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A waveform simulator for Sentinel-3 SAR Altimeter over land

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SENSITIVITY OF RADAR ALTIMETRY TO LAND PARAMETERS

- ALtimetry for BIOMass (**ALBIOM**) project
  - Forest biomass using Copernicus Sentinel-3 SAR altimeter (S-3 SRAL) data at Ku- and C-bands
- Complexity of the land surfaces
  - **No algorithm for a specific retracking of the land waveform**

Development of **an electromagnetic model able to reproduce the different scattering phenomena** that occur in the **interaction** of the radar altimetry pulse **with the vegetation medium**

- Adaptation to altimeter configuration of **Soil And Vegetation Reflection Simulator (SAVERS)**
  - GNSS-R signals from **land surfaces**
- Adaptation to altimeter configuration of **Tor Vergata Scattering Model (TOVSM)** and its combination with SAVERS
  - electromagnetic properties (scattering and extinction) of **vegetation elements**

SAVERS Simulator main characteristics

- Simulation of the power received by the altimeter over bare soil through monostatic integral radar equation

$$P_R = \frac{P_T \lambda^2}{(4\pi)^3} \int_A \frac{G^2 I^2(\tau' - \tau)}{R^4} \sigma^0 dA$$

  - **P_R and P_T are, respectively, the received and the transmitted power**
  - λ is its wavelength
  - **G is the antenna gain**
  - R is the distance of the differential area dA from the antenna
  - A is the integration area, i.e., the antenna footprint
  - **$I^2(\tau'-\tau)$ is the impulse response functions in time**
  - Pulse width determined by the signal bandwidth according to τ_c=1/B
  - **σ^0 is the bistatic scattering coefficient of elemental area dA**
    - ➢ **incoherent contribution through the AIEM model** developed in (Wu and Chen, 2004) applicable at both frequencies for the roughness parameters used in this study (Macelloni et al., 2000)
    - ➢ **coherent** (component predominant because of the nadir looking configuration) modeled following the approach described in (Comite at al. 2020), that **considers the Fresnel reflection coefficient eventually reduced due to the small scale roughness**

SAVERS Inputs

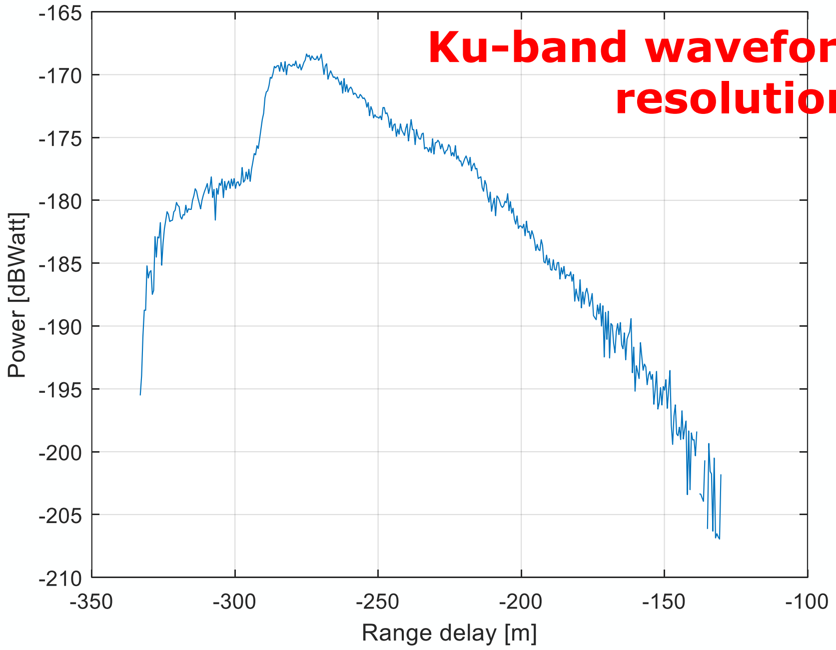
- **Geodetic satellite coordinates**
- **ECEF velocity coordinates**
- **Transmitted signal frequency**
- **Soil parameters**
  - roughness height standard deviation σz in cm,
  - correlation length lc in cm,
  - volumetric soil moisture content (SMC) in %, that is needed for the computation of the soil dielectric constant through the model by (Dobson et al., 1985).
- **Forest Height** (other forest variables, such as branch and trunk size are estimated through allometric equations found in the literature)
- **DEM**, used to take into account the topography
  - the 3 arcsec **SRTM DEM** interpolated on the SAVERS simulation grid (facets of 90 m x 90 m). In this way, the slope, aspect and local incidence and scattering angles for each facet of the simulation area are derived from the SRTM DEM elevation.

SAVERS Output

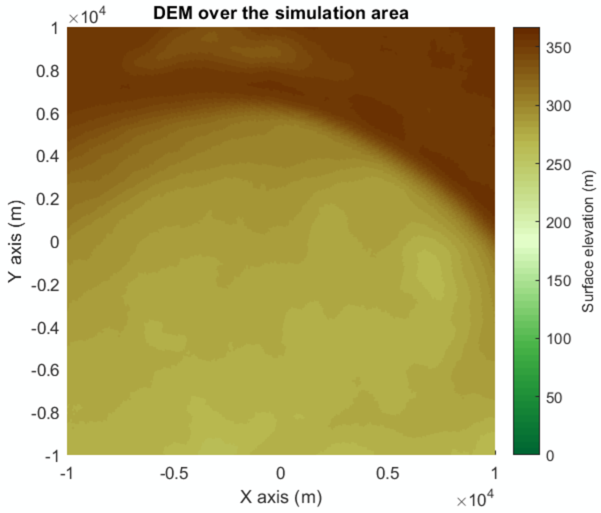
Power of the backscattered signal

vs.

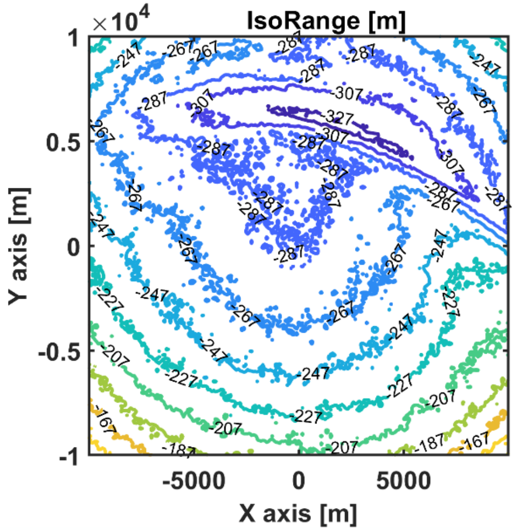
the range delay, (difference between the satellite distance from a generic point in the integration area and the satellite geodetic height)



Ku-band waveform in low resolution



DEM



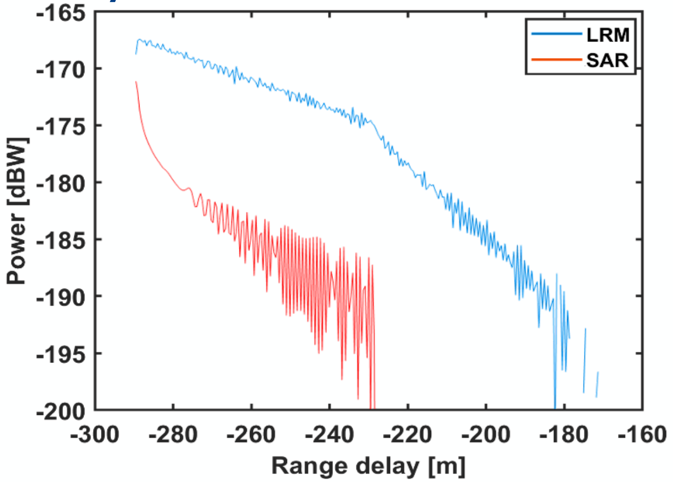
ISODELAY MAP

IsoRange map for the altimetric measurements at latitude of 17.83° , longitude of 17.15° and height of 804.8km

