Retrieval of Soil Moisture and Forest Biomass using CYGNSS Data and Artificial Neural Networks

E.Santi[1], S.Paloscia[1], S.Pettinato[1], M.P.Clarizia[2]

[1]Institute of Applied Physics - National Research Council, Florence, Italy
[2]Deimos Space UK Ltd. - Harwell, UK

Introduction

- The possibility of estimating bio-geophysical parameters as **soil moisture** (**SM**) and **forest biomass** is of great relevance for many studies on carbon cycle and climate changes.
- Global navigation satellite system reflectometry (GNSS-R) could represent a valuable tool for this application.
- This study aims at assessing the **potential** of the NASA's Cyclone GNSS (**CyGNSS**) data for observing SM and biomass.
- As reference values for the comparison, the Vegetation Optical Depth (**VOD**) and **SM** derived from **SMAP**, as well as the aboveground biomass (**AGB)** from the GEOCARBON Global Forest map proposed in 2016 by Avitabile et al. have been considered.
- The results of the sensitivity analysis suggested exploiting the **CyGNSS** capabilities in estimating AGB and SM 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

CyGNSS data

- CyGNSS data collected over land on a global scale within a latitudinal range of approximately +/-38° have been downloaded from https://podaac.jpl.nasa.gov.
- The observables used for the analysis are the **SNR**, already contained in the Level 1 CyGNSS files, the **calibrated SNR** as proposed by **Chew and Small (2018)** and the **Reflectivity** as proposed by **Clarizia et al. (2018).**
- These parameters have been computed for the period April – August 2017 and **re-gridded** on the **SMAP** and **Geocarbon** grids for enabling the comparison.

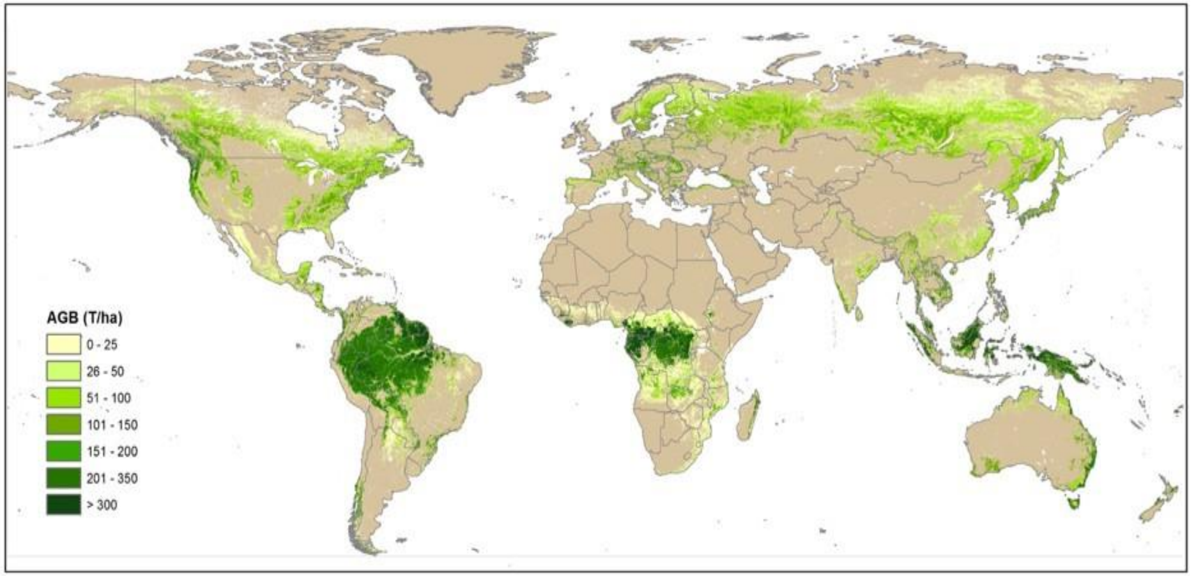
Reference data

SM and VOD :

- from SMAP L3 v.5 Radiometer global daily EASE-Grid data
- Soil Moisture [cm^3/cm^3]
- Vegetation Opacity (VOD)

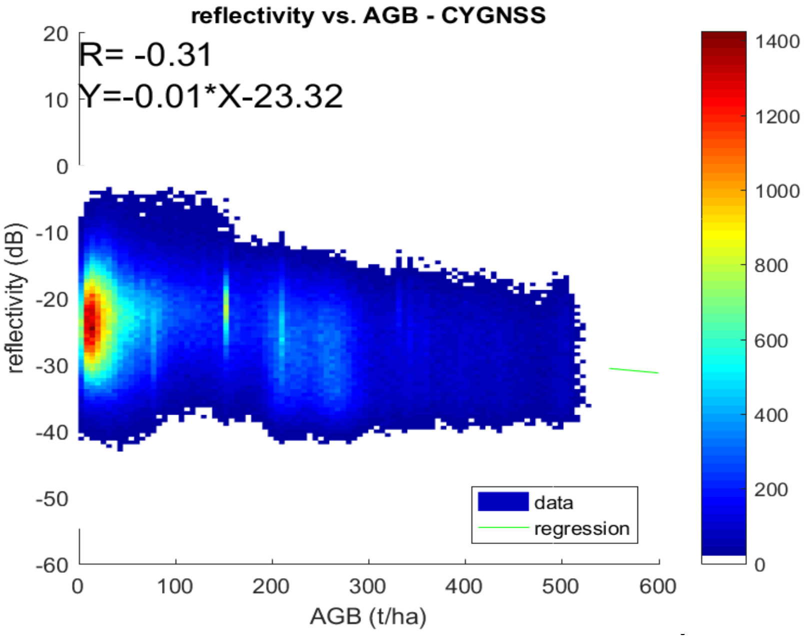
AGB:

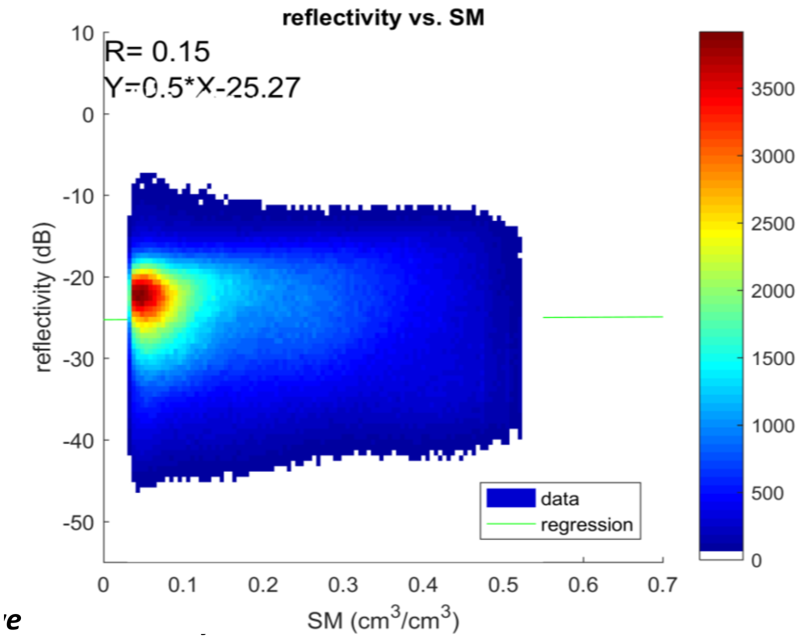
- AGB data derived from the GEOCARBON Global Forest map proposed in 2016 by Avitabile et al. (www.geocarbon.net).



