MAPPING DIVERSITY OF PLANT COMMUNITIES IN AMAZONIAN RAINFOREST WITH SENTINEL-2 SATELLITE IMAGERY.

JEAN-BAPTISTE FERET, UMR TETIS, INRAE (JB.FERET@TELEDETECTION.FR)

ALEXANDRE DEFOSSEZ, UMR ESPACE-DEV, IRD (ALEXANDRE.DEFOSSEZ@IRD.FR)

CONTEXT OF THE APPLICATION

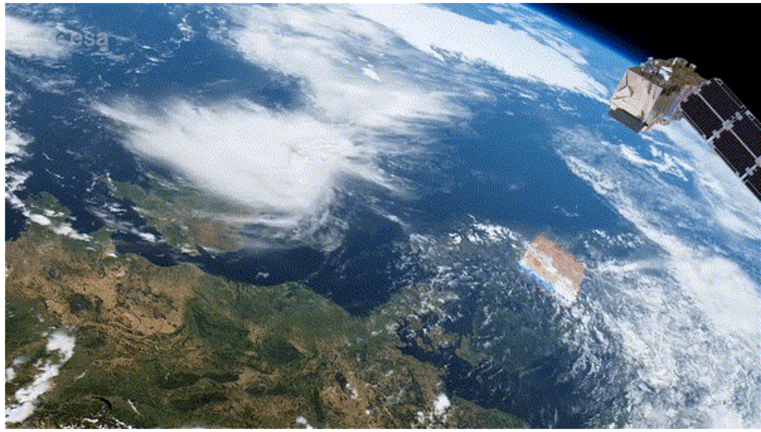
- Increasing pressure put on Amazonian tropical rainforest
  - Degradation and deforestation for natural resources and agriculture
  - Adaptation to climate change

- Increasing capacity for remotely sensed monitoring of tropical ecosystems
  - Satellite constellations acquire data with high temporal frequency: Copernicus, Landsat, Planet…
  - Methodological developments allow taking advantage of this information

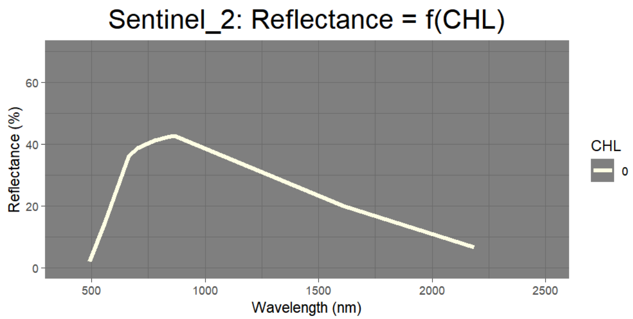
- Number of challenges for operational forest monitoring
  - Which sensors, which methods?
  - What type of relevant information to support forest stakeholders and decision making

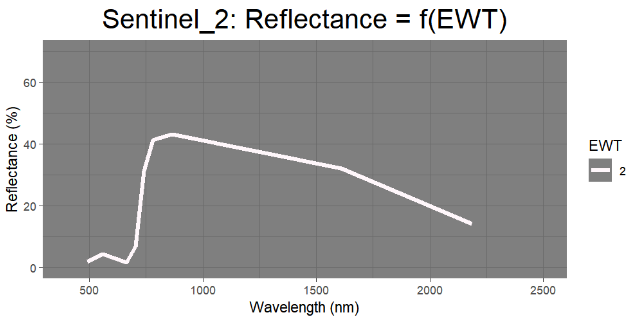
MONITORING TROPICAL FOREST OVER THE GUIANA SHIELD : ASSETS AND CHALLENGES OF OPTICAL IMAGERY

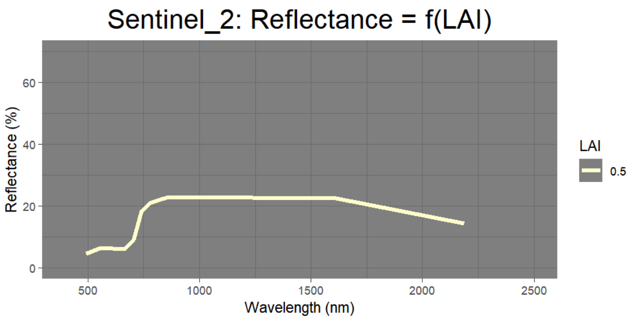
- Remotely sensed information to be used: Sentinel-2 images
  - 10 m spatial resolution
  - 5-days revisit
  - 10 spectral bands in the visible & infrared domains
  - Open access
  - Sensitivity of optical information to various vegetation traits (leaf & canopy) :



Leaf chlorophyll content	Leaf water content	Leaf Area Index







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- Challenges with Sentinel-2 image processing in tropical context
  - Very high and consistent cloud cover


