GNSS reflectometry for the retrieval of forest biomass

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Introduction

- This study aims at exploiting the **GNSS-R** sensitivity to the **forest biomass** and at assessing the **retrieval** with the data acquired by the TechDemoSat-1 (**TDS-1**) mission of Surrey Satellite Technology Ltd.
- The analysis has been carried out on **five test areas** worldwide, chosen as representative of forest types from boreal to equatorial.
- **The TDS sensitivity** to **forest biomass** has been evaluated by comparison with:
  - **Backscattering** in HH and HV pol. from **ALOS L-Band SAR**
  - **Woody Volume** generated from SAR data using an ANN algorithm developed at IFAC (Santi et al. 2017)
  - **AGB** improved pan-tropical map proposed by Avitabile et al. (2016).
  - Vegetation Optical Depth (**VOD**) derived from SMAP.
  - Tree height (***H***) estimated by the ICE-GLAS LiDAR mission.
- The results of the sensitivity analysis suggested exploiting the **TDS capabilities** in estimating the **forest biomass** by setting-up prototype retrieval algorithms **based on Artificial Neural Networks (ANN)**

The study was carried out in the framework of the "GNSS Overland" project funded by ESA

TEST AREAS

TEST AREA	LAT (min/max)	LON (min/max)	Forest Type
Brazil (Manaus)	-6/-2	-61.5/-58	(Flooded) equatorial forests
Uruguay (Algorta)	-32.8/-32	-57.8/-57	dense coniferous
Alaska (Fairbanks)	63/67.5	-152/-143	boreal open forests
Finland	65.5/69.5	20/30	boreal open forests
Argentina (Asuncion)	-26/-22	-63/-59	Shrubs/bushes/pampas

- Five test areas worldwide, chosen as representative of the most important forest types
- **TDS** data from July 2016 to July 2017
- ≃45 **ALOS** Images covering the same temporal period
- Extension and coordinates of each area to match the ALOS frame: 350 km x 350 km, according to the **ALOS Scansar** acquisition mode, except **Uruguay**, for which smaller **Stripmap** images (70 km x 70 km) were only available.

TDS data processing

- For each test area, all the TDS-1 data in a **+/- 15 days window from each ALOS acquisition** have been extracted.
- The **temporal window size** has been set as a **compromise** between the need of having **as more TDS data as possible** and of limiting the **temporal changes** in the observed surface conditions.
- The **slow dynamics of forest biomass**, especially in equatorial forests, helped in keeping these constraints.
- The following **GNSS-R parameters** have been considered:
  - **Reflectivity (dB)=10*log10(DDM_peak-Noise)+CF-10*log10(DSPR)**
  - **Reflectivity5x7 (dB)=10*log10(Received_power-35*Noise)**
  - **+CF-10*log10(DSPR)**
  - **SNR (dB)=10*log10(DDM_peak/Noise-1)**

DDM=Delay Doppler Map, **CF**: Calibration Factor, **DSPR**: Direct Signal powers resampled.

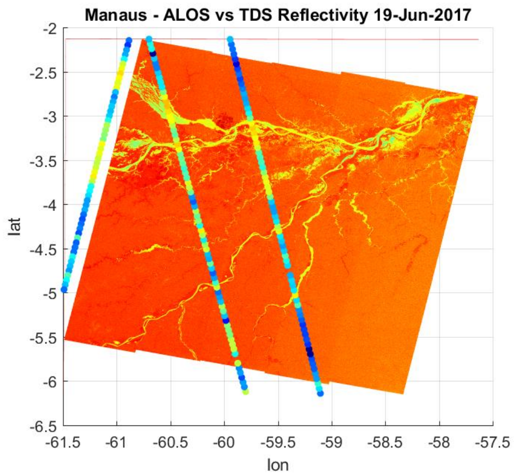
Understanding the sensitivity:

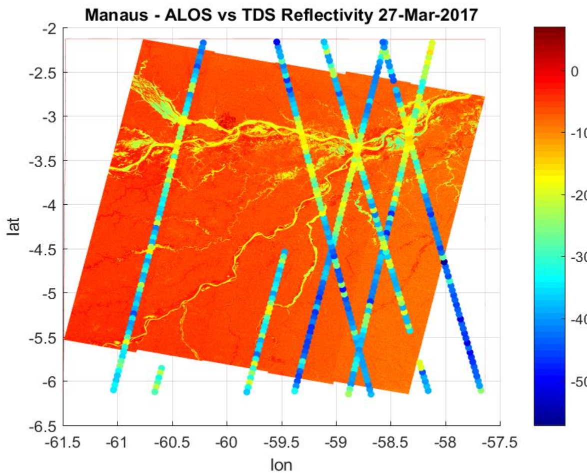
main outcomes of the sensitivity analysis on 5 test areas

boreal to equatorial forest

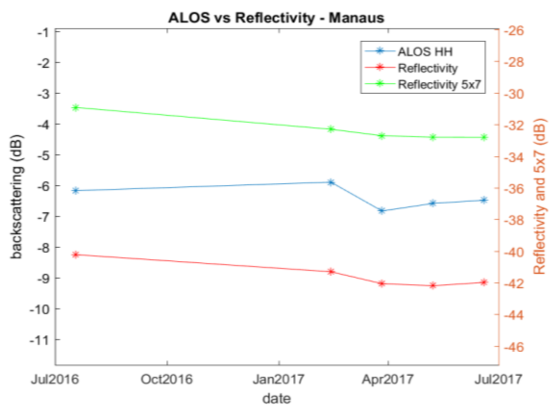
TDS vs. ALOS - Manaus

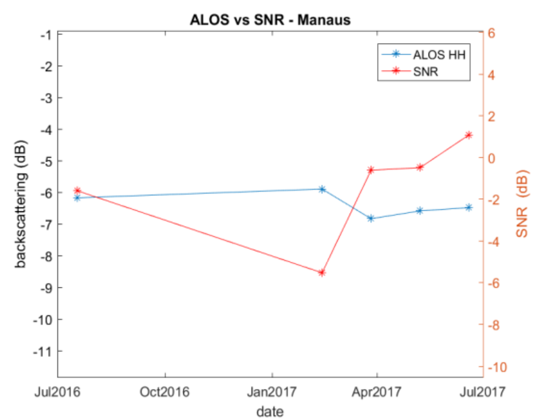
- ALOS shows very **high constant values** over forests (-6/-7 dB); low values over rivers and surrounding (flooded), Reflectivity has opposite behavior



