multivariable analysis of complex geophysical events with high spatial and time dynamics.