Sensitivity to SM, VOD and AGB

- The **expected decrease** of reflectivity when **Biomass** (both VOD or AGB) increases is confirmed (more details in the next presentation)
- A **very slight increase** whit **SM** was also found
- SNR did not show any correlation to the target parameters
- Correlation is poor → need of advanced algorithms for the retrieval (**ANN**)





Addressing the retrieval

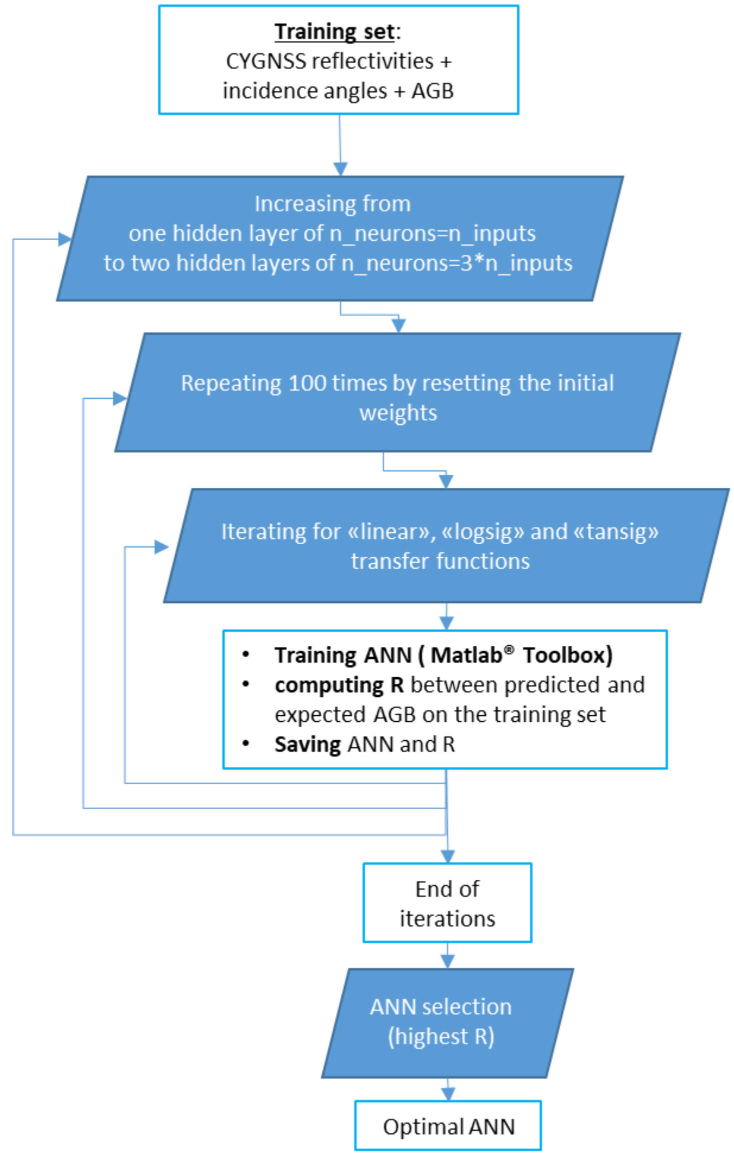
Implementing retrieval algorithms based on Artificial Neural Networks

ANN Architecture definition

- **Multi-Layer Perceptrons** ANN trained with the **back-propagation** (BP) learning rule
- Optimal ANN architecture (number of neurons and hidden layers) is defined iteratively for preventing overfitting and underfitting
  - Start: one hidden layer

    n. neurons= n. inputs
  - Stop: three hidden layers

    n. neurons= 4 x n. inputs
- Training repeated 20 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 for the given problem (best R).

