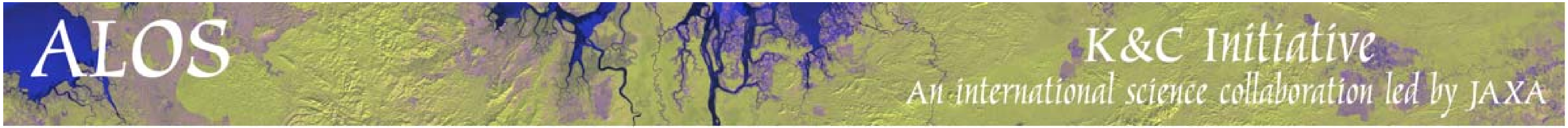


Wide area forest monitoring of Insular SE Asia and Guiana Shield

Dirk Hoekman
Wageningen University

20th Science Team meeting
RESTEC HQ, Tokyo, December 4-6, 2013

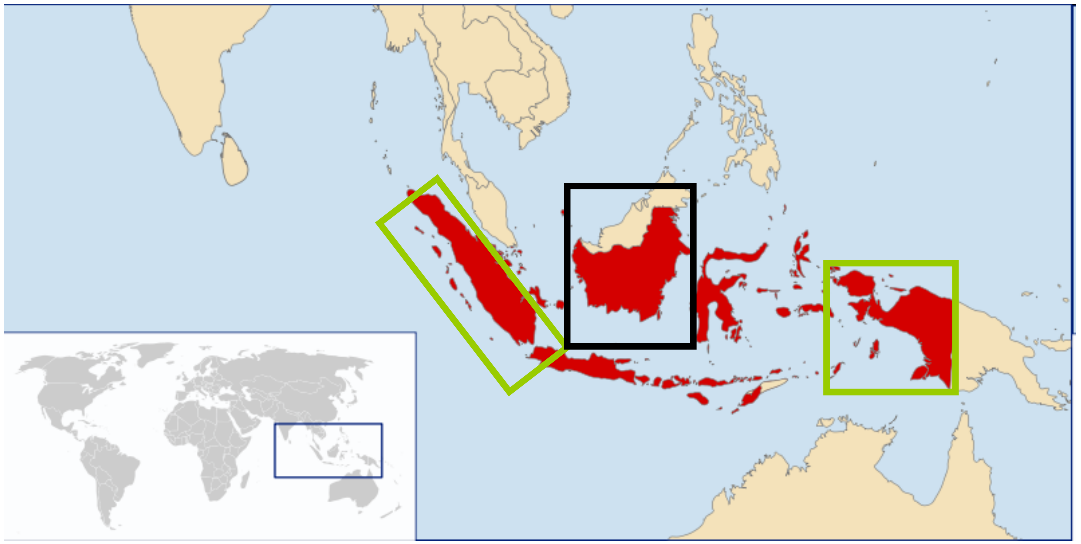
Collaborators

- LAPAN, Jakarta, Indonesia
- Equipe de Conservação da Amazônia (Amazon Conservation Team), Brasilia, Brazil
- IMAZON and SEMA-Pa, Belém, Brazil
- SarVision
- Wageningen University

Project area(s)

Focus on two major biomes with persistent cloud cover:

- **Guiana Shield**, with focus on Guyana, Suriname and Brazilian state of Para
- **Insular SE Asia**, with focus on Borneo, Sumatra and Papua (Indonesian part of New Guinea)



Project objectives

Primary objectives (done; see KC18)

The project primarily aims to develop techniques to improve time-consistency (and avoid error propagation) over wide areas.

This includes the automated adaptation of radar signatures to changing environmental conditions and the use of ScanSAR data to support classification in dynamic and irregularly inundated areas.

Note: Integration with Landsat is studied for development of high accuracy "GFOI Forest Information Products" (see KC18 and SDS-4)

Project objectives

Secondary objectives

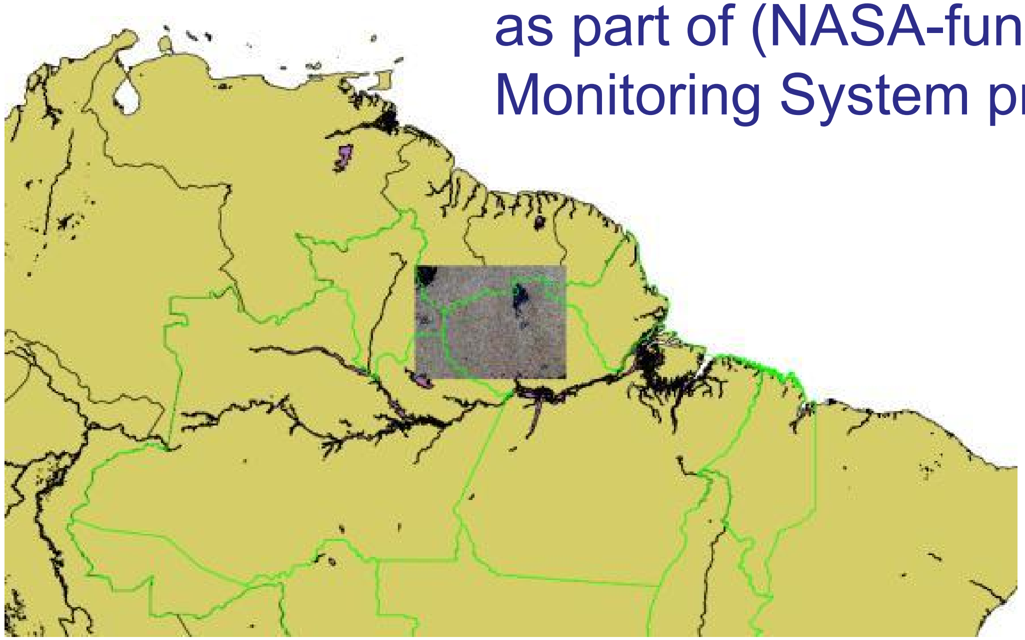
To improve **classification** and **biomass stratification** accuracy (and spatial resolution) it is intended to address technical issues such as:

- Further development of slope correction by adaptation to terrain characteristics (done; shown hereafter)
- Study of the utility of texture (and preferably using 10 m mosaic data)
- Processing of denser time series and application of multi-temporal speckle filtering (done; see KC18)

Schedule next 5 months

Mapping of "Calha Norte" using a time-series of 25 m strip data mosaics (13 observations in 2007-2010); in cooperation with IMAZON, SEMA-PA and ECAM; development of REDD-projects and environmental protection (examples shown hereafter)

Mapping of Borneo (idem); Biomass stratification map as part of (NASA-funded multi-sensor) Carbon Monitoring System project (with Bill Salas)



Note these data are available since early 2013. Orthorectification problems were solved late summer 2013.

Support to JAXA's global forest mapping effort

Validated land and forest cover maps of Borneo and Surinam show the potential of PALSAR for global forest mapping.

Possibly more areas follow soon such as a 500x700 km^2 area in the state of Para (early 2014), and other areas in Indonesia. The techniques were also applied in Colombia (TNC K&C project).

Ground truth: Photo flights in Suriname (2010), Borneo (2011), Guyana (2011) and possibly more (2014). Field campaigns in Guyana (2011) and several in Borneo (up to 2013) and possibly Brazil.

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Deliverables

- Wide area forest maps
  - Maps of Borneo (50 m, consistent 2007-2010 series)
  - Map of Surinam (50 m)
  - Map(s) of Borneo (25 m)
  - Map of “Calha Norte”, Brazil (25 m)
- Several papers (consistent mapping; slope effects; biomass stratification)
- Final report

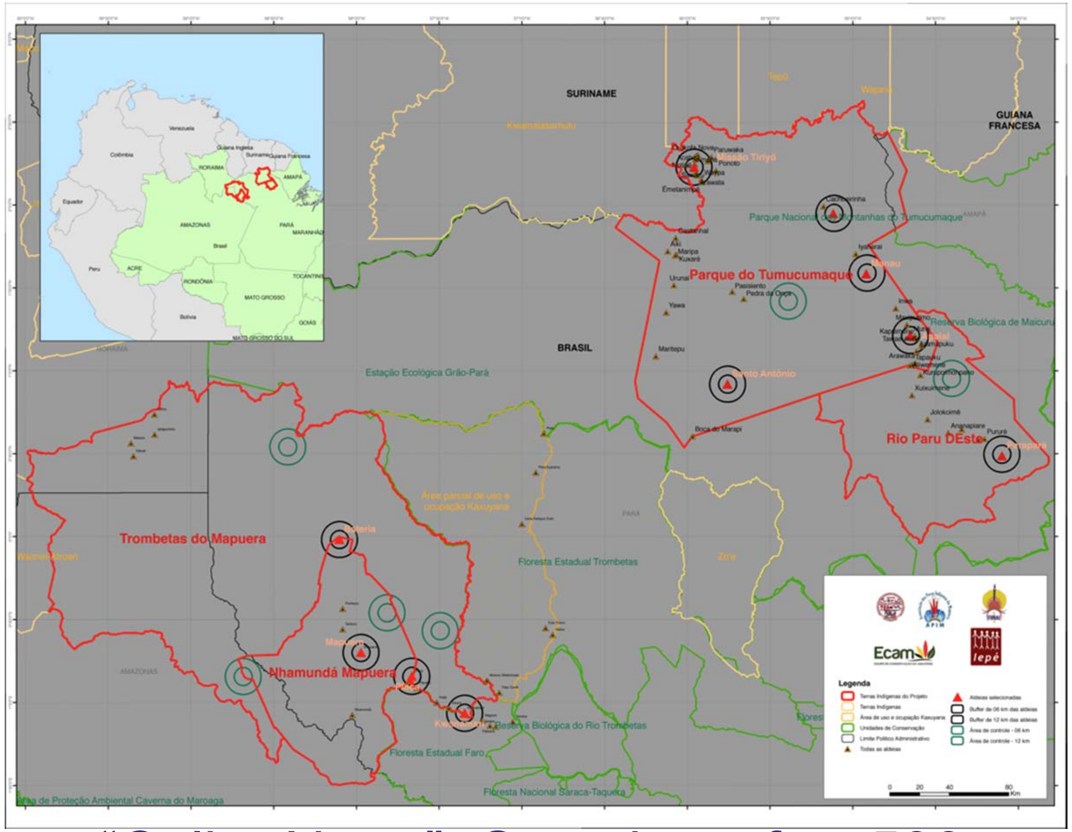
K&C studies yielded relevant progress and insights for wide area mapping (shown in previous presentations) such as: time series (consistent annual mapping, intercalibration, MT speckle filtering), automation, slope effects, adding C-band, …

Much development was done within radar capacity building programs in Indonesia (LAPAN), Suriname and Brazil (state of Para). Advantages of this approach are: (a) better access to local terrain data and knowledge; (b) map production by local partners necessary for law enforcement and reporting (legal status of maps)

Remaining problem: sparse ground truth, especially for hilly/mountainous areas, is best solved when done by country itself.