Mosaic of tiles with minimum cloud cover over French Guiana in 2017

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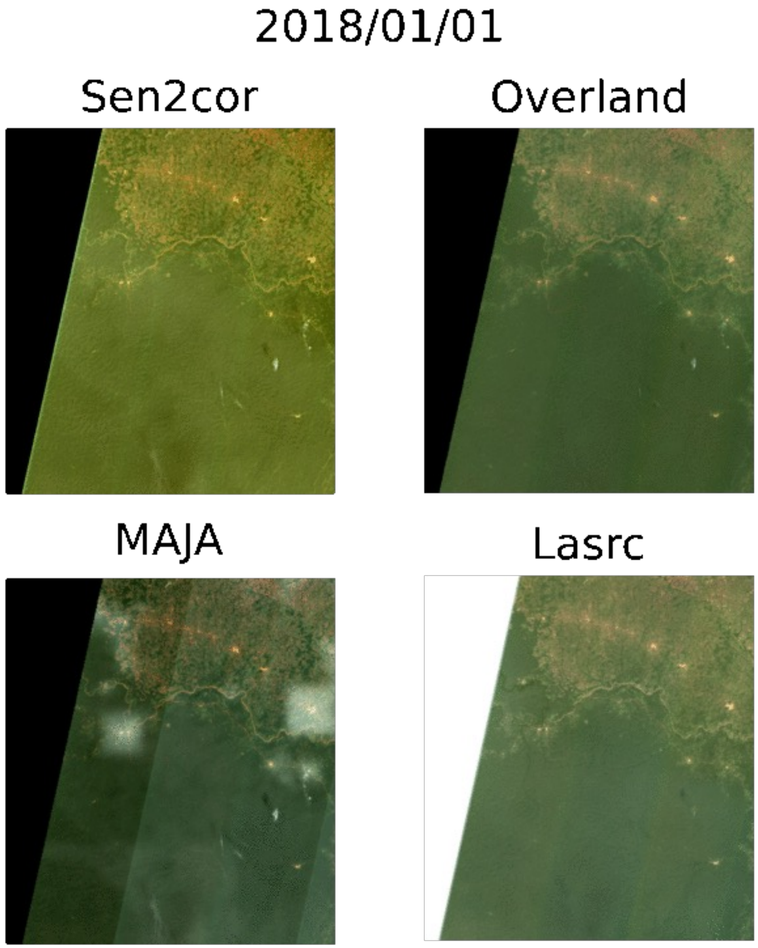
  - Atmospheric correction methods (ACM) do not perform consistently in time



Comparison of 4 ACM applied on S2 time series
(tile 33NVE, Cameroon)

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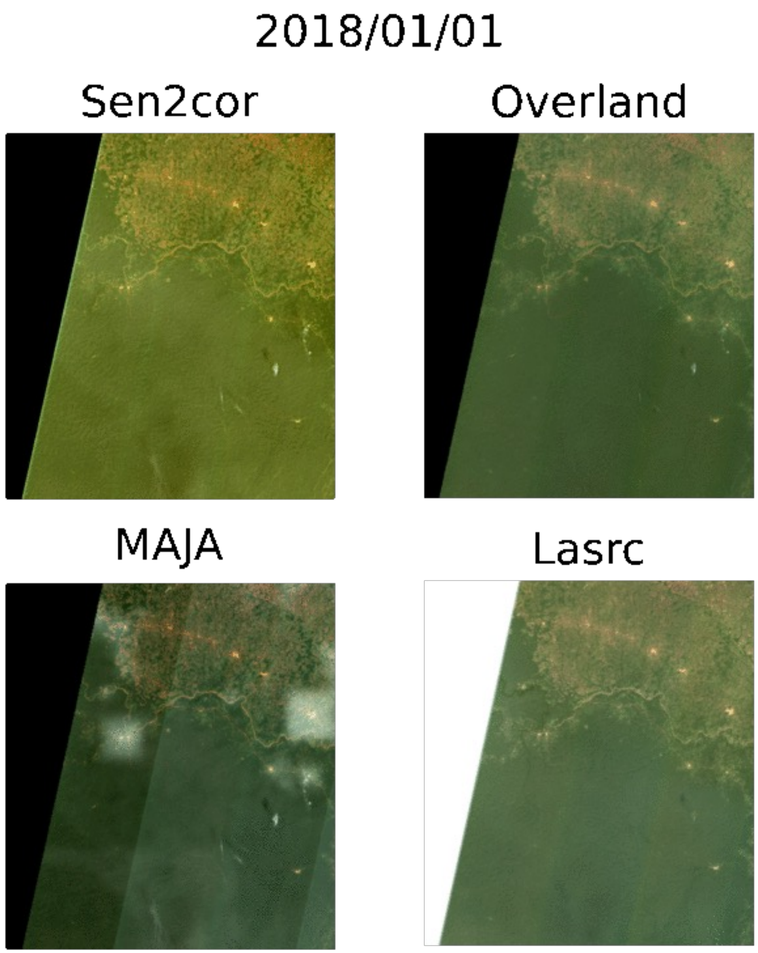
- Challenges with Sentinel-2 image processing in tropical context
  - Very high and consistent cloud cover

  → <u>Need to find methods to fill spatial gaps caused by clouds</u>

  - Atmospheric correction methods (ACM) do not perform consistently in time

  → <u>Need to identify ACM with good consistency in time</u>



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MONITORING TROPICAL FOREST OVER THE GUIANA SHIELD : METHODOLOGICAL FRAMEWORK

- Key hypothesis and core method
  - Spectral Variation Hypothesis applied to high spatial resolution images :

  → Spatial variability of spectral information can be linked to biological diversity

  - A variety of methods exist to relate spectral information to biodiversity

APPLICATION

Methods in Ecology and Evolution BRITISH ECOLOGICAL SOCIETY

biodivMapR: An R package for α- and β-diversity mapping using remotely sensed images

Jean-Baptiste Féret | Florian de Boissieu

https://jbferet.github.io/biodivMapR/index.html

ECOLOGY LETTERS

Ecology Letters, (2020) 23: 370–380 doi: 10.1111/ele.13429

METHOD

Partitioning plant spectral diversity into alpha and beta components

Etienne Laliberté,[1,2]* Anna K. Schweiger[1,2] and Pierre Legendre[2]

https://github.com/elaliberte/specdiv

Methods in Ecology and Evolution BRITISH ECOLOGICAL SOCIETY

APPLICATION Open Access

rasterdiv—An Information Theory tailored R package for measuring ecosystem heterogeneity from space: To the origin and back

Duccio Rocchini, Elisa Thouverai, Matteo Marcantonio, Martina Iannacito, Daniele Da Re, Michele Torresani, Giovanni Bacaro, Manuele Bazzichetto, Alessandra Bernardi, Giles M. Foody, Reinhard Furrer, David Kleijn, Stefano Larsen, Jonathan Lenoir, Marco Malavasi, Elisa Marchetto, Filippo Messori, Alessandro Montaghi, Vítězslav Moudrý, Babak Naimi, Carlo Ricotta, Micol Rossini, Francesco Santi, Maria J. Santos, Michael E. Schaepman, Fabian D. Schneider, Leila Schuh, Sonia Silvestri, Petra Šímová, Andrew K. Skidmore, Clara Tattoni, Enrico Tordoni, Saverio Vicario, Piero Zannini, Martin Wegmann ... See fewer authors

https://github.com/mattmar/rasterdiv

DEFINITION OF ALPHA & BETA DIVERSITY

→ α-diversity provides information on the local species richness and/or abundance