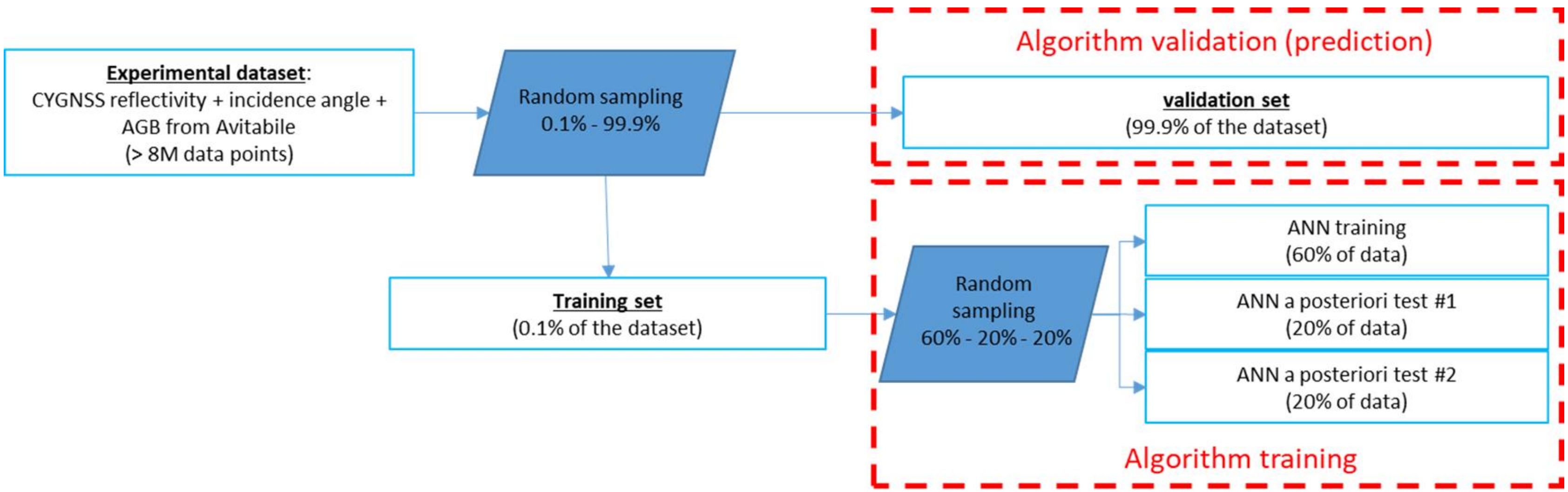


CyGNSS vs. AGB

Retrieval of AGB
Reference from Geocarbon

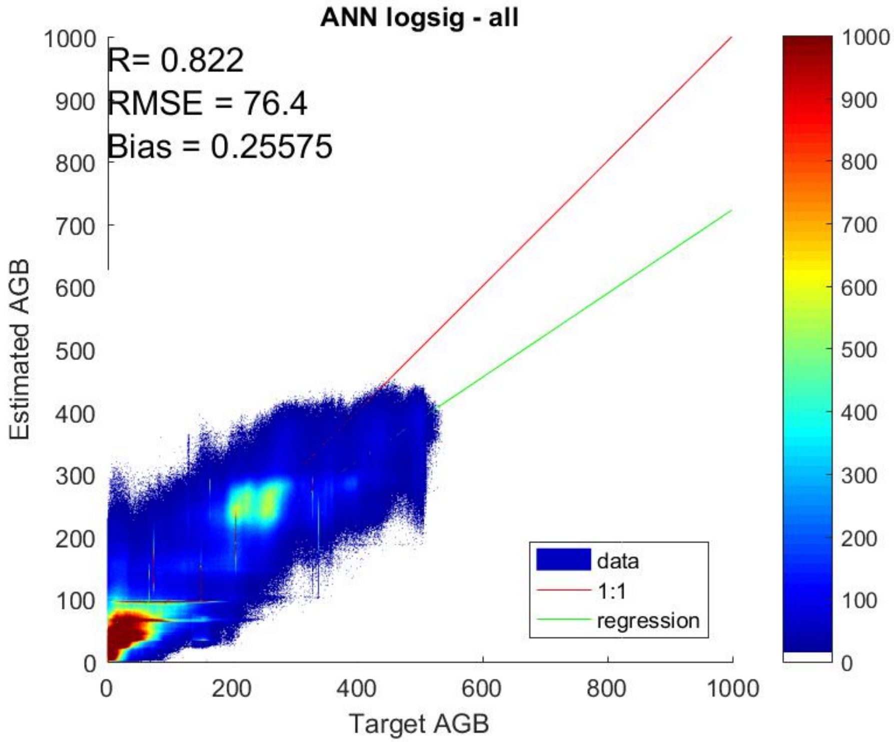
ANN training – CyGNSS vs. AGB

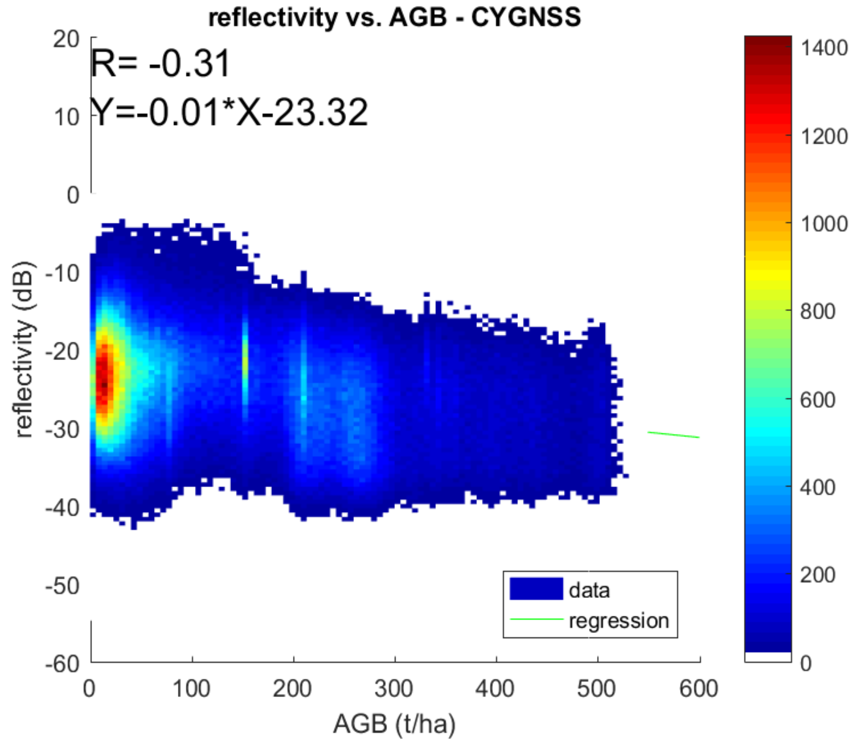
- Algorithm inputs are **reflectivity** and **incidence** from CyGNSS
- Output is **AGB**
- Both CyGNSS and **AGB regridded** at 0.05° spacing (≃ 5 Km) ≃8M data points
- 0.1% of data considered for training the algorithm and the remaining 99.9% for validation.
- Training set further subsampled in 60%, 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 validation and for having a posteriori test at each training iteration.



Algorithm validation

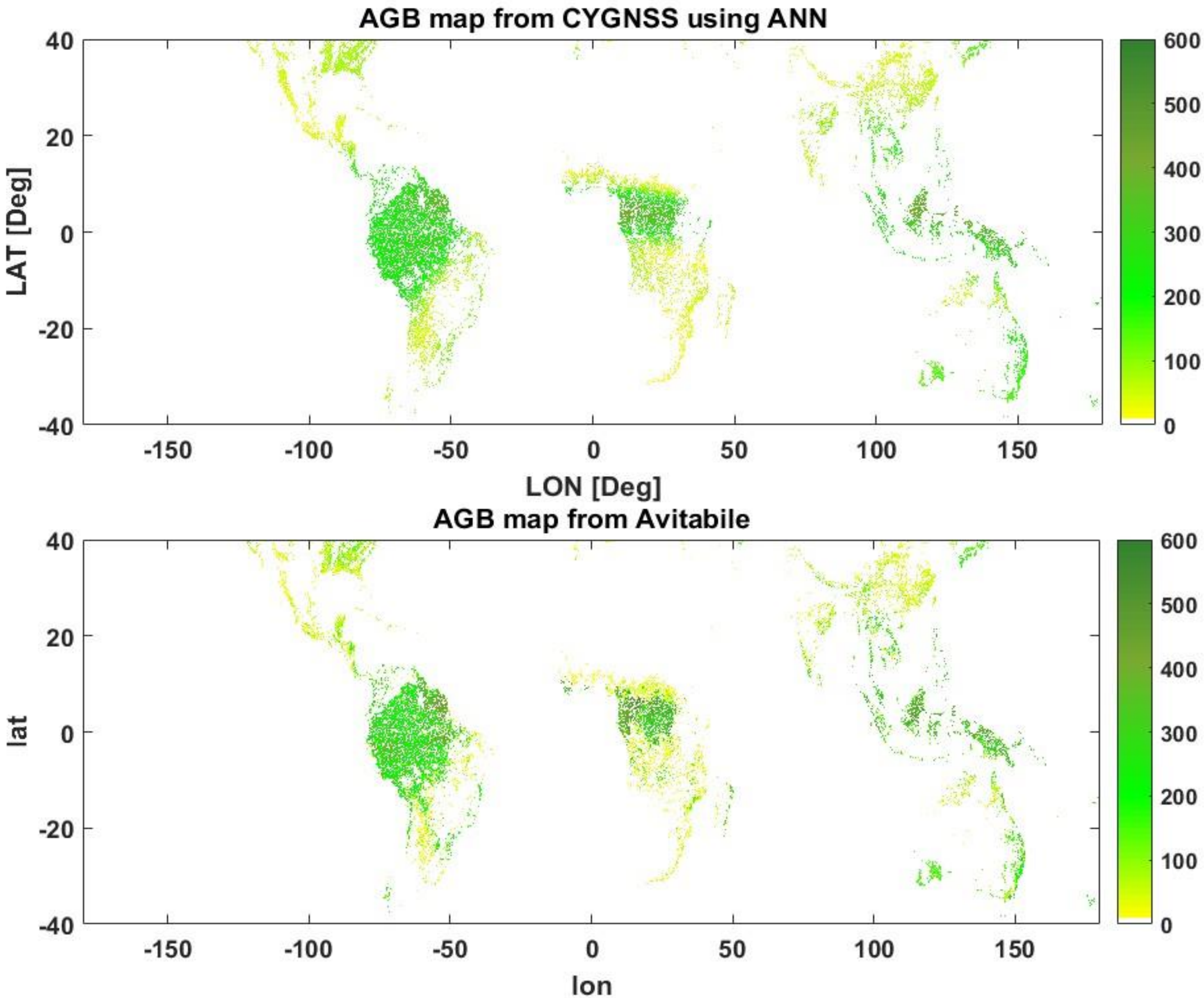
- Validation on the 99.9% of data not involved in the training





