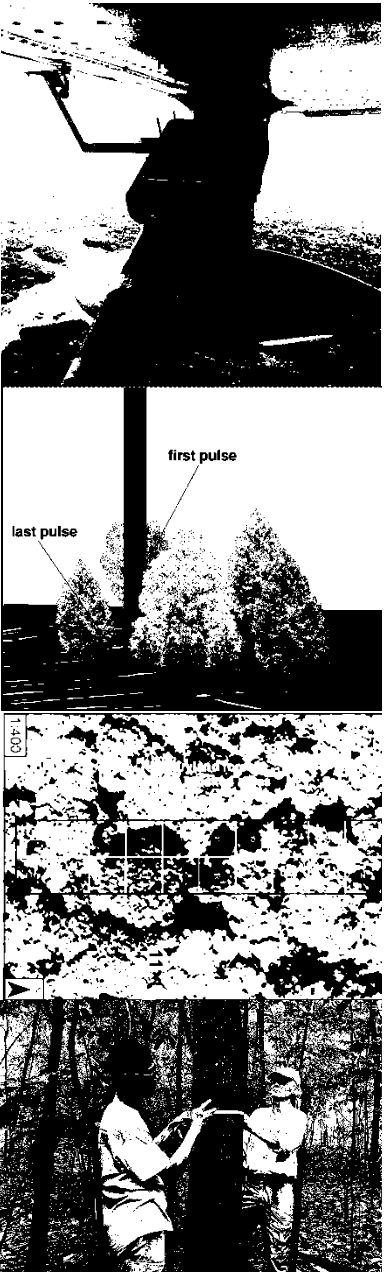

ANRICA

Austrian Natural Resources Management
and International Cooperation Agency

Cost-effective systems for multi-purpose national forest monitoring

Smart sampling
with high-tech
methods!

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XIV World Forestry Congress

Tuesday, 8th of September 2015

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Why Multipurpose National Forest Monitoring Systems?

Definition of NFI / NFM

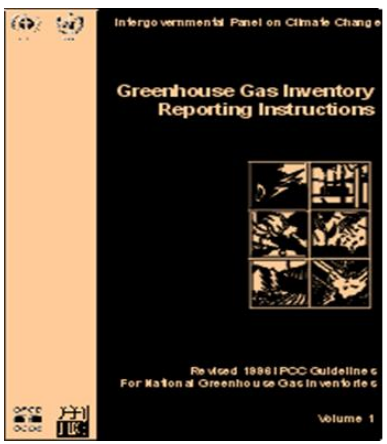
The goal of forest monitoring is to collect information on forest resources for decision making on

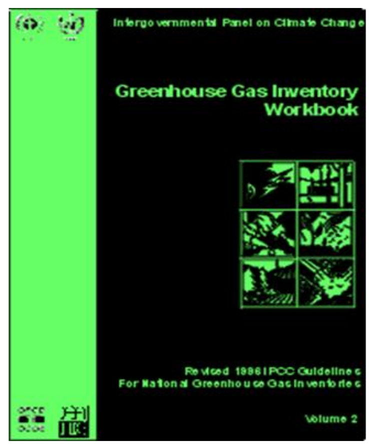
- *policies and strategies development,*
- *programs and actions towards sustainable forest management.*

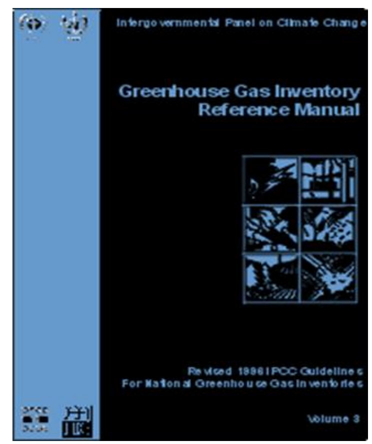
- NFI/NFM subject to research and development for many decades
- Over the years many different approaches to NFI/NFM depending on specific objectives and national contexts
- Post 1992: Significant increase in demand for information on forests and trees (i.e. UN conventions: UNFCCC, CBD, UNCCD, UNFF)

Reporting in the Context of Climate Change

UNFCCC	
IPCC-compliant carbon accounting	• 6 land-use classes • 5 carbon pools (incl. biomass, litter, soil etc.) • Principles: “transparent, accurate, comparable, consistent, complete”

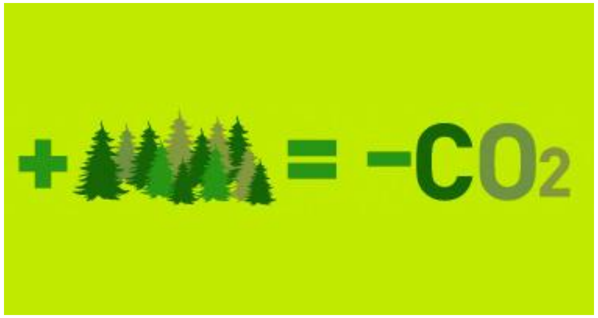






Reporting in the Context of Climate Change

UNFCCC	
REDD+	• Principles: „measurable, reportable and verifiable" • 5 activities considered (deforestation, forest degradation, conservation, SFM and increase in forest carbon stocks) • Multipurpose focus incl. co-benefits and safeguards



Reporting in the Context of SFM

Global / Regional / National Processes	
Forest Resources Assessment (FAO-FRA)	• Current status and recent trends for about 40 attributes of forest (incl. extent, condition and uses)
ITTO	• SFM C&I for natural tropical forests
National forest sector planning	• Production, conservation community uses etc.

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NFI /NFM issues encountered by Countries

Issues with NFI / NFM:

- Information for the various reports are collected on „ad-hoc“ basis (costly and inefficient)
- Same target parameters are assessed separately for different reports (duplication of work)
- Lack of consistency of methods and data over time (information on trends unreliable)
- Sub-optimal inter-agency cooperation at national level
- Fragmented assessments – NOT cost-effective

NFI Approach and Design Matters

NFI / NFM system requirements:

- Information must be comprehensive, accurate and verifiable
- One NFI system to meet the information needs of all reporting obligations
- Main target variables related to biomass/ carbon/ timber
- Results statistically sound (i.e. accuracy levels known)
- Design to allow continuous monitoring
- Cost-effective

Suriname NFI-Pilot Project

Development and Testing of a cost-effective and efficient NFI Methodology

Objectives

Cooperation between ANRICA and SBB-Suriname to test a novel approach using state-of-the-art remote sensing technology combined with systematic field inventory

Forest Situation in Suriname

- Remoteness of most of the forests;
- Difficult access and high costs of field sampling;
- Limited number of personnel;
- Little is known about the variability of forest stocking conditions across the country's forest types

Development and Testing of a cost-effective and efficient NFI Methodology

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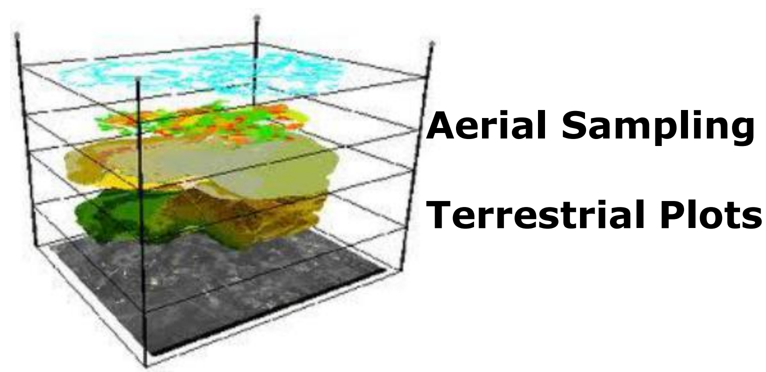
Two-Phase Inventory Design

Systematic lay-out of tracts covering the entire country

Assessment in two phases:

- Large-scale aerial sampling
- Terrestrial inventory

Main focus is on reducing field work as much as possible by maintaining high accuracy levels of results (i.e. sampling errors of AGB, timber stocks)



NFI - Suriname

Two-Phase Inventory Design

NFI System Component I:

Aerial Data Acquisition and Processing

NFI System Component II:

Terrestrial Inventory

NFI System Component I:
Aerial Data Acquisition and Processing

➢ Airborne Remote Sensing Platform

- Flight Campaign Suriname (piloting)
- Deriving Aerial Image Features

Data Acquisition and Mapping ADAM

Austrian Natural Resources Management and International Cooperation Agency

ADAM Hardware used

Sensors – georeferencing

- GPS phase receiver, (2 x DL4-L1L2 NOVATEL)
- Inertial measuring unit (IMU), iMAR-FSAS

the images can be directly geo-referenced without ground control points

Sensors – image capture

- Mid-format digital camera PROSILICA (20MP), flight height 1000: 17cm
- Near infrared camera

Control unit

- rugged PC and data storage

Independent power supply by alternator and batteries

Flight control system

Workflow for data processing

Direct geocoding concept

ADAM Hardware used

Sensors – georeferencing

- GPS phase receiver, (2 x DL4-L1L2 NOVATEL)
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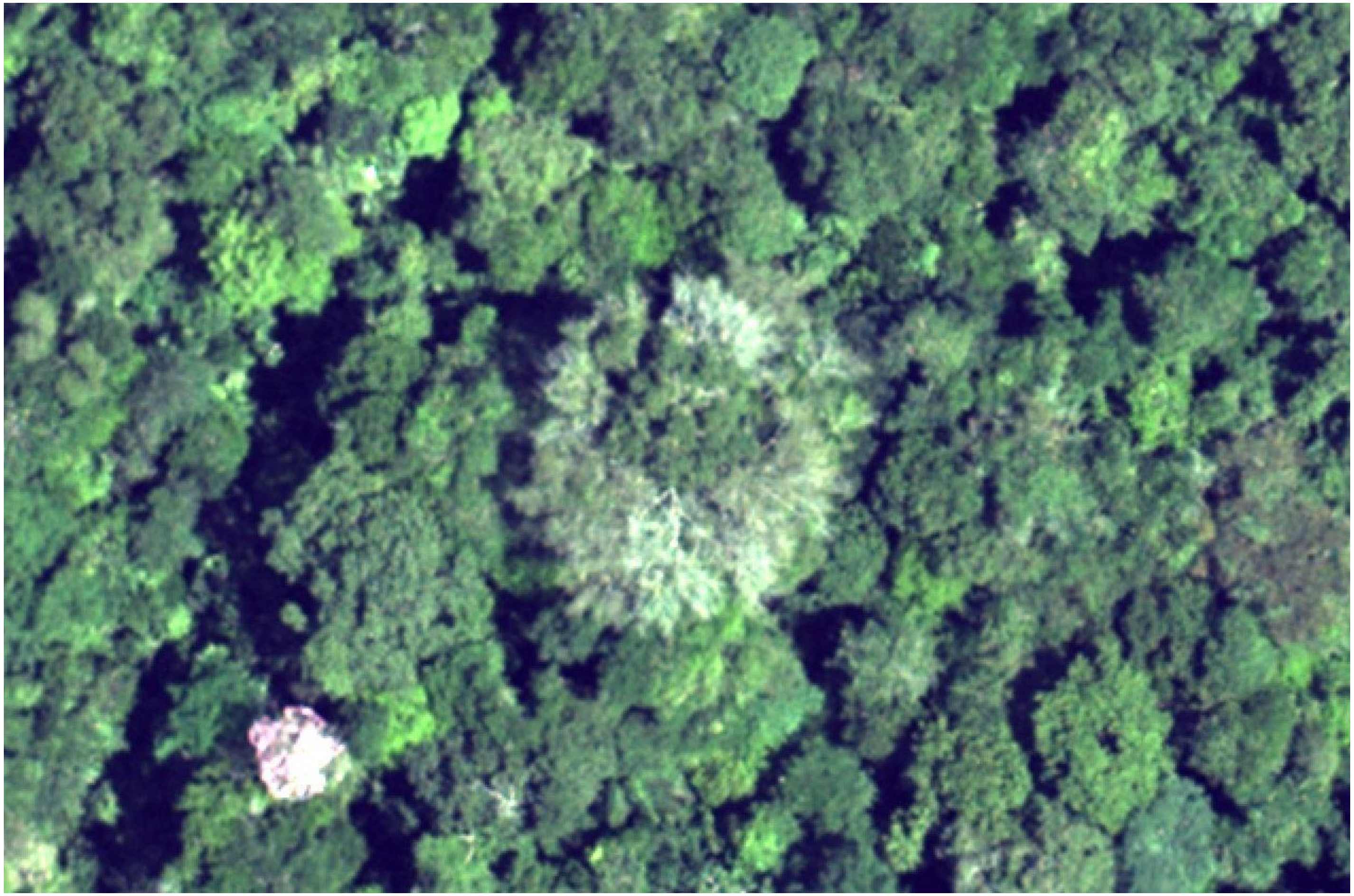
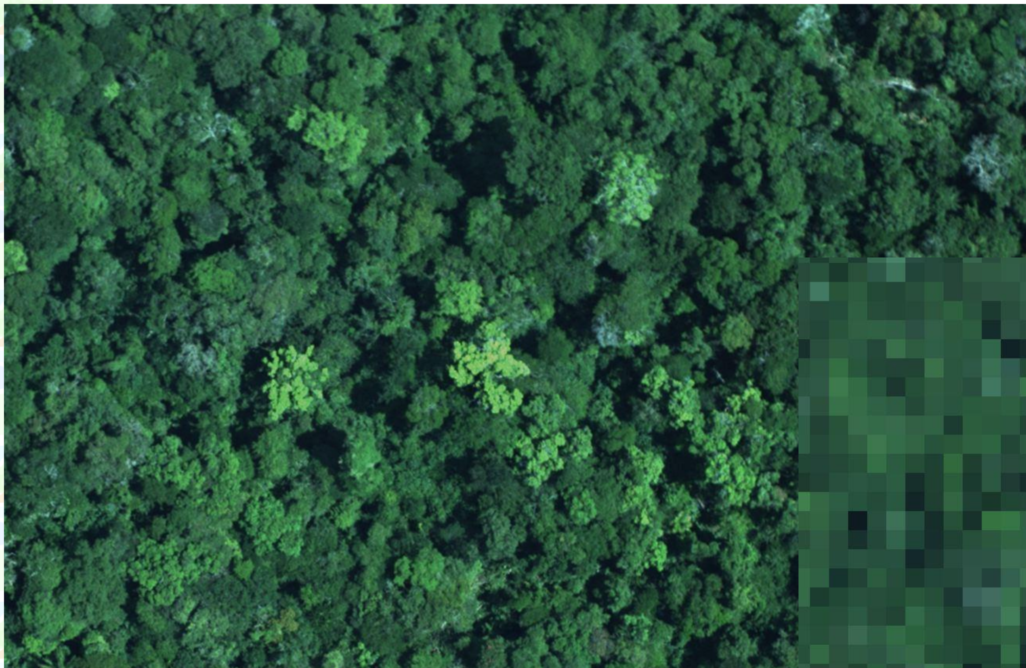
Workflow for data processing