SAVERS Output

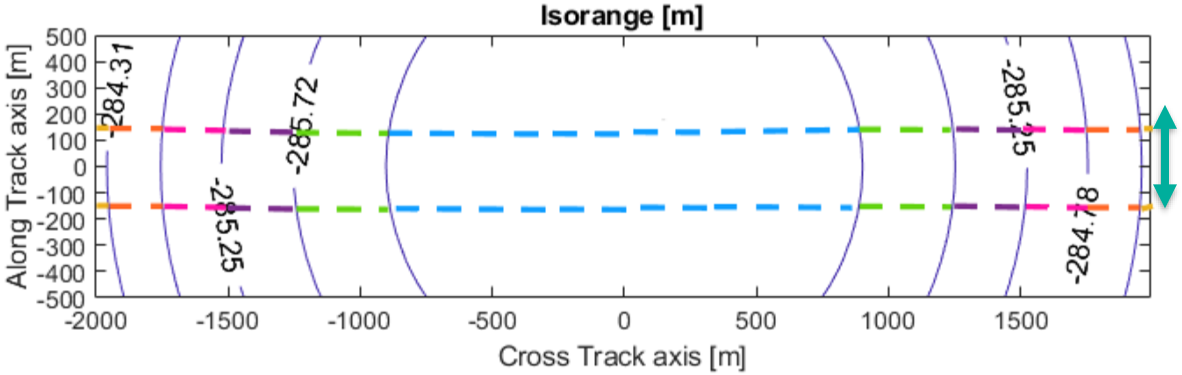
High resolution «SAR» simulations

synthetic flat surface



LRM
SAR

Zoom over 4x1km^2



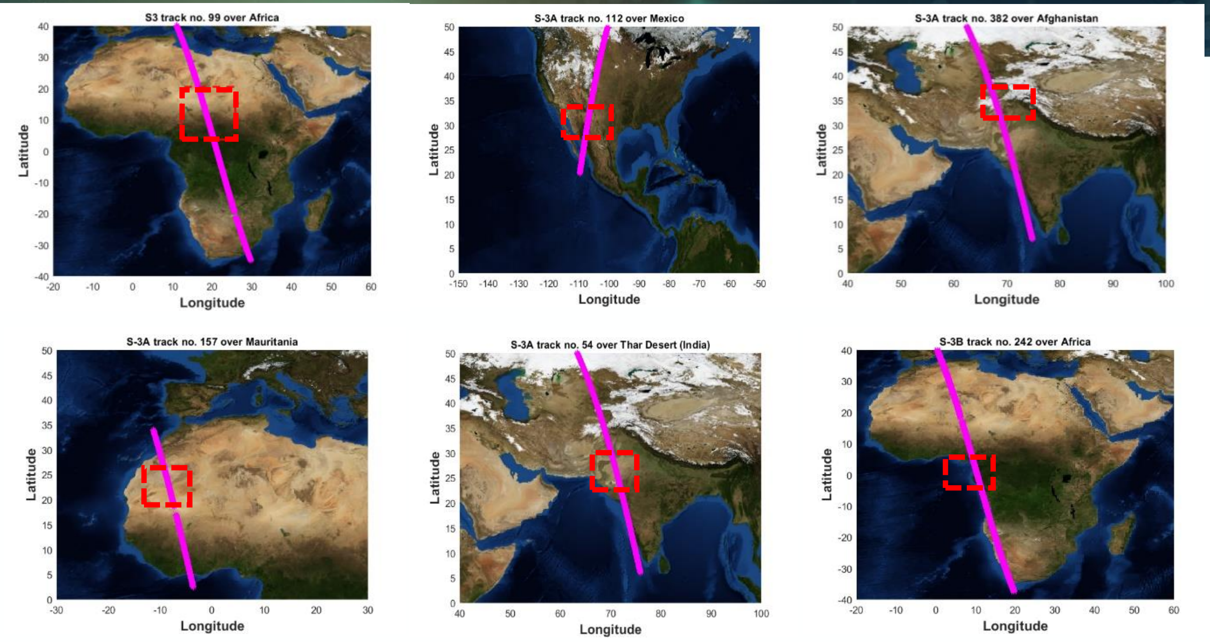
300m

Different colors of dashed line represent different resolution cells at intervals of 47cm range delay

- The simulation mimics **the SAR resolution without reproducing the signal processing of the S-3 SAR acquisition (multilook),** but limits the integration of the radar equation in the along-track direction within a distance of **300m**
- SAR simulated waveform shows a steep trailing edge because of fast decrease in the resolution area
- The facets at delays longer than -220m are so small that no significant power is backscattered
- When the ground resolution cell is much smaller than dA (integration cell), the power calculation gives oscillating values

STUDY SITES

- S-3A ascending track no.99 (April 2017)
- S-3A ascending track no.382 (March 2017)
- S-3A ascending track no.157 (April 2017)
- S-3A ascending track no.54 (March 2017)
- S-3A descending track no.112 (April 2017)
- S-3B ascending track no.242 (March 2019)

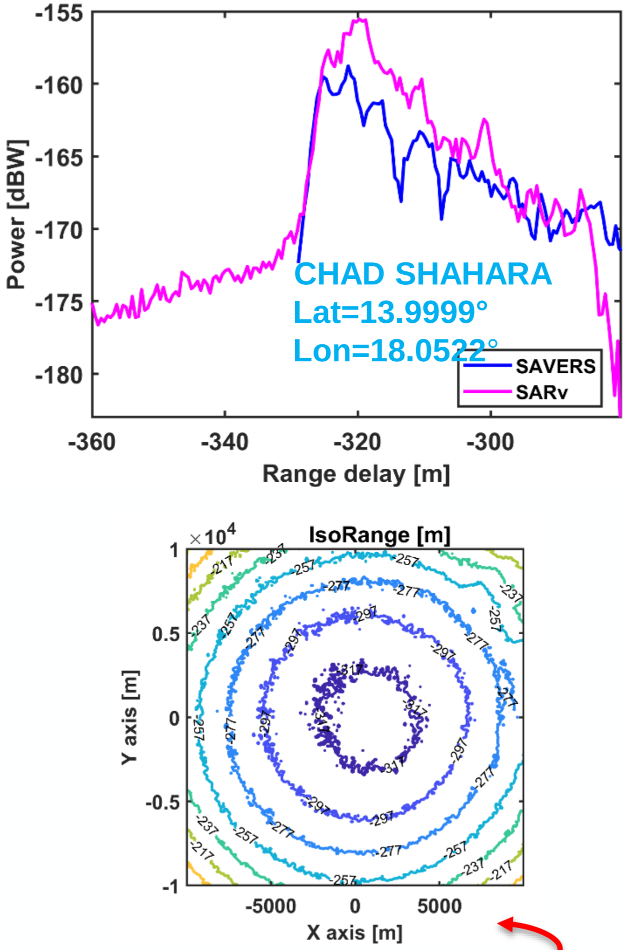


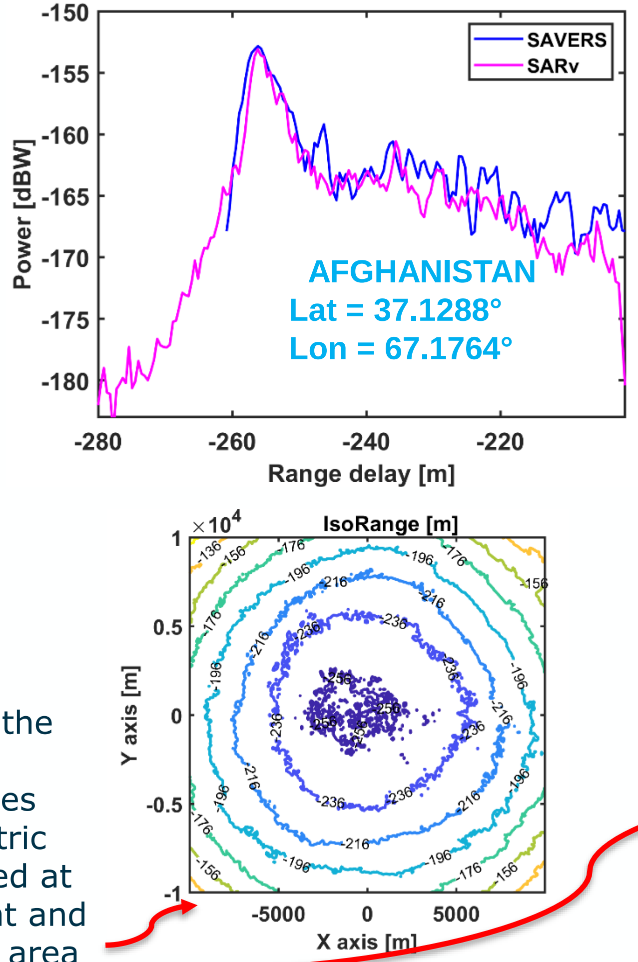
Ku-band SAR, Ku-band PLRM and C-band waveforms in Sentinel-3 L2 products (128 bins)
G-POD SARvatore for Sentinel-3 Service Ku-band waveforms (512 bins and true vertical dynamics in dBW)