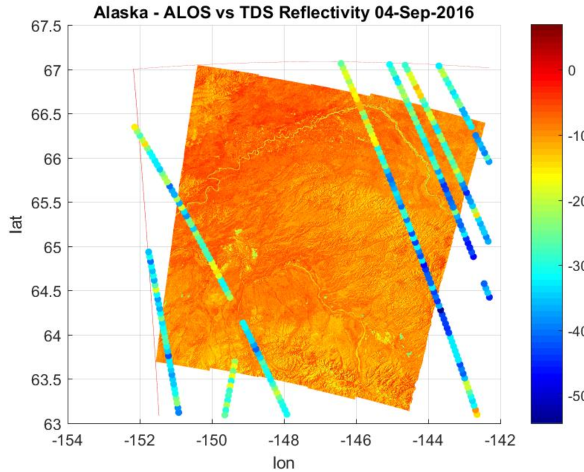


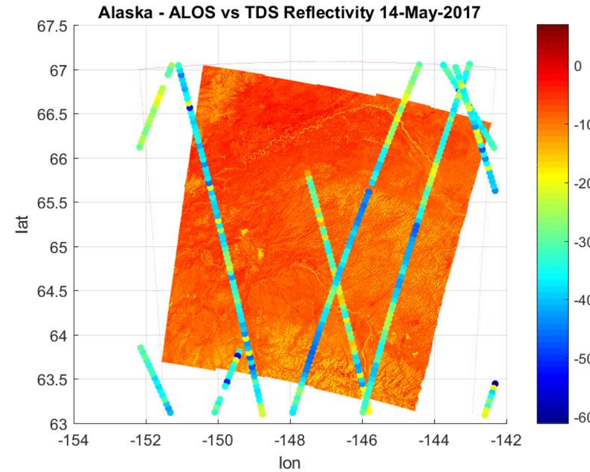
- Temporal trends on uniform areas of dense forest:
- ALOS and Reflectivity have similar trends, SNR is more fluctuating and showed an opposite trend that cannot be explained without ancillary information.

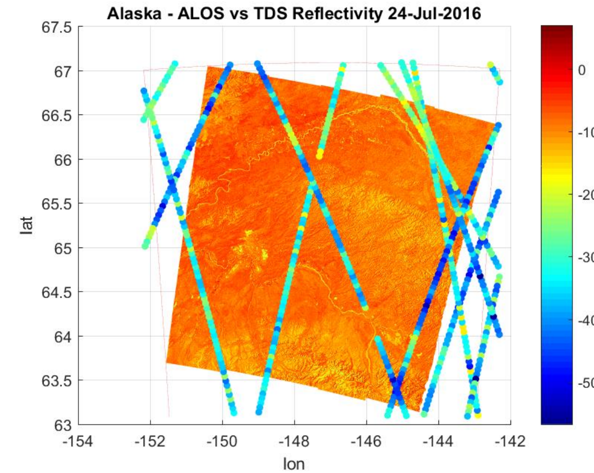




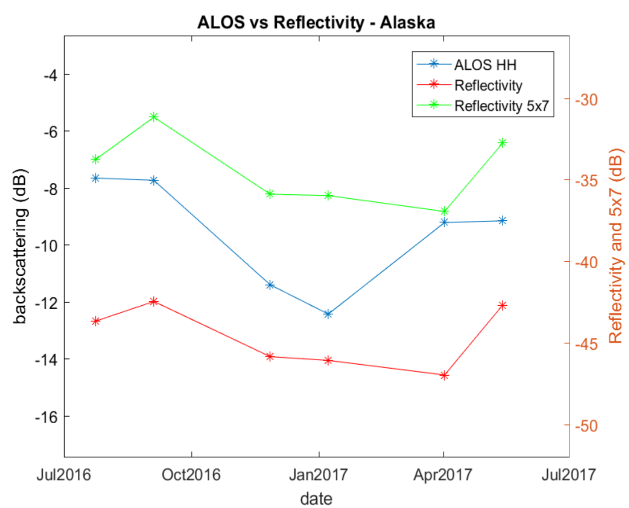
Alaska (Fairbanks) (boreal open forests)

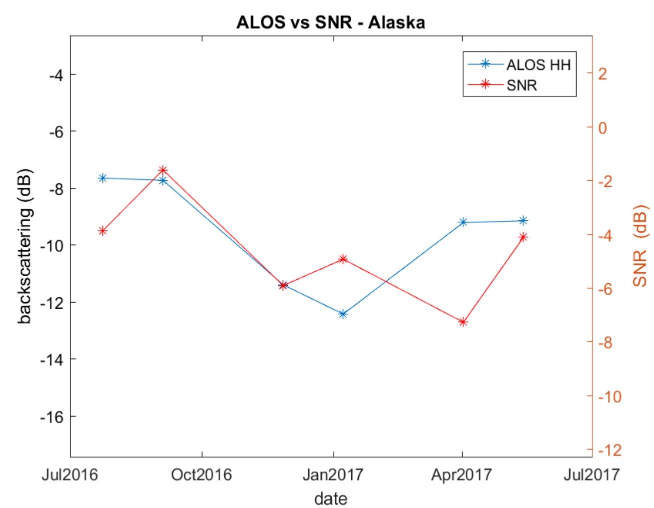






- ALOS σ^0 shows **a seasonal cycle** that is followed by both reflectivity and SNR (latter more fluctuating).
- Lower σ^0 and Refl. values in winter can be attributed to snow and/or frozen soil: this suggested excluding the data collected in winter from the further analysis.

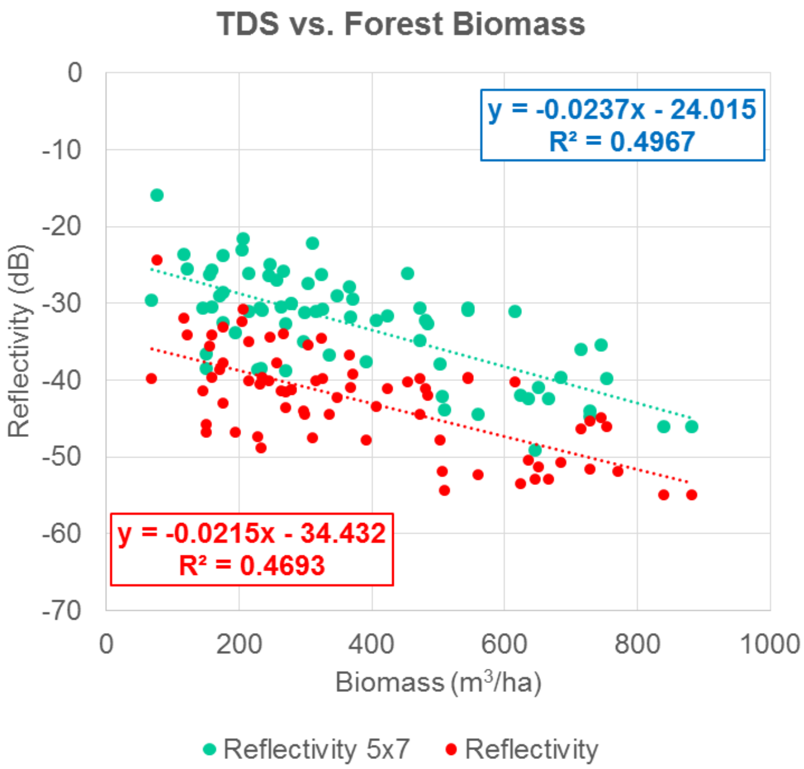




Reflectivity and SNR vs. Woody Volume

- **Reflectivity** vs. **Woody Volume (m^3/ha)** estimated from ALOS data (L-band) using the algorithm proposed by Santi et al. (2017)
- **sub-areas** of each test areas **have been identified**, in which **WV was almost uniform**,
- the spatial averages of **SNR Reflectivity** and **WV** have been computed on each sub area.