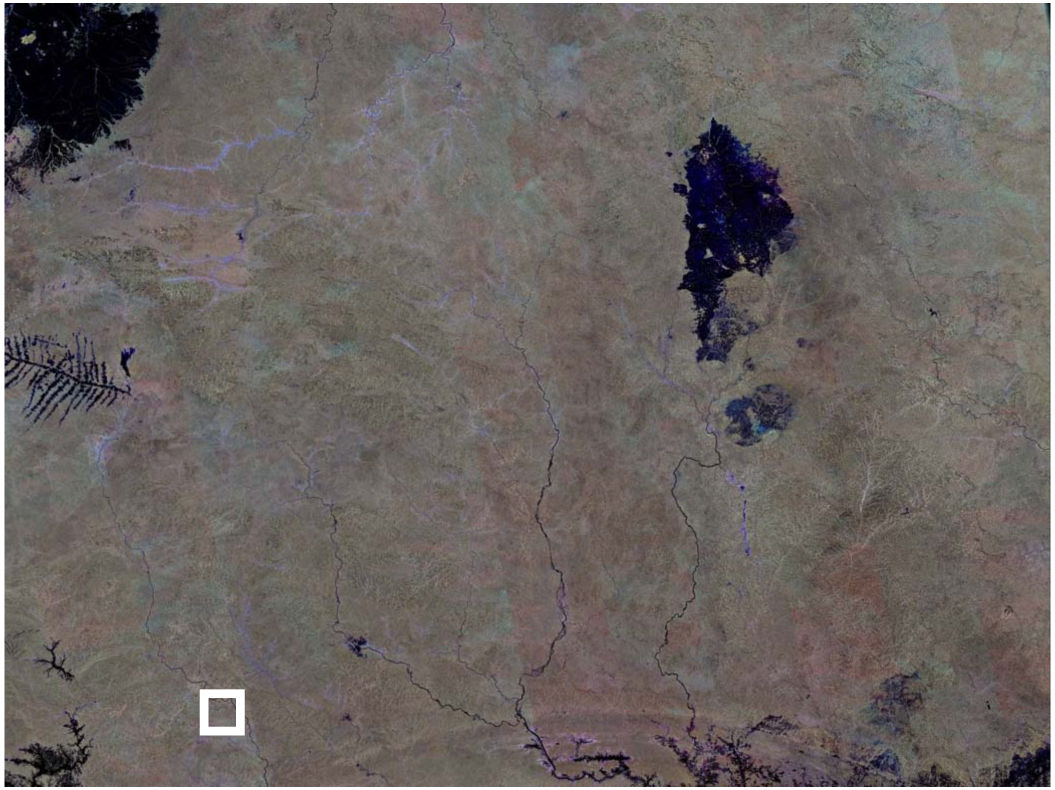
Own materials to show:

- Mapping of the “Calha Norte” (Brazil) sparse ground truth area
- Modeling and accounting for 2nd order slope effects in Rupunini (Brazil)



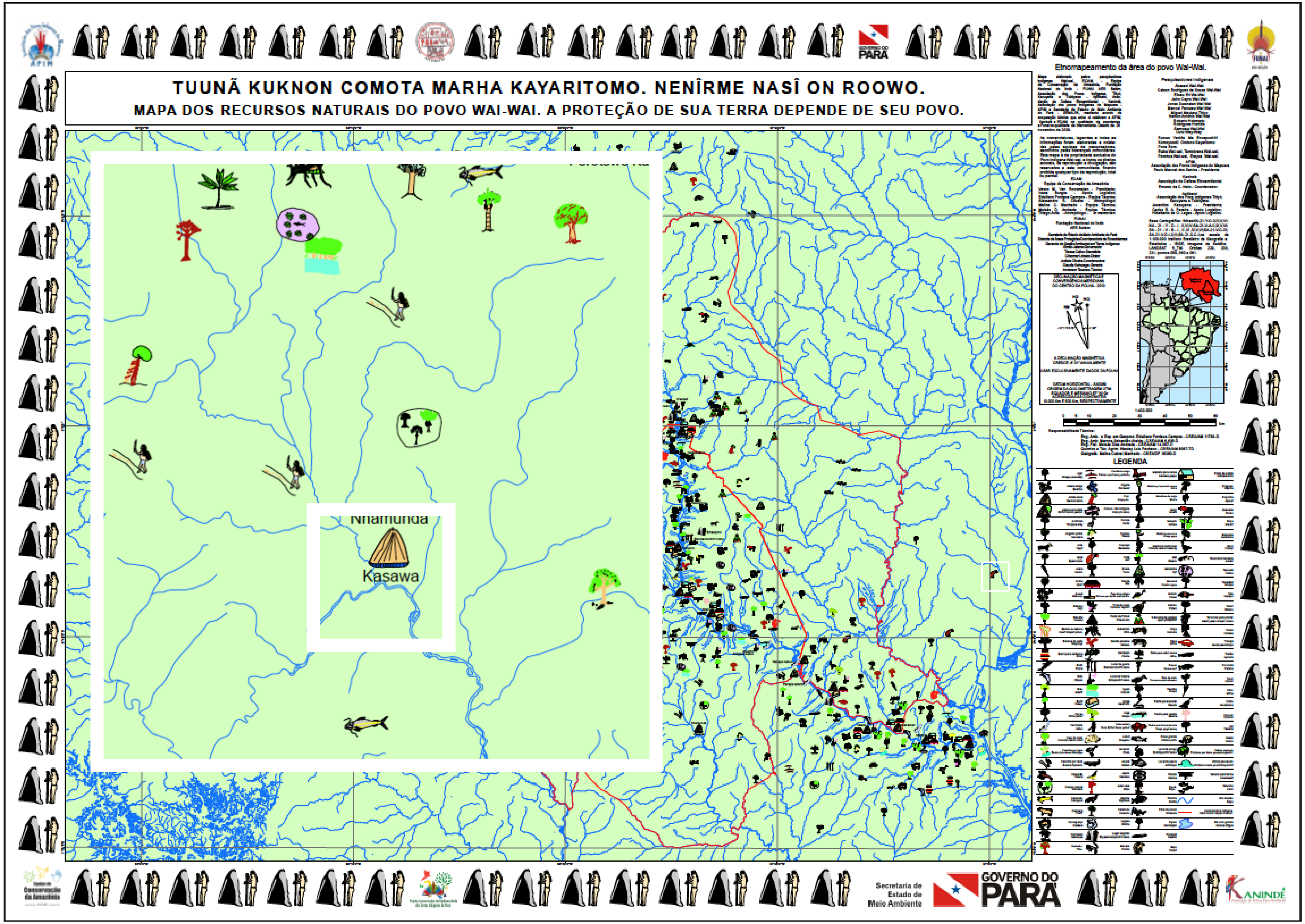
“Calha Norte”: Overview of ± 500 x 700 km^2 area of interest.

Trombetas-Mapuera and *Tumucumaque* indigenous parks.