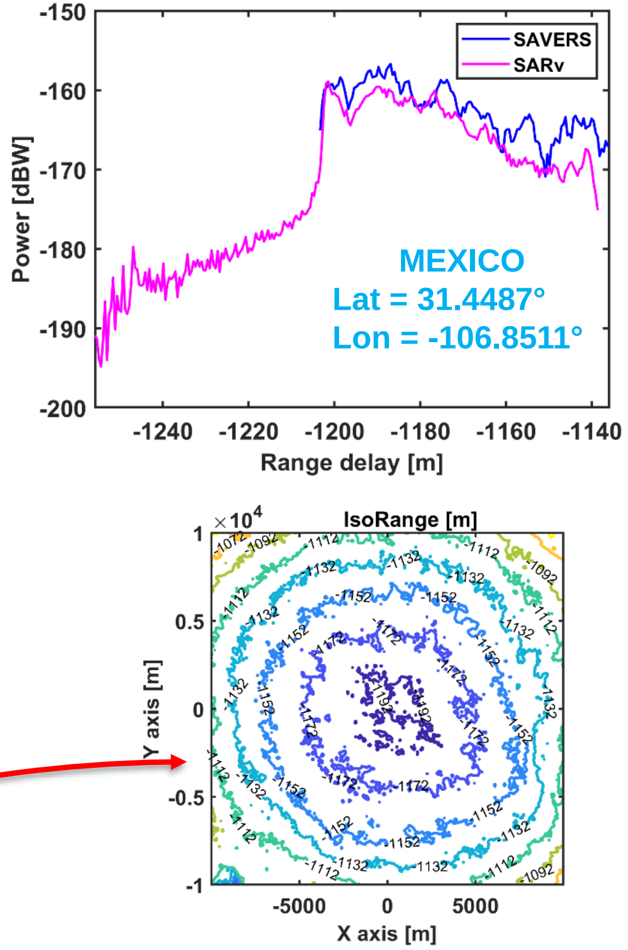
- **Desert areas** in Chad (Sahara desert) and Mexico (Chihuahua desert) and in Northern Afghanistan's **plains**
- Regions characterized by **variable elevation and complex topography**, but still **bare soils**, in Mauritania and in the Thar Desert in North-West India
- Regions characterized by the **presence of several kind of land covers** such as **herbaceous vegetation, shrubland, and mainly forest** in Central African Republic and a vegetated area in Gabon (West Africa)

COMPARISON WITH SARvatore DATA

FLAT SCENARIOS over bare soil





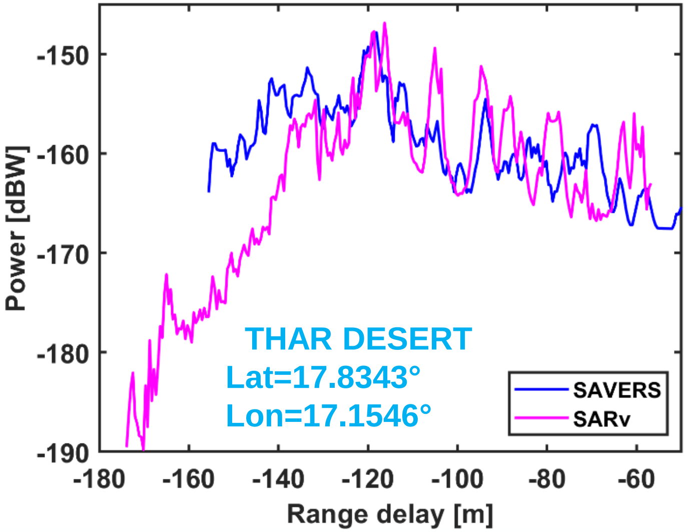


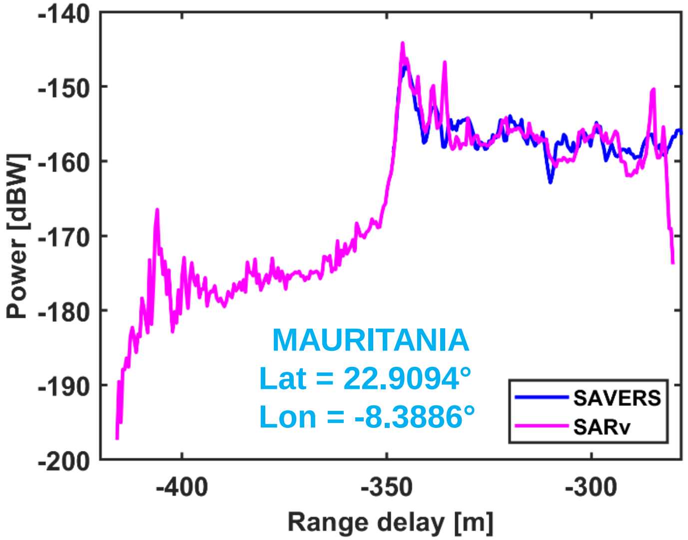
Projection on the ground of the altimeter pulses yields concentric annuli centered at the nadir point and with constant area

Good agreement of the leading and trailing edge slope

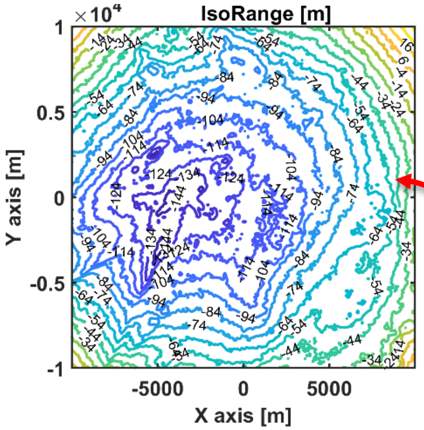
TOPOGRAPHY SCENARIOS
over bare soil

COMPARISON WITH SARvatore DATA

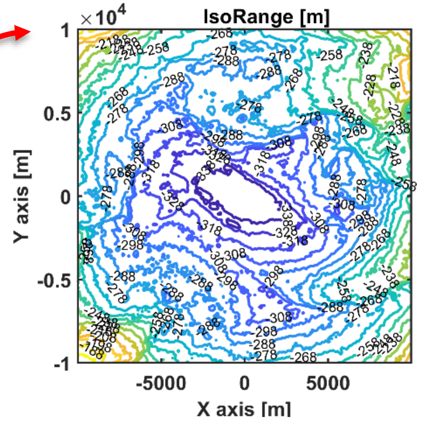




Good agreement of the leading and trailing edge slope



Concentric ring shapes of the iso-delay lines are distorted by the surface elevation

