OSTST Meeting
October 30- November 4, 2022

The cross-analysis of dual-instrument CFOSAT measurements: Towards multiparameter all-angle Ku-band Geophysical Modulation Function

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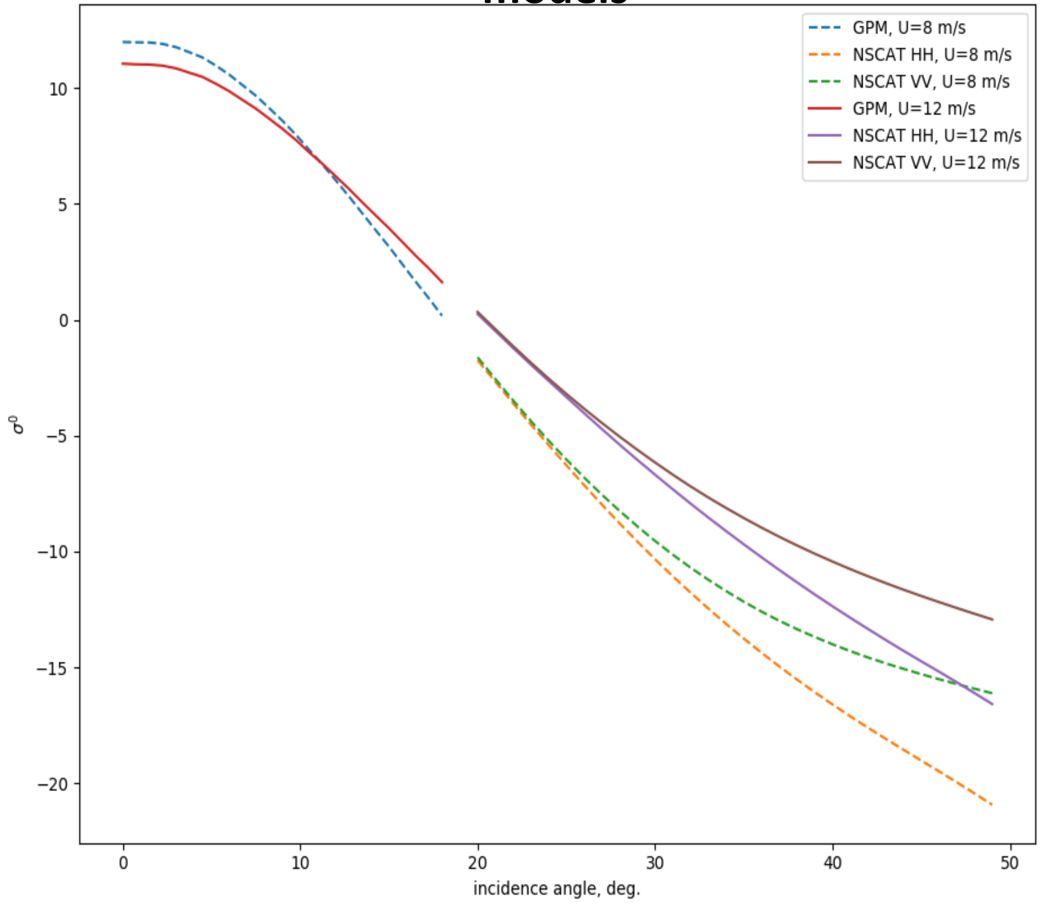
Motivation for the joint use of moderate angle and near-nadir radar observations

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 …

The combined use of collocated multi-angle radar observations potentially allows to improve the quality of retrieved geophysical variables, as well, to extend the number of variable which is possible to estimate.

All-angle Ku-band GMF from NSCAT4 and GPM models



IFREMER Wind and Wave Operational Center products

- The **Ifremer Wind and Wave Operation Center** (IWWOC) is the downstream French CFOSAT processing center, co-funded 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)

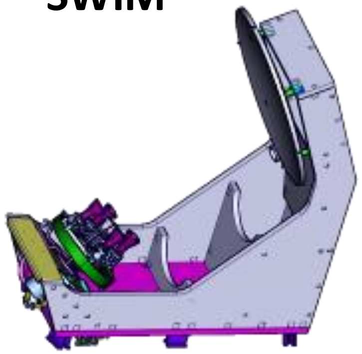
The first IWWOC products were **released to public early 2022**, through **ODATIS** (French federated access to national ocean data) / **CERSAT** portal :
- https://www.odatis-ocean.fr
- https://cersat.ifremer.fr/Data/Catalogue#/search?from=1&to=30

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

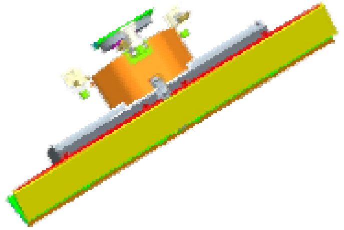
- FTP: ftp://ftp.ifremer.fr/ifremer/cersat/projects/iwwoc/swisca_l2s___/