→ β-diversity provides information on the variation in community composition along environmental gradients or according to a spatial or temporal pattern of communities

Shannon Index:

$$H' = -\sum_{i=1}^{S} p_i \log_2 p_i$$

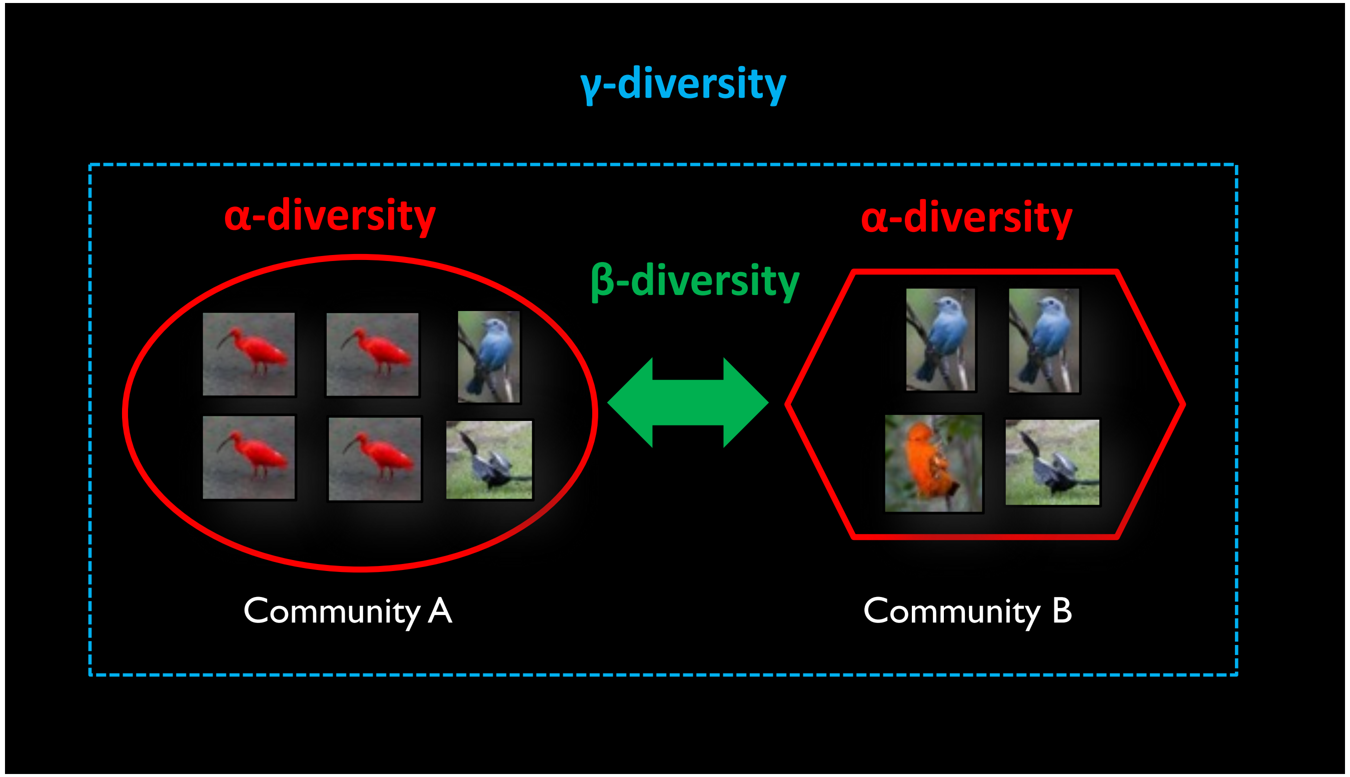
S : Species Richness, the total number of species in the environment

with $p(i) = n_i / N$

p(i) : The proportion of a species *i* in the environment.

n_i : The number of individuals of species i

N : The total number of individual including all species



Bray-Curtis dissimilarity:

$$BC_{jk} = 1 - \frac{2\sum_{i=1}^{p} min(N_{ij}, N_{ik})}{\sum_{i=1}^{p}(N_{ij} + N_{ik})}$$

N_{ik}: The abundance of a species *i* in a sample *k*

N_{ij} : The abundance of a species *i* in a sample *j*

min (…,…) : for a species *i* present in *j* and k, the minimum count of individuals between *j* and *k*.