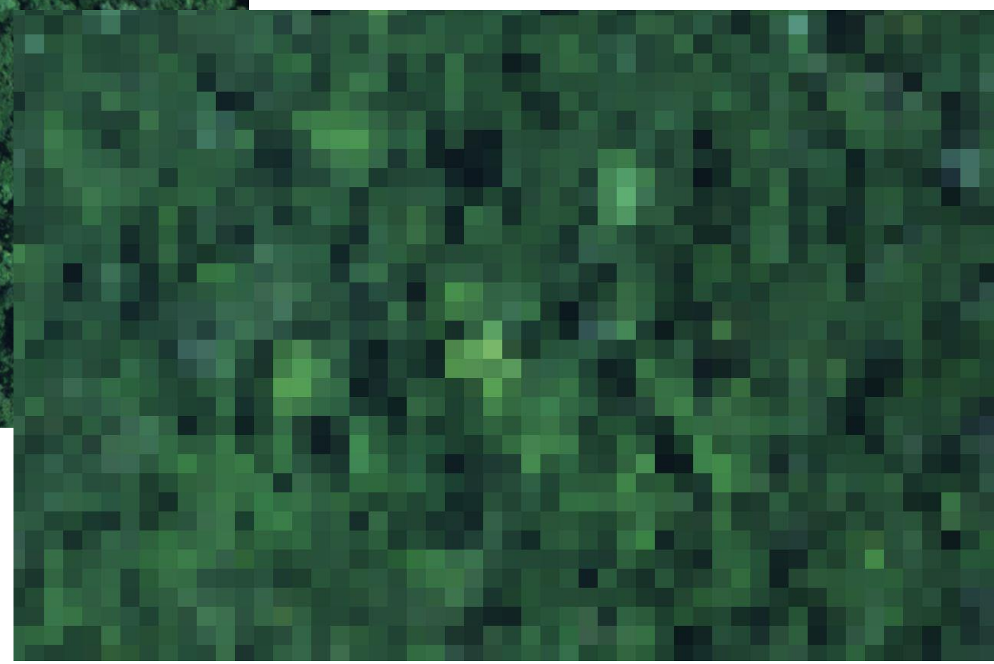
High Geometric Resolution



Simulation of Satellite Resolutions

0.2 m (ADAM)





6 m RapidEye

ADAM Hardware used

Sensors – georeferencing

- GPS phase receiver, (2 x DL4-L1L2 NOVATEL)
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Workflow for data processing

ADAM Hardware used

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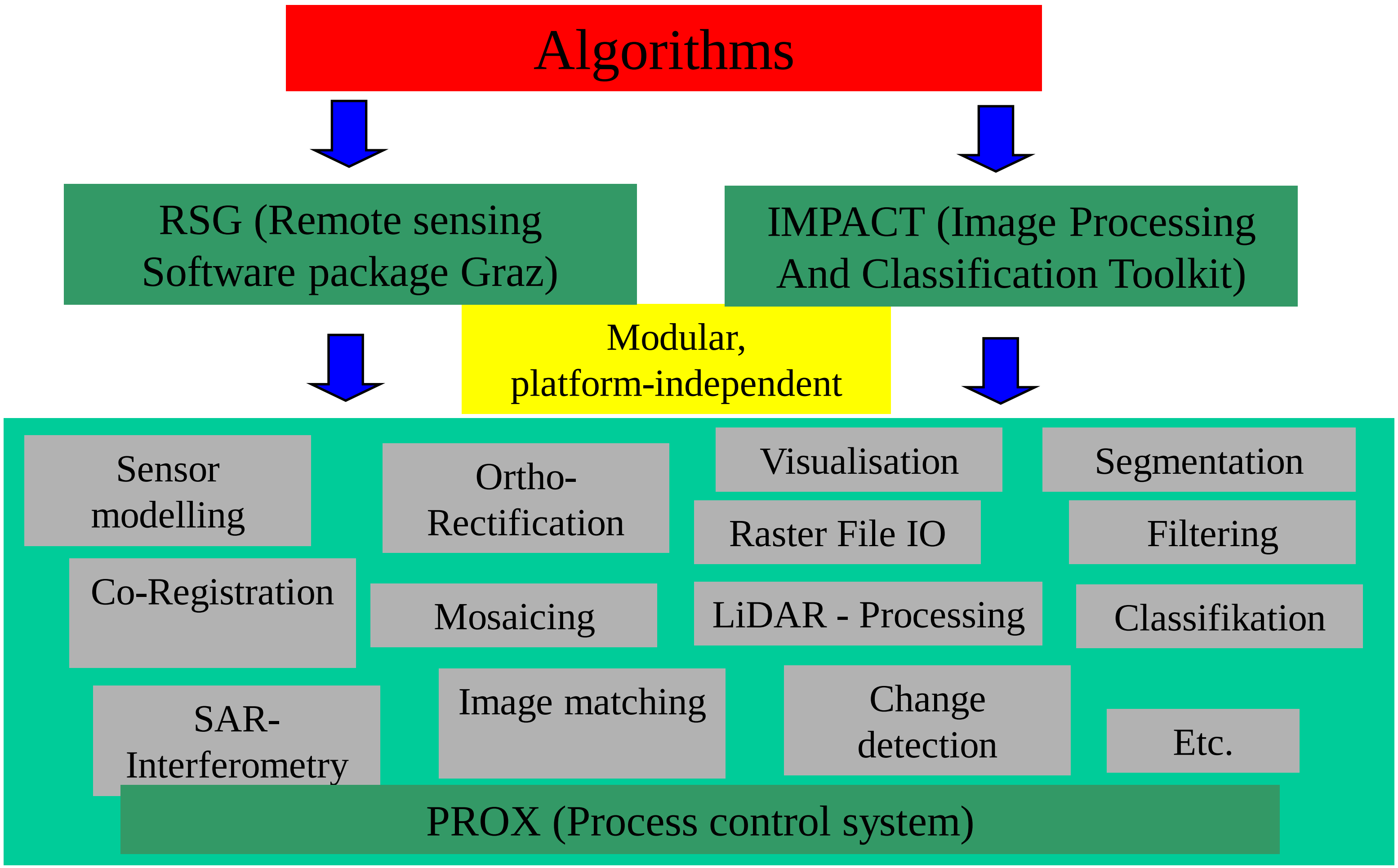
Flight control system