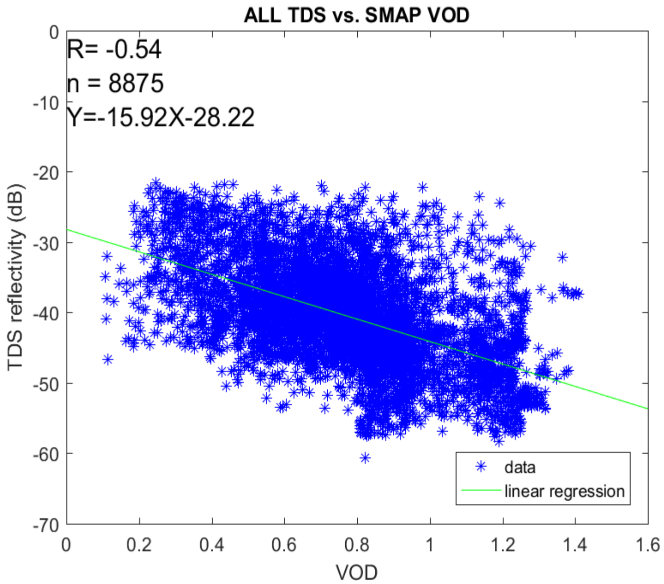
- **SNR** was instead almost **uncorrelated** to **WV**

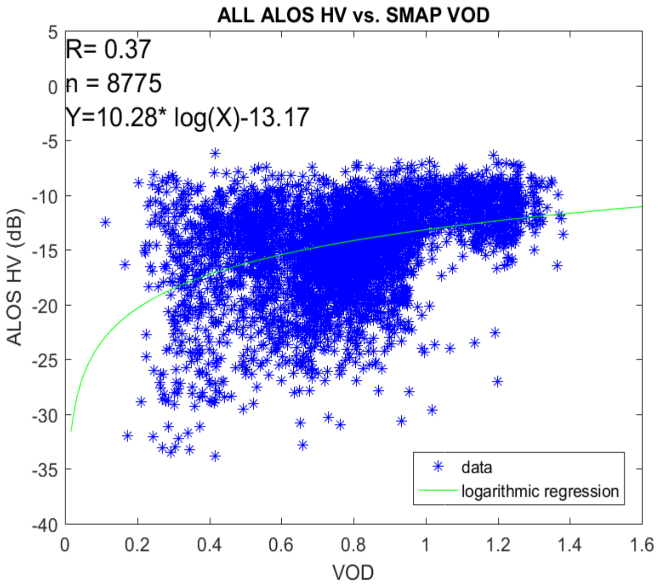


Reflectivity 5x7 → R=0.69
Reflectivity → R=0.67

Reflectivity vs. SMAP VOD

- TDS reflectivity vs. the vegetation opacity (VOD) at 36 km from the SMSMAP L2 (SPL2SMP) –"Option 3" product.
- As a reference, the corresponding (increasing) correlation between ALOS in both polarizations and VOD was lower, ranging from a R=0.2 in HH to R=0.37 in HV
- a clear saturation of ALOS is evident for higher VOD values.



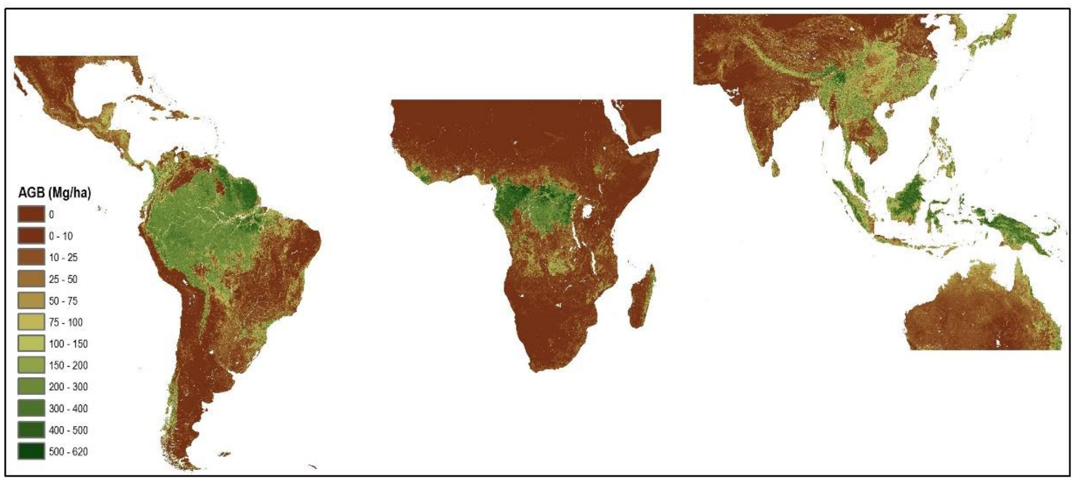


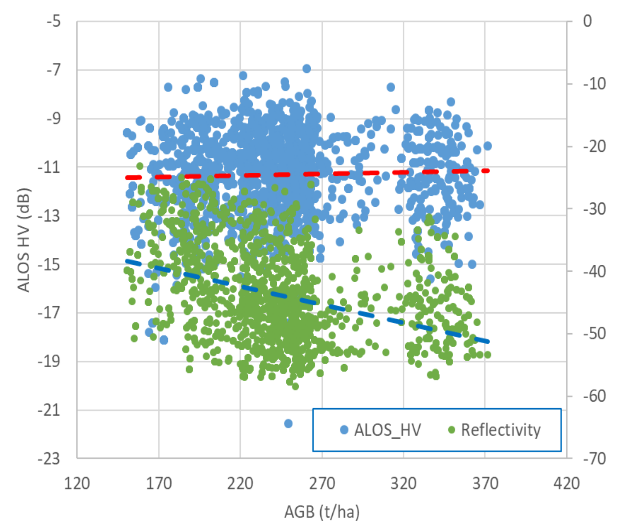
Reflectivity =-15.92 VOD- 28.22, R=-0.54

TDS Reflectivity vs. AGB

Comparison with the improved pan-tropical biomass map (AGB, in t/ha) proposed by Avitabile et al. (http://lucid.wur.nl/)

- The comparison was carried out for the **Argentina, Manaus and Uruguay** test areas, since the map by Avitabile is limited to latitudes <20°.
- Comparing TDS time series with a **single reference value** is challenging for low biomasses, since the seasonality of vegetation and soil moisture affects the signal. → **threshold AGB >100 t/ha**