p : Total number of species

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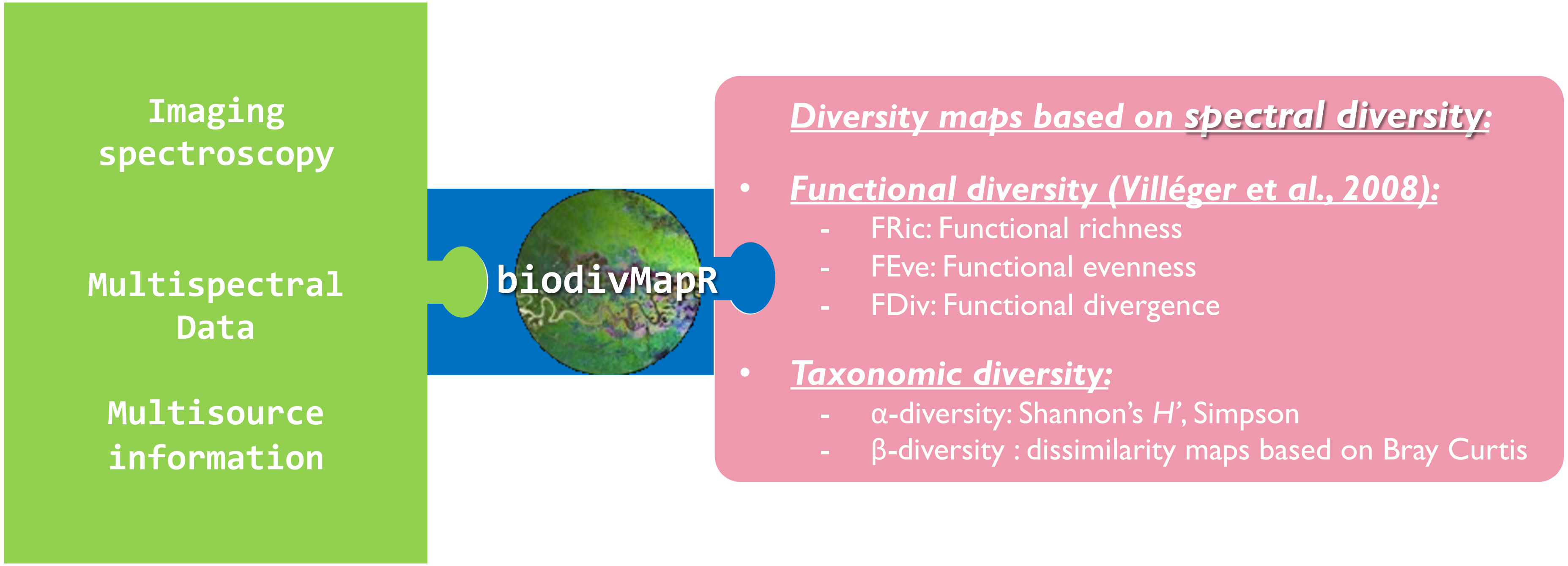
  - A variety of methods exist to relate spectral information to biodiversity
  - ***biodivMapR***: map spectral diversity metrics corresponding to α-diversity and β-diversity



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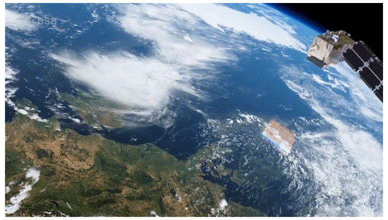

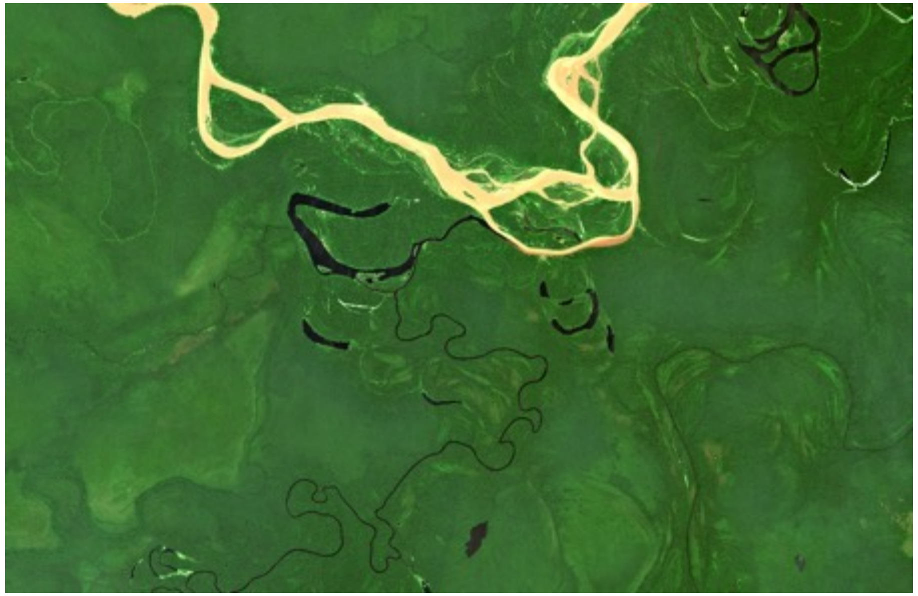

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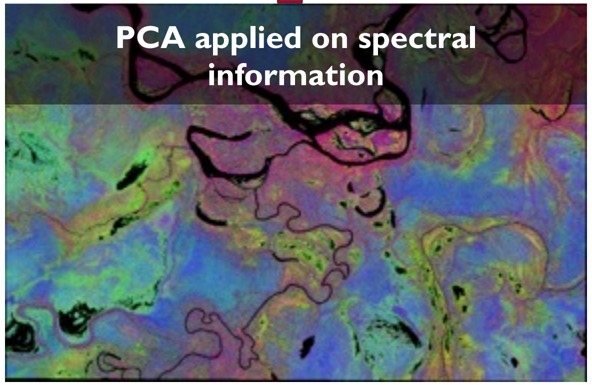
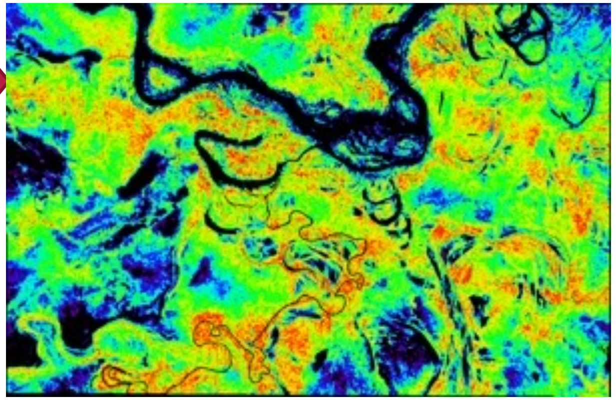
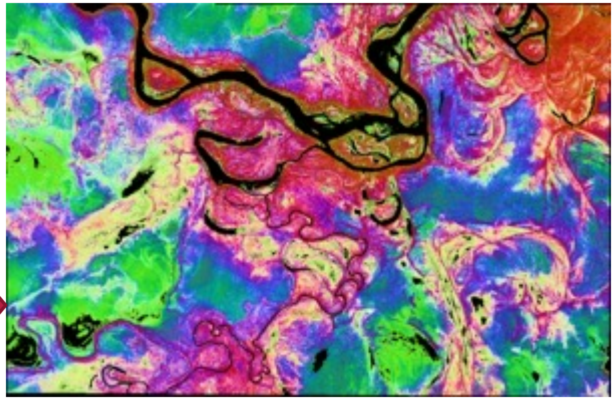
α-diversity map
Species richness
Shannon index
…