Workflow for data processing

Software at Joanneum Research



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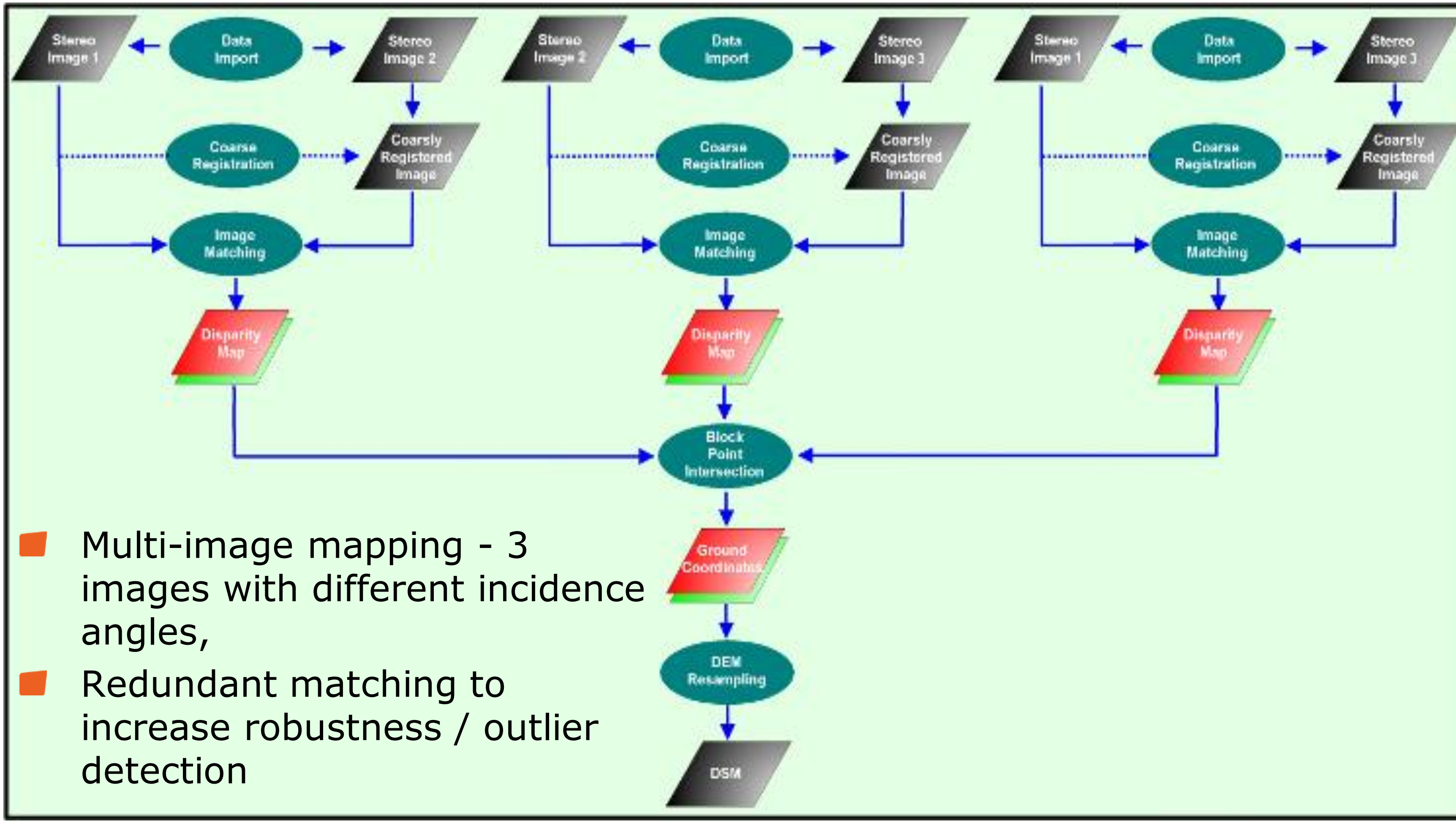
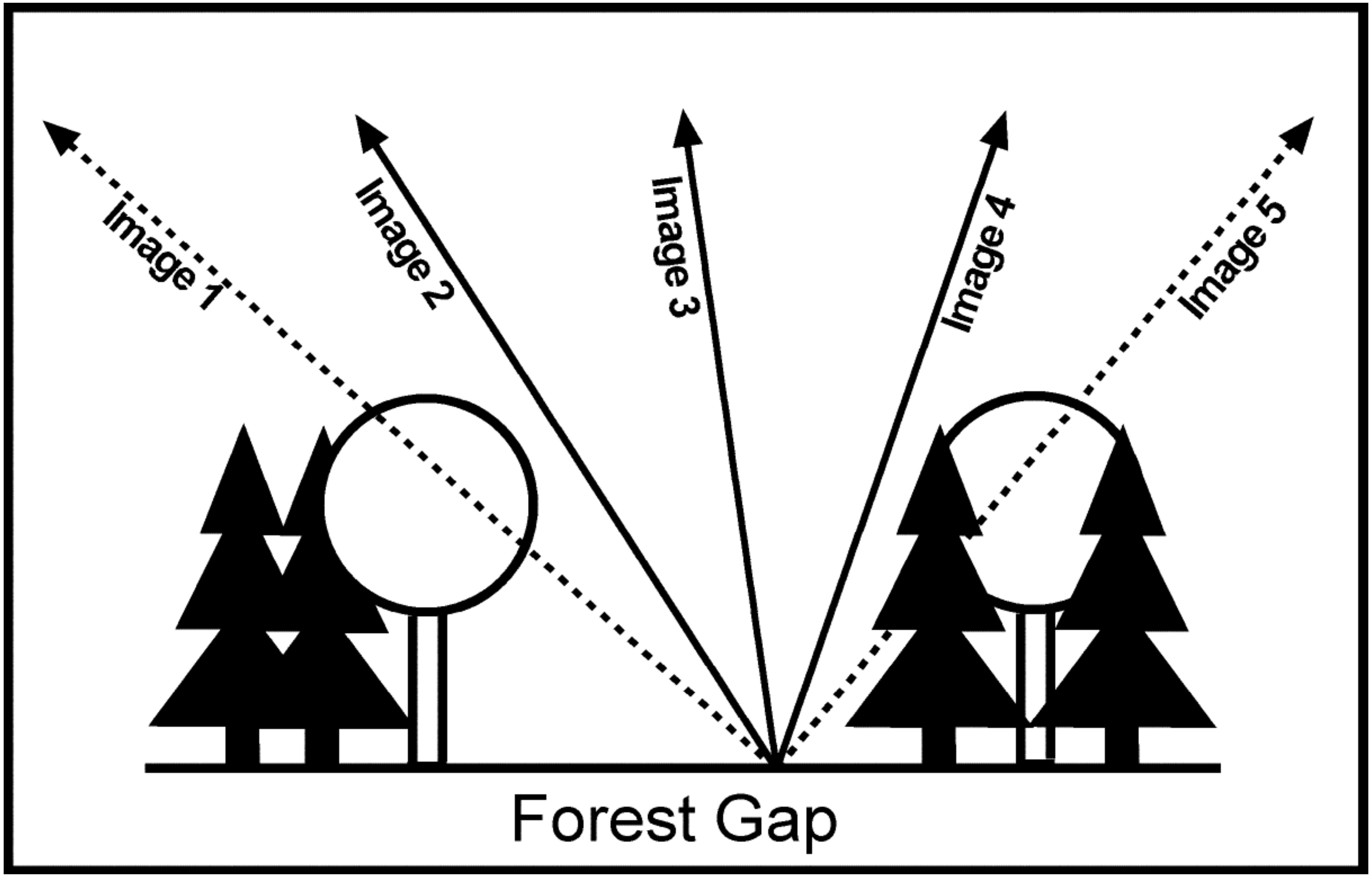
Photogrammetry - Workflow

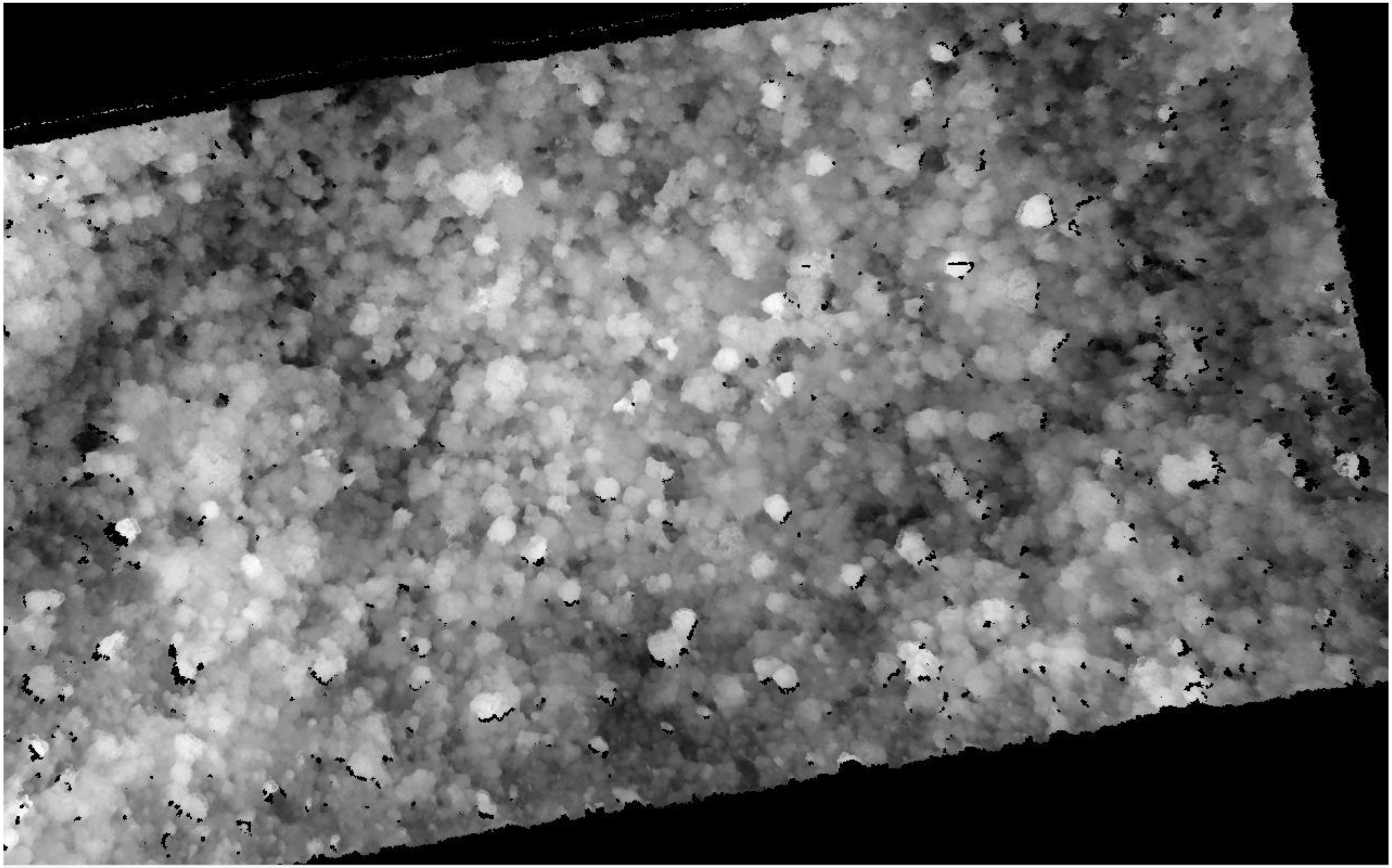


- Multi-image mapping - 3 images with different incidence angles,
- Redundant matching to increase robustness / outlier detection

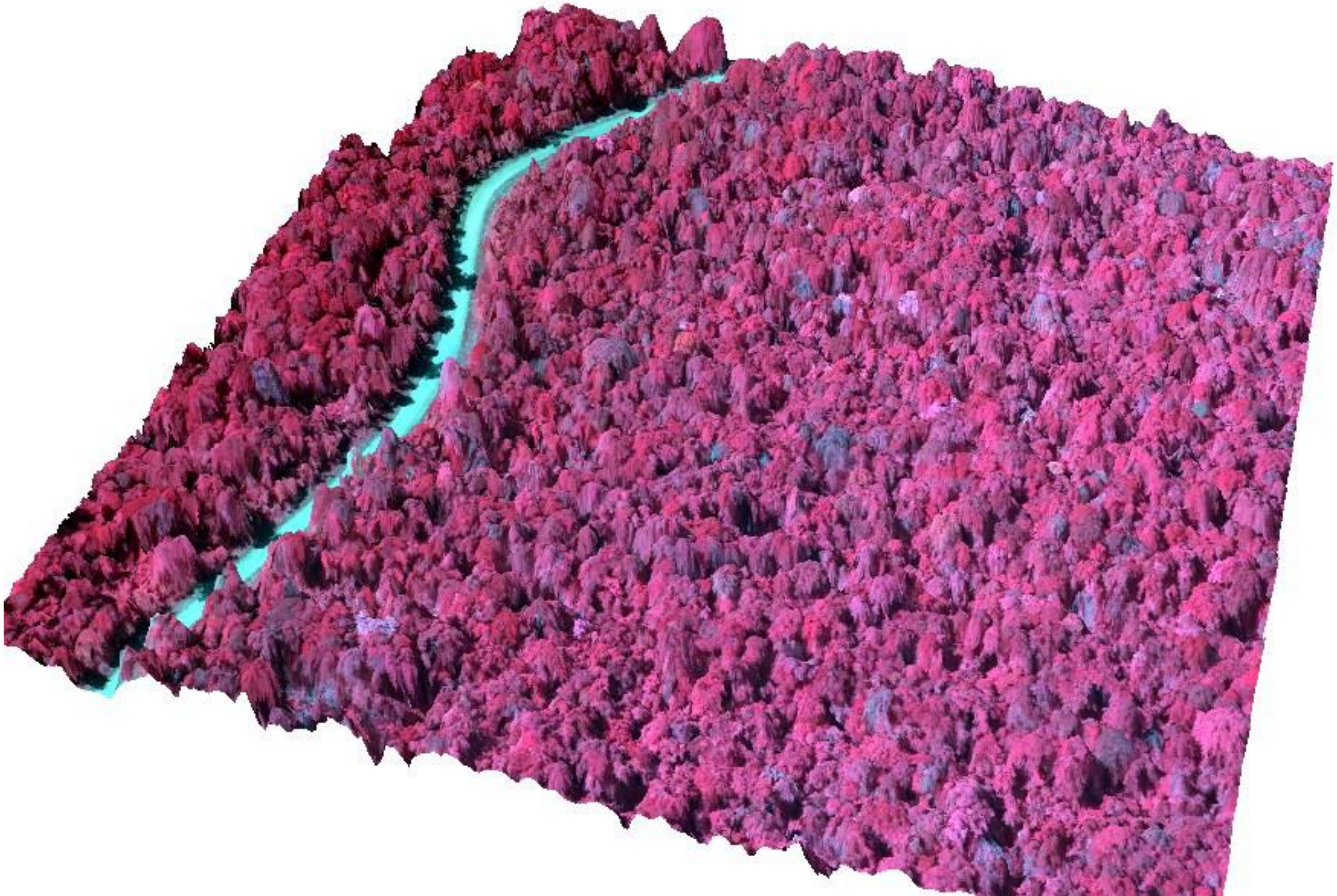
Photogrammetry
Multi-Stereo-Concept



Digital Surface Model (DSM)