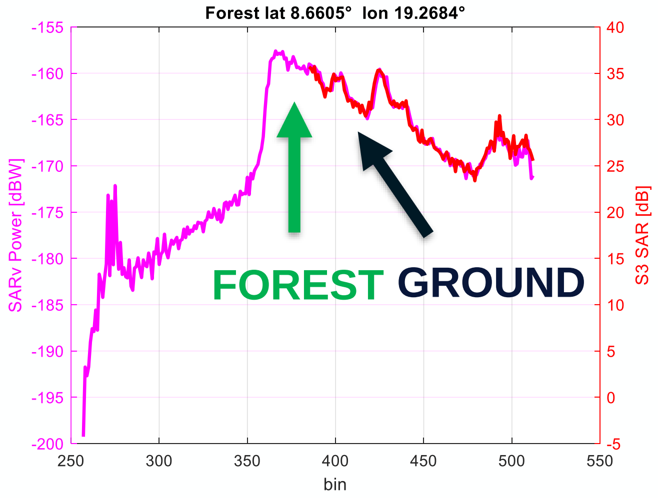


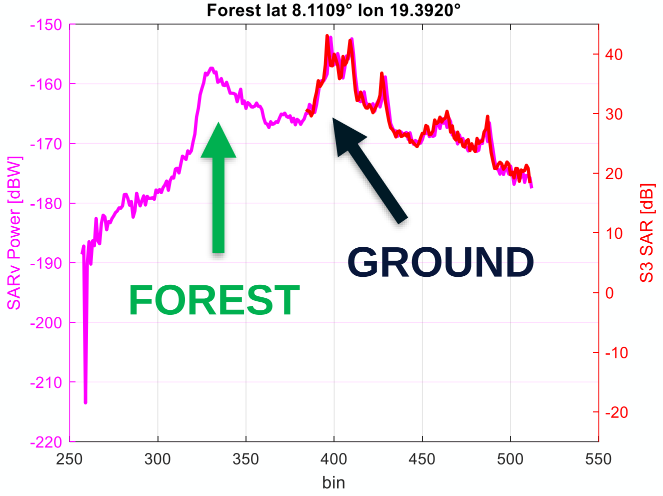
FOREST SCENARIO

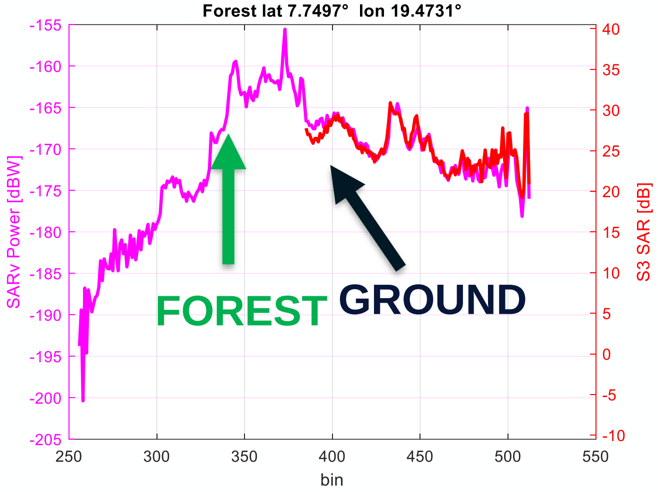
S-3 SAR vs SARvatore

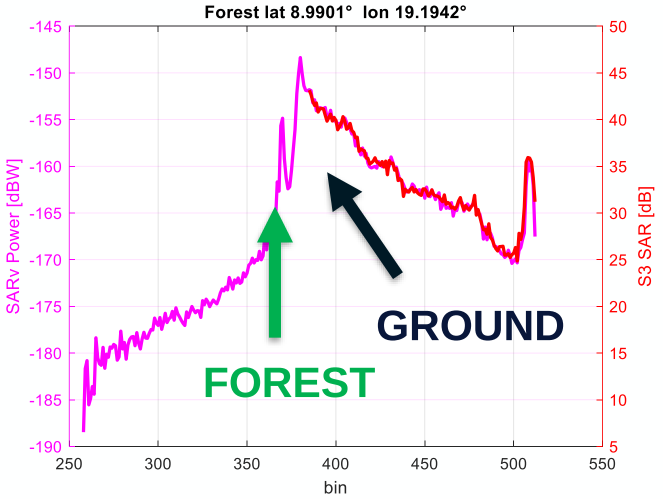
Hp ???

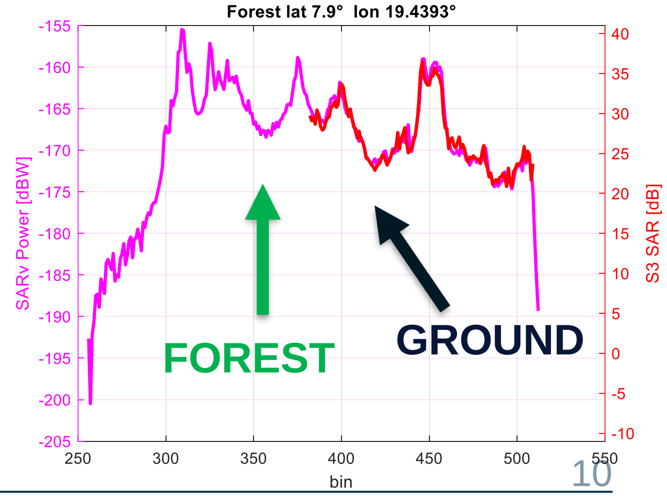
Central African Republic









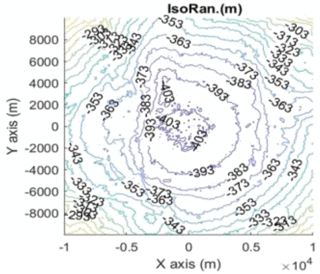


Over forest:

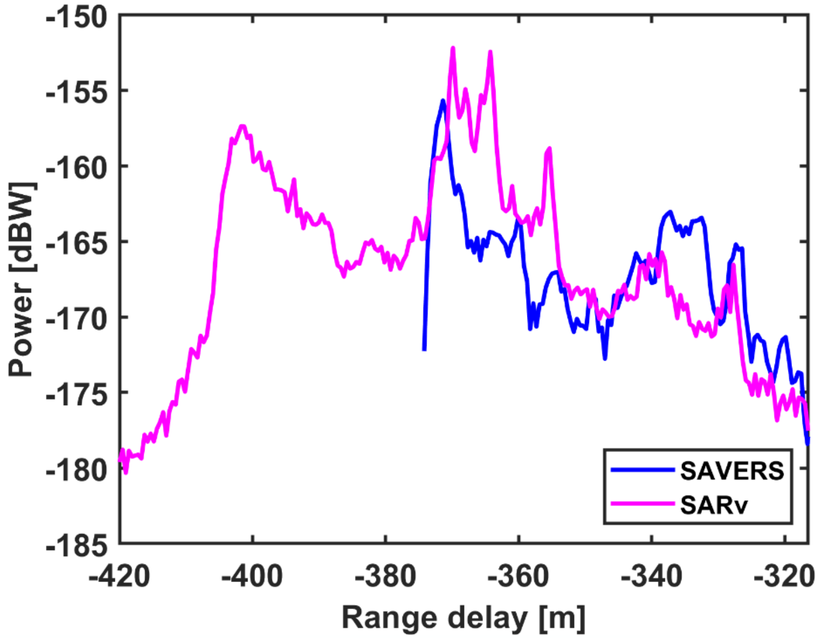
- S-3 does not reproduce all the peaks of SARvatore waveform
- S-3 shows a clear truncation that misses the leading edge (Jiang et al., 2020)
- SARvatore shows more than one peak

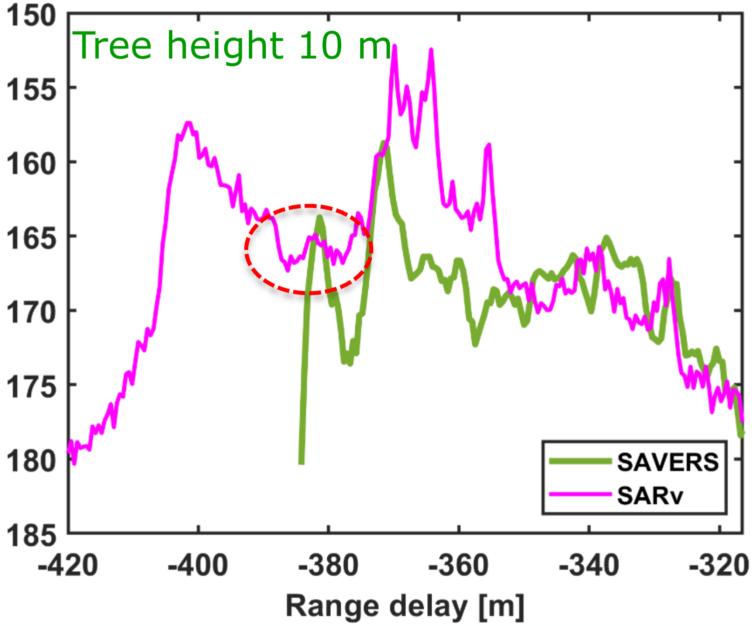
COMPARISON WITH SARvatore DATA

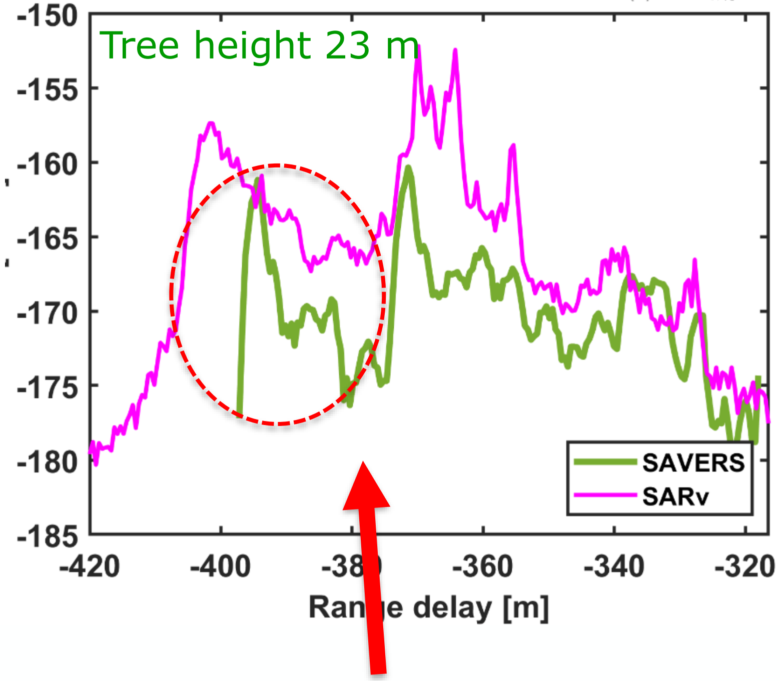
Central Africa Scenario
Lat=8.1109° Lon=19.3920°
Open loop