β-diversity map
Bray-Curtis dissimilarity: evidences differences in floristic composition





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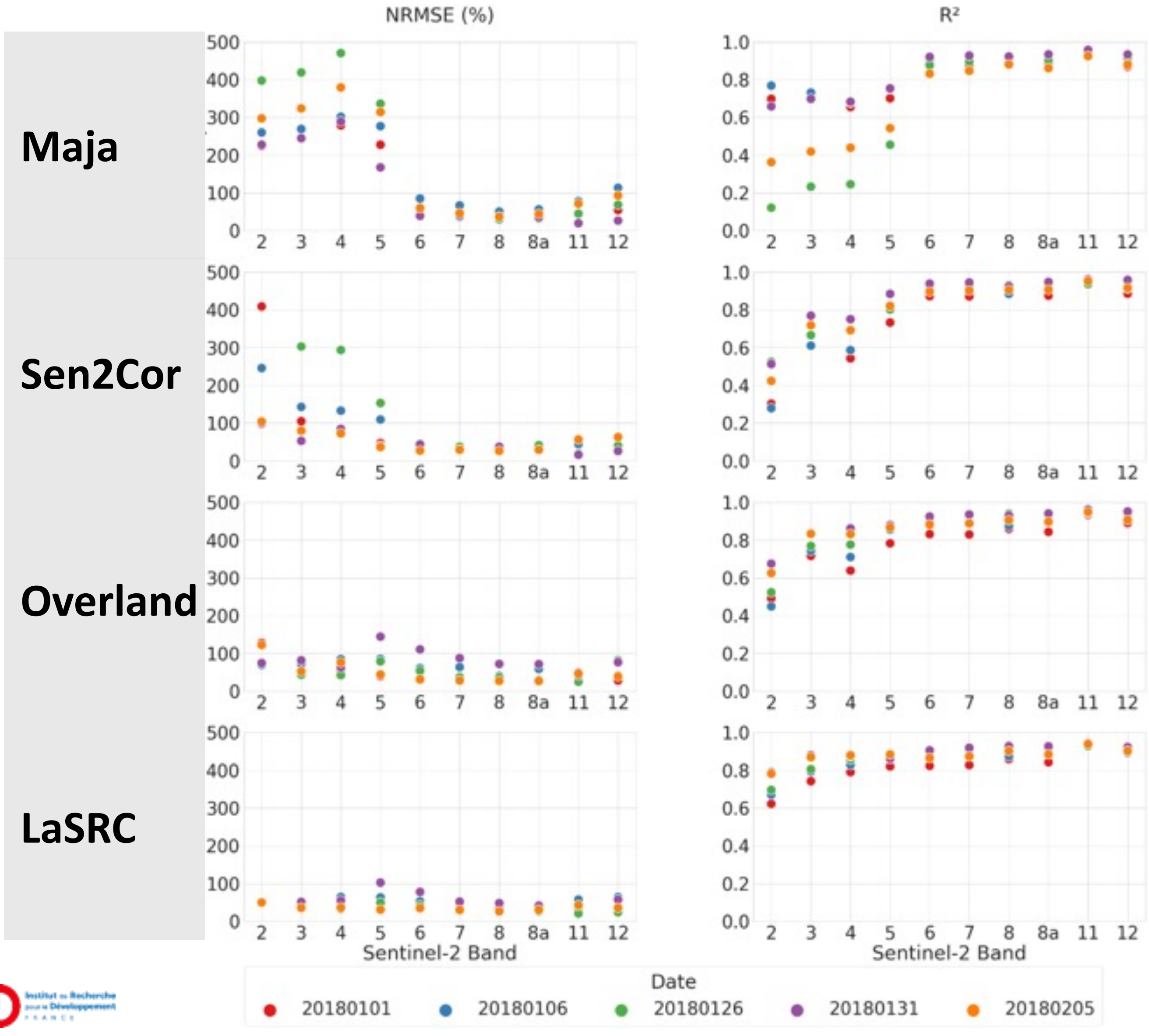
→ How to reduce uncertainty associated with atmospheric corrections ?

→ How to apply biodivMapR in the context of strong cloud cover and produce continuous maps ?

MONITORING TROPICAL FOREST OVER THE GUIANA SHIELD : ATMOSPHERIC CORRECTIONS FOR CONSISTENCY THROUGH TIME

- Method intercomparison (Chraibi et al., 2022)
- Maja & Sen2Cor show temporal inconsistency in the VIS domain
- LaSRC shows better temporal consistency over the VIS-NIR-SWIR domain
- Spectral indices show good temporal consistency, with limited bias between acquisitions

→ The package **sen2lasrc** (F. de Boissieu, 2022) was developed to allow atmospheric correction of Sentinel-2 with LaSRC



MONITORING TROPICAL FOREST OVER THE GUIANA SHIELD : PRODUCTION OF IMAGE COMPOSITES FOR SPECTRAL INDICES

- Spatial gap filling performed based on a time series of selected spectral indices
- Application of biodivMapR on spectral indices composites in order to map forest diversity
- Development and validation performed by *Alexandre Defossez*, funded by PROGYSAT

METHODOLOGICAL FRAMEWORK

- Are Sentinel-2 images (S2) usable for estimating spectral diversity in the Guiana Shield?
- Is spectral diversity spatially coherent with forest diversity estimated from field?