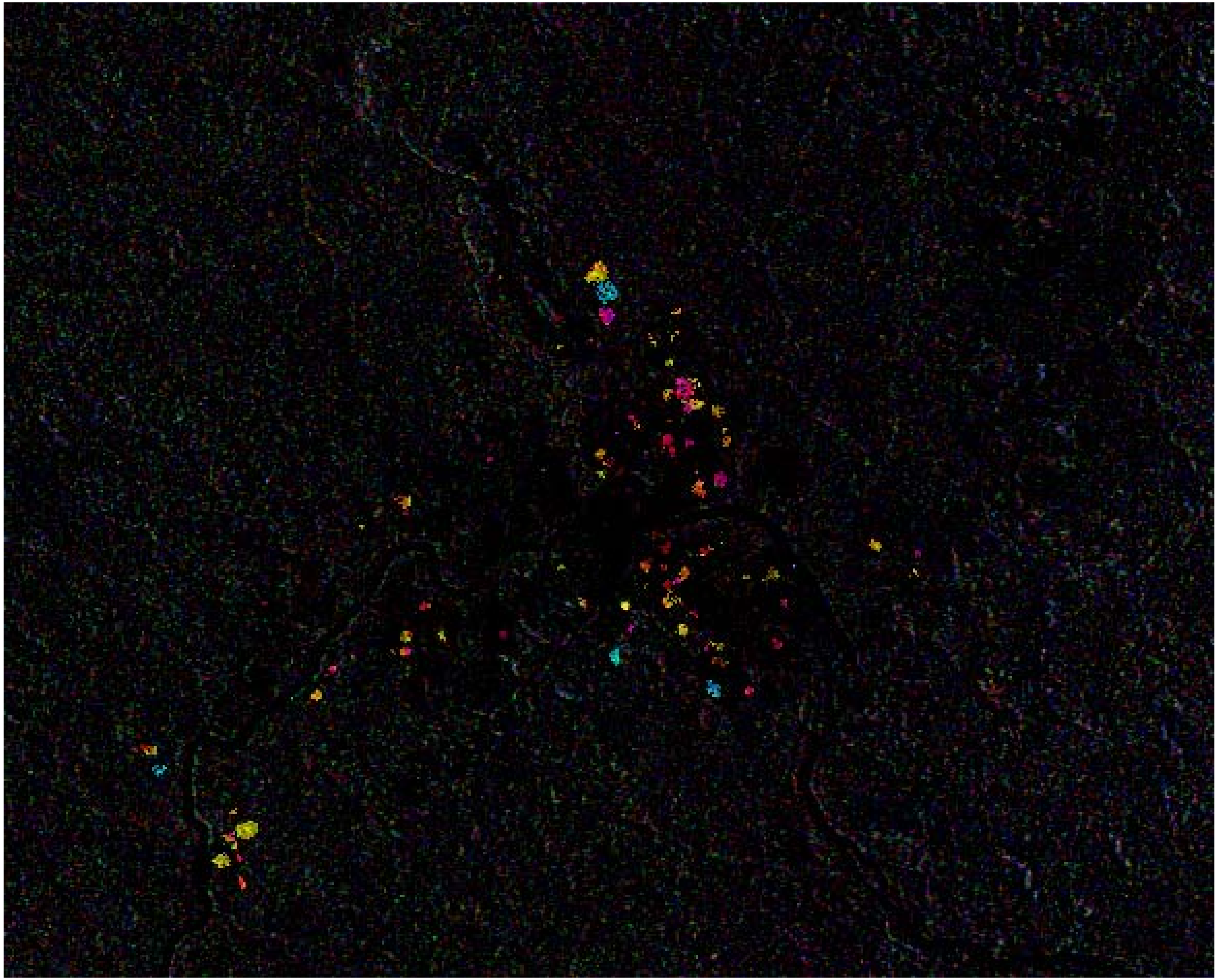


PALSAR mosaic of same area.

White box indicates approximate location of *Nhamundá Kasawa* village (± 15 x 12 km^2).



Cultural map of *Wai-wai*

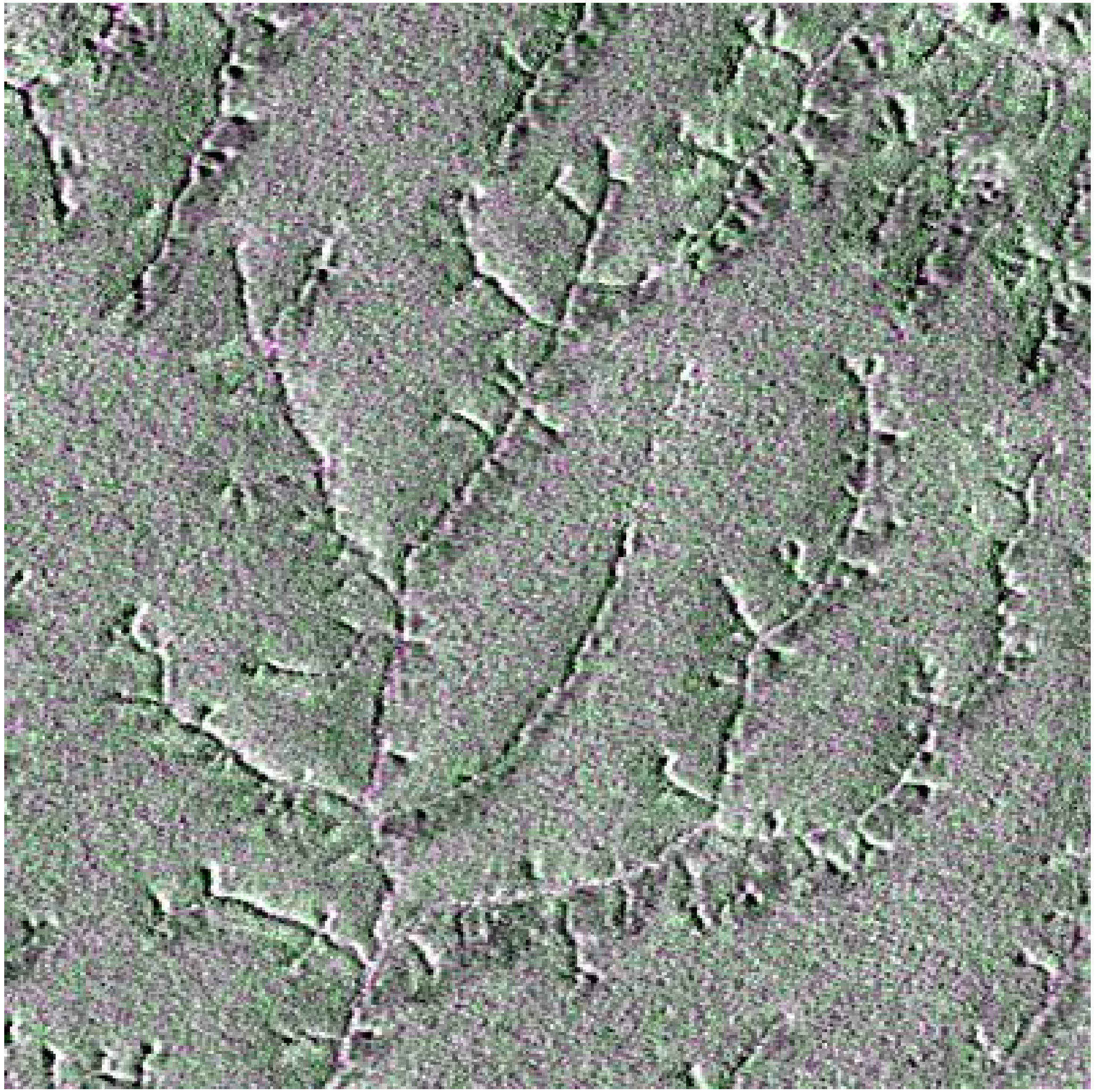


Large rivers in cultural map are derived from Landsat; small rivers from local knowledge

MT filtered 25 m res radar can see much more rivers than present on the cultural map (and on Landsat).

Small plots (>50m) of shifting cultivation are clearly visible in dedicated 25 m filtered time series. This example shows three (out of the 8 FBD) dates:
•22-Jul-2007 (red);
•11-Sep-2009 (green);
•14-Sep-2010 (blue).

Future application: monitoring of (legal) mining in indigenous parks by SEMAS-Pa.



25 m data shows many of the smaller rivers not well visible on 50 m strip data

MT filtered 25 m res radar can see much more rivers than present on the cultural map (and on Landsat).

Models to compensate for slope effects

There are two types of physical models that normalize the number of scatterers.

The first was introduced (1990) and validated (1993) by Hoekman and models the slope as an isotropic opaque volume scatterer. The second was introduced by Ulander (1996) and models the slope as an isotropic surface scatterer. Both are exact solutions.

In many publications other models are introduced. Most are approximations of the second model, or (semi-) empirical models that work for a specific type of terrain only and introduce large errors elsewhere.

Dense forests can be modeled very well by the first model. The second model would be valid for very rough surfaces on slopes, but these are relatively rare for radar.

In practice both models need correction in case (1) the validity of the model does not hold (for example when forest is not dense) or (2) because the scatter mechanisms change with (local) incidence angle.

To handle this appropriately the next is developed.

Some definitions:

Using:

θ_i	angle between zenith and backscatter direction, or incidence angle
θ_Δ	angle between surface normal and backscatter direction, or local incidence angle
ϕ_i	radar look direction
ϕ_s	slope direction (uphill)

The following can be computed:

ϕ_r	slope direction relative to range direction (= $\phi_{i-} - \phi_s$)
α_r	slope angle in range direction
α_{az}	slope angle in azimuth direction

and it follows that $\cos(\theta_\Delta) = \cos(\alpha_{az}) \cos(\phi_i - \alpha_r)$.