SWIM and SCAT collocated products

SWIM



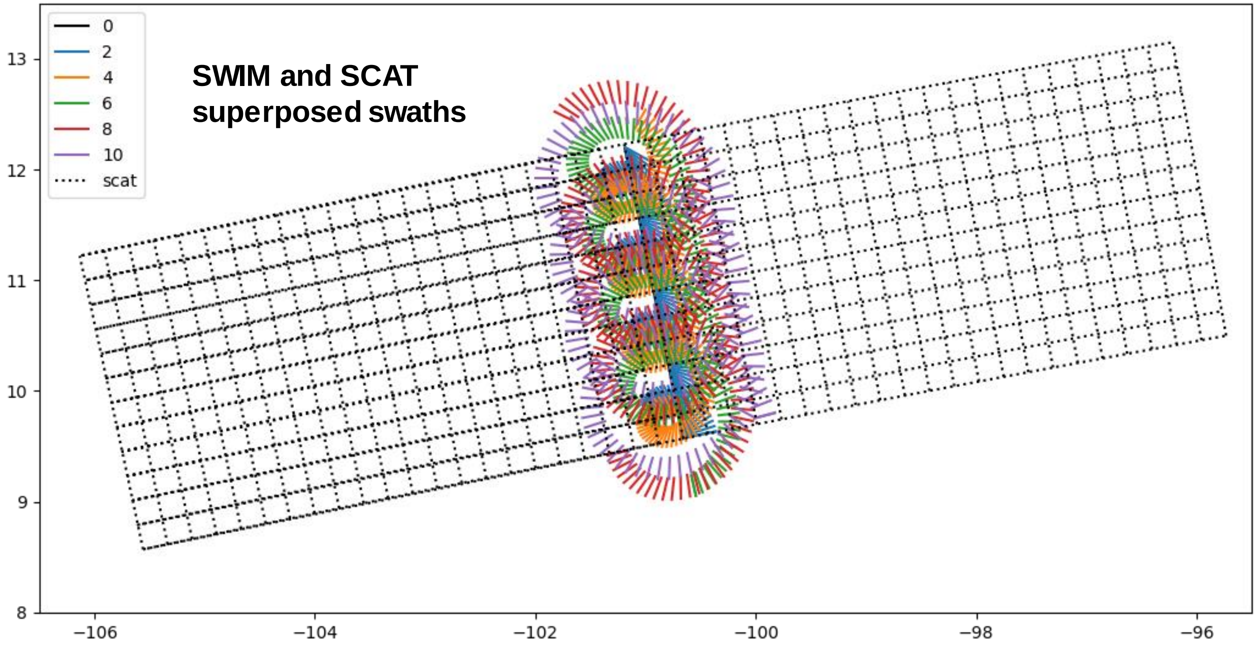
SCAT



IWWOC is working on two CFOSAT SWIM/SCAT combined L2 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



1st step:
Signal calibration.
Putting CFOSAT data into the common framework

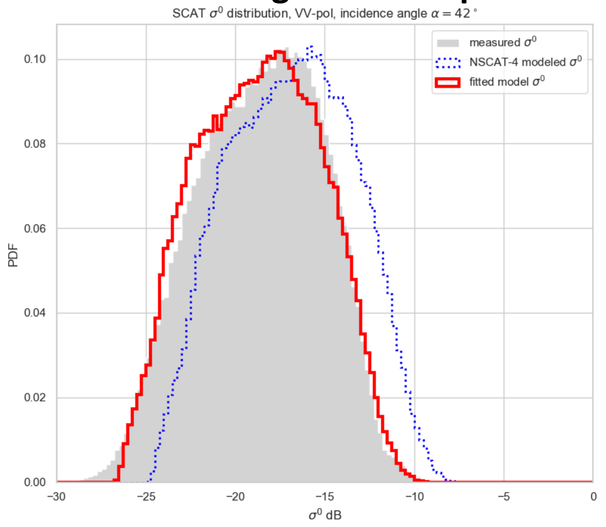
SWISCA L2S SWIM and SCAT signal inter calibration. Calibration approach

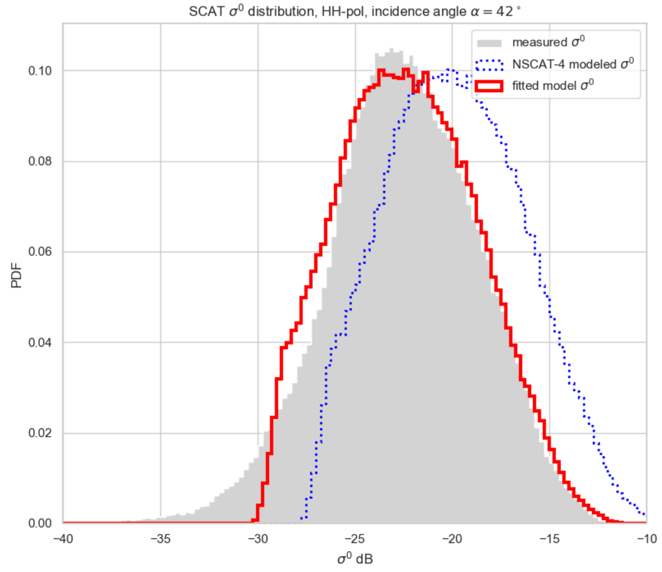
To use jointly different instruments the signal from all sources should be put to the common reference system. In this work we used NSCAT4 and GPM Geophysical Modulation Functions (GMF).

The calibration procedure is based on histogram matching:

- 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 instrument, incidence angle, azimuth and polarization.