Bare soil simulation







SARvatore-SAVERS BARE SOIL comparison

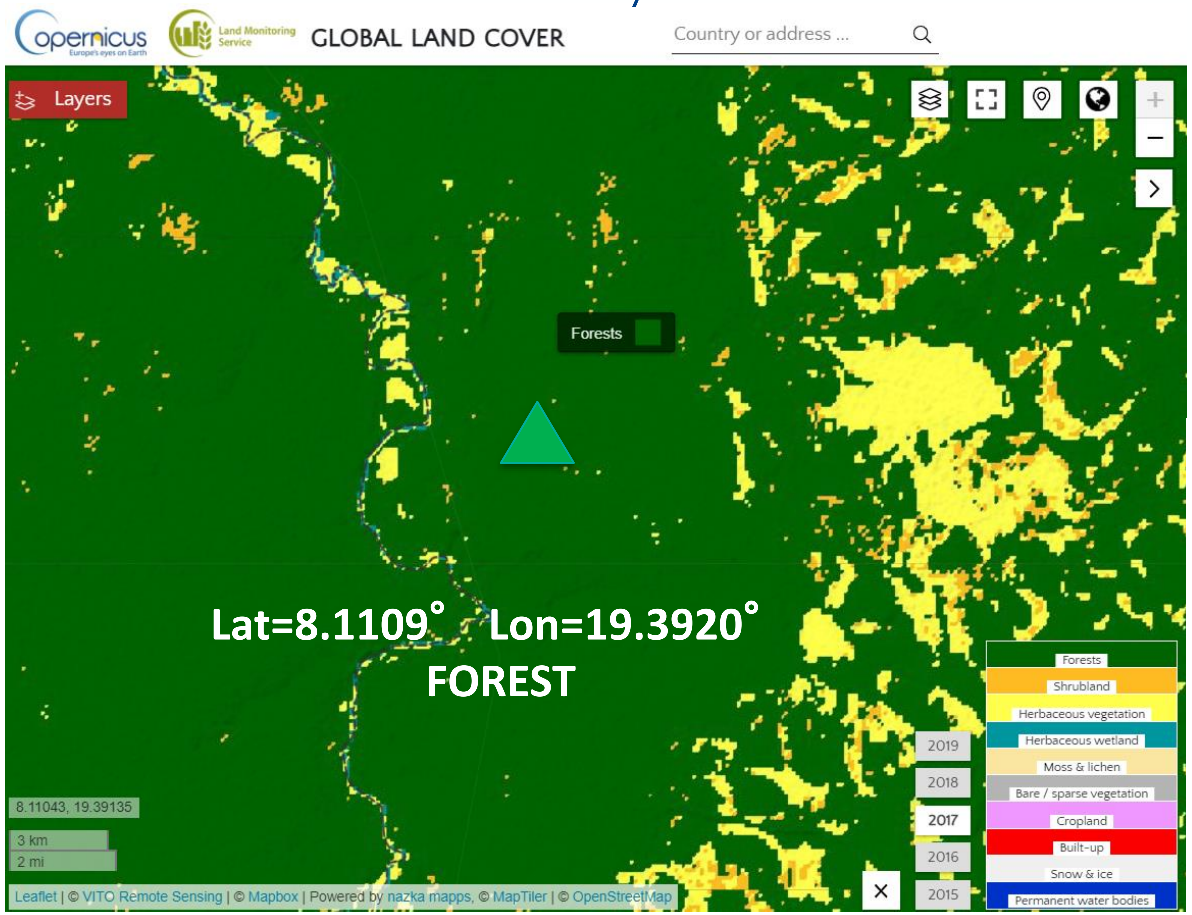
- Worse similarities

SARvatore-SAVERS FOREST comparison

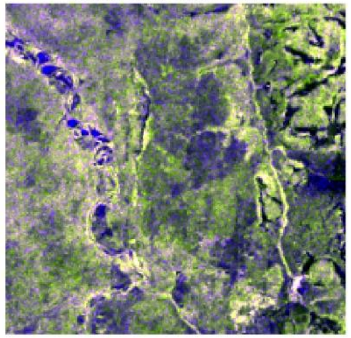
- Greater similarities with increasing values of forest height

LAND COVER & SENTINEL-1 SAR L1 images OVER CENTRAL AFRICA

Land Use and Land Cover (LULC) classifications at global scale for the year 2017

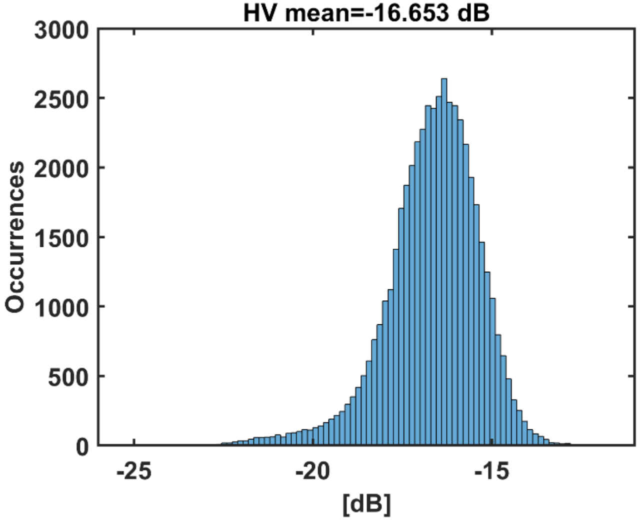


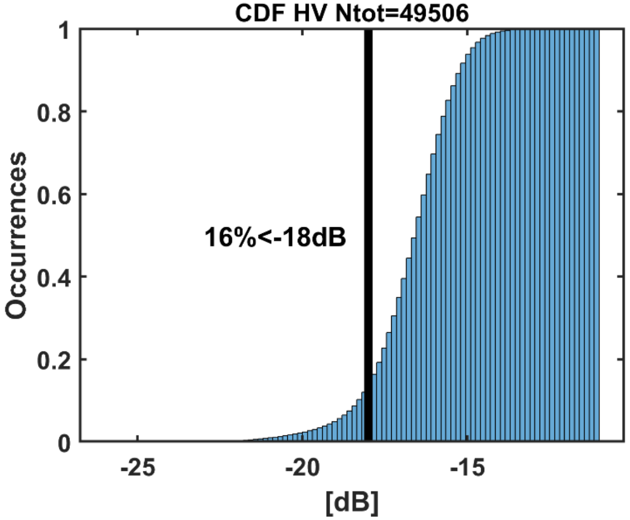
SENTINEL-1 SAR L1 RGB Image cuts of 20kmx20km around altimeter Nadir, and multilooked at 100m