The first model (slope normalization) is of the form: $\gamma = \gamma_f \, N_1(\theta_i \, , \alpha_r)$
The second model is of the form: $\gamma = \gamma_f \, N_2(\theta_i \, , \alpha_r \, , a_{az})$
They differ by a factor: $\cos(\theta_\Delta) \, / \, \cos(\theta_i)$

Second order correction depends on the terrain type *and* polarization and is of the form:

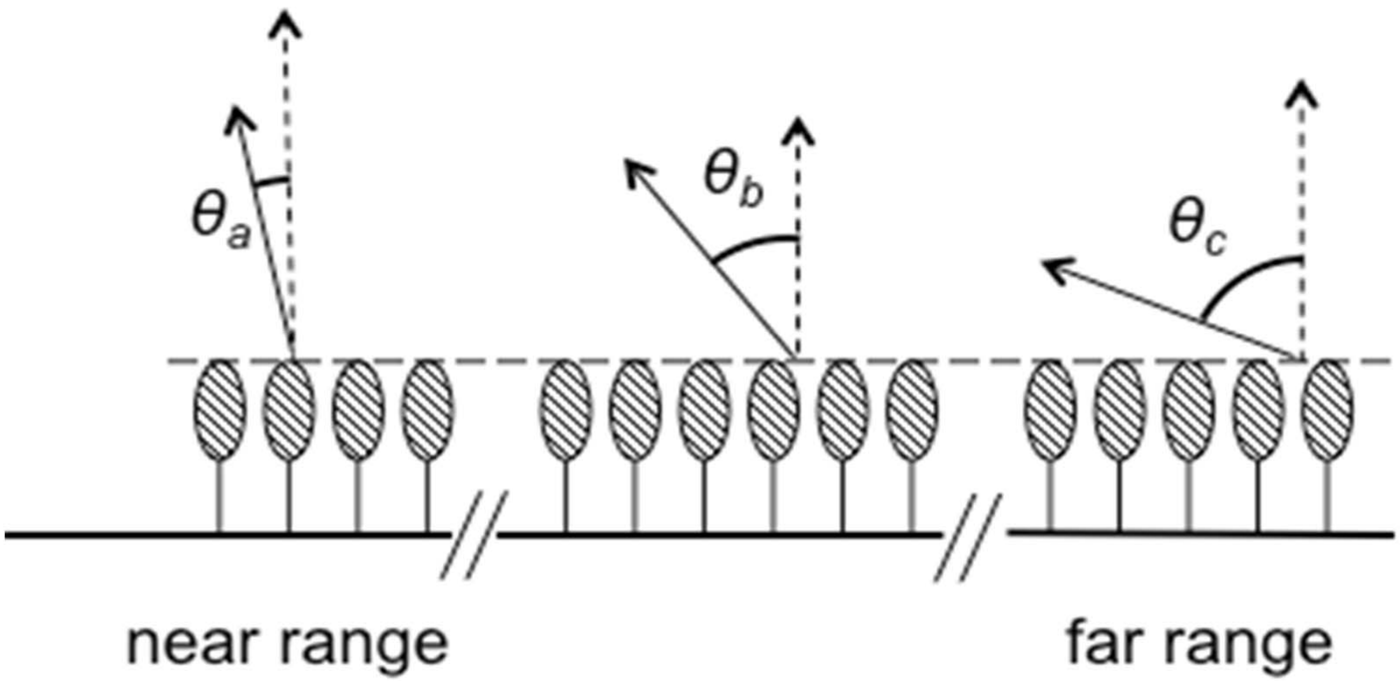
$$\gamma = \gamma_f \, N_1(\theta_i \, , \alpha_r) \;\; M_1(\theta_i \, , \alpha_r \, , a_{az})$$

where N_1 is the normalization for an isotropic volume scatterer and M_1 is the additional factor.

Note: consequently also M_1 and M_2 differ by a factor $\cos(\theta_\Delta) \, / \, \cos(\theta_i)$

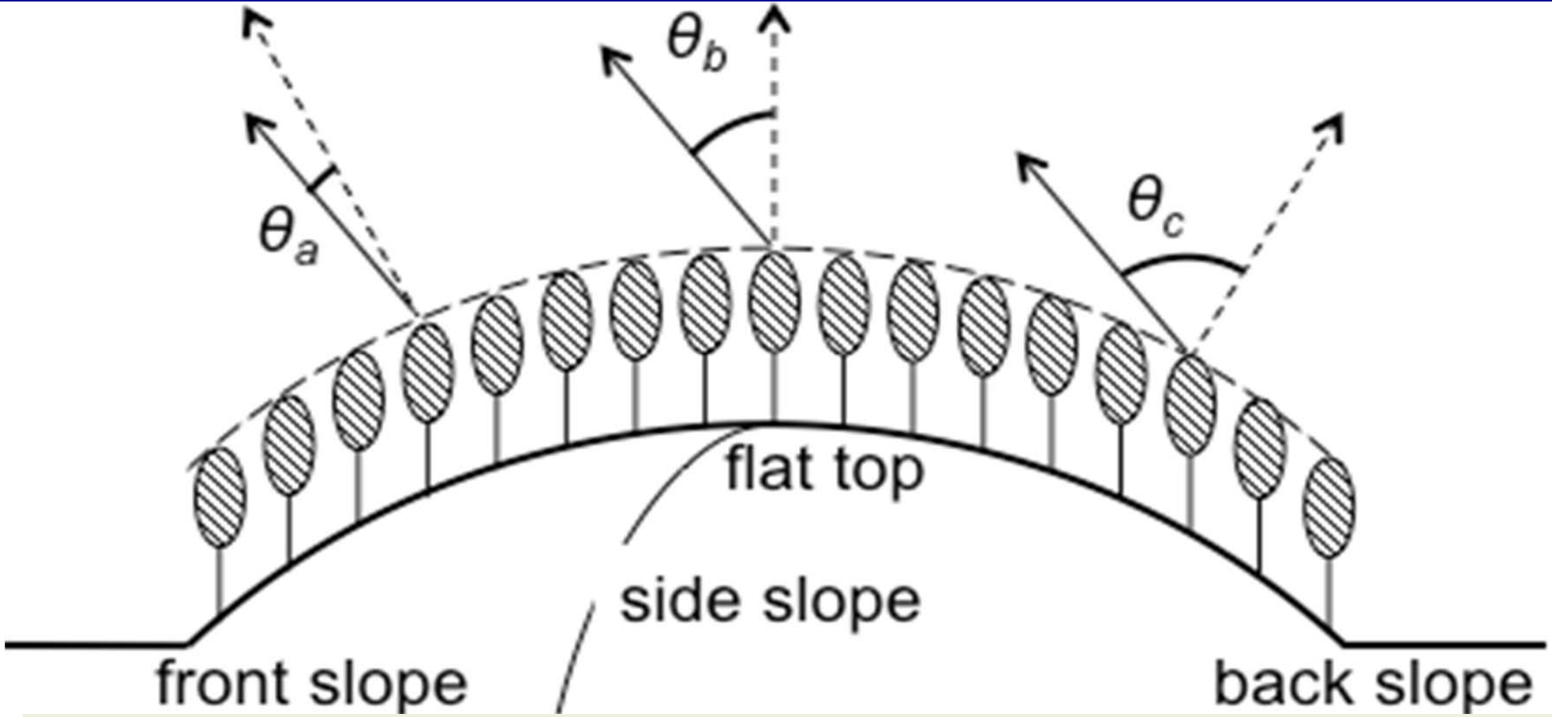
The second order correction N_1M_1 (or N_2M_2) is called the “third model”.

Slopes



Example of change in scattering mechanism as function of incidence angle: (a) At near range the incidence angle $\theta_i = \theta_a$ is small, the vertical penetration depth is large, and the soil surface may be visible through openings in the canopy. (b) At medium incidence angle $\theta_i = \theta_b$ the vertical penetration is less, but may be sufficiently low to cause a strong contribution from double bounce scattering between soil surface and trunk. (c) At far range the incidence angle $\theta_i = \theta_c$ is large and the vertical penetration depth can be low; backscatter may originate from the crown layer exclusively.