SCAT signal/GMF simulated histograms example





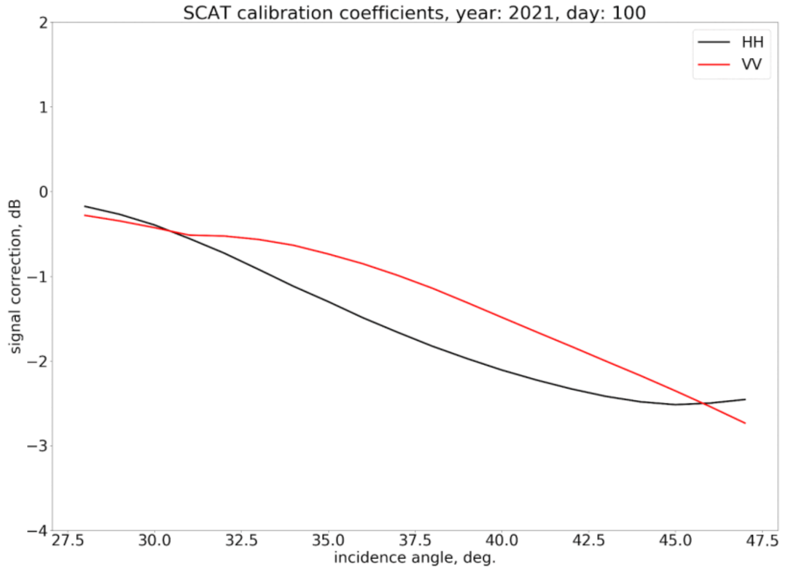
Calibration results: daily calibration coefficients for all incidence angles, polarizations and antenna azimuths

- Histogram matching calibration approach allows creating daily azimuthal calibrations for both CFOSAT instruments.

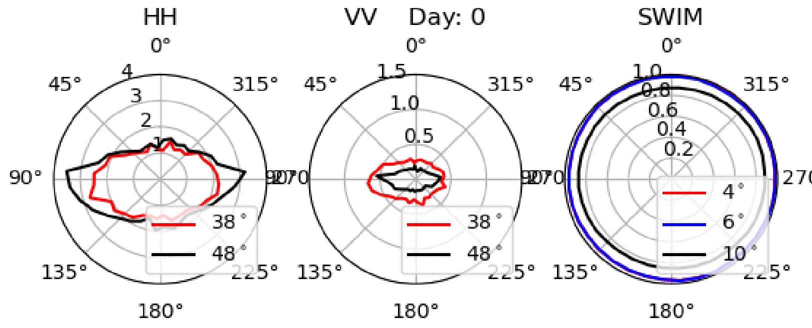
- SCAT calibration for both polarizations has the constant part, related to initial antenna-instrumental configuration. The additional fluctuating component could be attributed to satellite positioning and exploitation processes.

- The historical calibration coefficients applied to all IWWOC L2S products.

SCAT calibration for HH and VV polarization



Azimuthal CFOSAT calibration coefficients for the year 2021



Deriving CFOSAT Geophysical Modulation Function

Signal properties and standard GMFs (example of SCAT)

The calibrated CFOSAT dataset could be used to derive new GMF using similar methods as for NSCAT and GPM models. This is verification step.

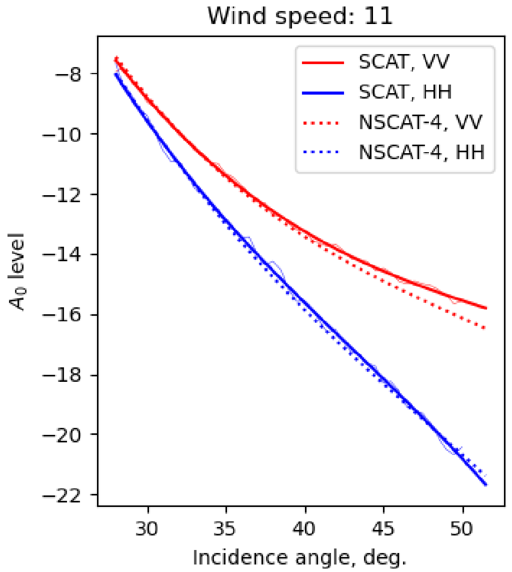
The GMF is estimated in the form of trancated Fourier serie:

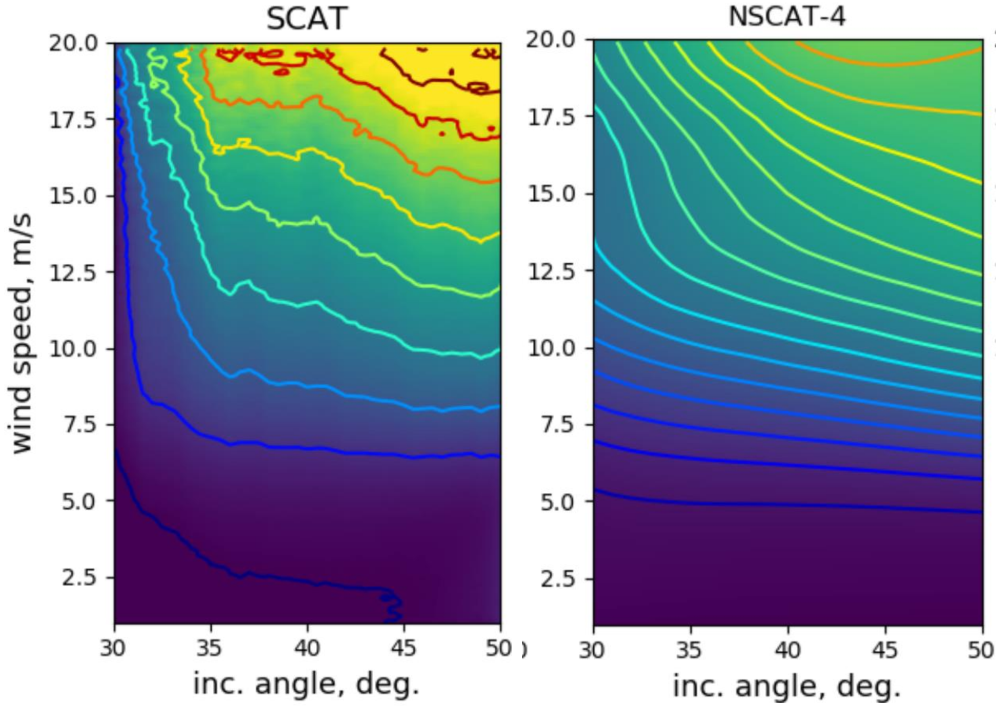
$$\sigma \approx A_0 + A_1 \cos\varphi + A_2 \cos 2\varphi$$