→ To answer these questions, we developed a 3-steps processing workflow :

Step 1
Spectral index composite images

- **Climatically** & **phenologically coherent** period for a given year: « season »
- **Temporally stable**: spectral indices

Step 2
Spectral diversity metrics

Spatial heterogeneity of spectral information:
α-diversity & β-diversity

Step 3
Validation with field data

Comparison of spectral diversity metrics with taxonomic diversity derived from plot inventories based on exact spatial extent

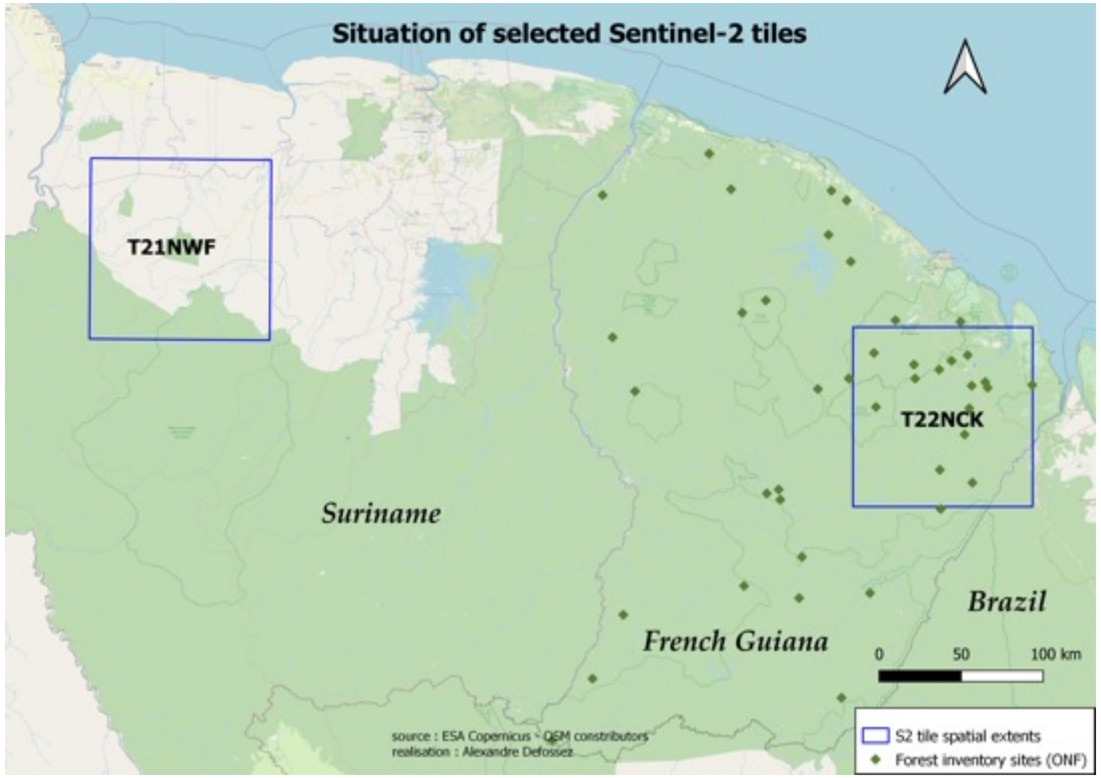
AVAILABLE DATA SETS & METHODS

- **Sentinel-2 tiles** : regions with contrasted cloudiness through Guiana Shield:
  → **T21NWF (Suriname):** lower cloud cover
  → **T22NCK (French Guiana):** higher cloud cover, forest inventory data available for validation

- **Forest inventories** from « Habitats » program of French National Forest Office (ONF):
  → 42 sites inventoried over French Guiana
  → 20 types of forest habitats identified

- ***sen2lasrc***: atmospheric correction with LaSRC & masks (waterbodies, clouds, shades, urban…)

- **R packages:**
  → *preprocS2*: S2 image preprocessing, possibility to download
  → *spinR*: computation of spectral indices from S2 images
  → *biodivMapR*: spectral diversity indices & validation method



COMPUTE & SELECT SPECTRAL INDICES

- Selection of a cloudless acquisition in a tile's subset
- Computing spectral indices with *spinR*
- Examination of correlation matrix
- Spectral indices selection : **avoid redundancy and focus on well documented indices**

Download and perform atmospheric corrections with **Sen2lasrc**

- ***Tile:*** 21NWF (subset) - Date: 2018/10/25
- ***Mask:*** clouds, shades, non-vegetation pixels
- ***Resolution:*** 10m