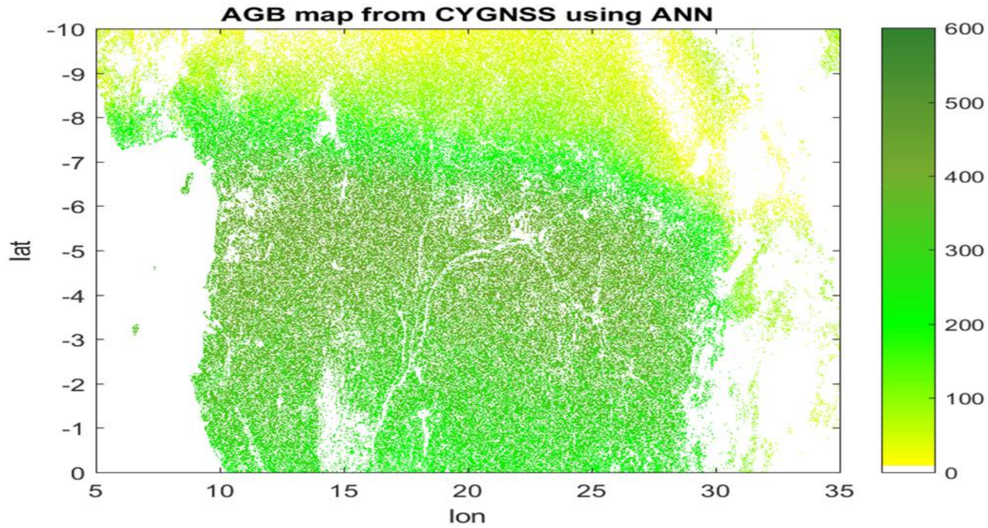
R=0.82 – RMSE=76.4 (t/ha)

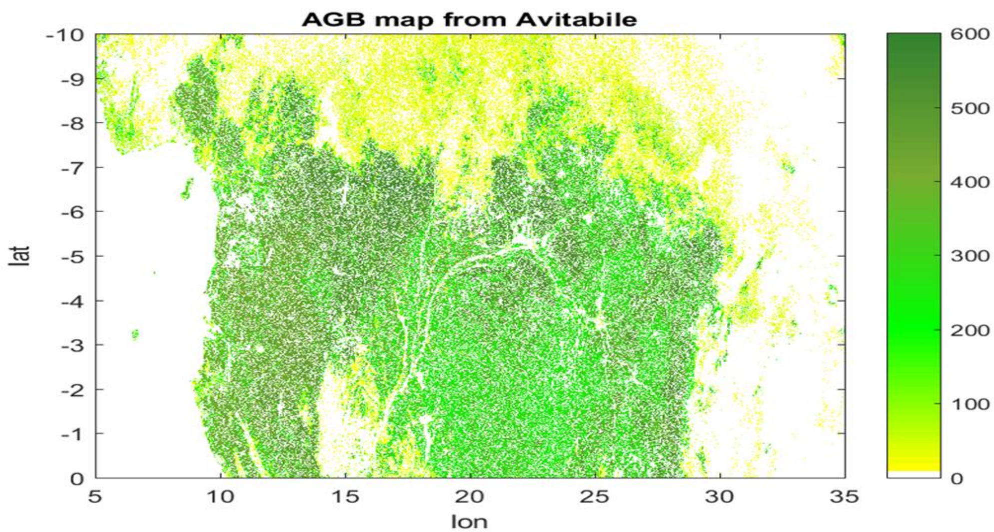
CYGNSS vs GEOCARBON: AGB maps



CYGNSS vs GEOCARBON: AGB maps

- Quite promising result but ANN does not detect local patterns → **TBD**
- Possibly due to the reference AGB: a **«static» maps** is **not** the **optimal** reference for comparison, moreover it has been obtained with older data (before 2014).