The first coefficient A0 determines the general level and structure of GMF and could be expressed using up-, down-, and cross-wind sigma0 observations:

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

The main NSCAT-4 GMF features were reproduced from SCAT observations. However, specific instrumental signatures (swath distortion, noise level) are different.





Wind vector inversion using multi-angle GMF for SWIM and SCAT

Wind vector inversion using standard Maximum Likelihood approach

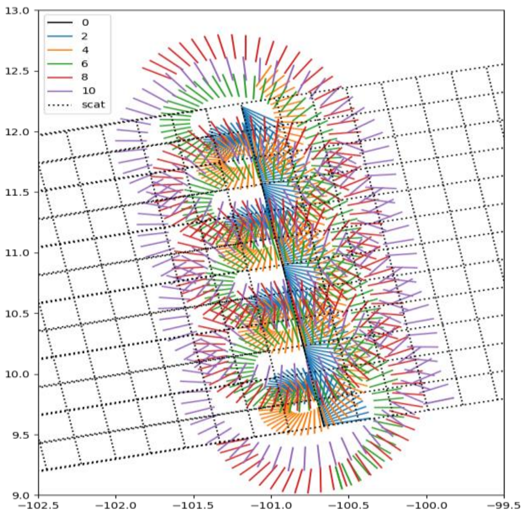
Wind vector could be estimated from multiple sigma0 measurements using the **Maximum Likelihood Estimator** (MLE) approach.
Accordingly, CFOSAT dual-instrument measurements MLE writes:

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

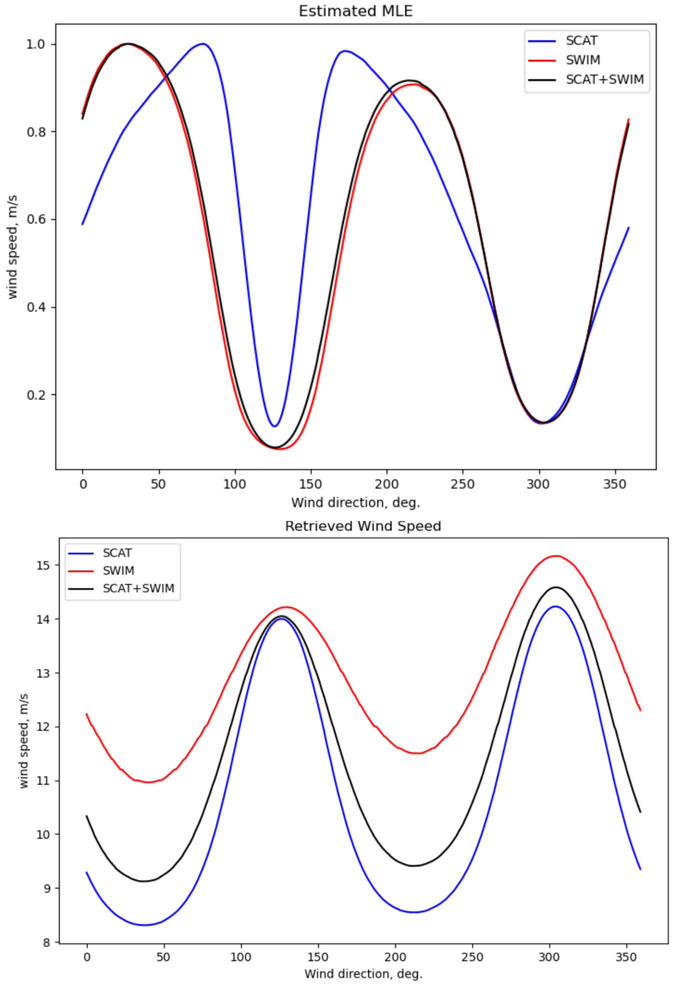
Near-nadir and moderate incidence angle radar observations have the opposite reaction on wind speed change.
As well, the different acquisition resolutions for SWIM and SCAT have different azimuthal sensitivity properties for different instruments.

Only very careful calibration of all data sources allows the joint use of both instruments for wind vector inversion!