BOA Reflectance (L2A) + Mask

Computation of spectral indices

N Spectral Indices

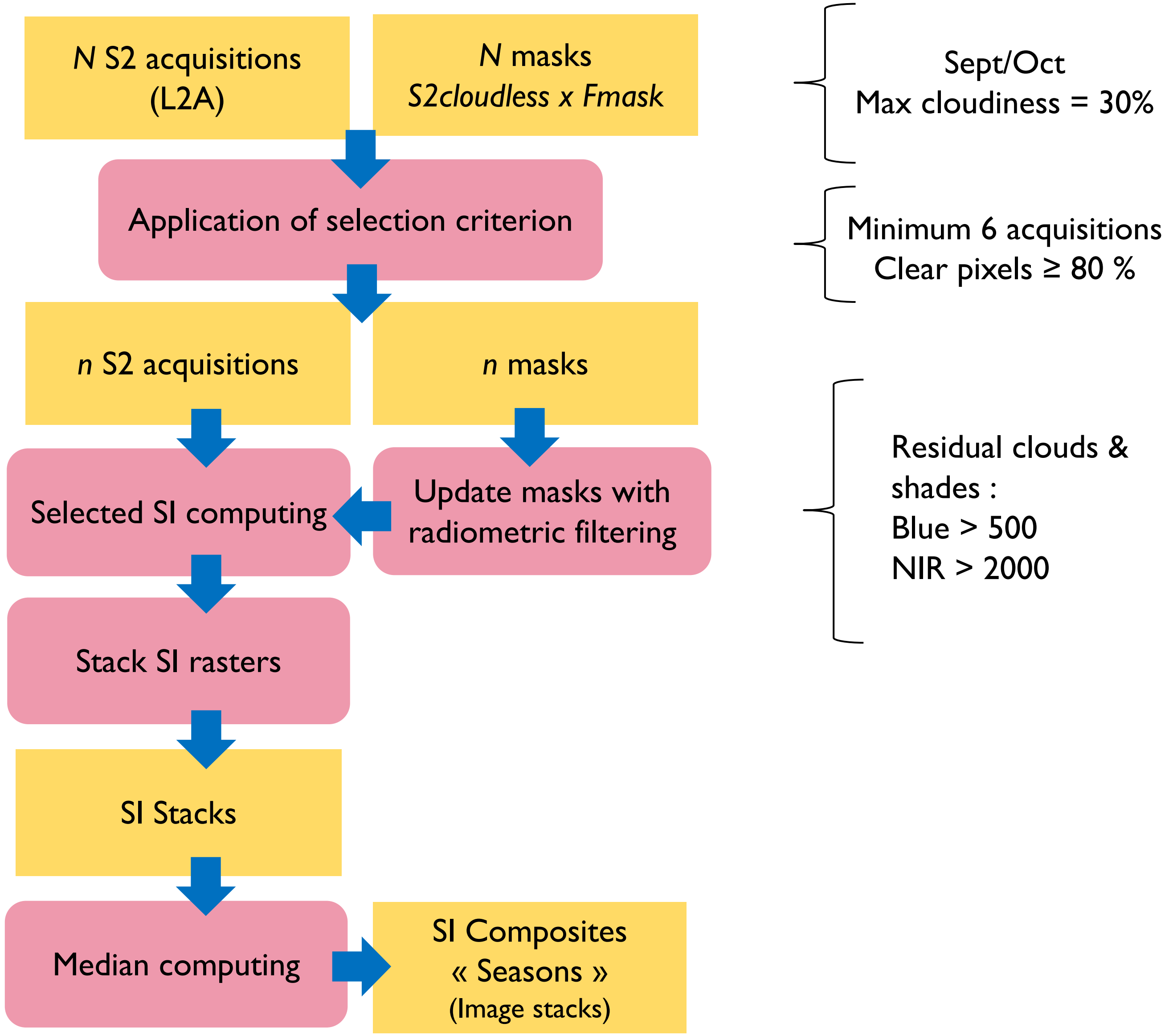
Computation of a correlation matrix

Spectral indices selection

EVI	*Enhanced Vegetation Index*
CRI1	*Carotenoid Reflectance Index 1*
NDVI	*Normalized Difference Vegetation Index*
CR_SWIR	*Continuum Removal Short Wave Infra Red*

STEP I: PRODUCTION OF COMPOSITE IMAGE

- A criterion is define to select S2 acquisitions
- Median of EVI, CRI1, NDVI & CR_SWIR is computed for each pixel of the raster stack



STEP 2: MAP SPECTRAL DIVERSITY

- From SI composite image, « spectral species » are computed for each pixel
- In windows of 100m² of spectral species raster, Shannon index and BC dissimilarity are computed

Spectral indices Composites

↓

Spectral species computing

K-means clustering
Nb clusters = 50
Window size = 10 px

↓

Spectral species image

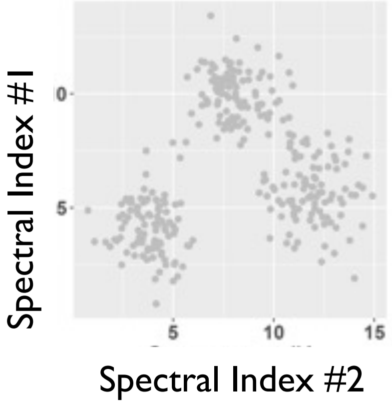
↓ ↓

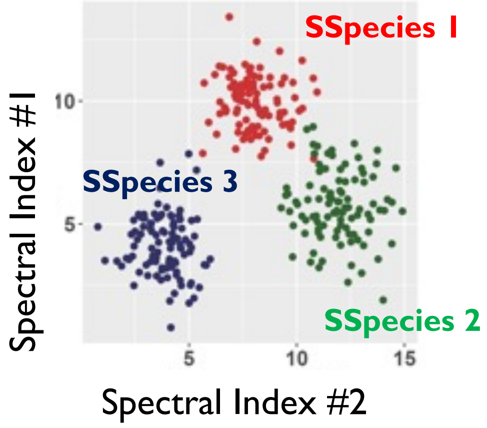
Shannon Index computing | Bray-Curtis dissimilarity computing

↓ ↓

Alpha diversity image (Shannon Index) | Beta diversity image (Bray-Curtis dissimilarity)