3D DSM View

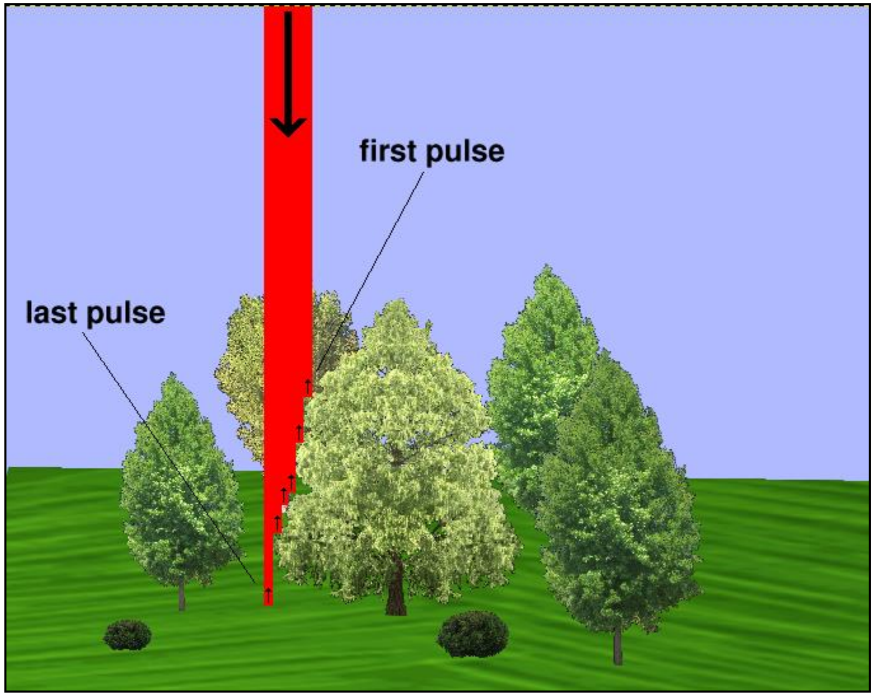


Improved System

- Optical Camera Phase One ixA 180 (80 MP)

- LIDAR – Riegl VQ580

System improvements



Measurement of travel time

- First pulse: measurement location and intensity of first laser pulse returned → Information on vegetation surface
- Last pulse: measurement of location and density of last pulse returned → Information on round surface

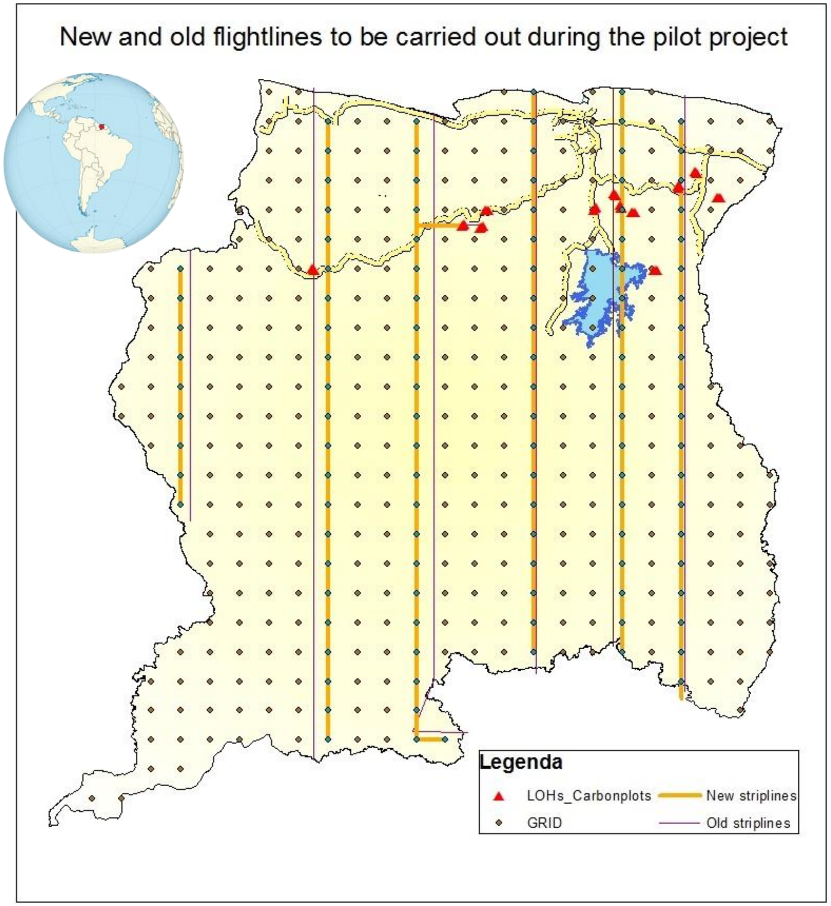
Advantages of ADAM

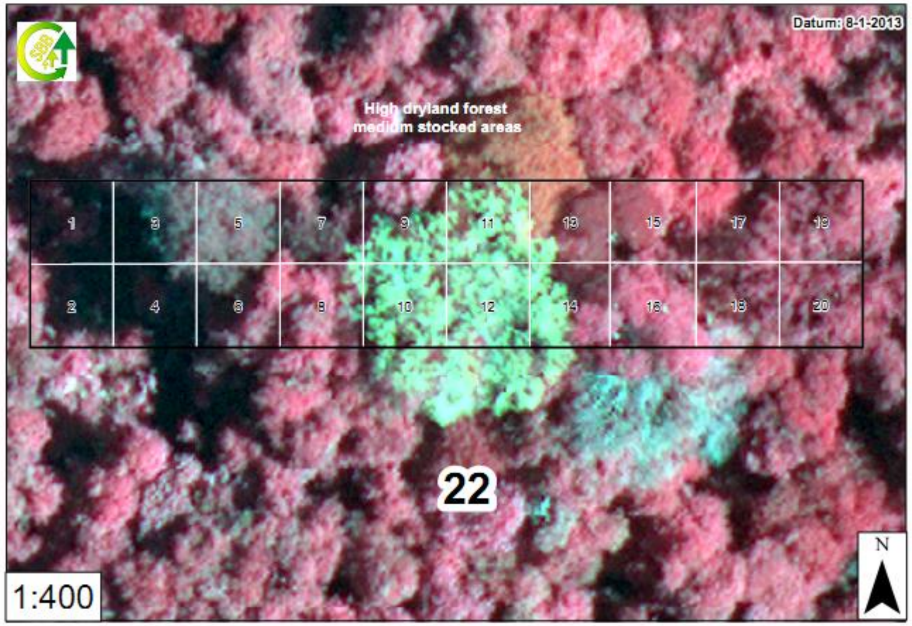
- Adam can be operated world-wide on most common Cessna types (certified for Cessna 182)
- ADAM can be operated as multi-sensor system
- Direct geocoding without ground control points with high geometric accuracy
- High geometric resolution with new camera system
- More or less weather independent (ADAM can operate under clouds)
- 3D – terrain and forest canopy models can be derived

NFI System Component I: Aerial Data Acquisition and Processing

- Airborne Remote Sensing Platform
- ➢ Flight Campaign Suriname (piloting)
- Deriving Aerial Image Features

Selection of Flight Corridors





- Map derived from satellite image classification of forest types
- Locations of corridors aim to capture the spectrum of forest types and stand conditions found in Suriname
- More than 10.000 images taken during flight campaign

High Geometric Resolution

NFI System Component I: Aerial Data Acquisition and Processing

- Airborne Remote Sensing Platform
- Flight Campaign Suriname (piloting)
- ➢ Deriving Aerial Image Features

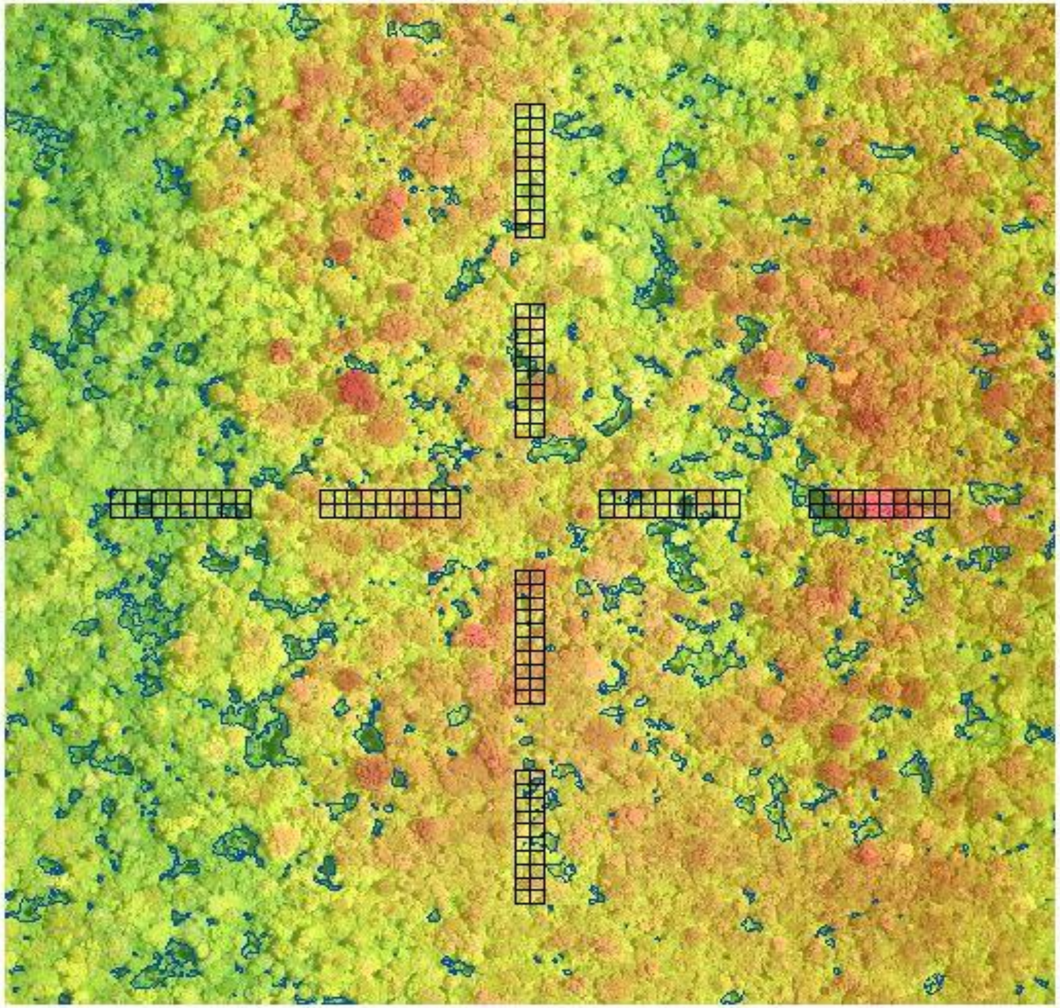
Best performing features

1. Forest canopy density
2. Canopy roughness (DSM standard deviation)
3. Crown Volume

- Option 1: Volume by difference of DSM - SRTM
- Option 2: Volume by difference of DSM - DTM derived from photogrammetry