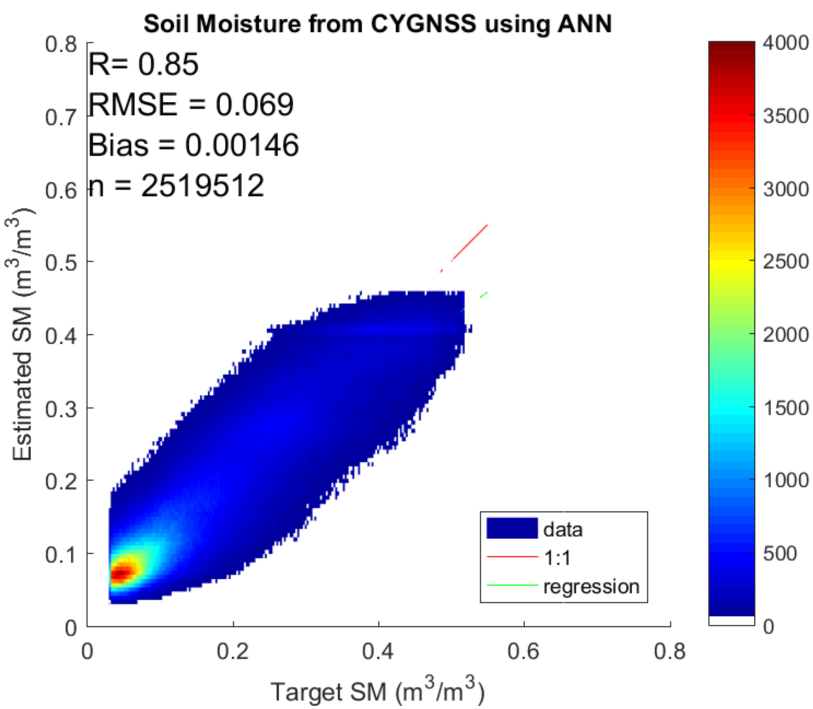


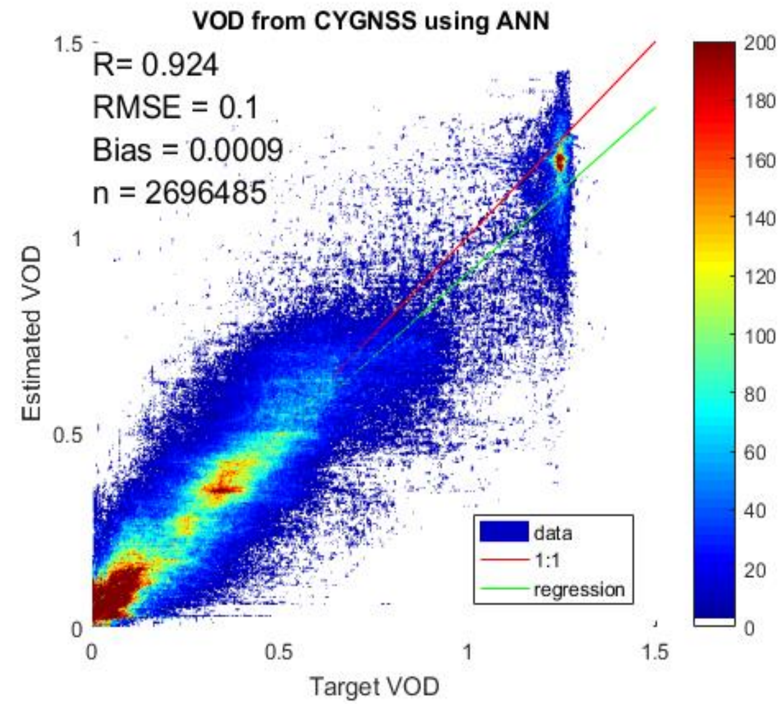
CyGNSS vs. SMAP

Retrieval of SM and VOD Reference from SMAP

CYGNSS vs. SMAP

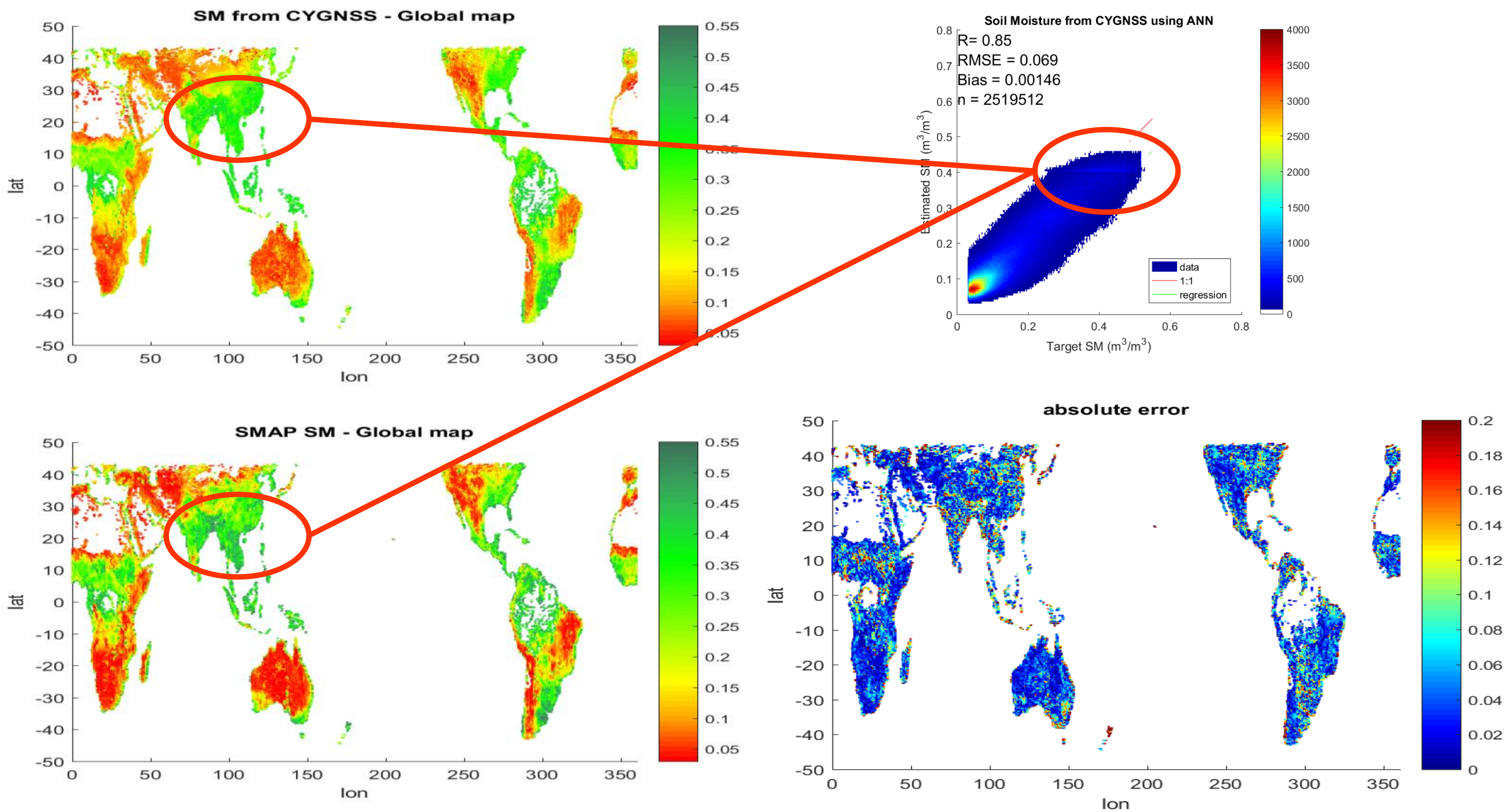
- **VOD** and **SM** estimated from CYGNSS data using ANN
- CYGNSS and SMAP VOD/SM gridded on EASE GRID
- ≃ 2,7 M data - Training on 1% of data, test on 99%
- **Inputs**: SNR, reflectivity and angle from CyGNSS + lat/lon
- **Output:** VOD or SM