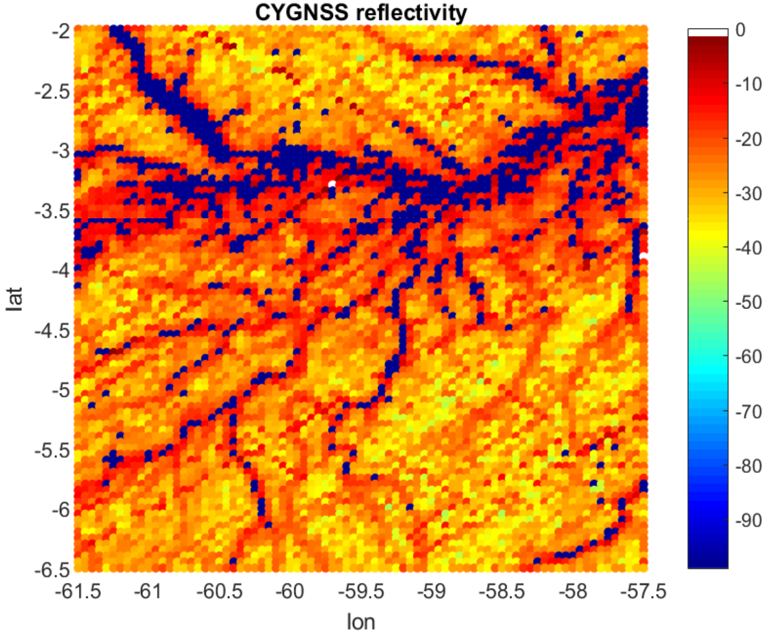


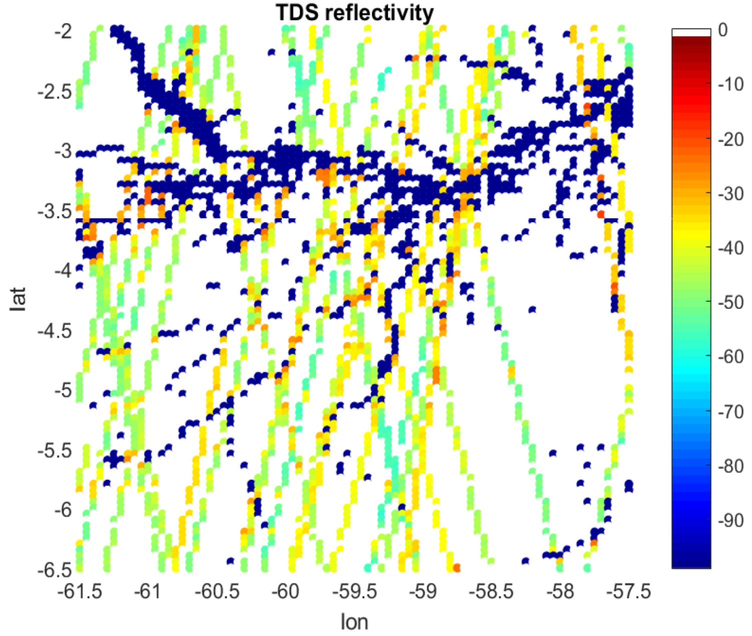


Reflectivity =-0.06*AGB-28.31, R=-0.43

Comparison TDS – CYGNSS on Manaus

- Comparison on common data: 2017 April to July + November
- Data resampled on a fixed 5 Km grid
- Differences in incidence angle
- Differences in reflectivity computation
- Large differences in coverage:

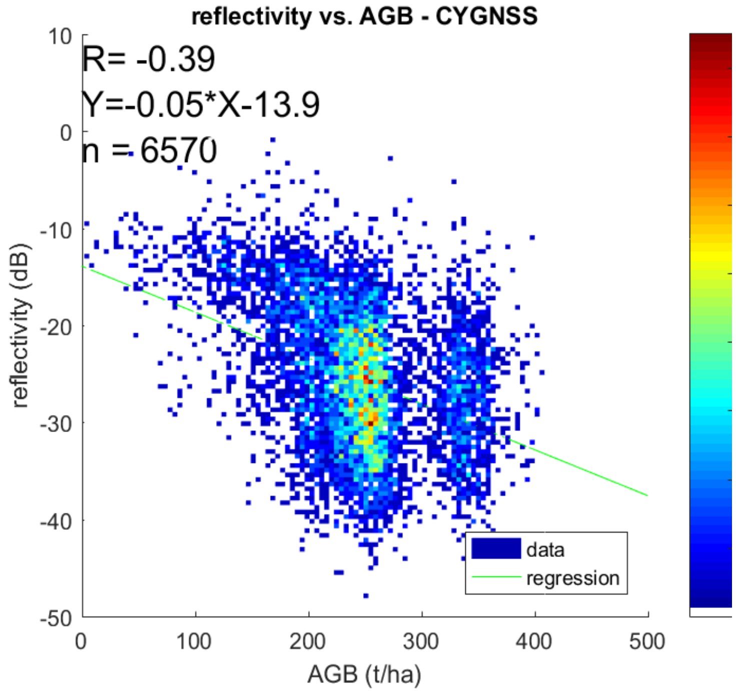


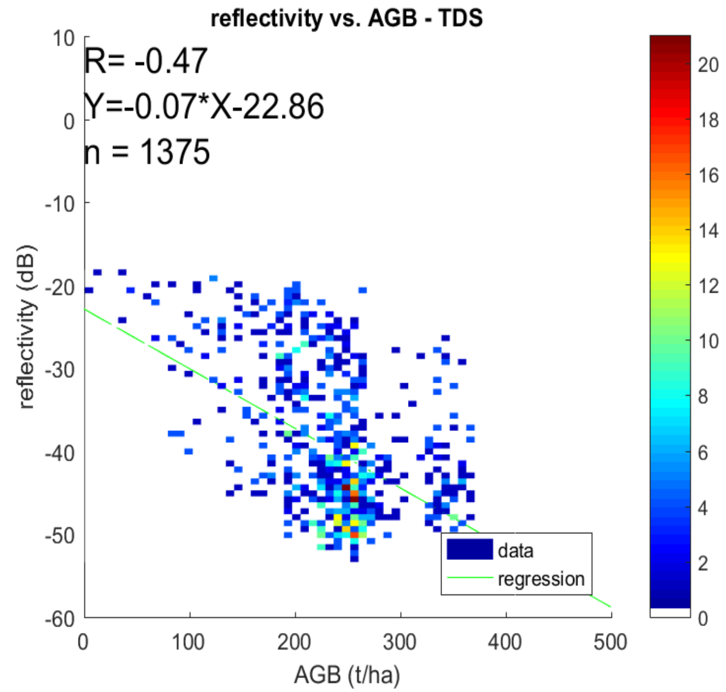


Comparison TDS – CYGNSS: Manaus

- Sensitivity on the entire dataset available for each sensor
- Similar results:

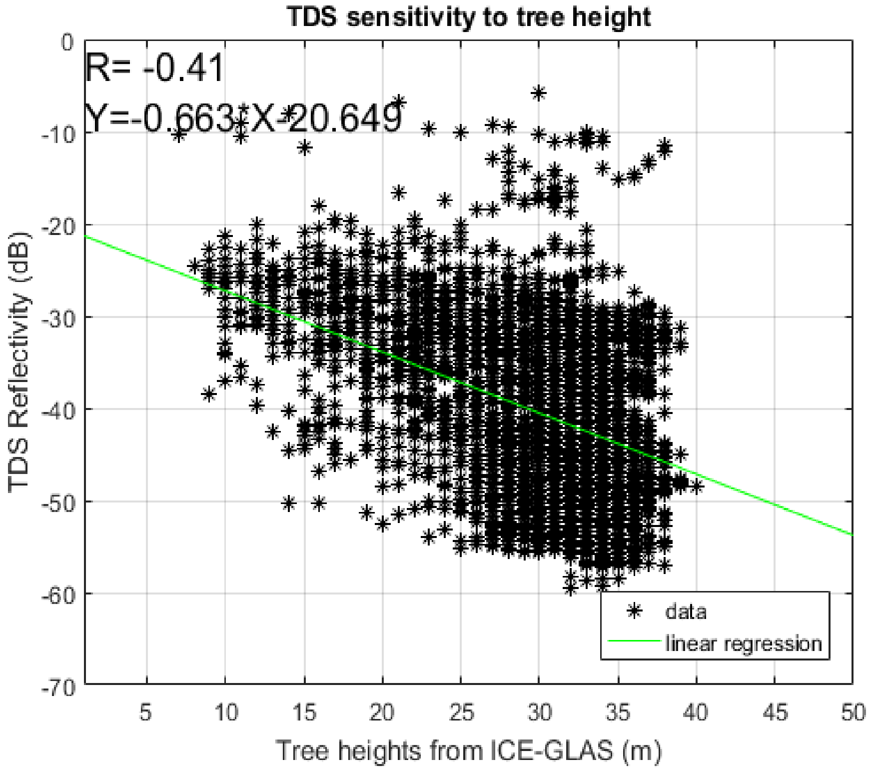
-0.39 < R < -0.47 -0.07 < slope < -0.05





TDS Reflectivity vs. ICE-GLAS

- Tree height estimated from TDS data using ANN
- Reference data derived from the ICE-GLAS LiDAR acquisitions
- **Manaus** area investigated, others in progress.



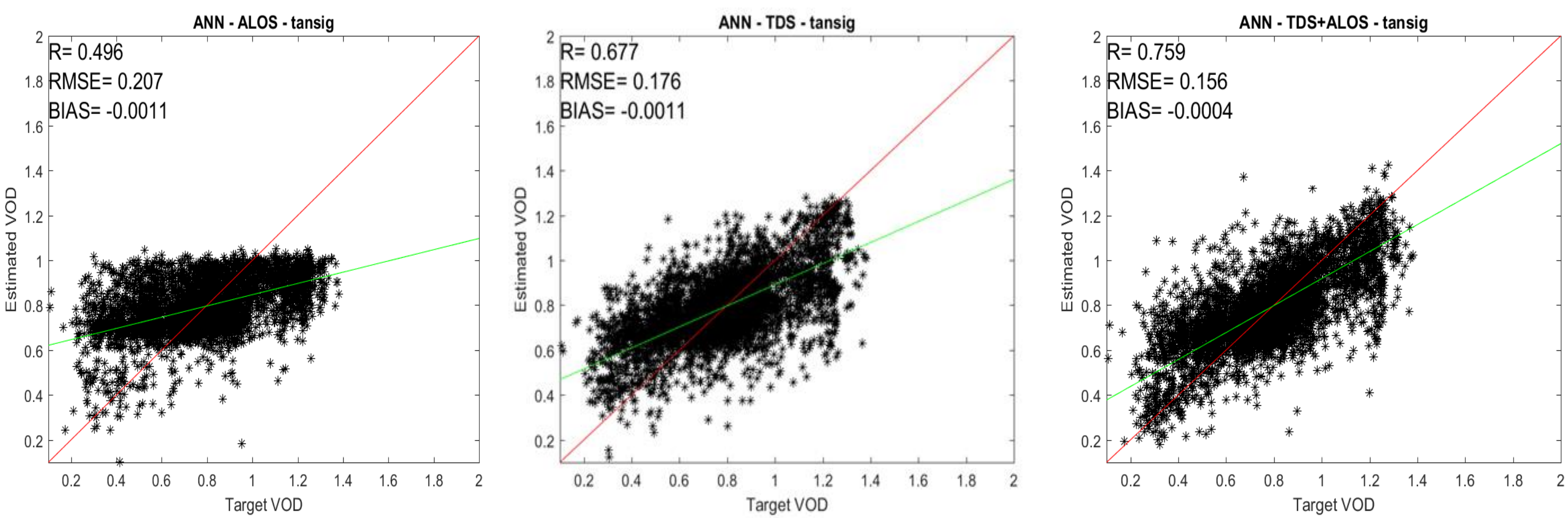
Reflectivity =-0.66*H-20.65, R=-0.41

Assessing the retrieval

investigation on the TDS capabilities in estimating forest biomass, carried out by setting-up prototype retrieval algorithms based on ANN

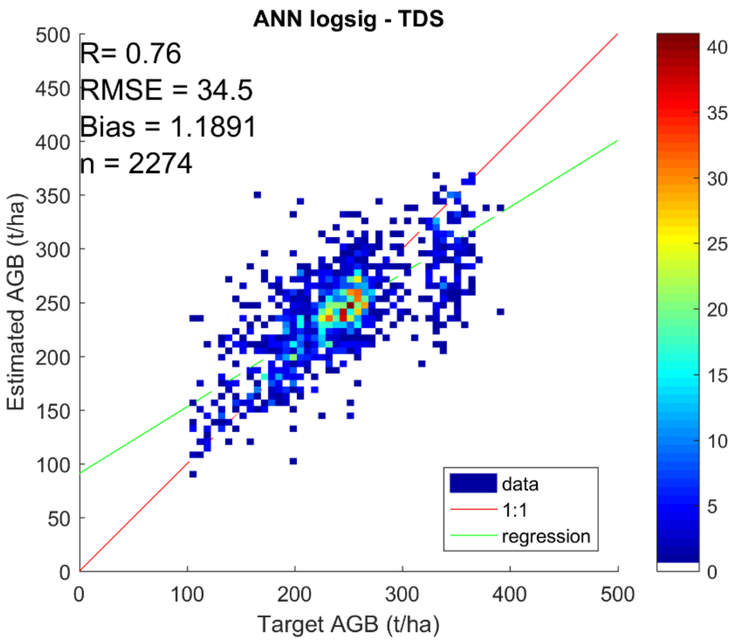
VOD retrieval

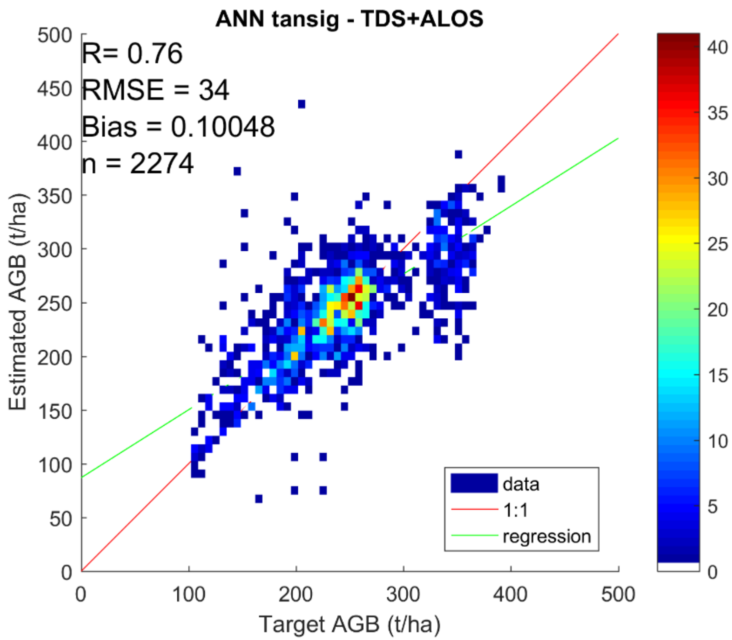
- **Two ANN** have been implemented, for evaluating the feasibility of retrieval using **TDS data only** (ANN1), and **TDS data in synergy with ALOS** (ANN2).
- **ANN1 inputs** were the TDS Reflectivity and the corresponding incidence angle; **ANN2** also accounted for ALOS $\sigma 0$ (HH and HV)
- **Output** is the **VOD**.
- Another **ANN (ANNref)** that only accounts for **ALOS data** has been implemented for comparison.