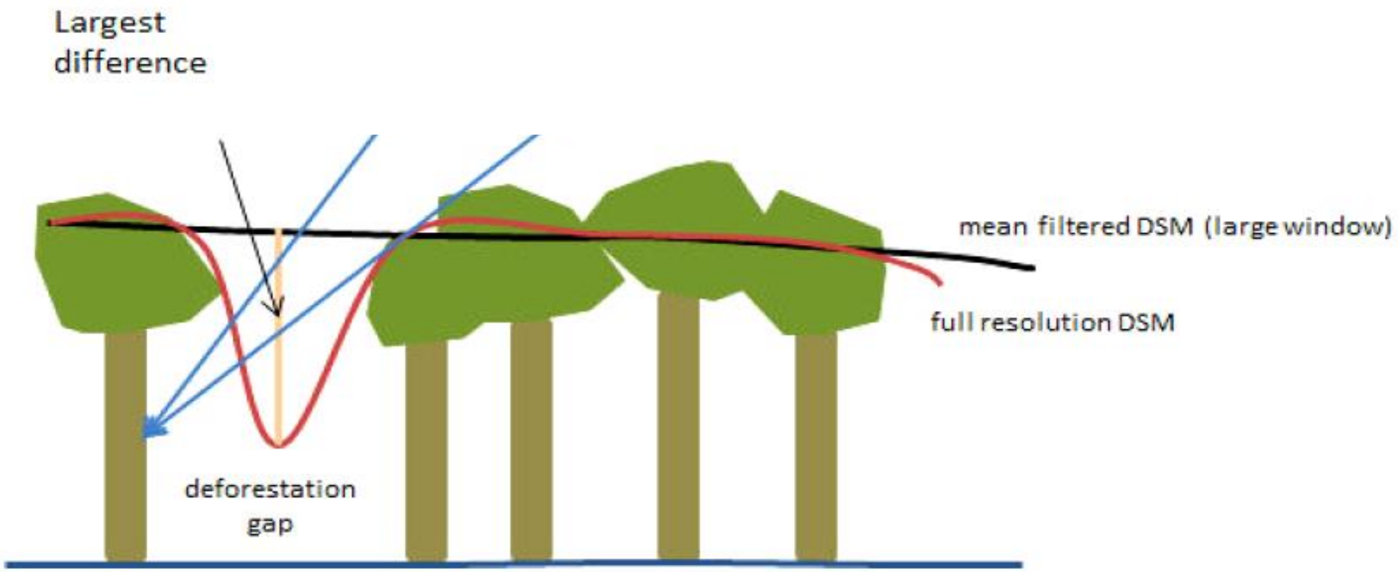
4. Number of trees (average crown size)

Feature 1: Canopy Density



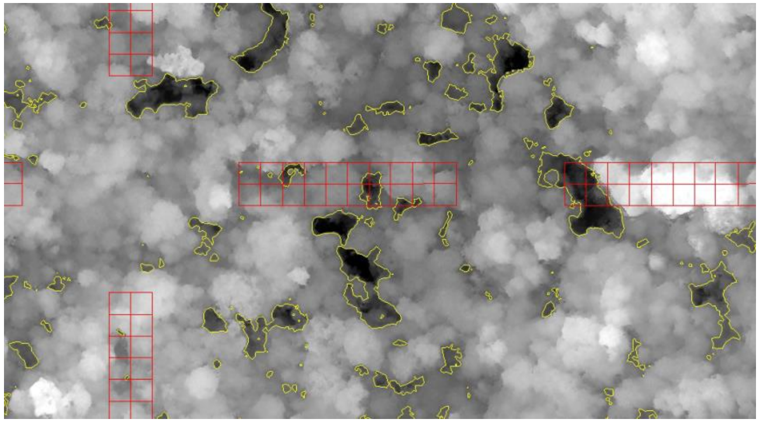
Definition:
Proportion of non – gap areas and total area

Feature 1: Canopy Density

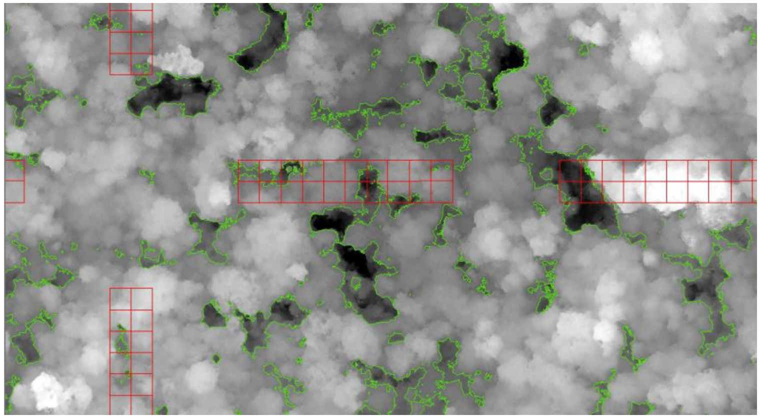


Feature 1: Canopy Density

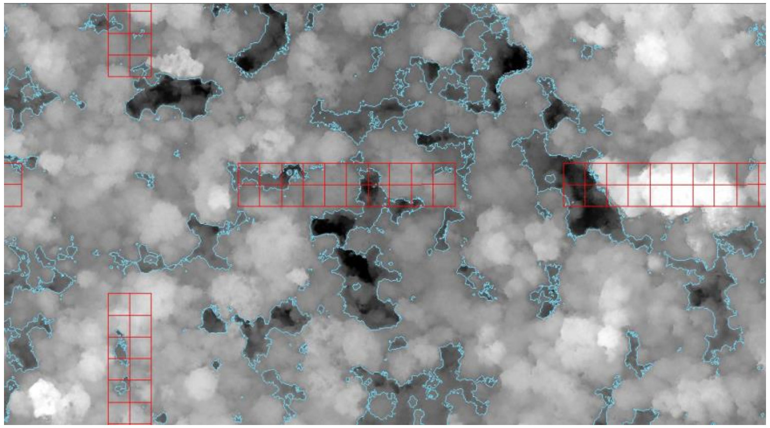
Low Threshold



Medium Threshold



High Threshold



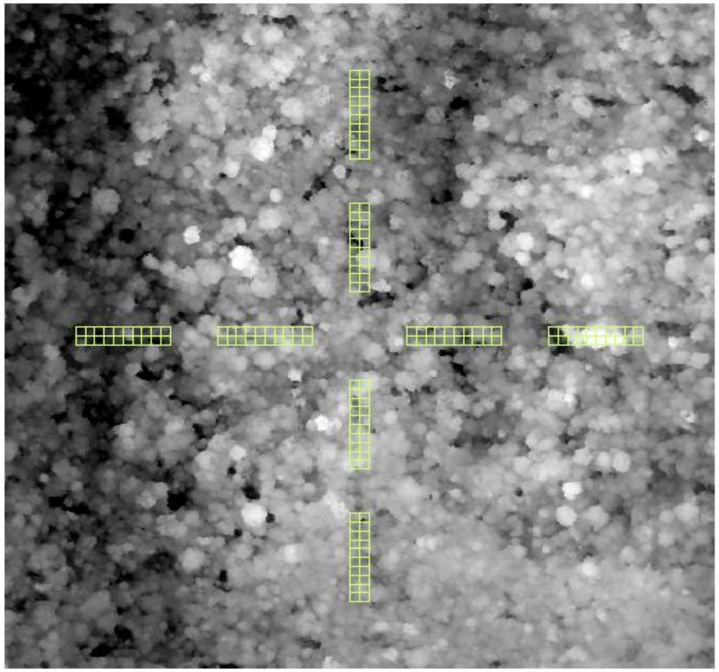
Feature 2: Standard Deviation - Roughness

Definition:

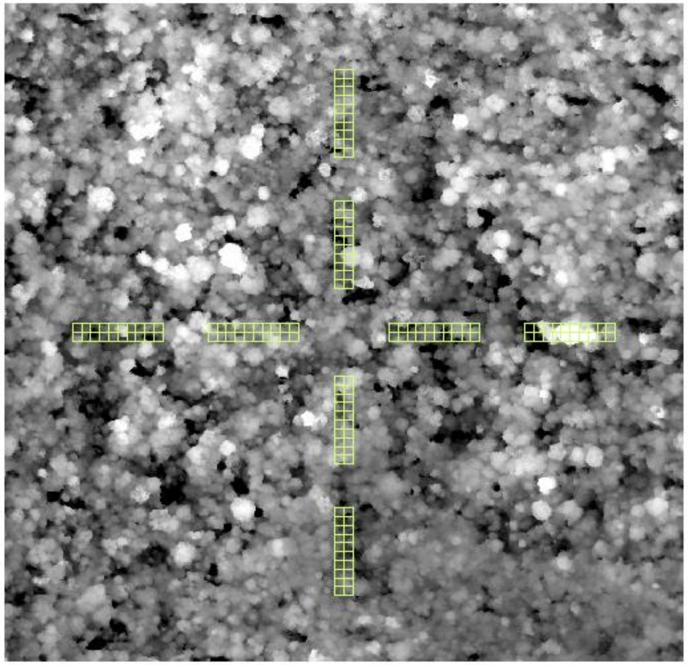
Feature 2 is the standard deviation of the relative height difference between DSM and SRTM terrain height model. SRTM used to minimize the influence of the terrain.

Feature 2: Standard Deviation - Roughness

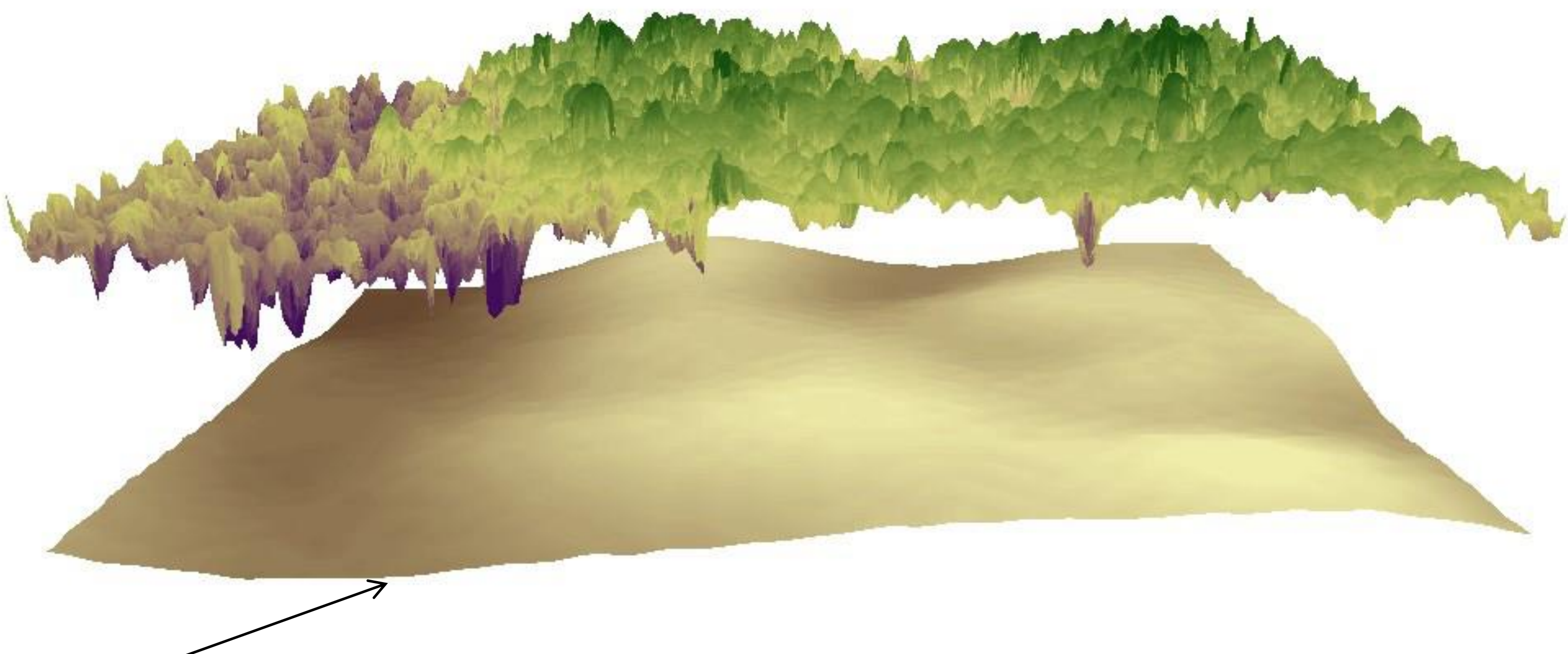
Original DSM



DCM - SRTM



Feature 3: Crown Volume



Either from SRTM or DTM derived from photogrammetry, in future derived by LiDAR data with improved precision