CDF HV POLARIZATION

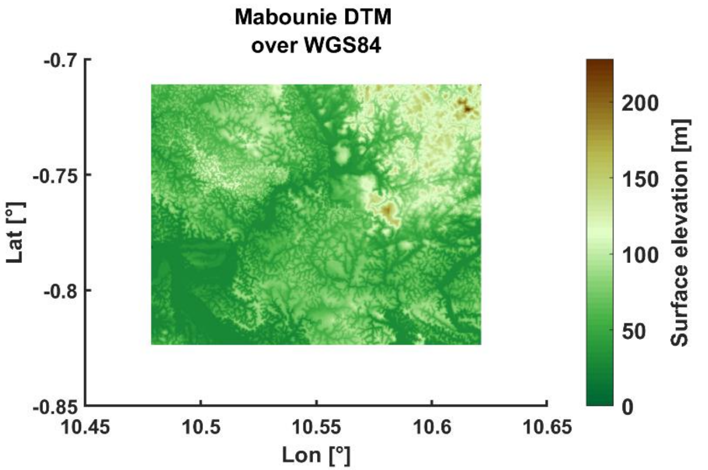
16% of pixels has σ^0<-18dB
FOREST

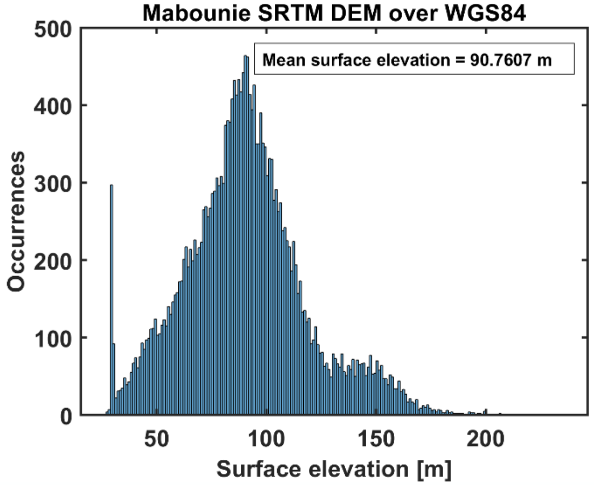


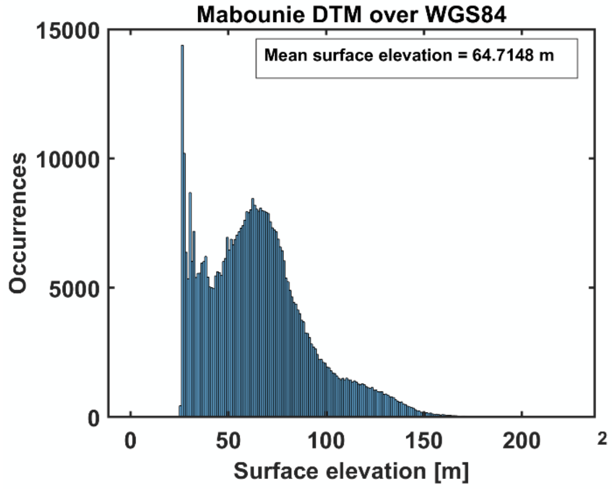


AFRISAR SITE: MABOUNIE DTM

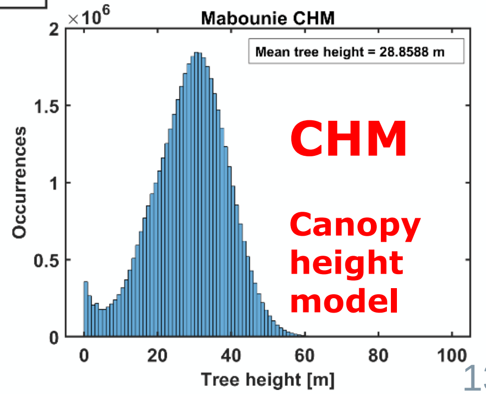
- **SRTM InSAR measurements are not sufficient** to clearly locate the ground level, typically **over forests**
- In order to verify the hypothesis of a bad evaluation of the surface height by the SRTM DEM, the **SRTM DEM over Mabounie** coordinates has been compared with **Mabounie lidar DTM** provided by the AfriSAR campaign







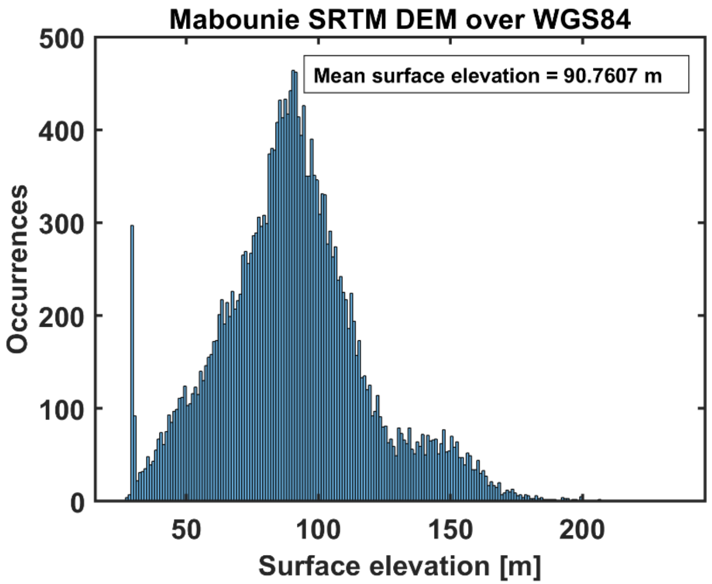
ΔElevation ≈ 26 m

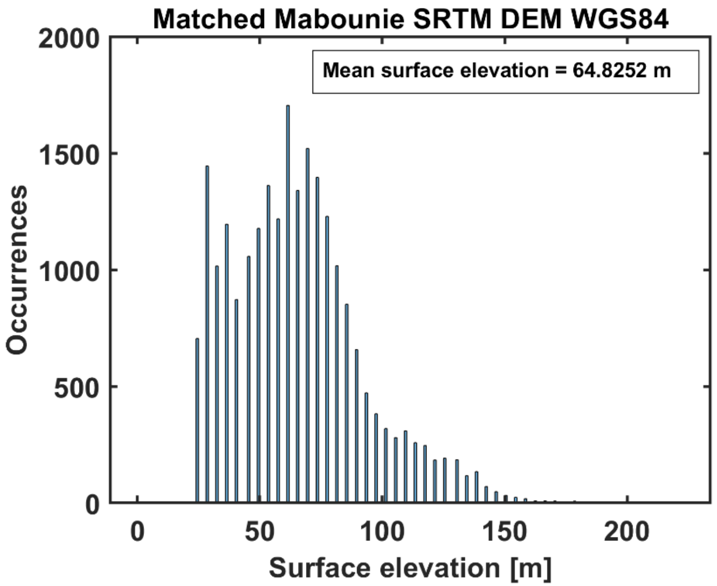


The comparison confirms that **the error of the SRTM DEM over vegetated areas corresponds to the tree height** of the area

AFRISAR SITE: HISTOGRAM MATCHING

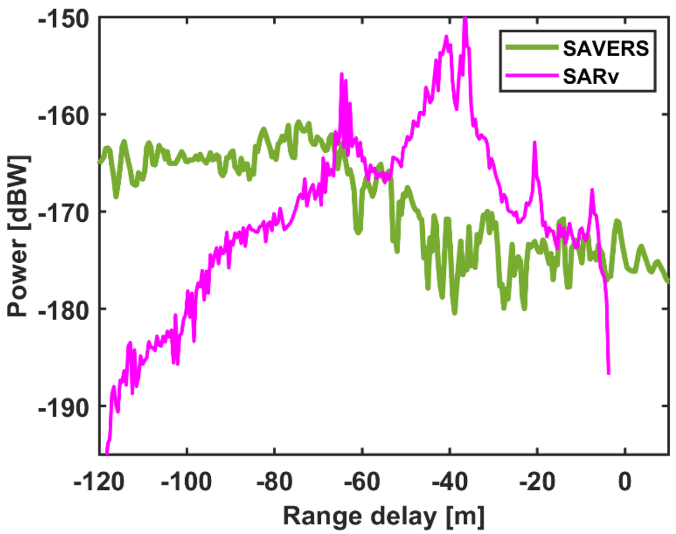
- **To reduce the error** introduced on the computation **of the range delay** in the simulations due to the inadequacy of the SRTM DEM over forest, **a histogram matching technique has been applied on the SRTM DEM patch over Mabounie**, using as reference the Mabounie DTM histogram

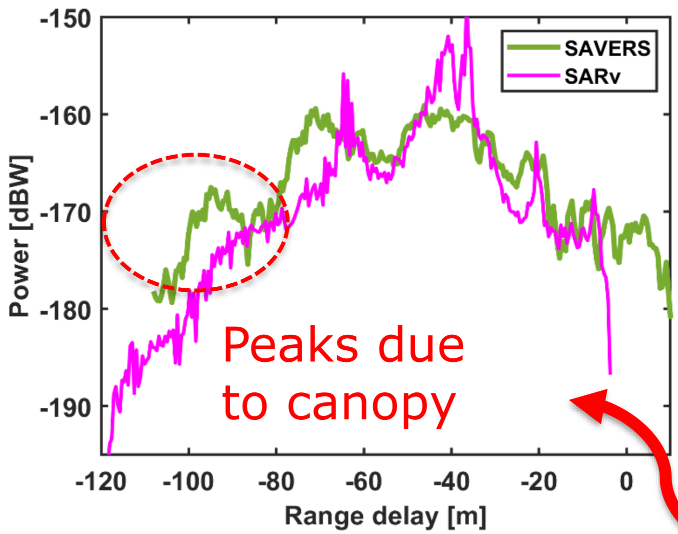


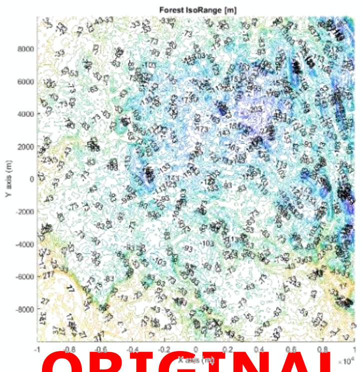


The matching method has produced a **reduction of the original surface elevation of about 26 m**