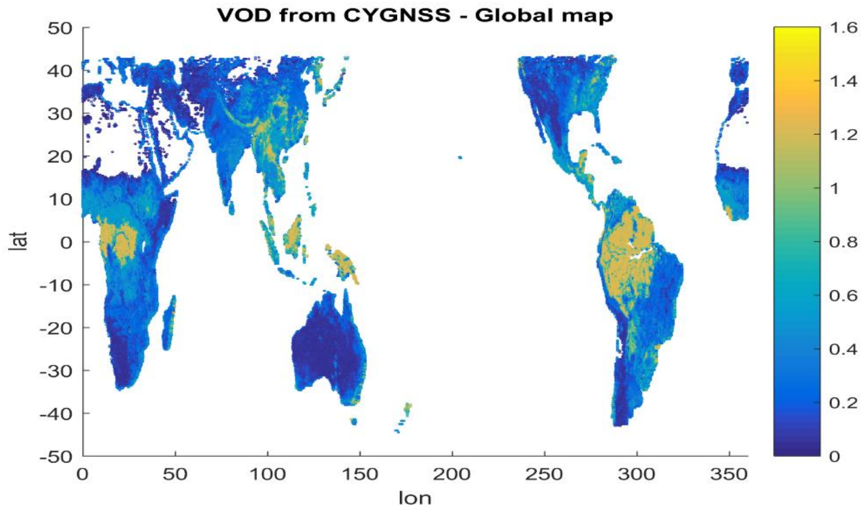
CyGNSS vs. SMAP SM: average maps

- ANN tends to slightly underestimate the higher values

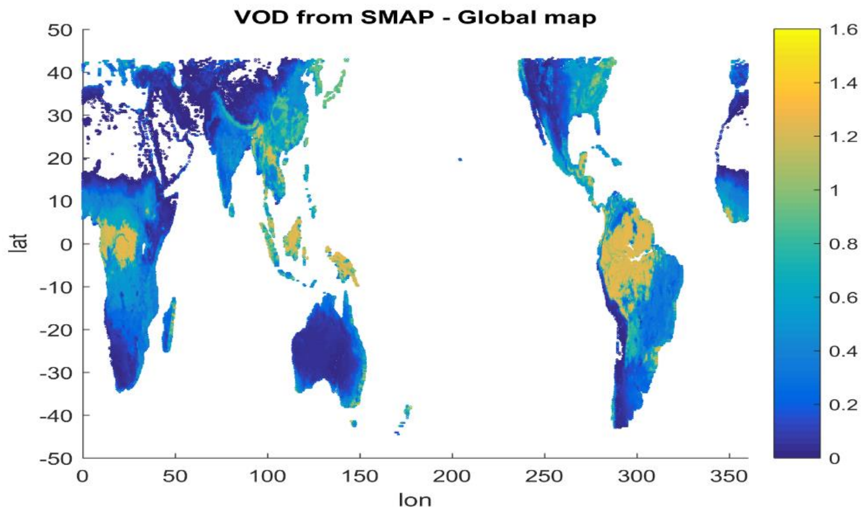


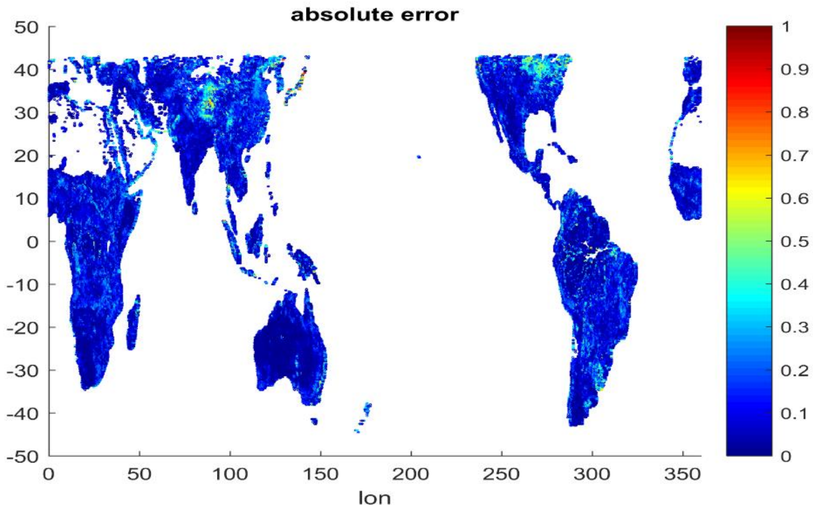
CyGNSS vs. SMAP VOD: average maps

CyGNSS

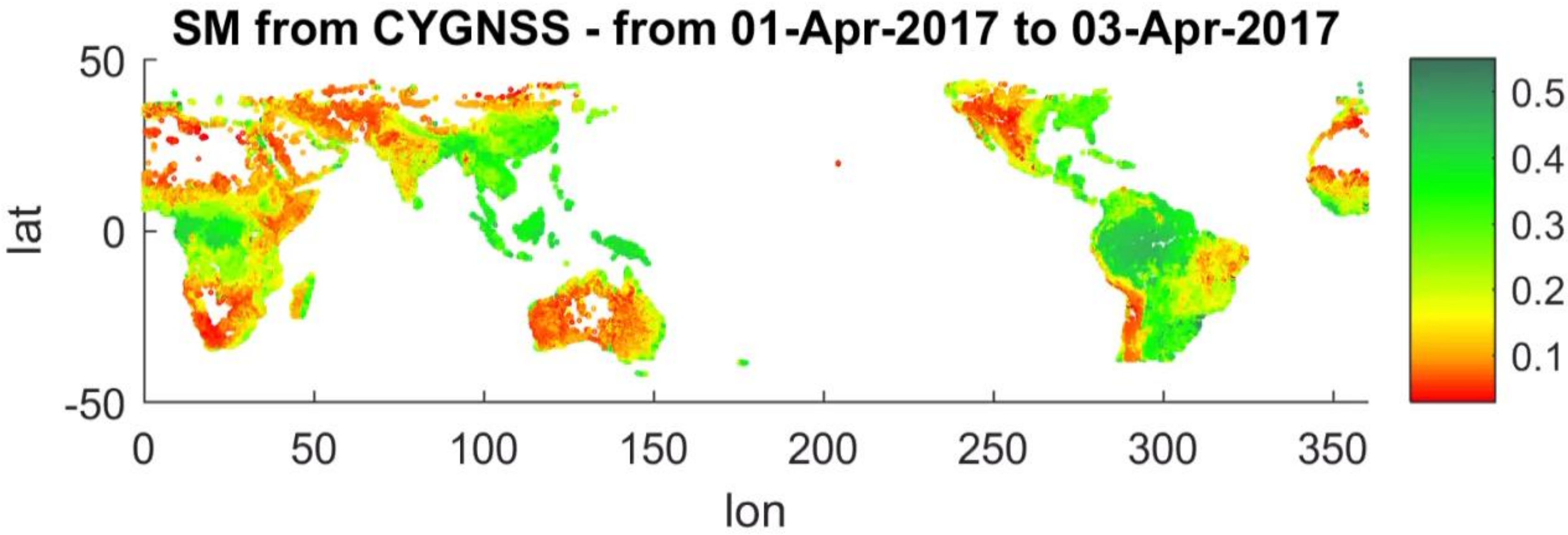


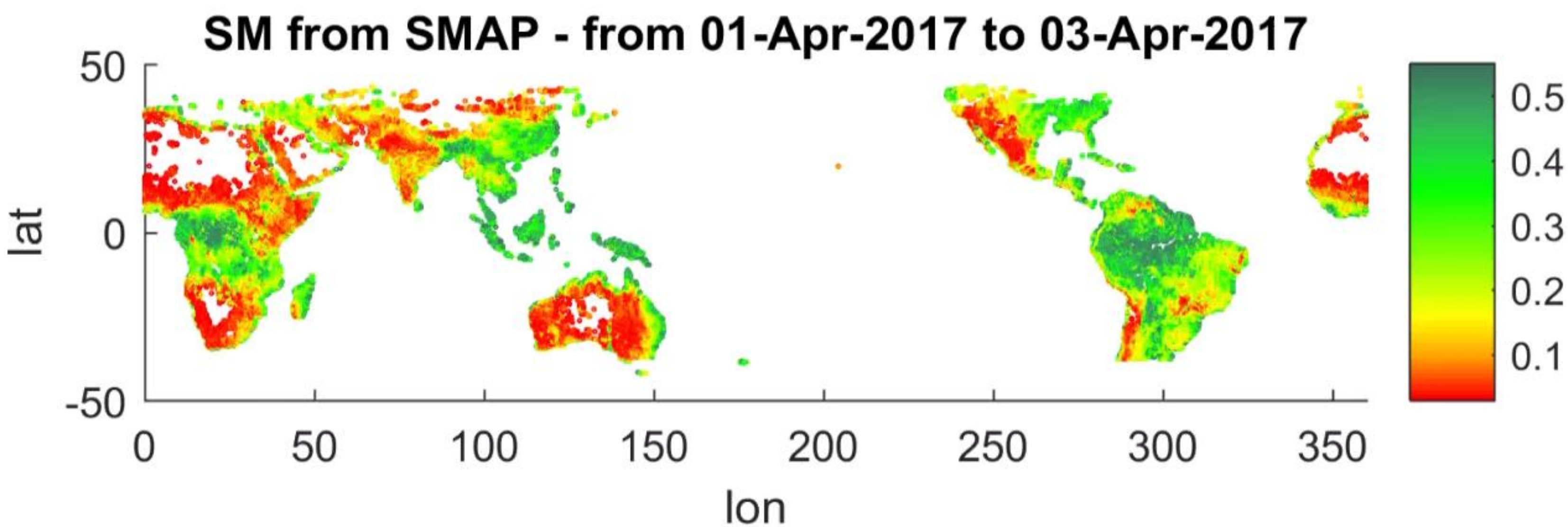
SMAP



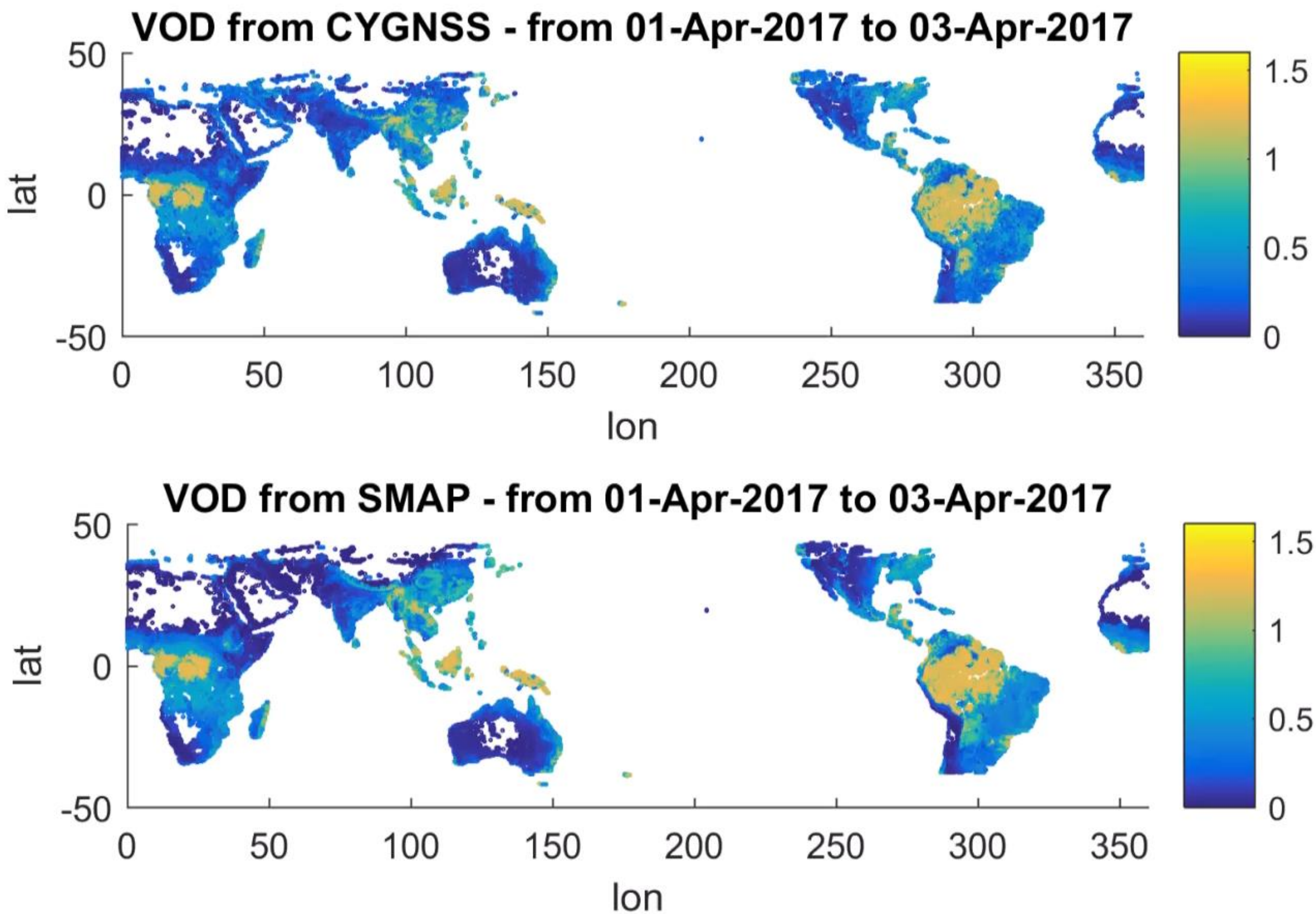


SM 3-days maps from CyGNSS





VOD 3-days maps from CyGNSS



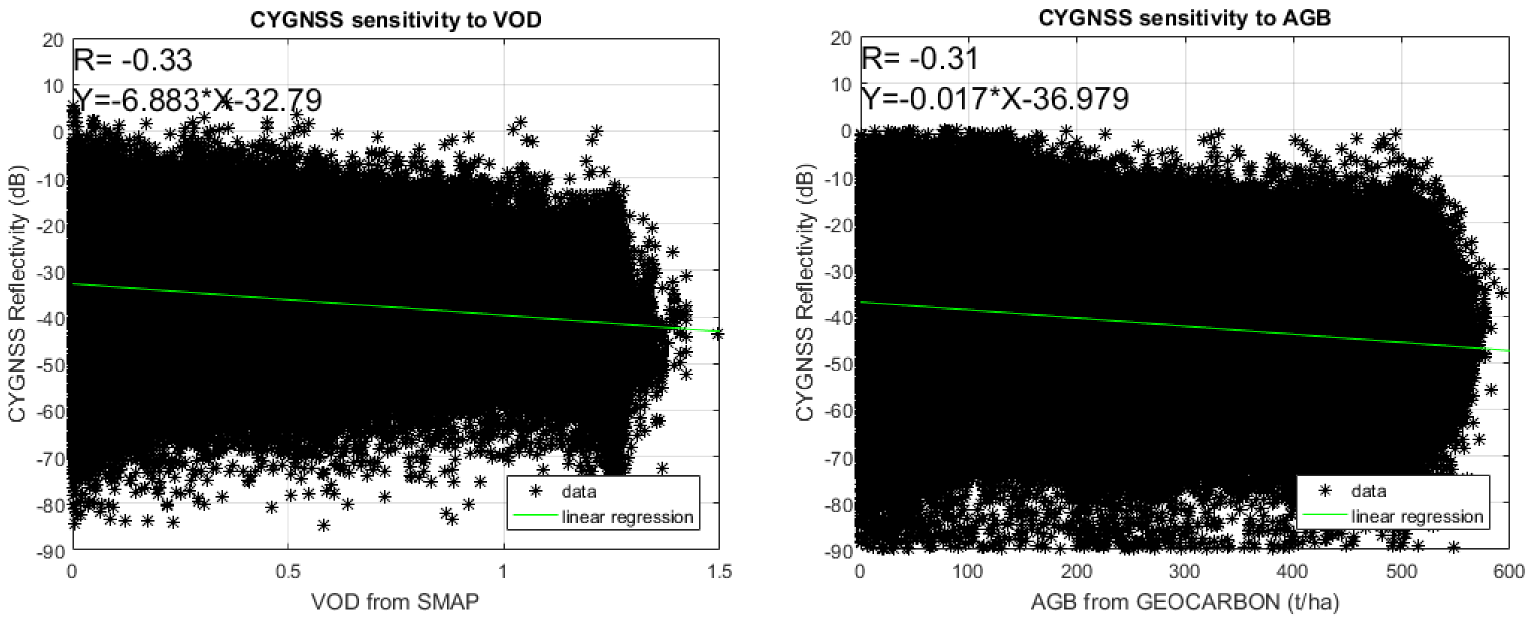
Some conclusions