Feature 3: Crown Volume

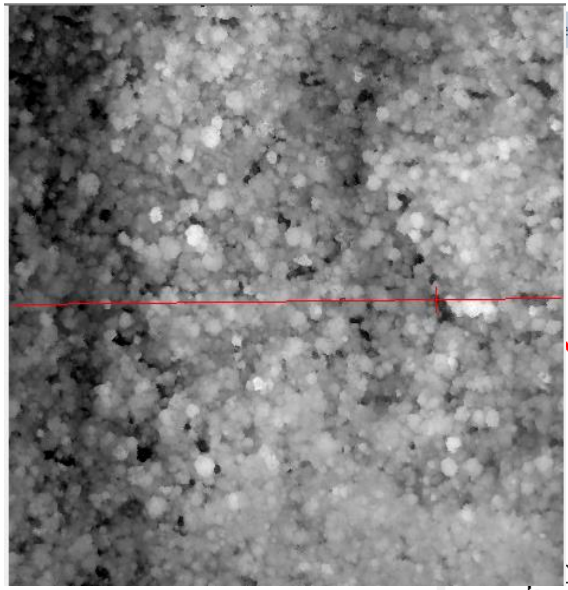
Option 1: Definition

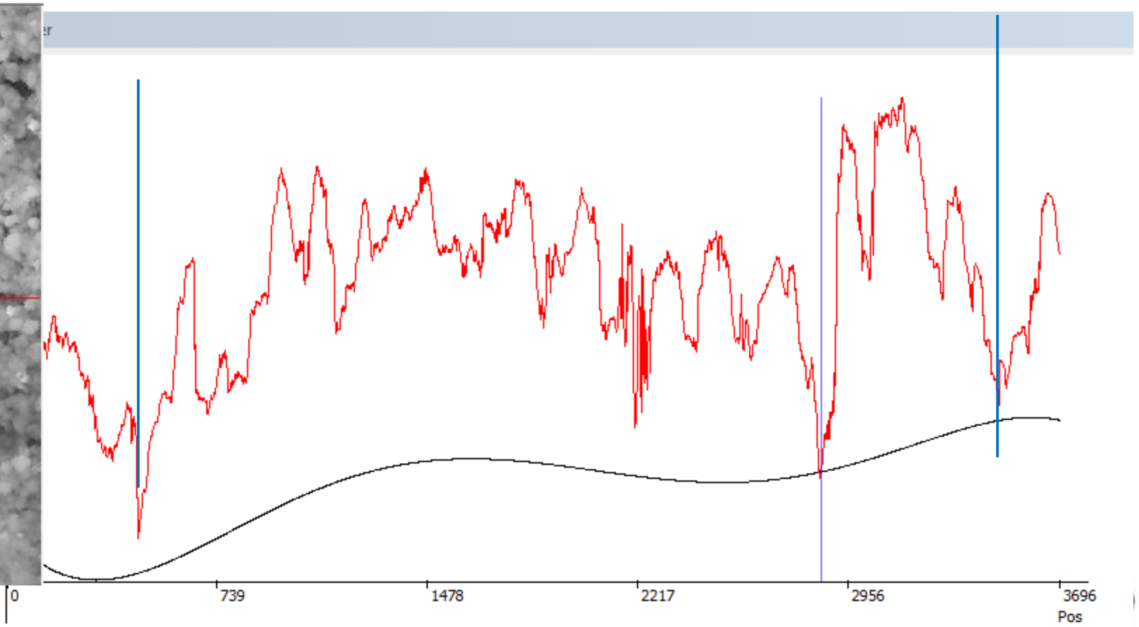
Difference of DSM derived from aerial images and "terrain model" derived from SRTM within the area of the sample plot. Despite the fact that the SRTM model is only a rough estimate of the terrain it reflects the main characteristics of the terrain.

Feature 3, Option 2: Volume (Difference of DSM – DTM Photogrammetry)

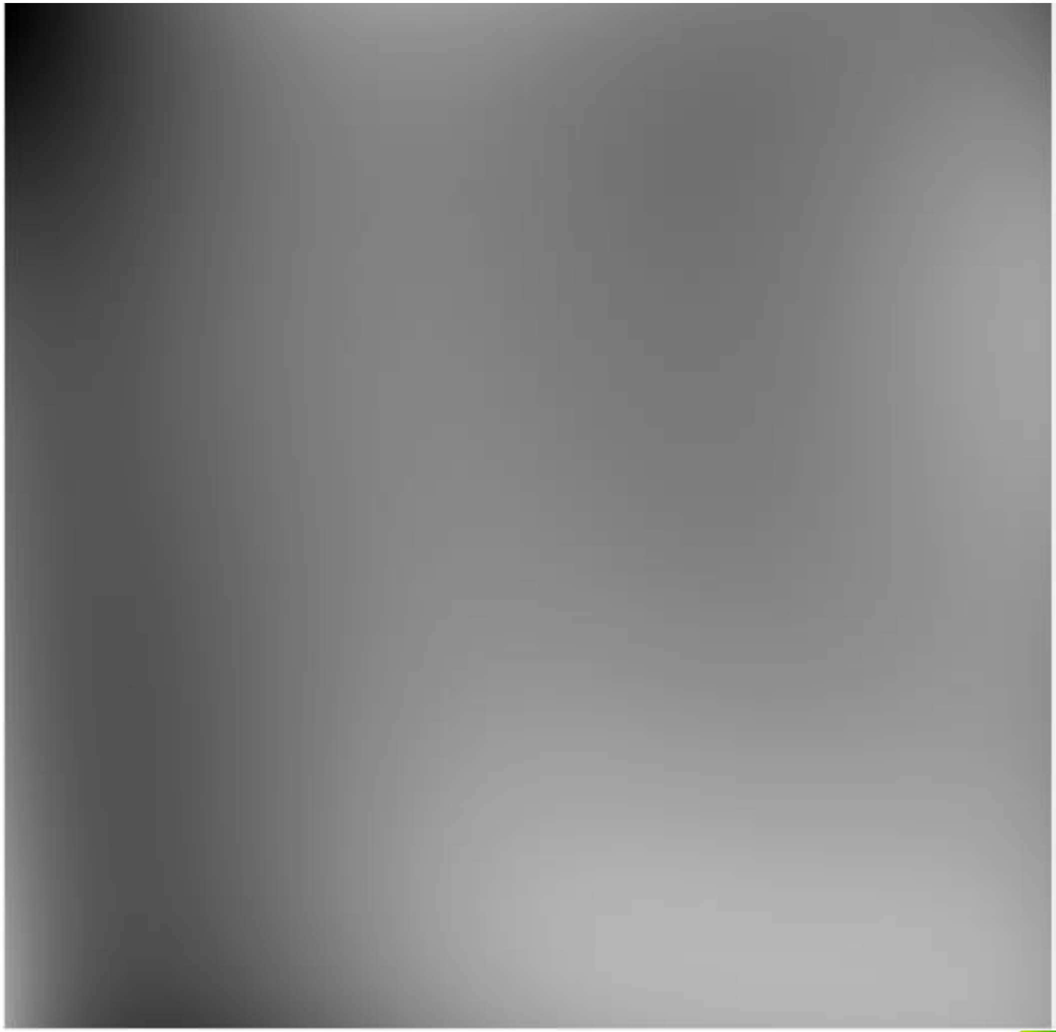
Option 2: Definition:

Difference of DSM derived from aerial images and terrain model derived from the stereo images within the area of the sample plot. Gaps in the forest are used to derive points on the ground applying a minimum filter and interpolation of the deepest detected ground points.





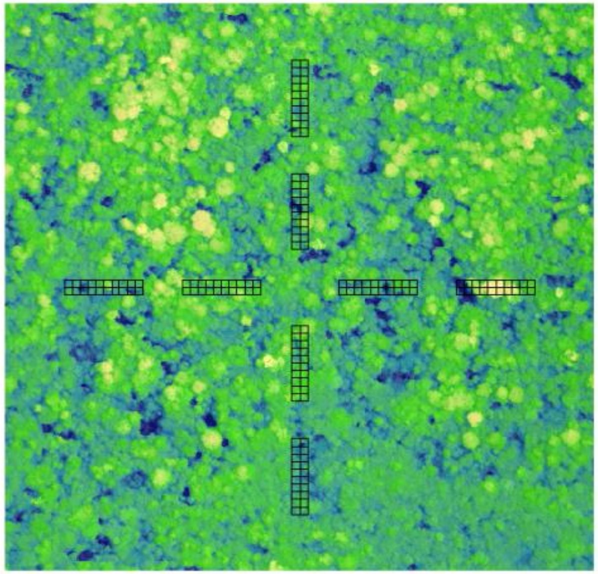
Feature 3, Option 2: Volume (Difference of DSM – DTM Photogrammetry)



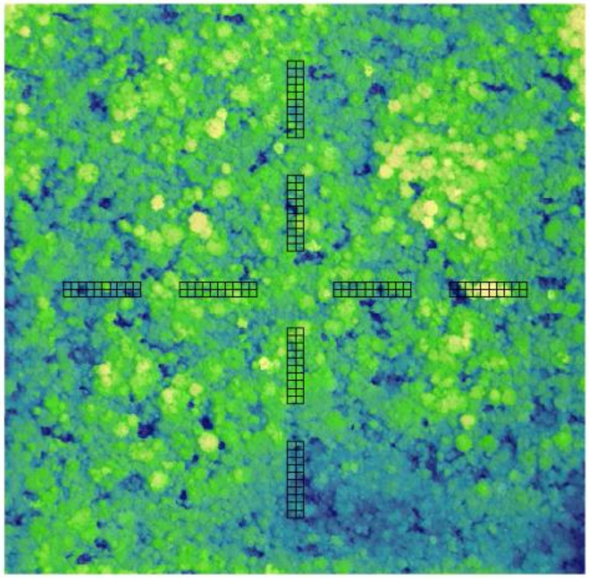
DTM Derived from Gap Interpolation

Comparison Option 1 and Option 2 (SU 5956)

DSM - SRTM



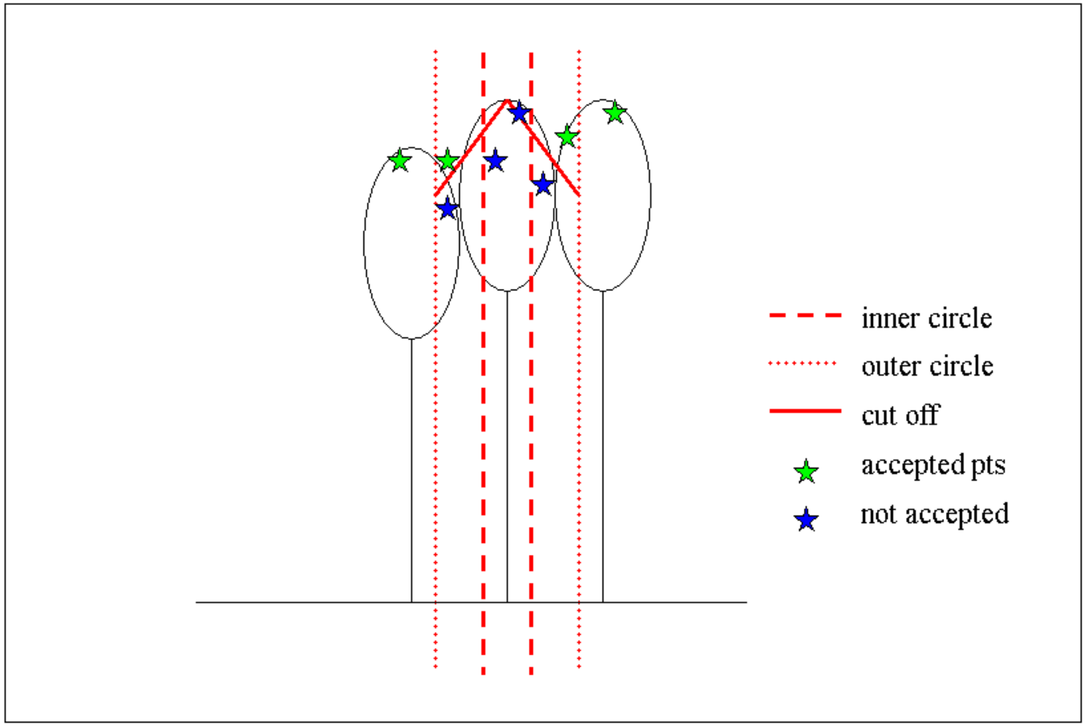
DSM - DTM



Feature 4: Number of Tree Tops

Definition:

Feature 4 represents the number of tree crowns within the sample plot. For this purpose a tree top detector was applied to the data using different assumptions on the average crown size.