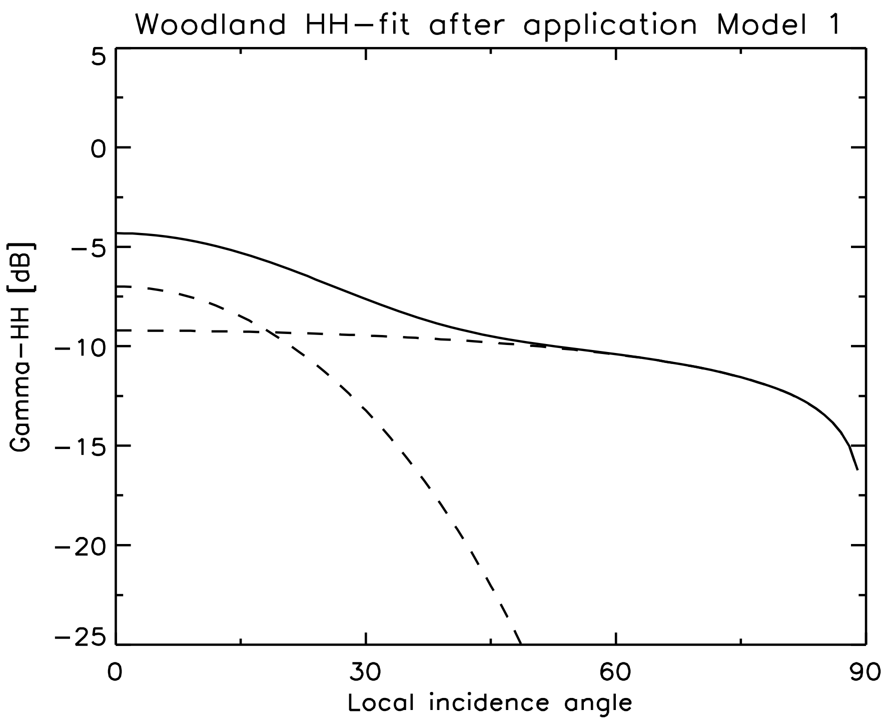
Slopes

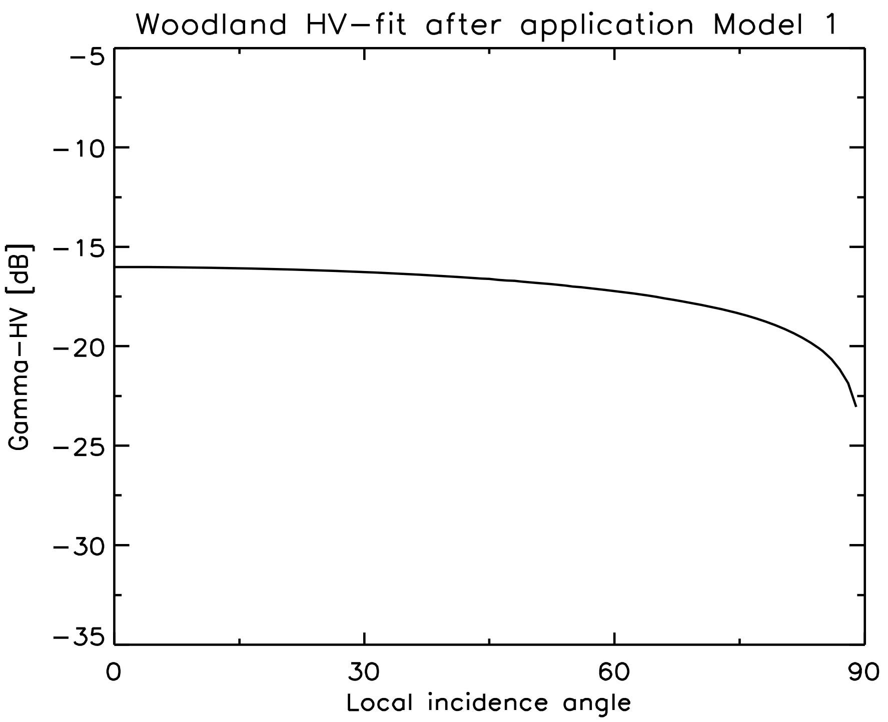


Example of change in scattering mechanism as function of local incidence angle: In comparison with flat terrain, changes in backscatter mechanisms in hilly terrain can occur at short distances, even at identical incidence angles. Moreover, backscatter mechanisms can differ from those found on flat terrain. (a) At the front slope the local incidence angle $\theta_\Delta = \theta_a$ can be small, and the vertical penetration depth can be large, however, the double bounce contribution is absent because of the tilt of the soil surface. (b) At the flat top the local incidence angle $\theta_\Delta = \theta_b$ has a medium value and the double bounce contribution is present. However, at the side slope similar values for the local incidence angle are found, but here the double bounce contribution is absent. (c) At the back slope the local incidence angle $\theta_\Delta = \theta_c$ has a large value, the vertical penetration can be low, and, even though the double bounce contribution is absent, the situation may be comparable to flat terrain case where the incidence angle $\theta_i = \theta_c$.

Slopes

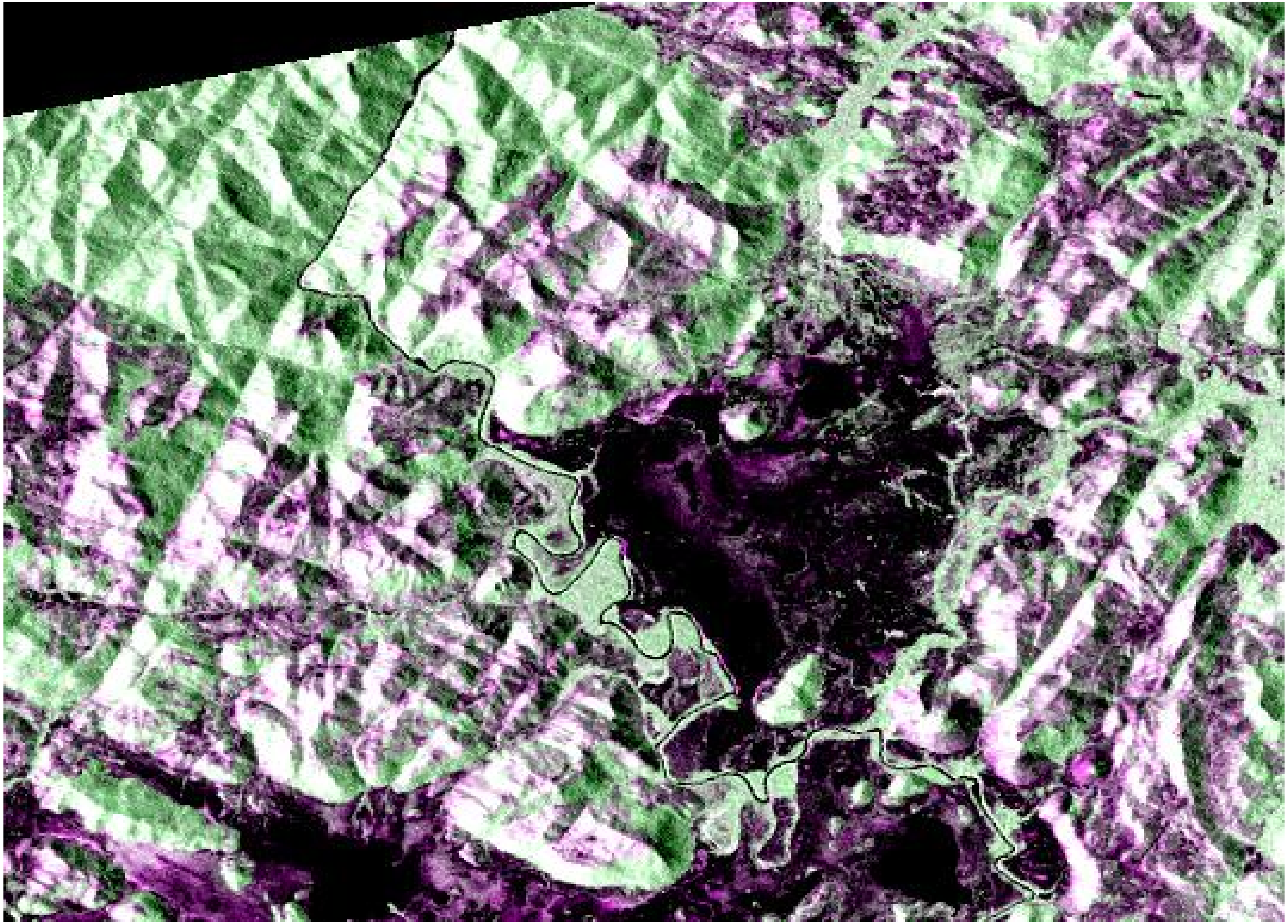
Marginal distributions of $M_1(\theta_i, \alpha_r, a_{az})$: $M_1(\theta_\Delta)$ for HH (left) and HV (right)





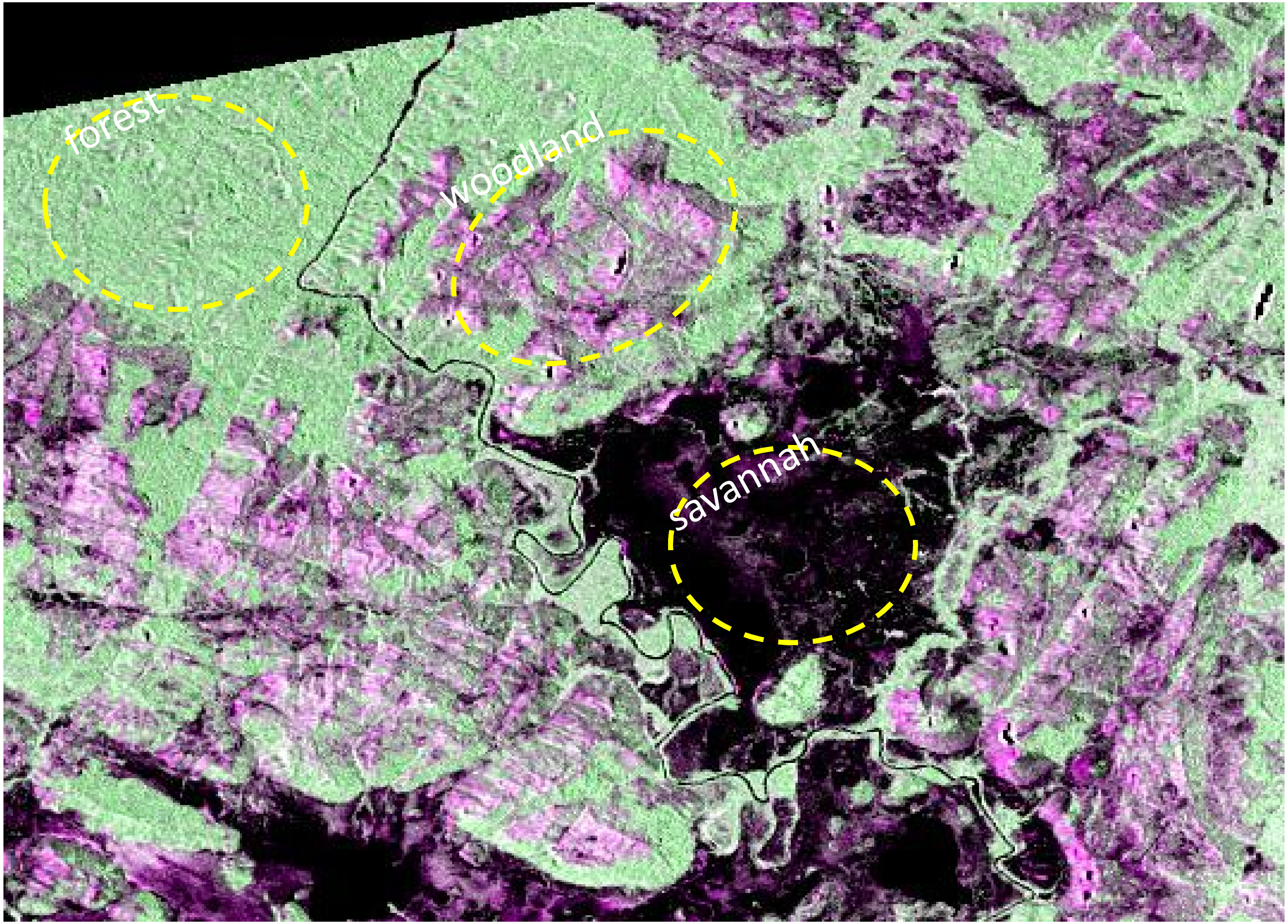
After normalization for the variation in the amount of scatterers using reference model 1, the backscatter of woodland still has a dependency on the slope angles caused by a change in scattering behavior. This dependency can be modeled by simple semi-empirical relationships. (Left) The dependency as function of local incidence angle for HH-polarization can be modeled as the sum of a medium rough soil surface component (prominent at small angles) and a volume component (relatively angle independent). (Right) For HV-polarization the surface component is negligible, while the volume component is comparable in shape, but has a lower level. Backscatter is shown in dB.