AGB retrieval

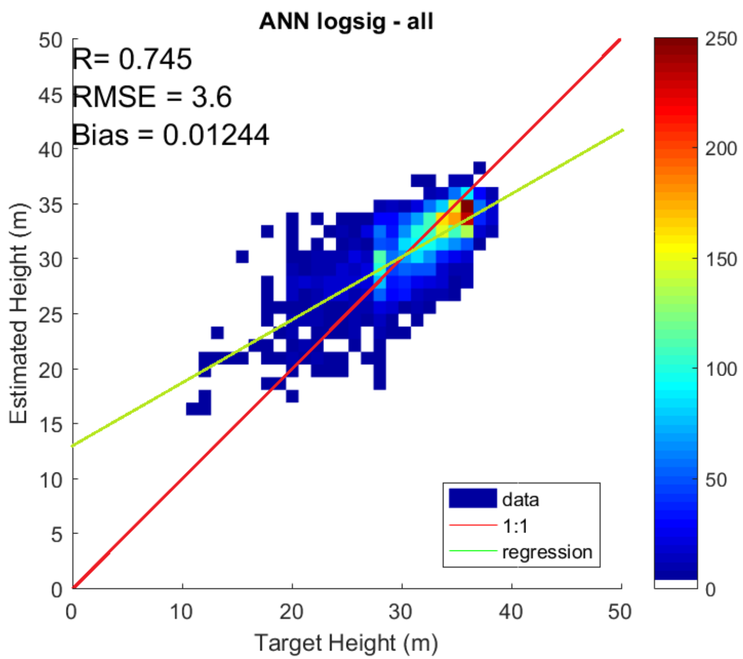
- Another implementation to estimate AGB from TDS data using ANN
- Total ≃ 5000 data
- Training 50% of data, testing 50%
- ANN inputs are TDS reflectivity and incidence, output is AGB (reference from Avitabile)
- Synergy TDS + ALOS also attempted → NO IMPROVEMENTS!





Tree Height Retrieval

- Similar process to estimate tree height from TDS data using ANN
- Total ≃ 6000 data
- Training 50% of data, testing 50%
- ANN inputs are TDS reflectivity and incidence, output is the tree height



Tree heights from ICE-GLAS (m)

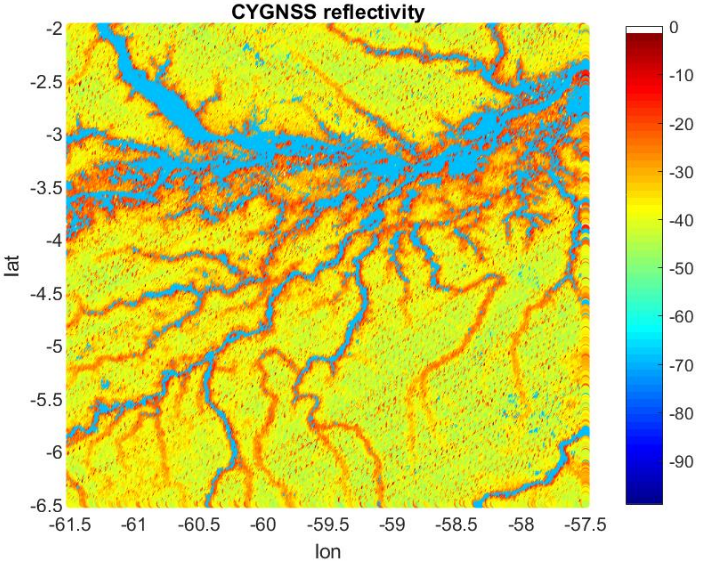
Some conclusions

- **Reflectivity** seems able to catch the Biomass behaviors: retrievals are feasible provided that advanced algorithms (e.g. ANN) are used.
- Retrieval exercises using TDS exhibited **similar results (R > 0.75 in all cases)**
- **Global retrievals** are still to be better exploited since again, the **«static» maps (AGB or Height)** are **not** the **optimal** reference for comparison, moreover they refer to previous years (before 2014).
- In this respect VOD seems to be more adequate, since it is the only parameter available at global scale and with frequent revisiting; **however, it is not a direct measure of biomass** and spatial resolution is low.

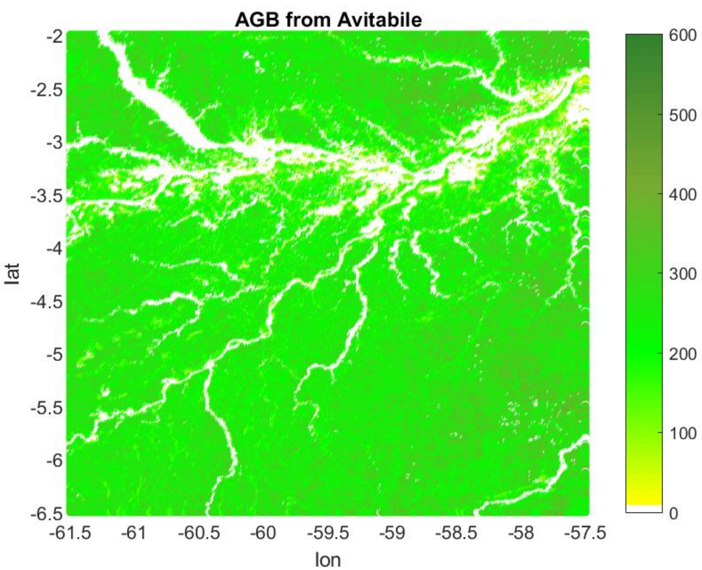
In summary

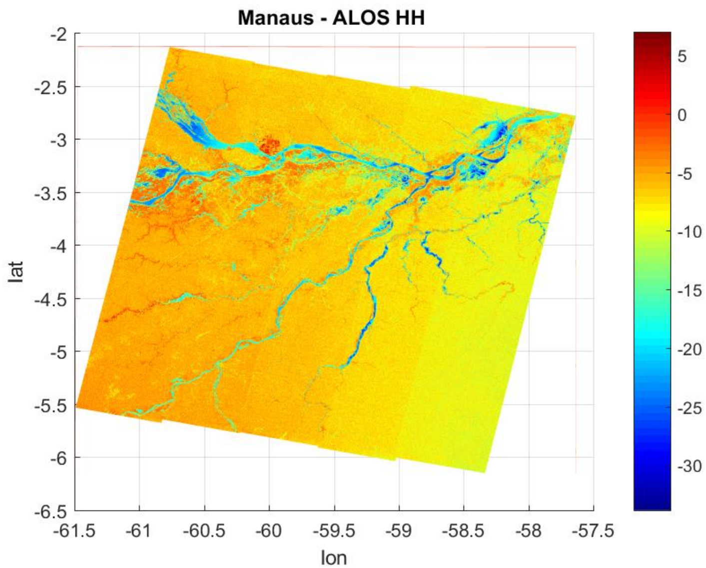
- The study demonstrated that GNSS-R can be used for estimating vegetation biomass at different spatial scales.
- Interesting possibility of using GNSS-R data in synergy with other sensors (e.g. ALOS SAR).