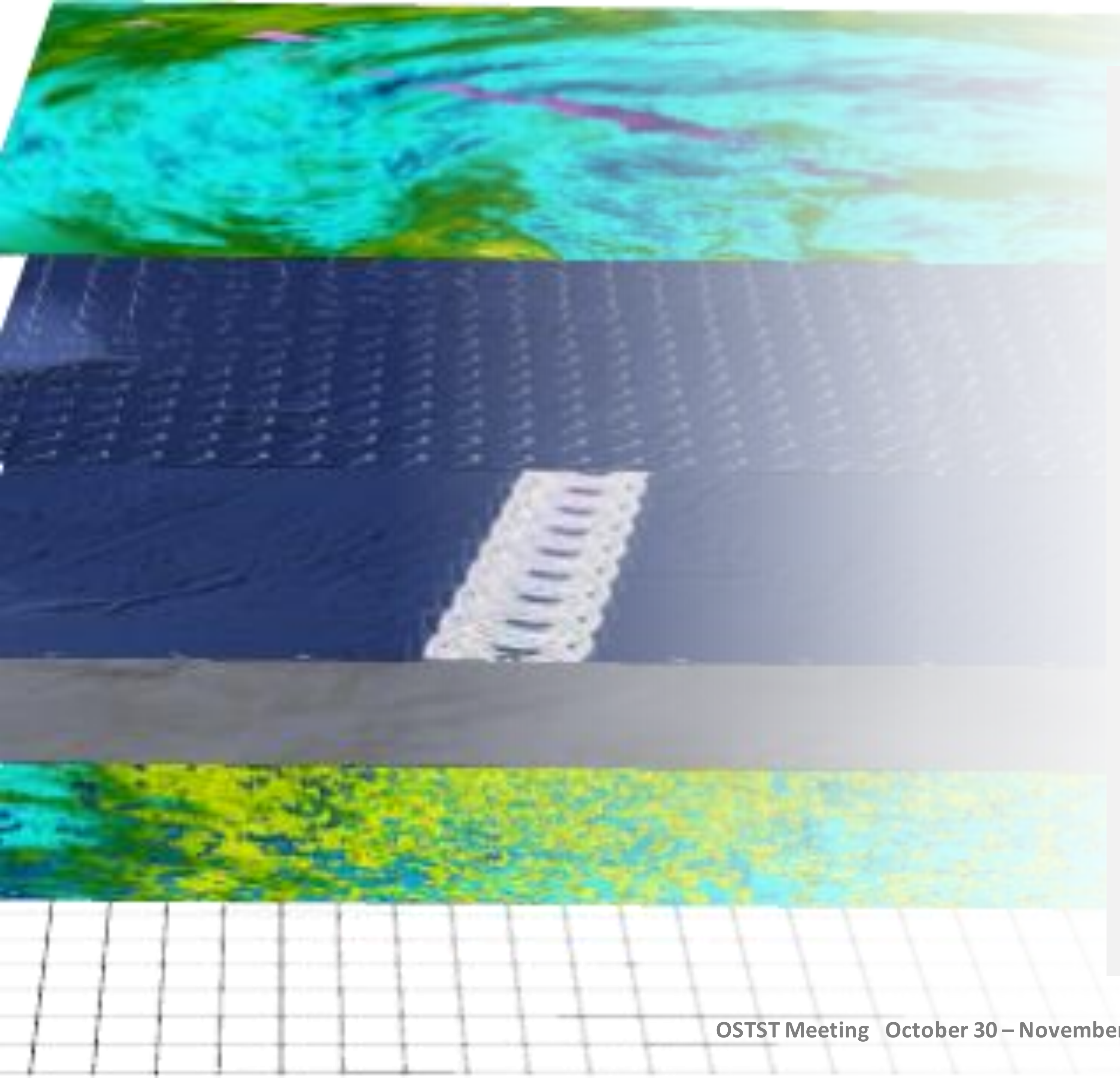
SWIM and SCAT observation patterns collocation. Central Part



Example of wind vector inversion for the nadir CFOSAT cell. 8 sigma0 from SCAT and 36 sigma0 from SWIM



Adding more variables to 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

Long CFOSAT observation series are suitable 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>

Adding new variables: sea surface current vector

Test cases using ASCAT reference dataset:

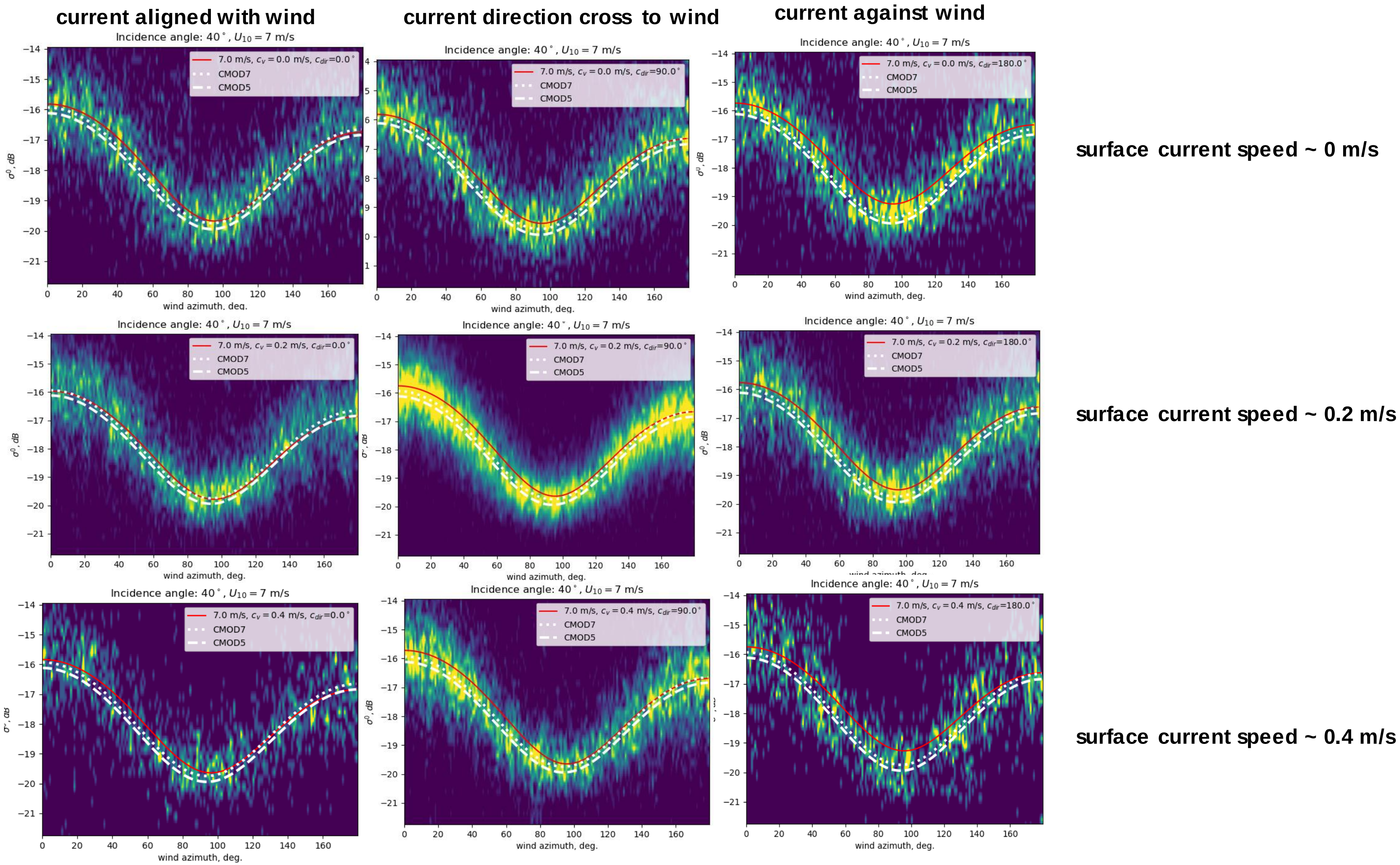
- New variables could be added to the backscattering model.

- 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

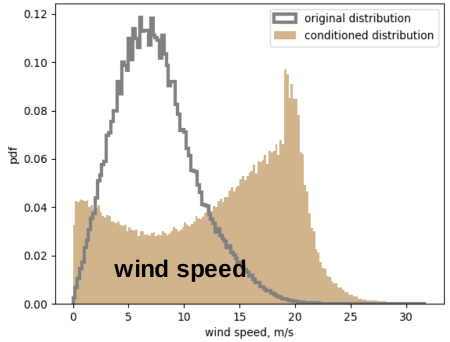


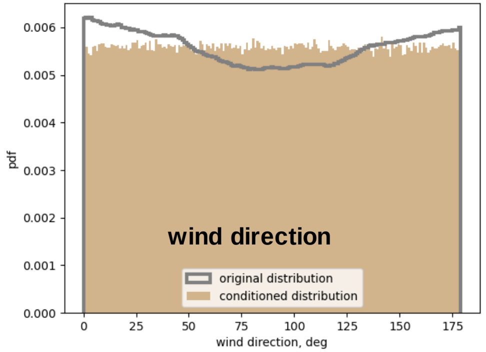
Building neural network: input data quality analysis, uniformization and normalization of observation dataset

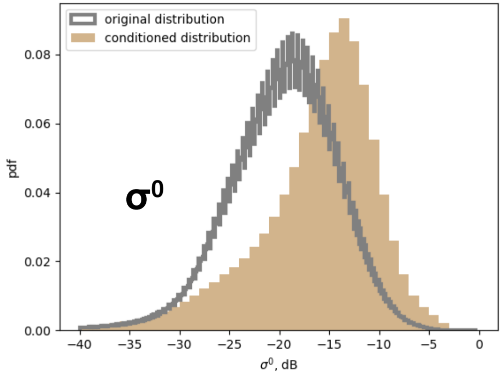
Geophysical variables are distributed unevenly. This means that we will most likely learn values that belong to a narrow interval.