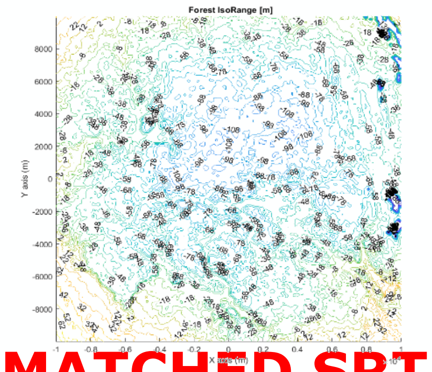
AFRISAR SITE: HISTOGRAM MATCHING







ORIGINAL SRTM DEM



MATCHED SRTM DEM

GABON
Lat=-0.7600°
Lon=10.6089°
Tree height= 23m

Over the coordinate **latitude = -0.7600°** and **longitude = 10.6089°**, we can appreciate **good similarities through the use of the histogram matching in the simulation**

CONCLUSION

- The analysis of the waveforms demonstrates that the **increasing surface complexity increases the complexity of the waveform shape.**
- The simulations related to forested surfaces present at least **two peaks, due to the top of canopy and to the ground.**
- Despite the composite patterns, **the developed simulator proved its capability to reproduce the main characteristics of the S-3 SARvatore waveforms**, both for bare soil and forest.
- **The range delay estimated by SAVERS agrees quite well with S-3 measurements over bare soils**, with and without topography, however, **does not work well over forest scenarios**.
- To explain the range mismatch, we made the hypothesis that **the SRTM DEM included in the simulator to evaluate the range delay was not enough accurate over areas covered with vegetation**.
- **Through the histogram matching technique a better correspondence** has been obtained between the simulated and experimental waveforms **over the Mabounie site where a lidar dtm is available**.

- For further info on the **ALBIOM Project** you could visit https://eo4society.esa.int/projects/albiom/

- And read our **two PAPERS published on IEEE TGRS (2022)**

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An Electromagnetic Simulator for Sentinel-3 SAR Altimeter Waveforms over Land Part I: Bare Soil

Giuseppina De Felice Proia, *Member, IEEE*, Marco Restano, Davide Comite, *Senior Member, IEEE*, Maria Paola Clarizia, *Senior Member, IEEE*, Jérôme Benveniste, Nazzareno Pierdicca, *Senior Member, IEEE*, and Leila Guerriero, *Member, IEEE*

***Abstract*—ALtimetry for BIOMass (ALBIOM) is a Permanent Open Call Project funded by the European Space Agency (ESA) to explore the possibility of forest biomass retrieval by using Copernicus Sentinel-3 (S-3) Synthetic Aperture Radar Altimeter (SRAL) in low- and high-resolution mode at Ku- and C-bands. It represents an original work in the research of new techniques for vegetation observation using altimetry data. Because of the complexity of the land surfaces, no algorithm has been developed for a specific retracking of the altimetric land waveform. This calls**

and shape of the altimeter echoes it can be difficult to determine which bin corresponds to the terrain nadir return in the altimeter waveform, and what kind of cover is. Most of the effort considers ground-based processing (i.e., retracking) optimized for ocean application in order to obtain some results over land. For this reason, developing an electromagnetic simulator of land waveforms is of paramount importance, and it may clarify the role of the different geometrical and dielectric properties of

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An Electromagnetic Simulator for Sentinel-3 SAR Altimeter Waveforms over Land Part II: Forests

Giuseppina De Felice Proia, *Member, IEEE*, Marco Restano, Davide Comite, *Senior Member, IEEE*, Maria Paola Clarizia, *Senior Member, IEEE*, Jérôme Benveniste, Nazzareno Pierdicca, *Senior Member, IEEE*, and Leila Guerriero, *Member, IEEE*

***Abstract*—Forests play a crucial role in the climate change mitigation by acting as sinks for carbon and, consequently, reducing the CO_2 concentration in the atmosphere and slowing global warming. For this reason, above ground biomass (AGB) estimation is essential for effectively monitoring forest health around the globe. Although remote sensing–based forest AGB quantification can be pursued in different ways, in this work we discuss a new technique for vegetation observation through the use of altimetry data that has been introduced by the ESA-funded**

role of forests is considered. Over the last decades, the scientific community has recognized forest biomass as one of the Essential Climate Variables (ECVs), fundamental in understanding carbon sources and sinks and in diminishing haziness in our awareness of the climate system [3]. Biomass can be estimated indirectly in different ways by means of remote sensing [4]. This has produced a large literature on biomass evaluation, yet it is commonly agreed that neither a

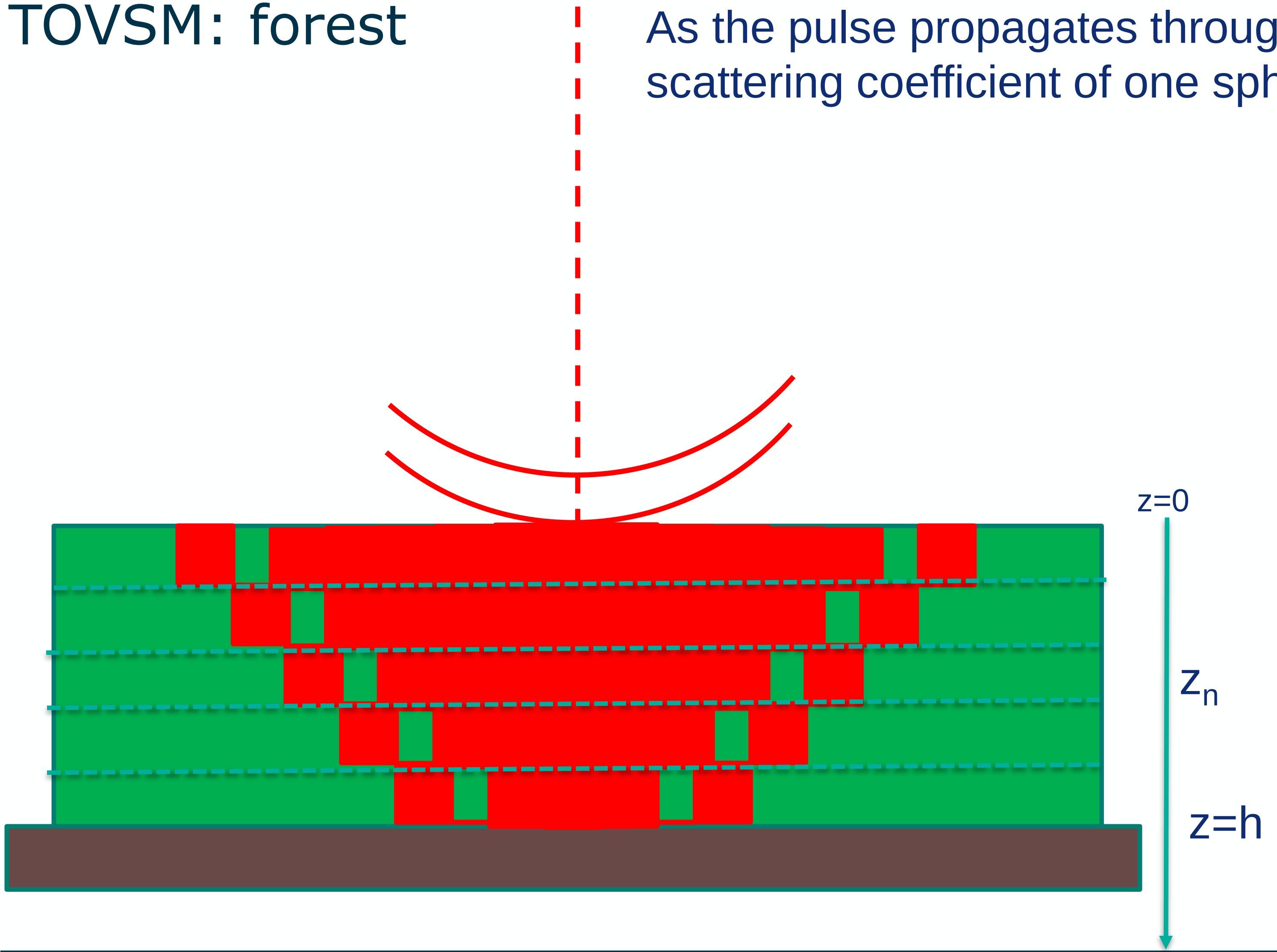
THANKS

FOR YOUR ATTENTION!