- CYGNSS seems able to catch the Soil Moisture and Biomass behaviors: retrieval is feasible provided that advanced algorithms (e.g. ANN) are used.
- Retrieval exercises returned similar results (0.82<R<0.92 in all cases)
- **Reflectivity** seems the most suitable parameter for the retrieval on land, **SNR** does not add much (more in the next presentation)
- **Global retrievals** have to be better exploited since the **«static» map (AGB)** is **not** the **optimal** reference for comparison
- In this respect **SM** and **VOD** from **SMAP** seem more adequate; however, are both derived from **another L- band sensor,** not from direct measurements.
- The prosecution of this study will consider using other datasets and involving more CyGNSS observables
- The possibility of using CyGNSS in **synergy** with **other satellite sensors** (SAR, MW radiometers, optical) will also be exploited

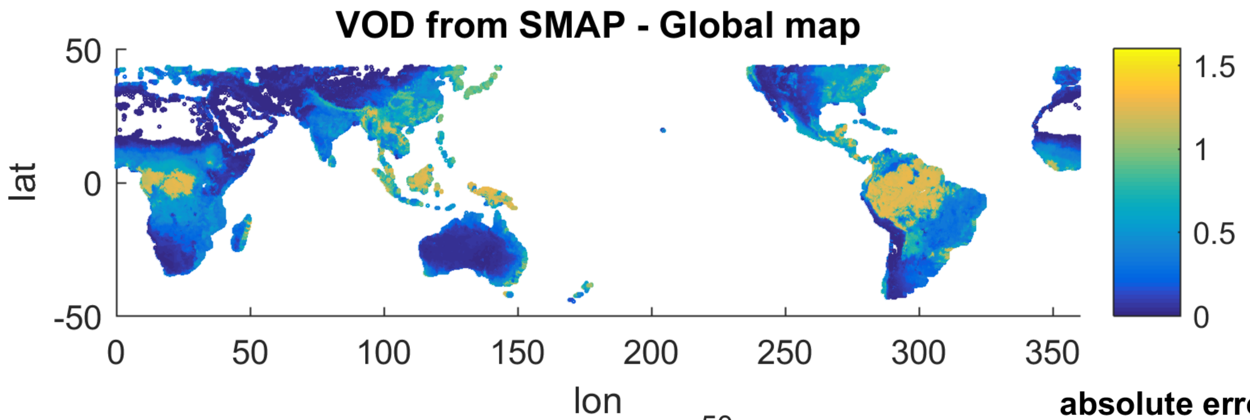
END

Previous results: Global analysis

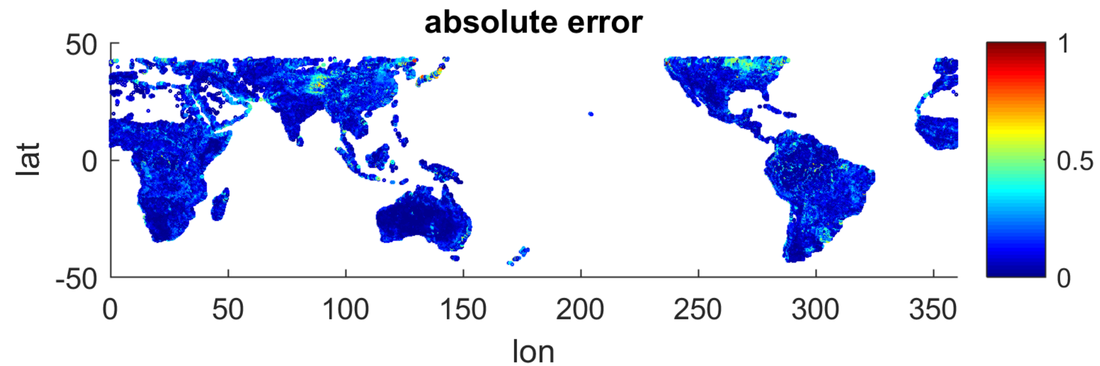
- One year of CYGNSS data (2017)
- CYGNSS vs. SMAP VOD (R~-0.31)
- CYGNSS vs. AGB from pantropical map (R~-0.31 slope -0.02 dB*t/ha)

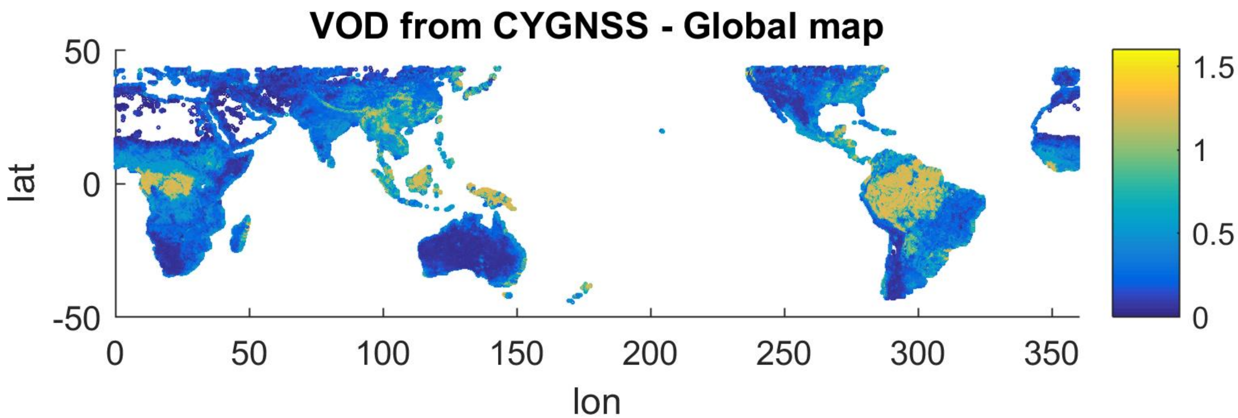


CyGNSS vs. SMAP VOD



SMAP





CyGNSS