Slopes



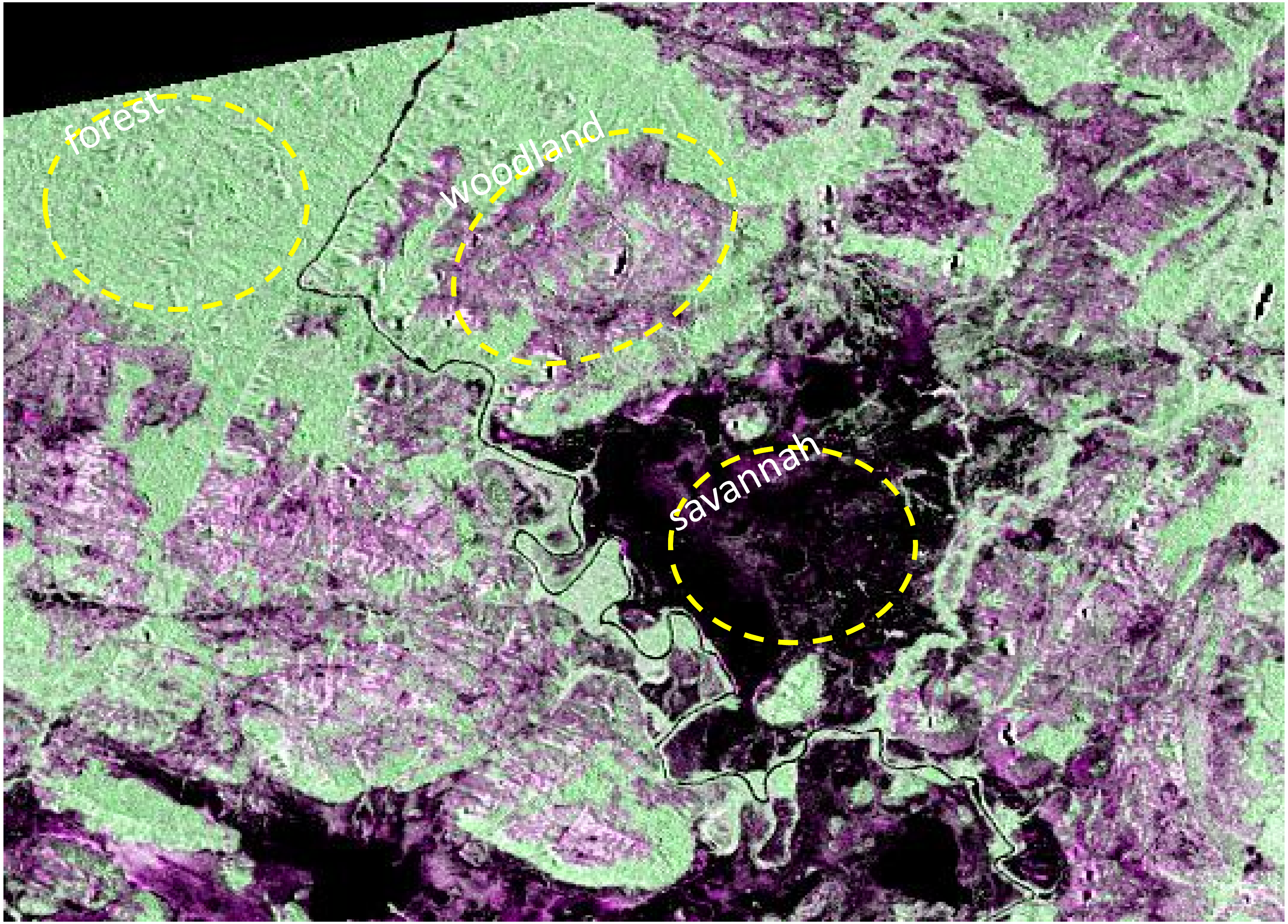
FBD image: calibrated and orthorectified. Location: Rupununi, Northern Brazil.