BACKUP SLIDES

TOVSM: forest

As the pulse propagates through the crown, the altimeter sees the scattering coefficient of one spherical shell at a time.



The incident and scattered power are attenuated by the above layers.
Both **volume scattering and attenuation increase as the number of layers increases**.

Through **Matrix Doubling**, it is possible to calculate the backscattering coefficient of each shell, adding one layer at a time.

N.B. TOVSM is a discrete scattering model, i.e. vegetation is not a homogeneous layer, but an ensemble of discrete scatterers

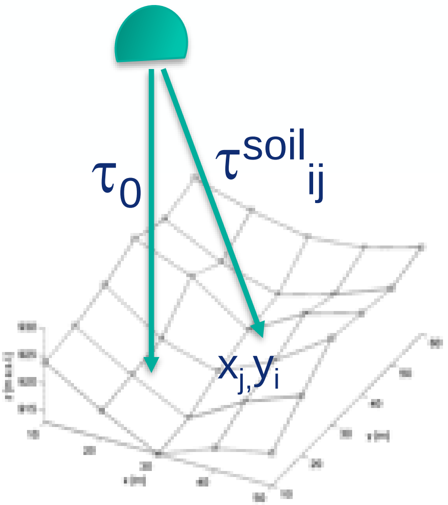
TOVSM: Combination with SAVERS model

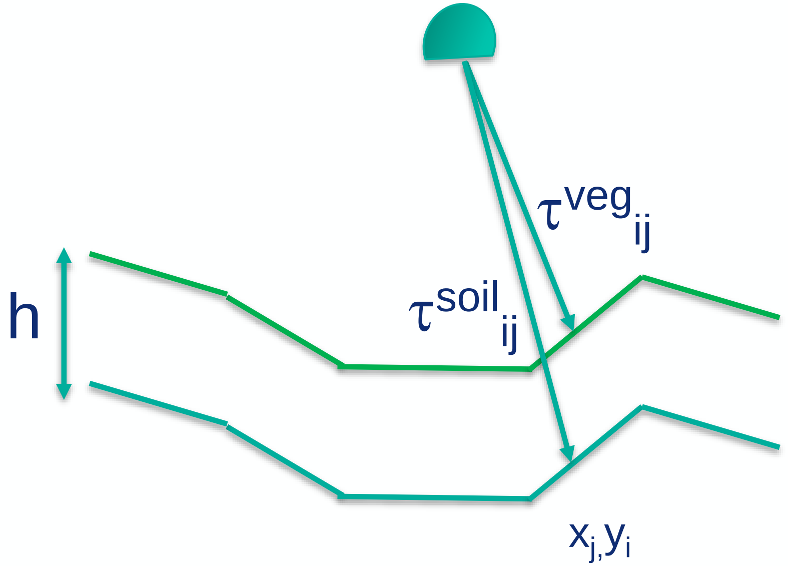
SAVERS is able to model the difference between the range/time delay τ^{soil}_{ij} of the altimetric signal received from any point on the observed surface (x_j, y_i) and the one received from the subsatellite point on the ellipsoid τ_0, considering a DEM=f(x,y).

A second DEM is calculated that takes into account the forest height h:

$$DEM^{veg}=f(x,y)+h$$

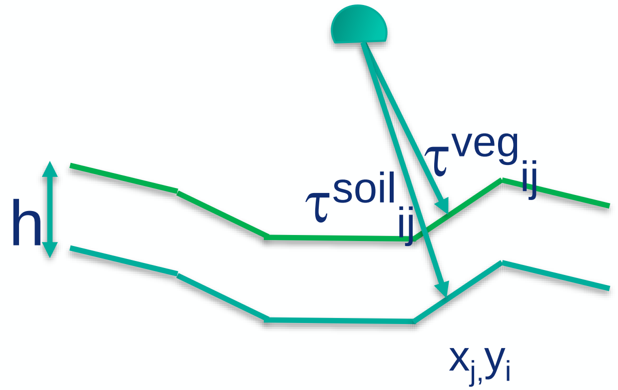
(h is supposed constant for each $x_j y_i$)





TOVSM: Combination with SAVERS model

For each surface element with coordinates (x_j, y_i) **two delays**, τ^{soil}_{ij} and τ^{veg}_{ij}, are compared with the sample delay τ', and then used to calculate the impulse response function.



The contribution from element $x_{j,}y_i$ will be included in the radar equation weighted by the Impulse function and coupled with

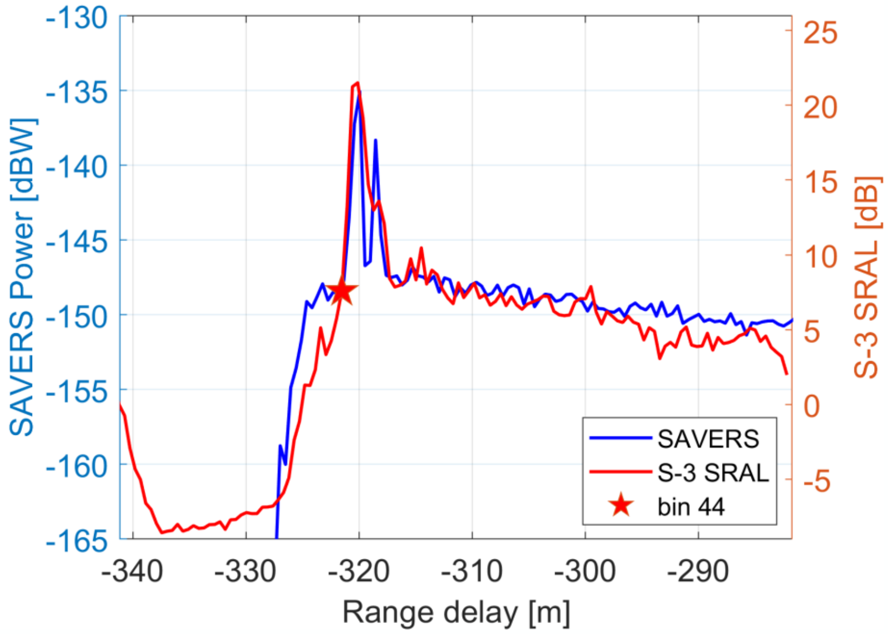
σ^0=Aσ^{0soil} or with **σ^0_{veg}** **created with the TOV model**

COMPARISON WITH S-3 SRAL DATA

FLAT SCENARIO over bare soil

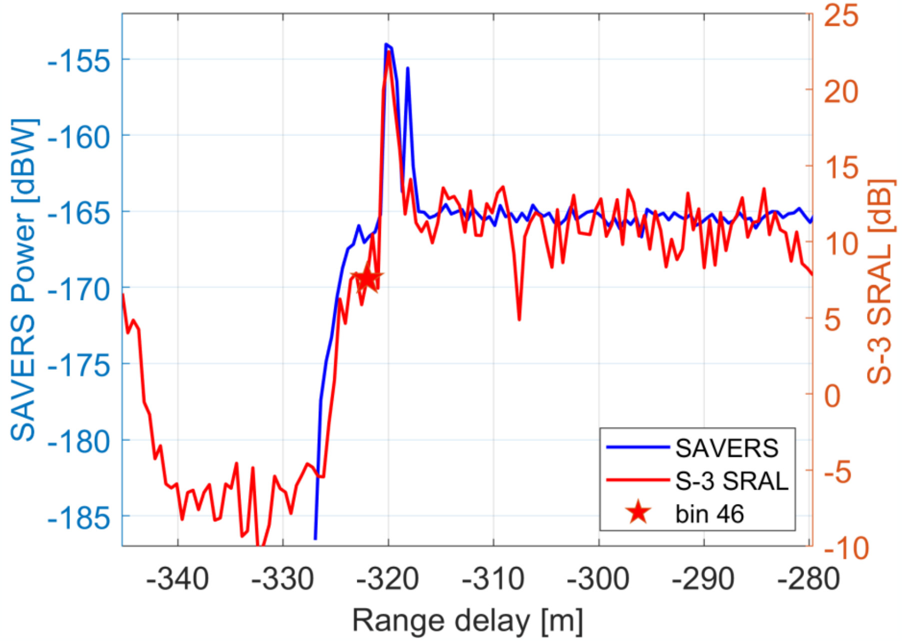
CHAD SAHARA
Lat=13.9999°
Lon=18.0522°

❑ PLRM Ku-band



- **Good agreement in leading and trailing edge slope**

❑ C-band



- **Good agreement of the leading and trailing edge slope**
- Experimental trailing edge is rather noisy (more than Ku-band)