Open issues: sensitivity to open water



- When analyzing the reflectivity from both TDS and CYGNSS (previous presentation)**, a noticeable sensitivity to open water** was detected**, apparently** higher than SAR and optical data.
- **Potential for mapping applications** of rivers/floods?

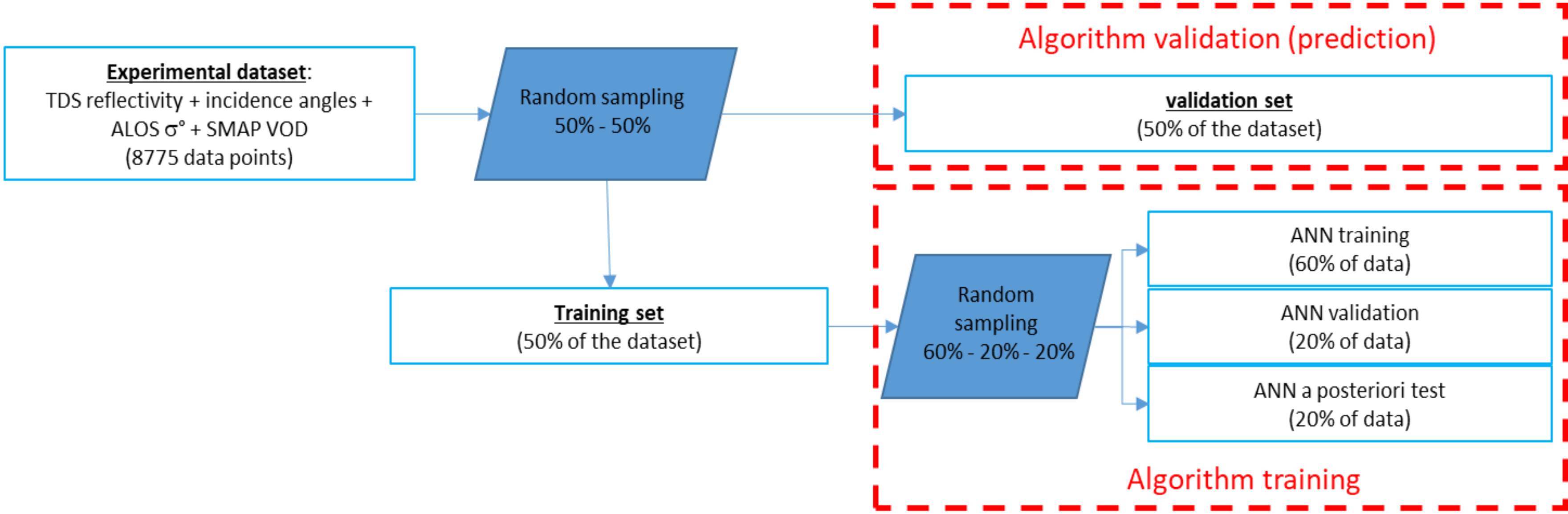




END

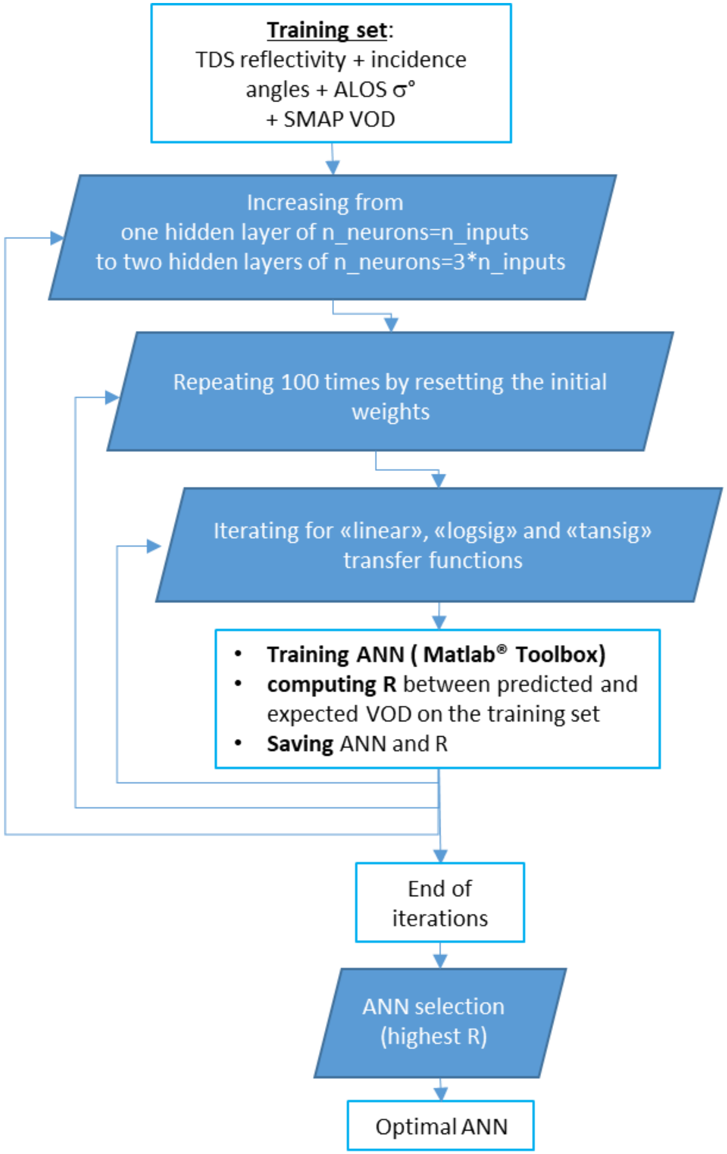
Architecture definition and training

- From the overall dataset (8875 data points) 50% of data is considered for training the algorithm and the remaining 50% for validating it, by predicting VOD from set of TDS data not considered in the training
- The training set is further subsampled randomly in 60%, 20% and 20% subsets: the first subset served for iteratively adjusting the ANN weights and connection strengths using BP; and the second and third subsets were used for validating the training and having a posteriori test at each training iteration.
- ANN is validated on the validation set, not involved in the training.