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





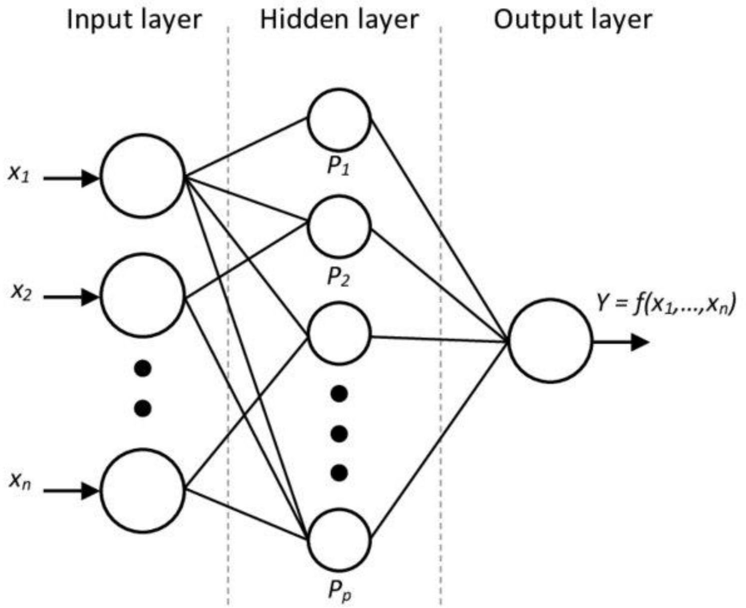


Selecting an optimal neural network configuration and learning parameters

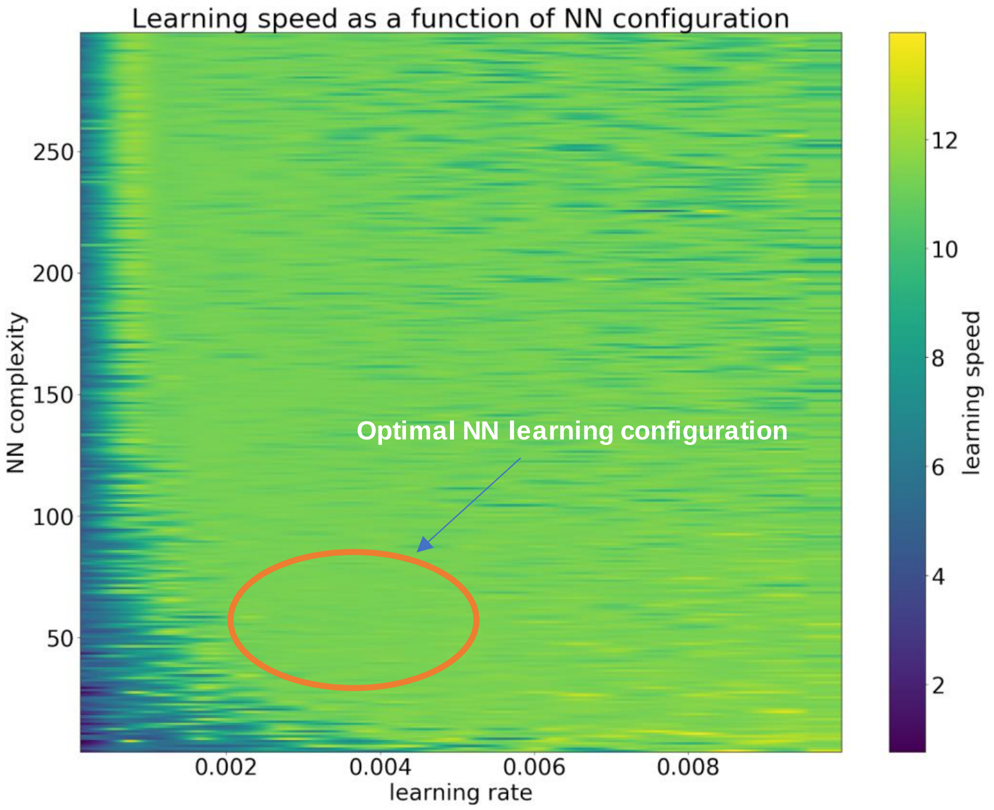
Iterative approach for optimal neural network configuration.

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

Generalized NN configuration



NN performance map



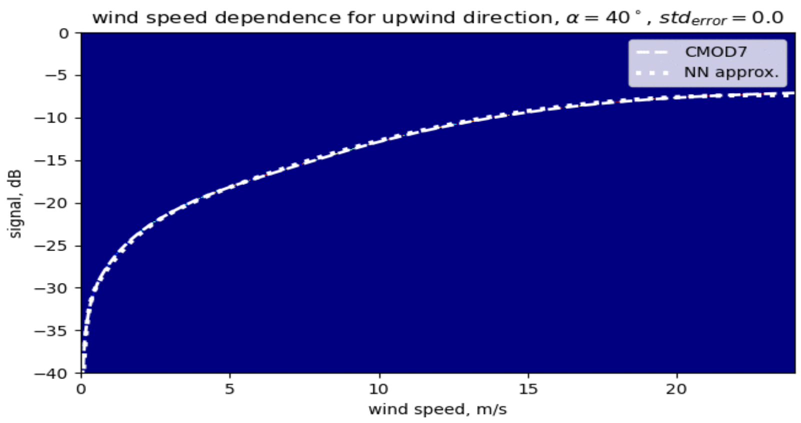
Effect of noise and model uncertainties on neural model approximation

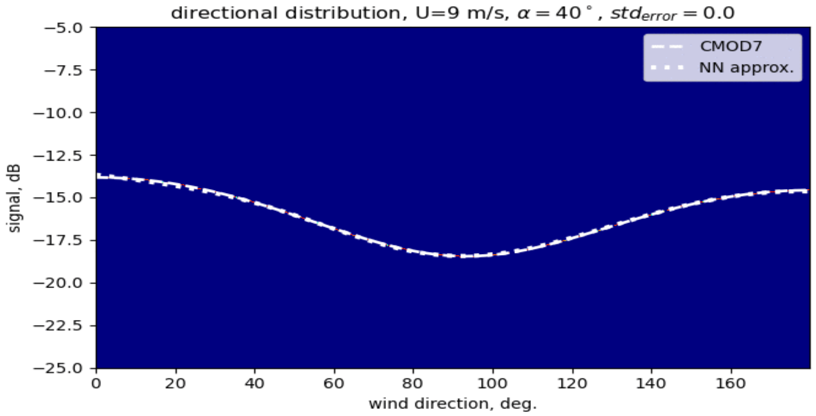
- The required quality of GMF cannot be achieved even with “infinite” learning dataset at some level of noise, errors or data uncertainties