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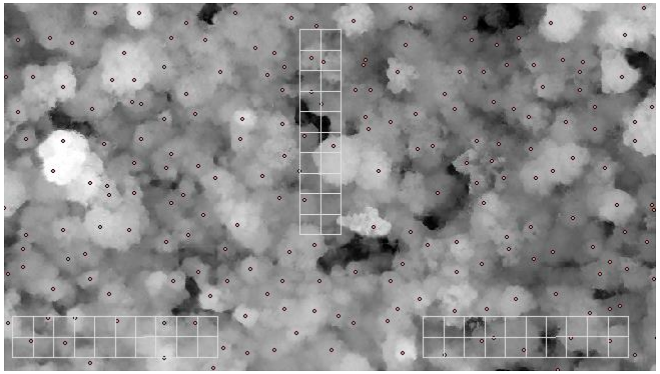
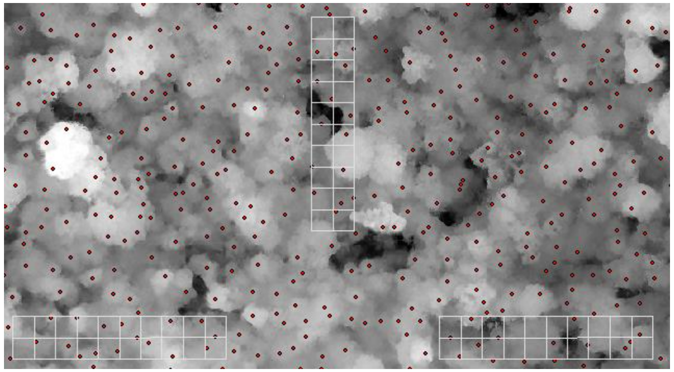
Feature 4: Number of Tree Tops

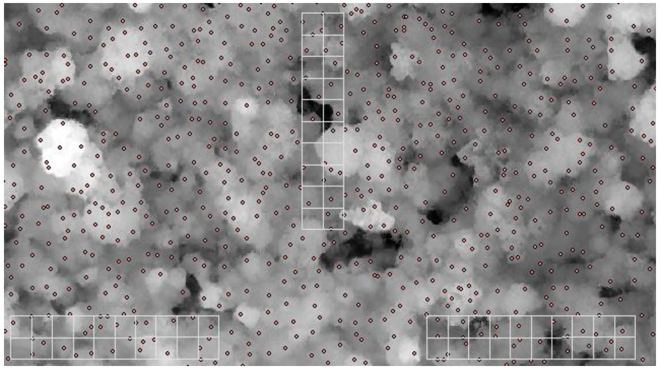
Crown Size 10m



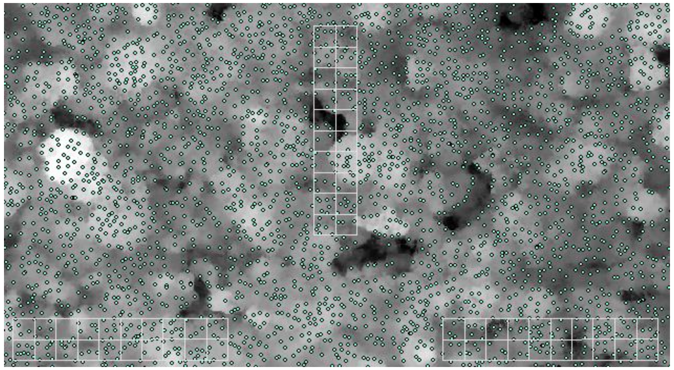
Crown Size 7m



Crown Size 5m



Crown Size 3m



Summary

- Flight / Data costs comparably low as Cessna aircrafts are available in any country (no costly transfer of special aeroplanes for flight campaign needed)
- Extraction of features from the aerial images can be done automatically with a satisfactory accuracy
- But: 3D-Features can be derived more precisely by LiDAR – Data (LiDAR – System available!)
- The aerial image features are further used to develop aerial volume equations for above-ground biomass and timber volume (NFI Component II)

Field work

NFI System Component II:
Terrestrial Inventory

- **Two-phase Inventory Concept**
- Terrestrial Plot Design
- Combining Terrestrial and Aerial Data
- Reduction of Terrestrial Plots and Expenses

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Two Phase Inventory

- Main Goal: Reducing the number of expensive terrestrial plots

- Terrestrial plots are expensive because
  - it takes a long time to measure
  - they are often difficult to access
  - larger teams of field and support staff needed

Two Phase Inventory

- Terrestrial plots are essential because many types of information can only be obtained by actually visiting the plot, for example:
  - Tree diameters
  - Tree species
  - Dead wood
  - Biodiversity
  - Interviews with local communities
- The number of terrestrial plots is reduced as much as possible, but not further!
- The sample has to remain representative

NFI System Component II:
Terrestrial Inventory

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- Two-phase Inventory Concept
- ➢ Terrestrial Plot Design
- Combining Terrestrial and Aerial Data
- Reduction of Terrestrial Plots and Expenses

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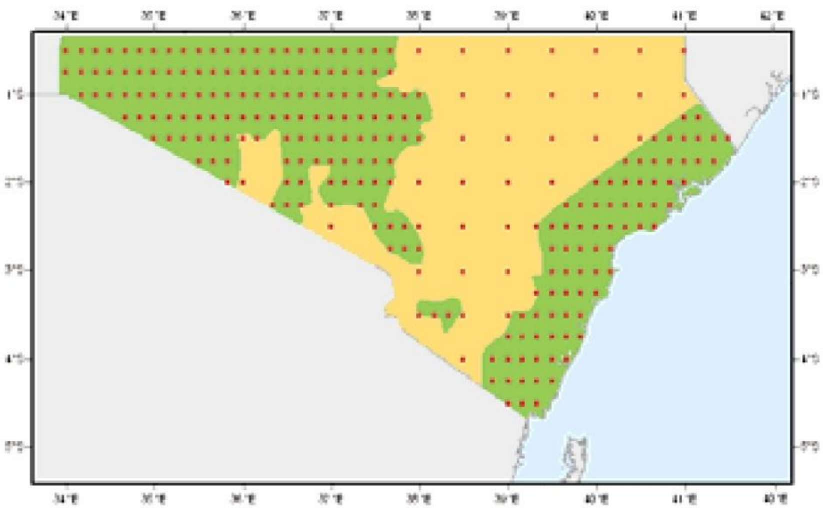
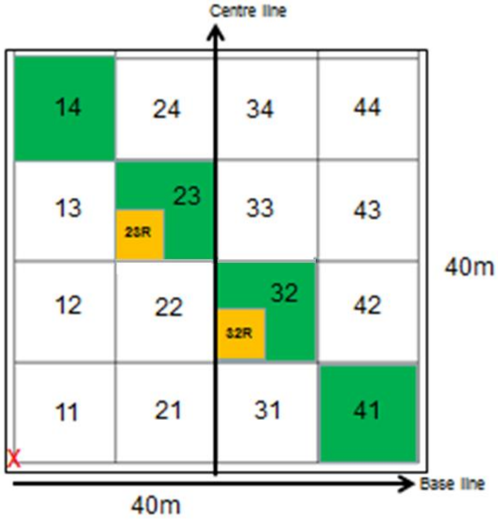
Terrestrial Plot Design

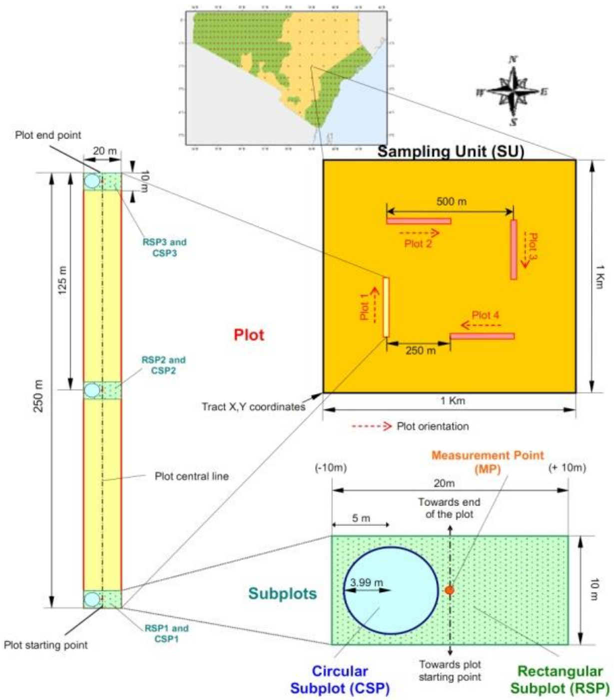
- Regular permanent grid over the whole country
- Random starting point
- Sampling density may vary for different strata, for example production forest and protection/ conservation forest



Plot Design

- On each grid point a single plot or plot cluster
- Clusters reduce travelling costs
- Plot design is flexible and can be adapted to the customer's needs and the specific circumstances





NFI System Component II:
Terrestrial Inventory

- Two-phase Inventory Concept
- Terrestrial Plot Design
- ➢ Combining Terrestrial and Aerial Data
- Reduction of Terrestrial Plots and Expenses

Combining Terrestrial and Aerial Data

- Calculate values of target variables for each plot using either pantropical formulas or locally parameterised functions
  - Biomass
  - Timber volume
- Use features from aerial data as independent variables in multivariate linear regression
- Employ feature selection procedure, for example try all possible combinations or stepwise regression

The Regression Model

- Correlation between aerial features and target variable (biomass, timber volume) is key
- Volume covered by crowns is best indicator → need good terrain model → laser scanning is recommended
- The result of each feature combination is evaluated by calculating the AIC
- Account for multiple input variables by using the adjusted R^2, avoids overfitting
- The normal R^2 would be too optimistic, features that don't provide additional information could be included
- The best model is chosen for each target variable

The Regression Estimate

- Unbiased estimate of population mean:

$$\bar{y} = \bar{y}_t + b \cdot (\bar{x}_{ae} - \bar{x}_t)$$

- *y* is e.g. biomass in t/ha
- $\bar{y}_t$ is the mean of the terrestrial sample
- *b* is a vector of regression coefficients
- $\bar{x}_{ae}$ is the vector of means of the features in the aerial sample
- $\bar{x}_t$ is the vector of means of the features of the plots that are in both the terrestrial and the aerial sample

Combining Terrestrial and Aerial Data

- The adjusted R² of the regression is the key value for precision and efficiency
- Systematic sampling: Double(!) sample size reduces the standard deviation of the estimate of the population mean to only ~71% (not 50%)

$$V(\bar{y}) = \frac{S_t^2(y)}{n_t}$$

- Two-phase sampling: The same effect as twice the sample size can be obtained by using two-phase sampling and reaching an R² of 0.5

$$V(\bar{y}) = \frac{S_t^2(y) \cdot (1 - R^2)}{n_t} + \frac{S_t^2(y) \cdot R^2}{n_{ae}}$$

The Core of the Efficiency

$$V(\bar{y}) = \frac{S_t^2(y) \cdot (1 - R^2)}{n_t} + \frac{S_t^2(y) \cdot R^2}{n_{ae}}$$

- n_{ae} is the size of the aerial sample (large)
- n_t is the size of the terrestrial sample (expensive)
- S_t^2 is the variance of the terrestrial sample
- Right fraction has large denominator → becomes negligible
- R^2 'moves' the variance to the right fraction
- The bigger R^2, the less variance remains

The Core of the Efficiency

ANRICA

$$V(\bar{y}) = \frac{S_t^2(y)\cdot(1-R^2)}{n_t} + \frac{S_t^2(y)\cdot R^2}{n_{ae}} \rightarrow 0$$