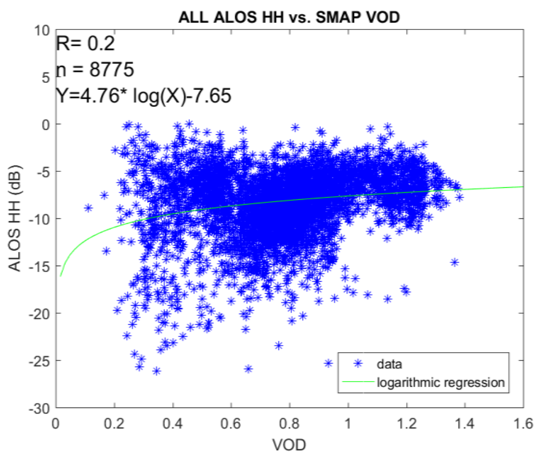
ANN training

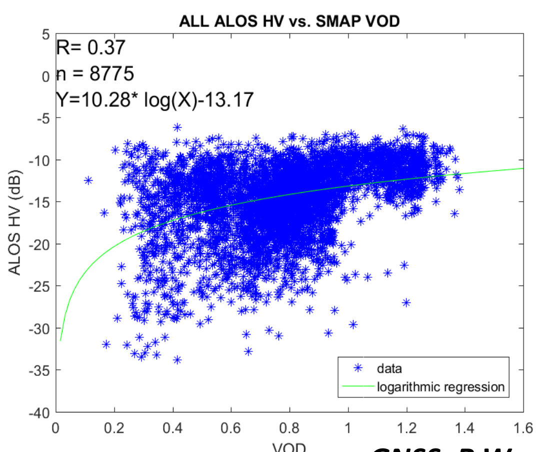
- Optimal ANN architecture (number of neurons and hidden layers) is defined iteratively for preventing overfitting and underfitting
  - ❑ Start: one hidden layer of 4 neurons
  - ❑ Stop: two hidden layers of 12 neurons (3x n. inputs)
- Training repeated 100 times for each architecture, by resetting each time the initial weights.
- Training also repeated for each transfer function available (linear, tansig and logsig)
- Output is the "optimal" ANN architecture for the given problem in terms of R, RMSE and BIAS.

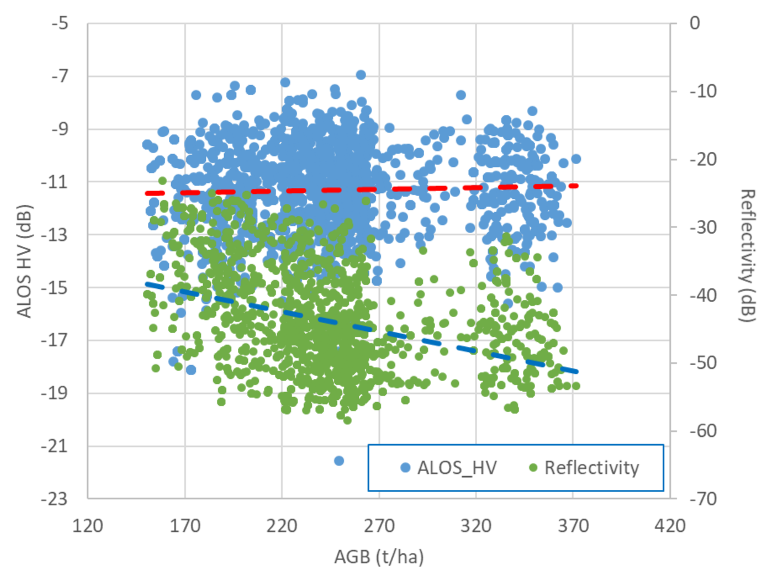


ALOS σ° → VOD

- As a reference, the corresponding (increasing) correlation between ALOS in both polarizations and VOD was lower, ranging from a R=0.2 in HH to R=0.37 in HV, and exhibiting a clear saturation effect for higher VOD values

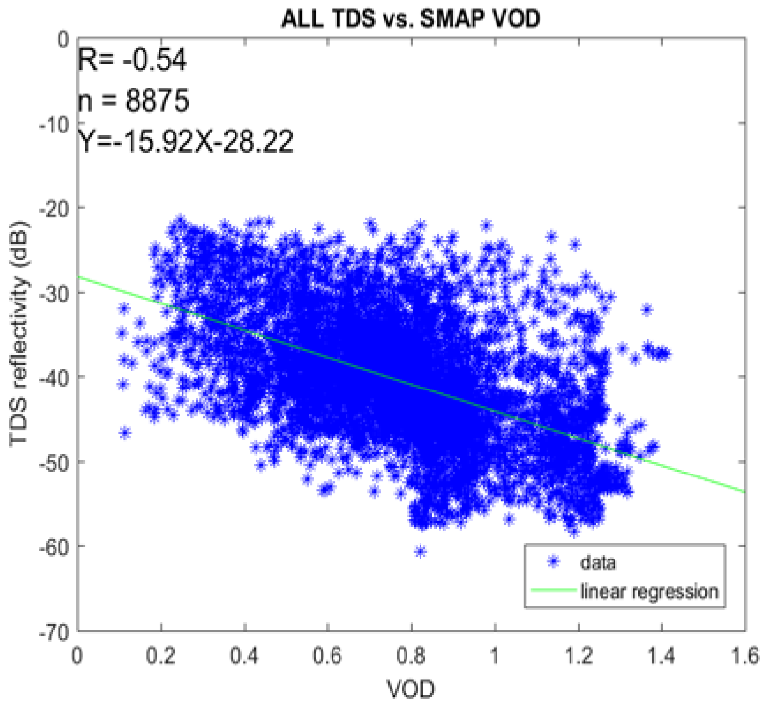


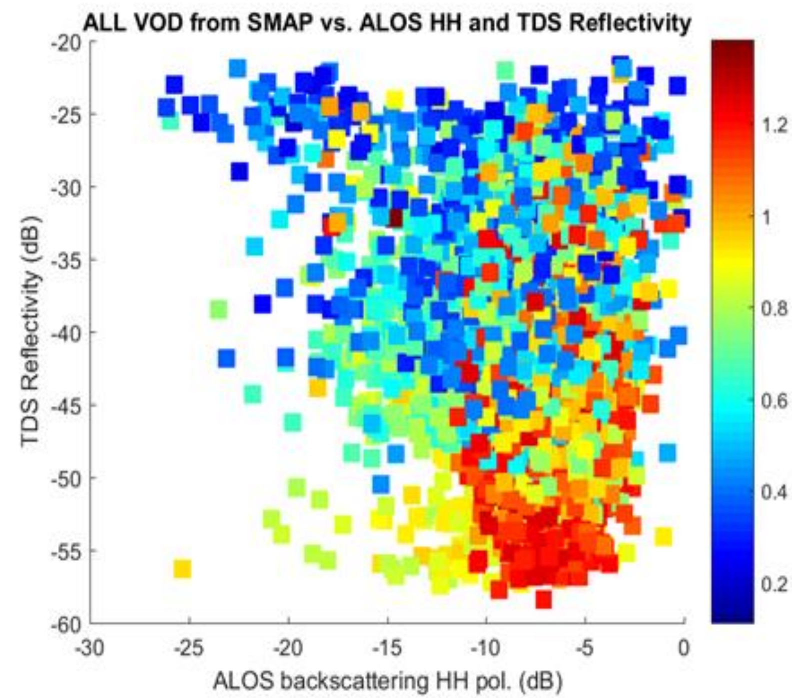




TDS Reflectivity vs. SMAP VOD

- TDS reflectivity vs. the estimated vegetation opacity (VOD) at 36 km from the SMSMAP L2 Radiometer Half-Orbit 36 km EASE-Grid (SPL2SMP) – ”Option 3” product.
- Encouraging sensitivity of TDS-1 data to VOD and arguably, to any other parameter directly related to the forest biomass.





Reflectivity =-15.92 VOD- 28.22, R=-0.54

"specific" ANN algorithm

- The different sensitivities of TDS Reflectivity to VOD on different test areas suggested to implement a dedicated ANN for each area.
- "specific" ANNs have been implemented and trained considering only data from Manaus.
- 50% of data for training each ANN and the remaining 50% for testing.