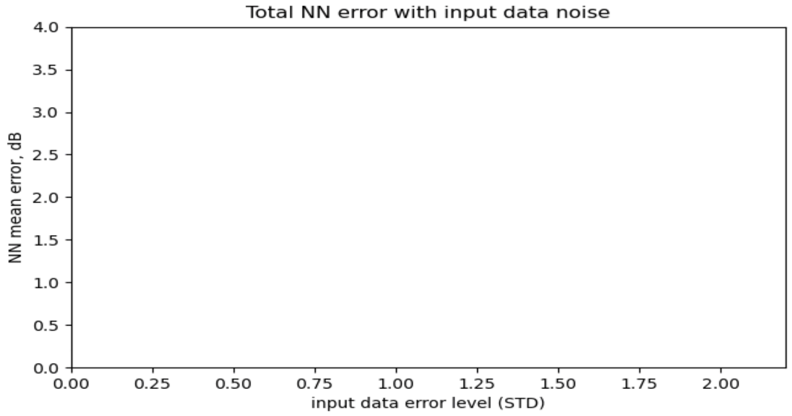
- Noise in the data leads to increase of sigma0 in up/down and cross wind dynamics. This effect makes derived GMF less directional and privilege wind vector aligned or perpendicular to an antenna direction

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

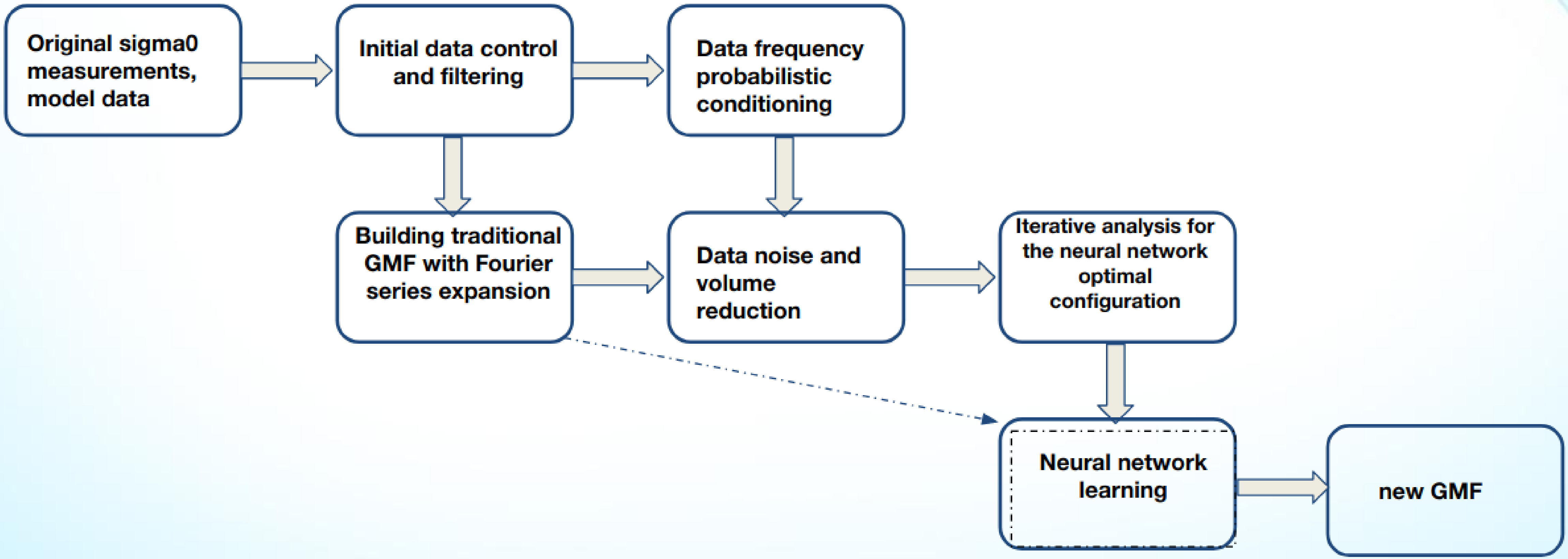
- Neural network attribute to strong sigma0 deviations more weight with respect to averaging techniques. This property allows to adjust approximation very quickly with a signal change. Bad for unstable signal, good for calibration purposes







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.

- Need of physical driven approach for data interpolation and extrapolation to complete training datasets

Summary

- CFSOAT is the promising mission which provides unique dataset of collocated dual-instruments radar measurements in Ku-band
- Nadir, near-nadir, and moderate incidence angle radar observations are very complementary to each other. Potentially this is the way to new high-quality, high-resolution geophysical remote sensing observations.
- Precise calibration/reprocessing work for all data sources need to be done to ensure the quality of geophysical retrieval.
- Straightforward methodology is proposed to build complex multi-parameter GMFs for multi-instrumental geophysical variable retrieval
- ML approach allows to include more additional variables to the model: sea surface currents, SST, sea wave spectrum, ascending/descending satellite passes, rain, ice, etc.