- n_{ae} is the size of the aerial sample (large)
- n_t is the size of the terrestrial sample (expensive)
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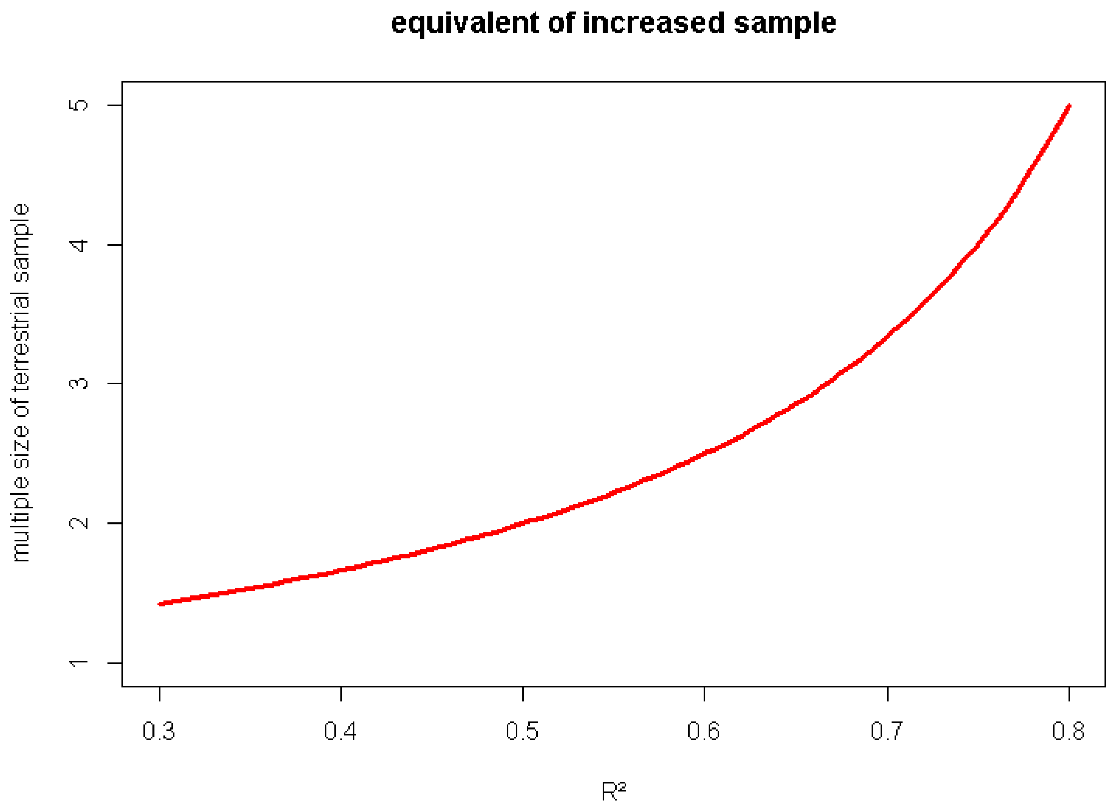
Combining Terrestrial and Aerial Data

R^2	sample size
0.30	1.43
0.40	1.67
0.50	2.00
0.60	2.50
0.70	3.33
0.75	4.00
0.80	5.00



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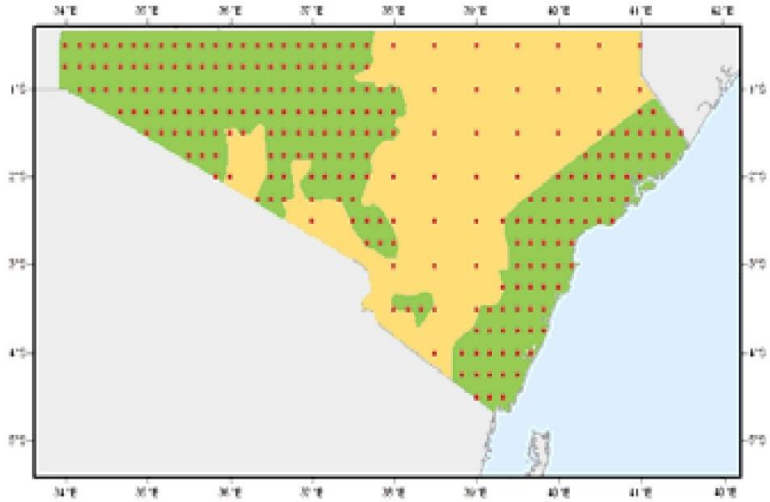
NFI System Component II: Terrestrial Inventory

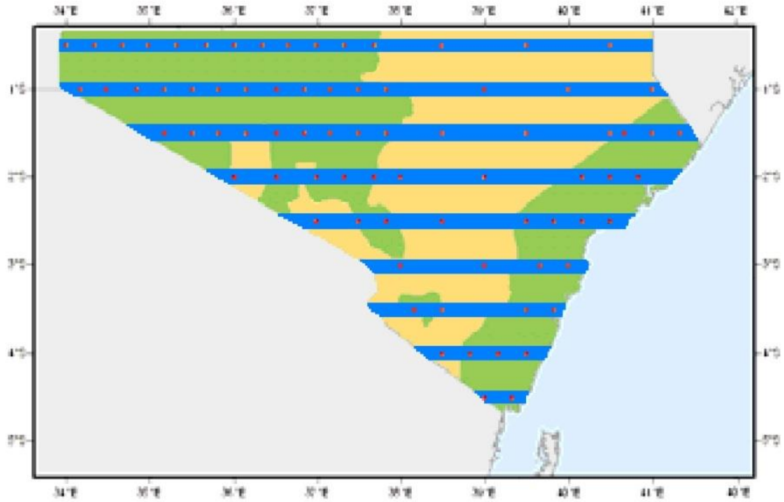
- Two-phase Inventory Concept
- Terrestrial Plot Design
- Combining Terrestrial and Aerial Data
- ➢ Reduction of Terrestrial Plots and Costs

Reduction of Terrestrial Plots

Systematic sampling
Conventional terrestrial inventory



Two-phase sampling with reduced terrestrial plots



Reduced Expenses depending on R^2

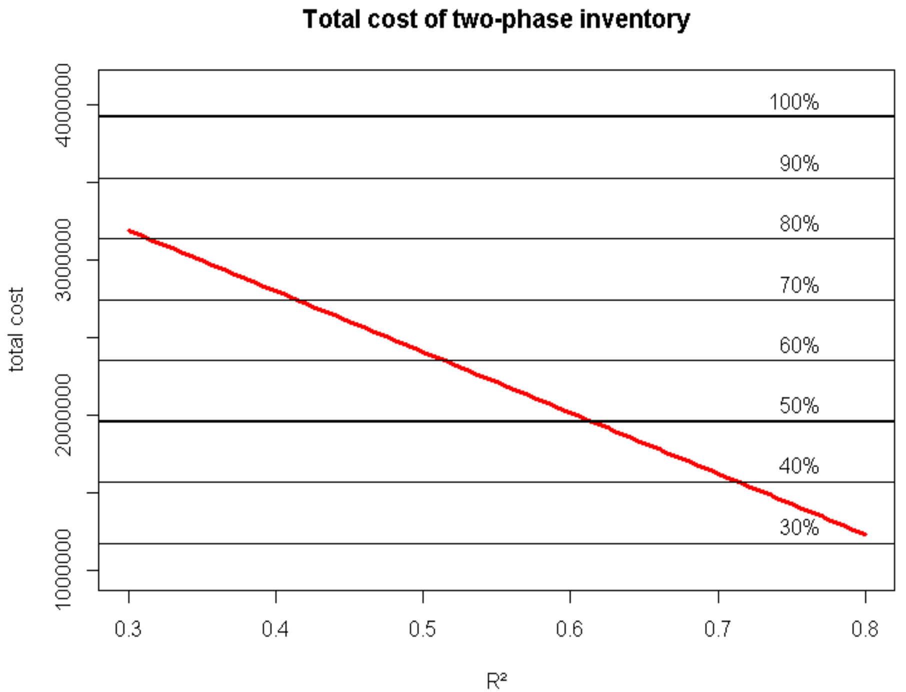
- Example for an conventional terrestrial inventory:

Cost of surveying a field plot	USD 10,000
Standard deviation of biomass	70%
Desired precision (95% CI)	± 5%
Number of plots	392
Total cost	USD 3,920,000

Reduced Expenses depending on R^2

- Applying the two-phase inventory
- Adding flight campaign
- Cost: 450,000 USD

R^2	Number of plots	Total cost (USD)	Saving in %
0.30	274	3,194,000	18.5
0.40	235	2,802,000	28.5
0.50	196	2,410,000	38.5
0.60	157	2,020,000	48.5
0.65	137	1,822,000	53.5
0.70	118	1,626,000	58.5
0.75	98	1,430,000	63.5
0.80	78	1,234,000	68.5



Reduced Expenses due to Two-phase Sampling

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COSTS	Conventional terrestrial	Two-phase
Cost of surveying a field plot	USD 10,000	USD 10,000
Standard deviation of biomass	70%	70%
Desired precision (95% CI)	± 5%	± 5%
Cost of flight campaign	-	USD 450,000
R^2	-	0.6
Number of plots	392	157
Total cost	USD 3,920,000	USD 2,020,000

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Cost-effective NFI Implementation

Cost-effectiveness achieved through

- applying aerial biomass and timber models
- large number of aerial samples

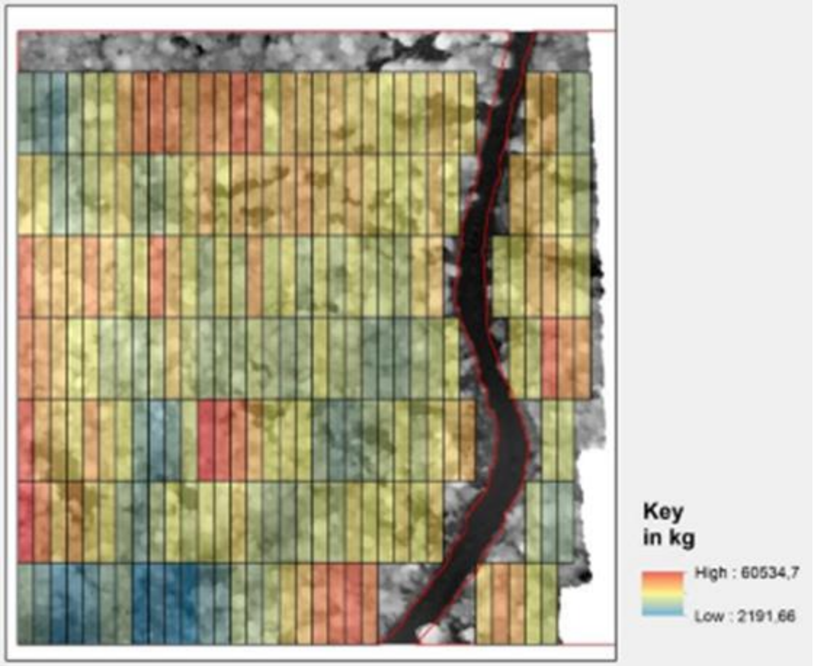
Terrestrial plots aim at

- Development of aerial models

Above-ground biomass, carbon stocks, timber volume etc.

- Assessing additional essential inventory information

Species composition/distribution, tree health, regeneration, site parameters, growth/ mortality, NTFP, bio-d indicators etc.



Cost-effective NFI Implementation

Country	Terrestrial Inventory	Two-phase Inventory
Philippines	389[1]	190
Cameroon	236[1]	120
Suriname	400[2]	180

[1] FAO 2008. National Forest Monitoring and Assessment – Manual for integrated field data collection National Forest Monitoring and Assessment Working Paper NFMA 37/E. Rome
[2] Result of Suriname NFI Pilot Project

- Maintaining a systematic inventory grid covering the entire country
- Reducing number of field plots and inventory costs by appr. 50%
- High accuracy of target parameters
- Consistent re-measurement (permanent plots)
- Collecting comprehensive information including adequate assessment of other ecological and socio-economic parameters

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