Slopes



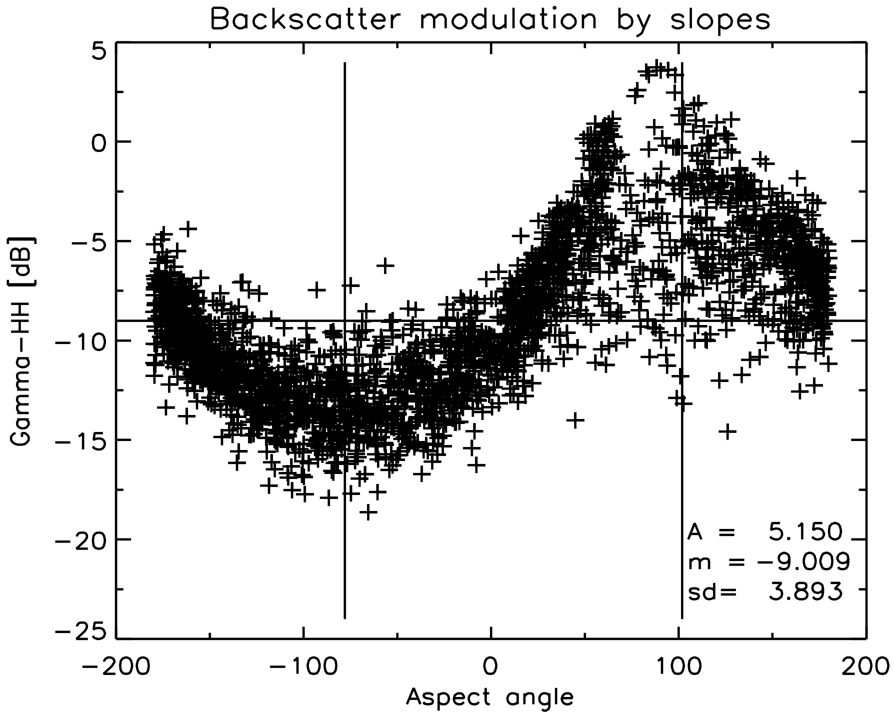
Step 1: single model relief correction

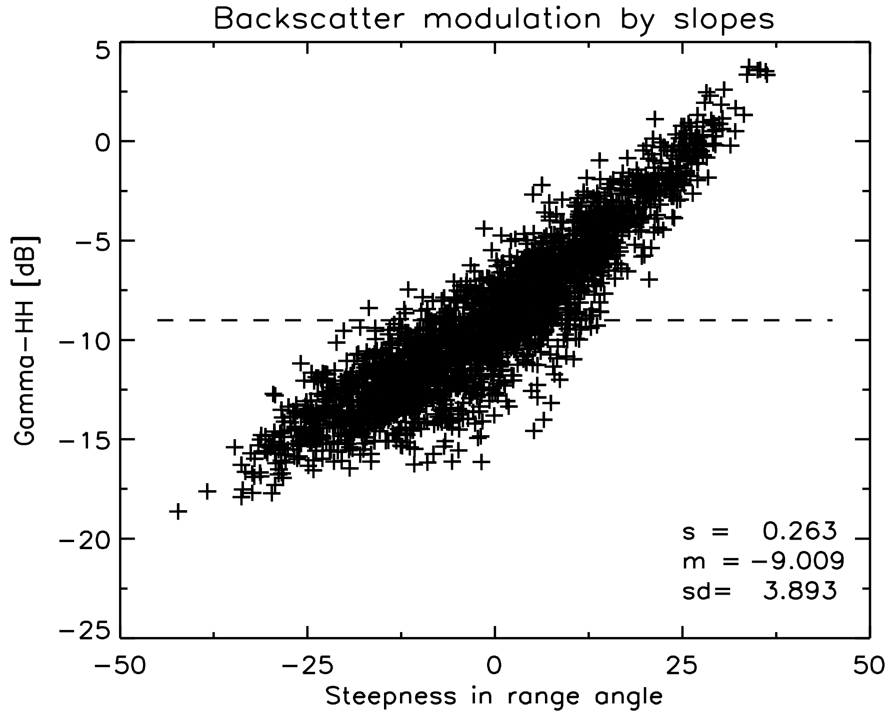
Slopes



Step 2: multi model relief correction

Slopes

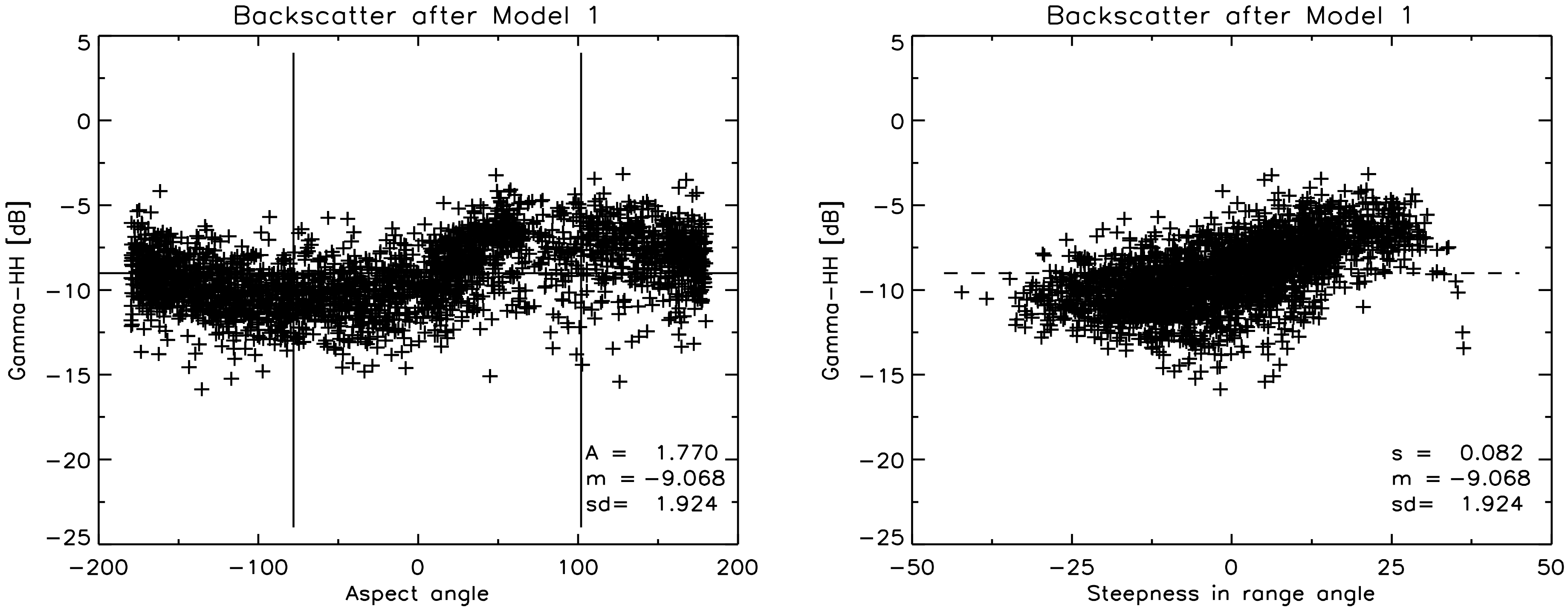




HH-backscatter (γ) for woodlands as function of aspect and steepness in range angles for: (top row) original data; (middle row) after correction for isotropic opaque volume scattering (or Model 1), and; (bottom row) after tuning for additional (anisotropic) scattering effects (or Model 3).

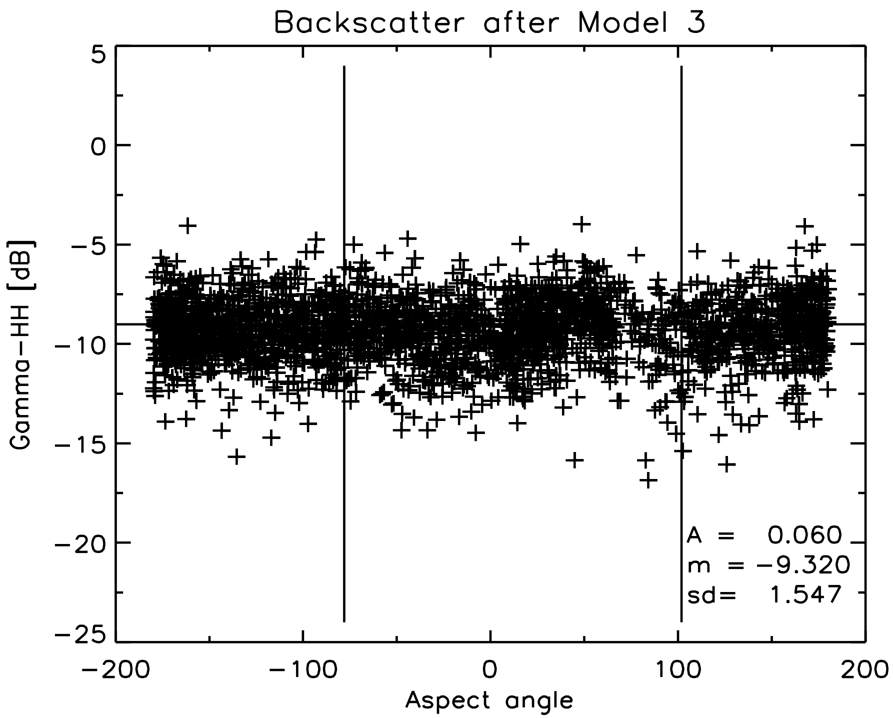
The vertical lines in the left three images indicate the backscatter and forward scattering directions; the horizontal lines in all six images indicate the mean backscatter level in the original data. The numbers in the bottom left stand for amplitude (*A*), slope (*s*), mean (*m*), and standard deviation (*sd*) of the backscatter coefficient γ [dB]. *A* is the amplitude of a sine function fit (left image) and *s* is the slope of a linear fit (right image).

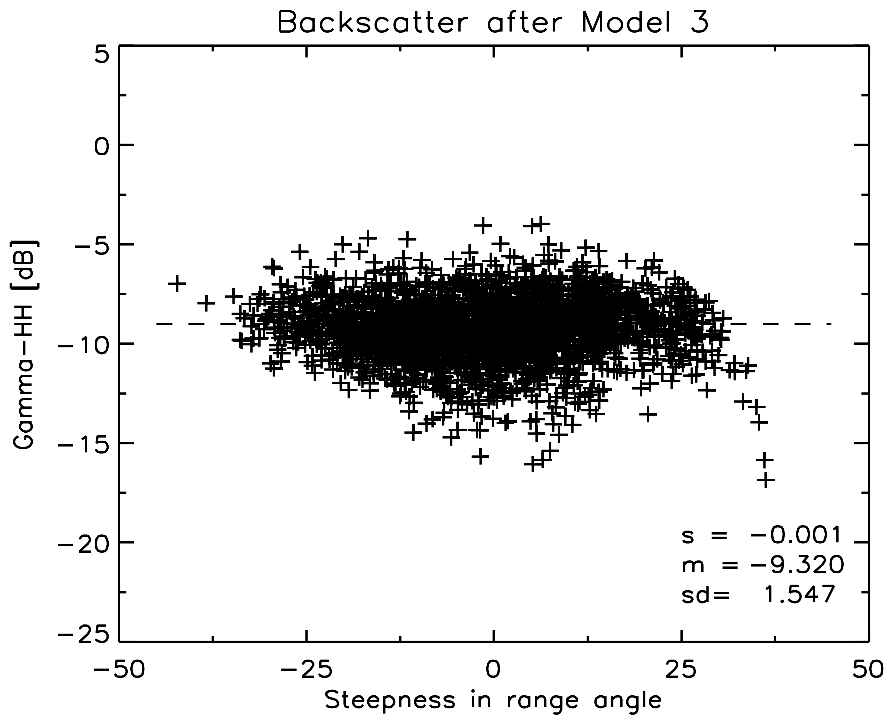
Slopes



HH-backscatter (γ) for woodlands as function of aspect and steepness in range angles for: (top row) original data; (middle row) after correction for isotropic opaque volume scattering (or Model 1), and; (bottom row) after tuning for additional (anisotropic) scattering effects (or Model 3).

Slopes





HH-backscatter (γ) for woodlands as function of aspect and steepness in range angles for: (top row) original data; (middle row) after correction for isotropic opaque volume scattering (or Model 1), and; (bottom row) after tuning for additional (anisotropic) scattering effects (or Model 3).

Slopes

Table 1a. Forest stratified mean, s.d., slope, amp

HH-pol	*m*	*s.d.*	*s*	*A*	HV-pol	*m*	*s.d.*	*s*	*A*
Original	-9.58	2.76	0.1840	3.61	Original	-14.00	2.57	0.1727	3.36
Model 2	-10.14	1.43	0.0664	1.36	Model 2	-14.56	1.23	0.0551	1.15
Model 1	-9.71	1.05	0.0061	0.21	Model 1	-14.13	0.93	-0.0052	-0.03

Table 1b. Woodland stratified

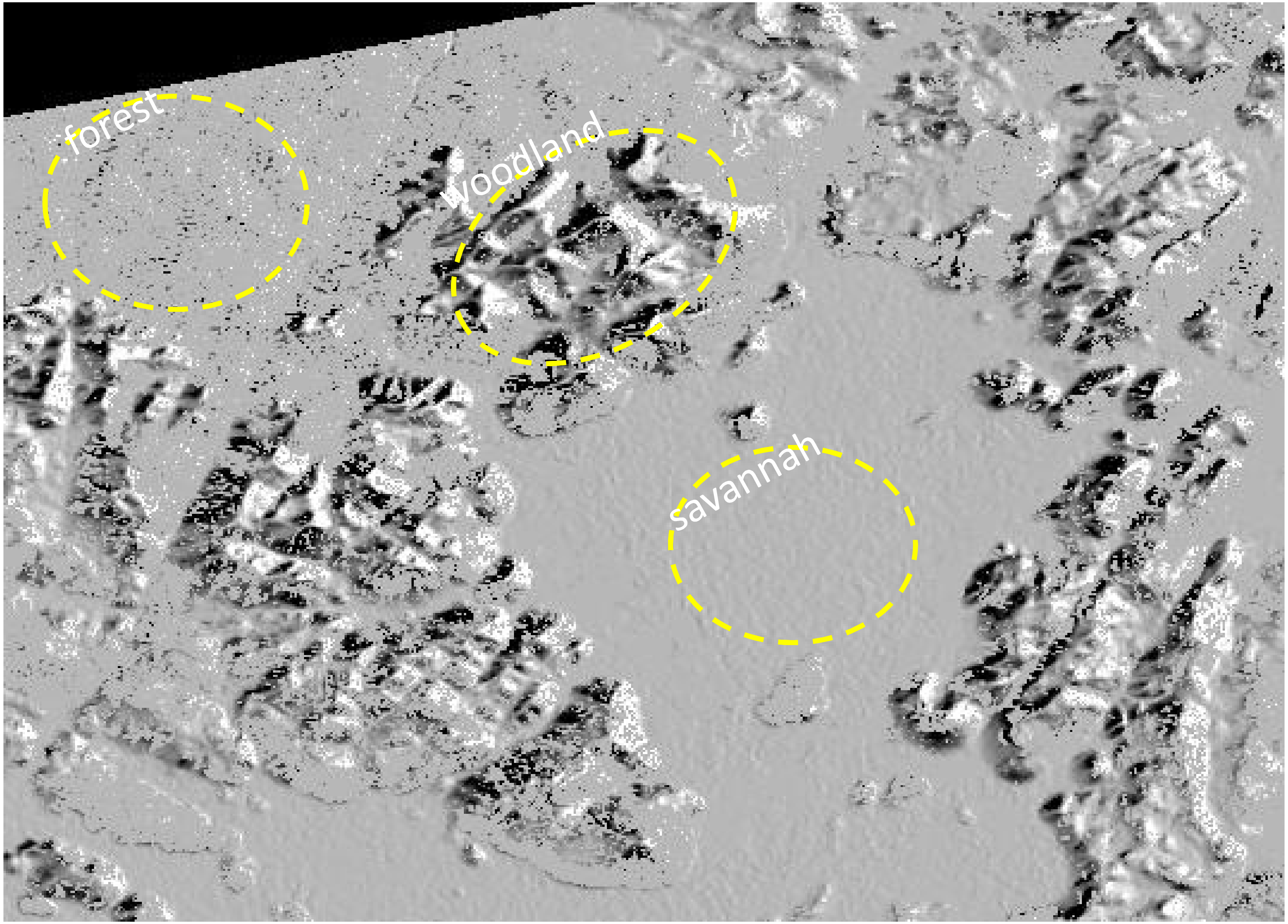
HH-pol	*m*	*s.d.*	*s*	*A*	HV-pol	*m*	*s.d.*	*s*	*A*
Original	-9.01	3.89	0.2634	5.15	Original	-17.18	3.15	0.2046	3.96
Model 2	-9.55	2.49	0.1450	2.93	Model 2	-17.72	1.85	0.0862	1.76
Model 1	-9.07	1.92	0.0824	1.77	Model 1	-17.24	1.54	0.0236	0.58
Model 3	-9.32	1.55	-0.0008	0.06	Model 3	-17.50	1.46	-0.0050	0.01

The second order correction N_1M_1 (or N_2M_2) is called “Model 3”.

Model 1 in general gives a better correction than Model 2, and Model 1 is near perfect for most forests on slopes.

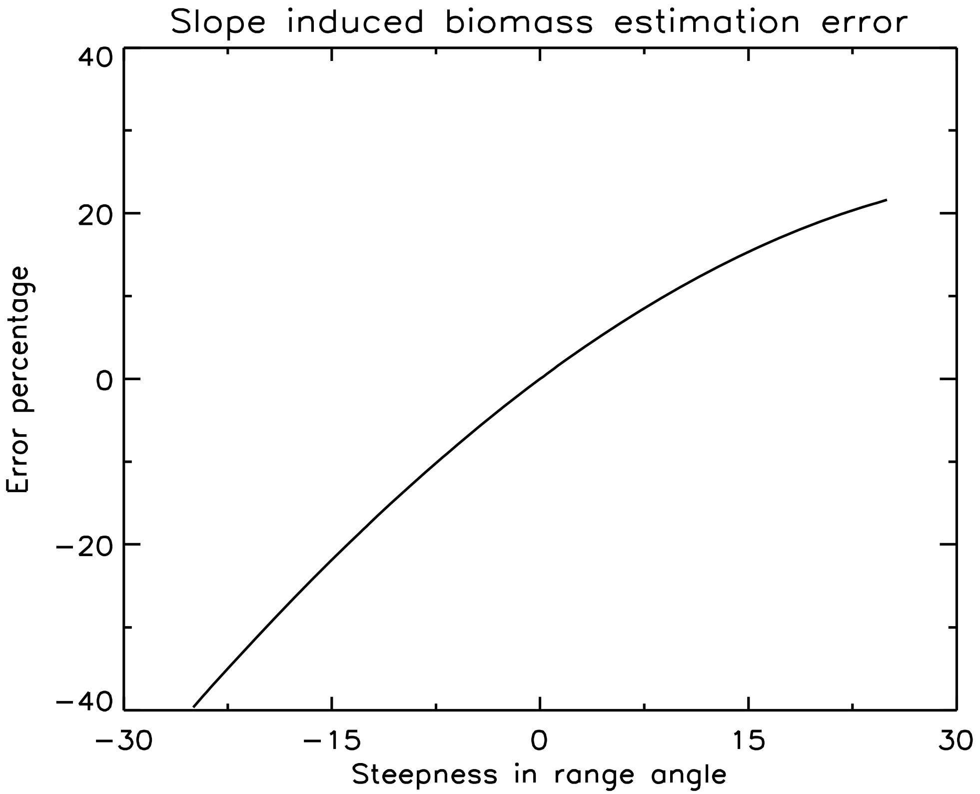
Additional correction (“step 2”) results in Model 3, which is polarization and terrain type dependent, and can be tuned using a simple semi-empirical model (for M_1), based on the behavior of $\gamma_f(\theta_i)$.

Slopes



Additional corrections for HV (Step 2 improvements)

Slopes



In case the second slope correction step is omitted, large errors in biomass estimation can occur. In this example, in case the true biomass is 50 ton, the estimation could be as much as 60 ton for the steep parts of the facing slope and 30 ton for the back slope.

Note this error occurs in the woodland land cover class only. For dense forests the estimations would still be correct.

The increase of biomass on facing slopes would be underestimated; on the back slope the reverse is true.

The problem may be even more prominent in P-band data.

Slopes

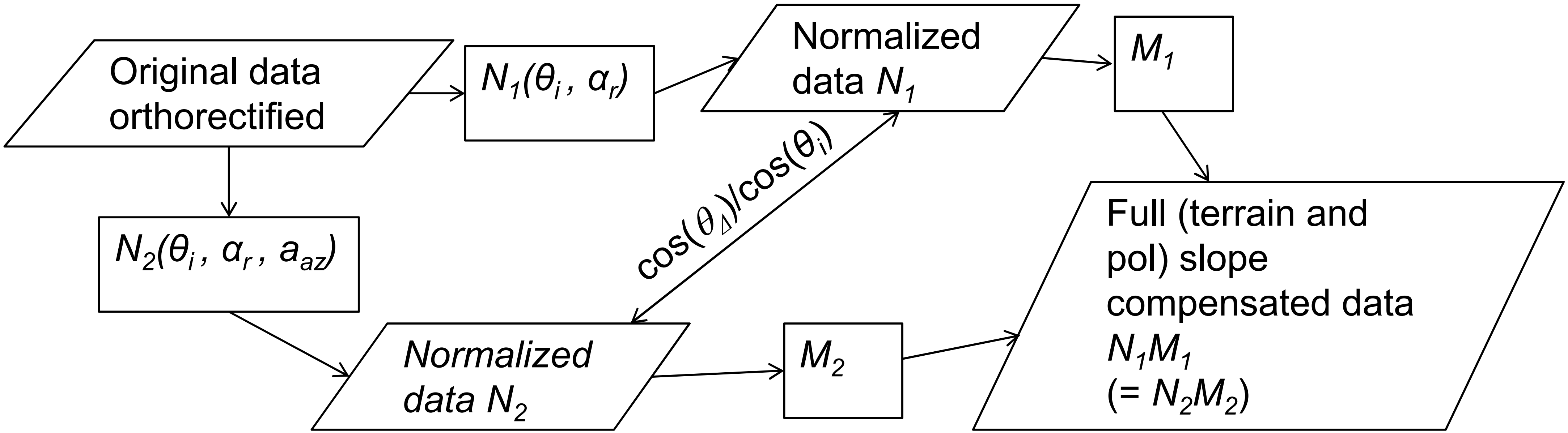
Note that there are two ways to implement the secondary order slope corrections.

(1)By making a new synthetic image where all slope effects are compensated and the backscatter for terrain on slopes is the same as the backscatter of the same terrain on flat areas. This can be done by first applying the normalization N_1, stratify the image (in feature space, and apply the correction M_1 per stratum.
(2)Use the second order slope correction term to amend the class statistics, i.e. class statistics are not only a function of polarization and incidence angle, but also of the two slope angles. Next apply a techniques such as MRF.

Both techniques have proven to work well. Under certain circumstances one of these two techniques may be preferred.

Advice to JAXA

(1) For mosaic data: apply N_1 (or N_2) and provide extra data layer with three angles (θ_i, α_r, a_{az}). Then user has full flexibility (see Fig.)



(2) Make at least one extra mosaic in the other (i.e. descending for FBD) direction

Acknowledgement

Moore Foundation for financial support in radar capacity building in state of Para.

This work has been undertaken within the framework of the JAXA Kyoto & Carbon Initiative. ALOS PALSAR data have been provided by JAXA EORC

Thank you