Spectral Indices distribution



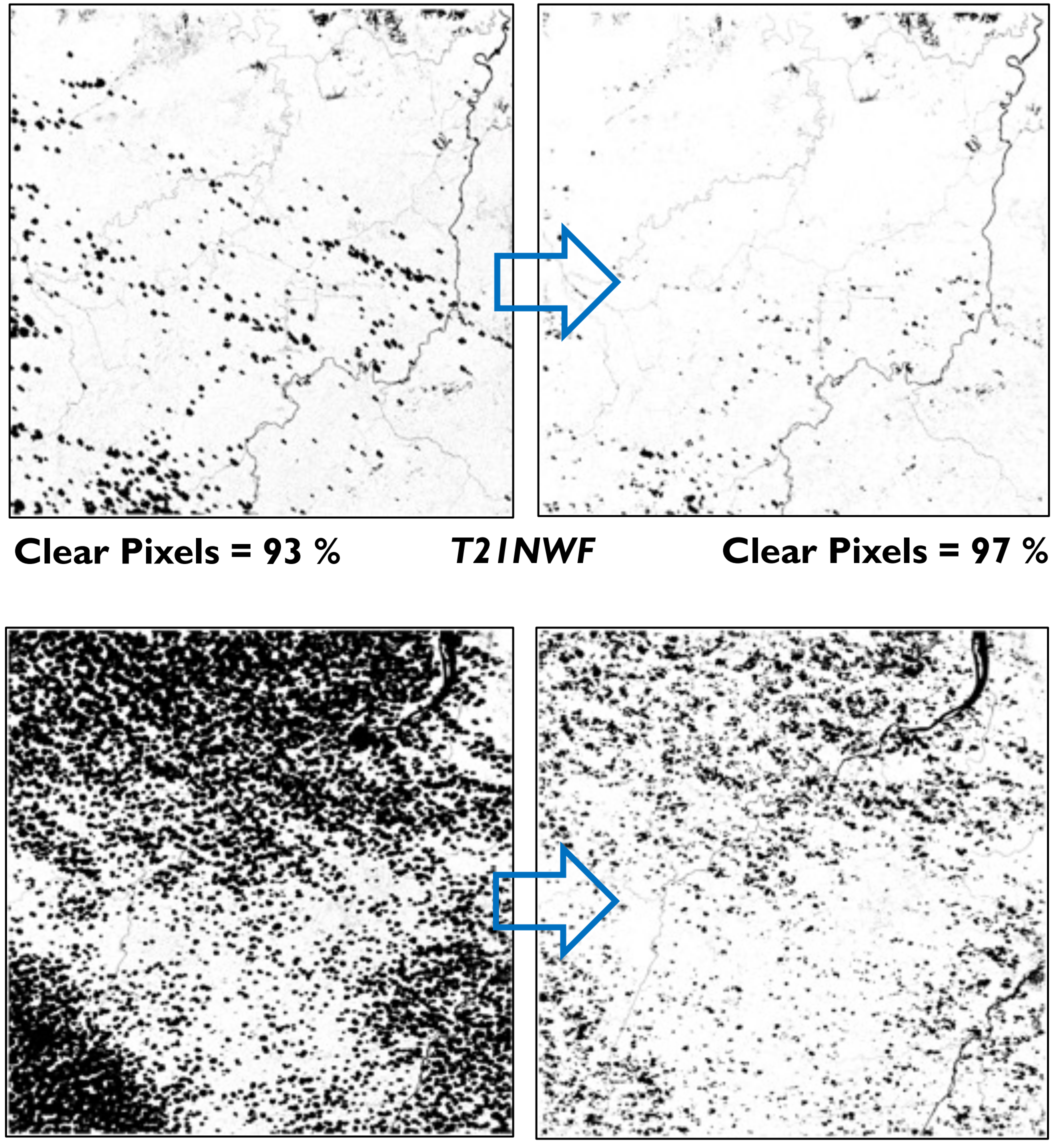


REDUCTION OF CLOUDINESS RATES WITH COMPOSITE IMAGES

- Tiles with contrasted cloudiness contexts
- **“Best” individual acquisition images *vs* composite images**

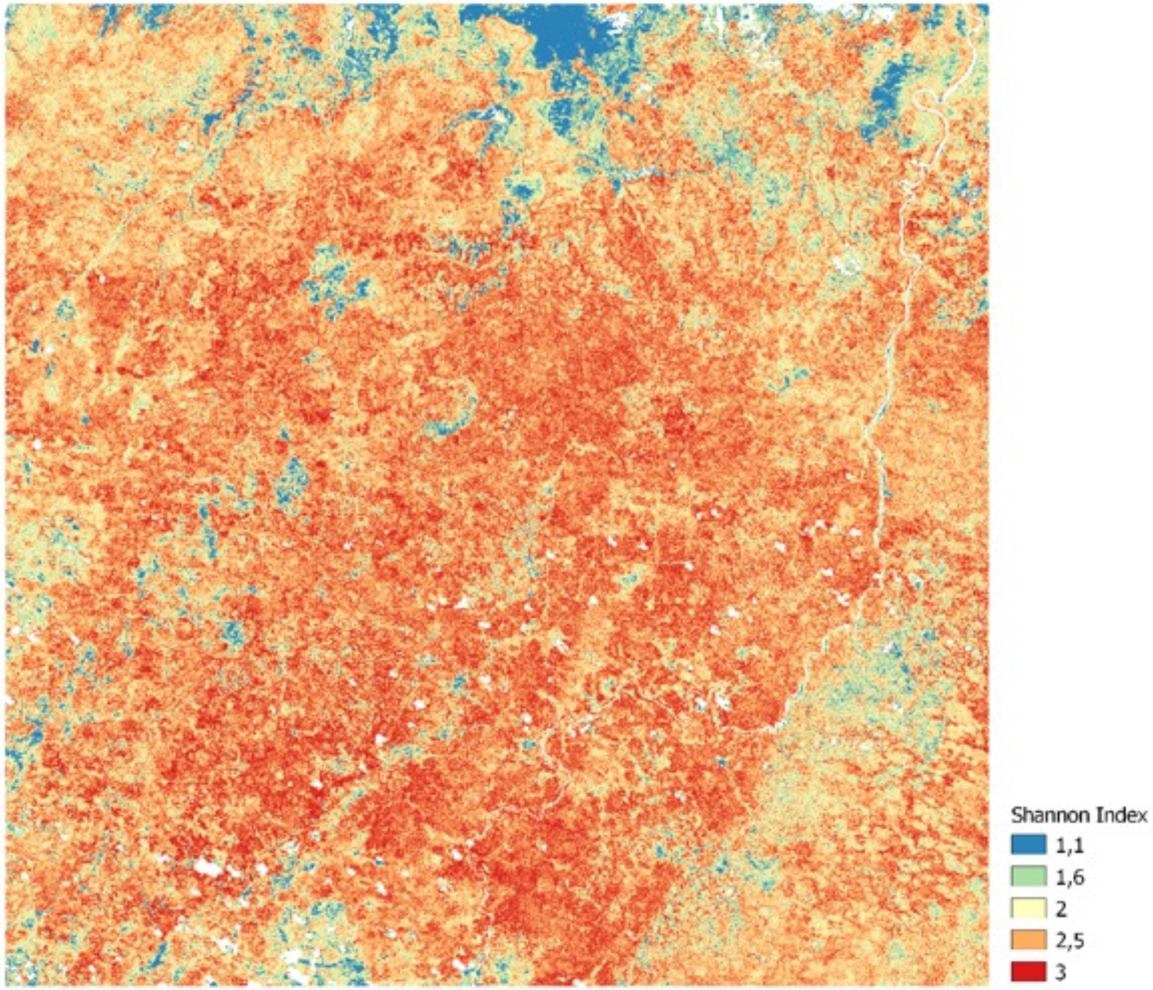
(Season 2018)

→ Production of composite images allows to reduce significantly the couldiness rates, especially in high cloudiness contexts

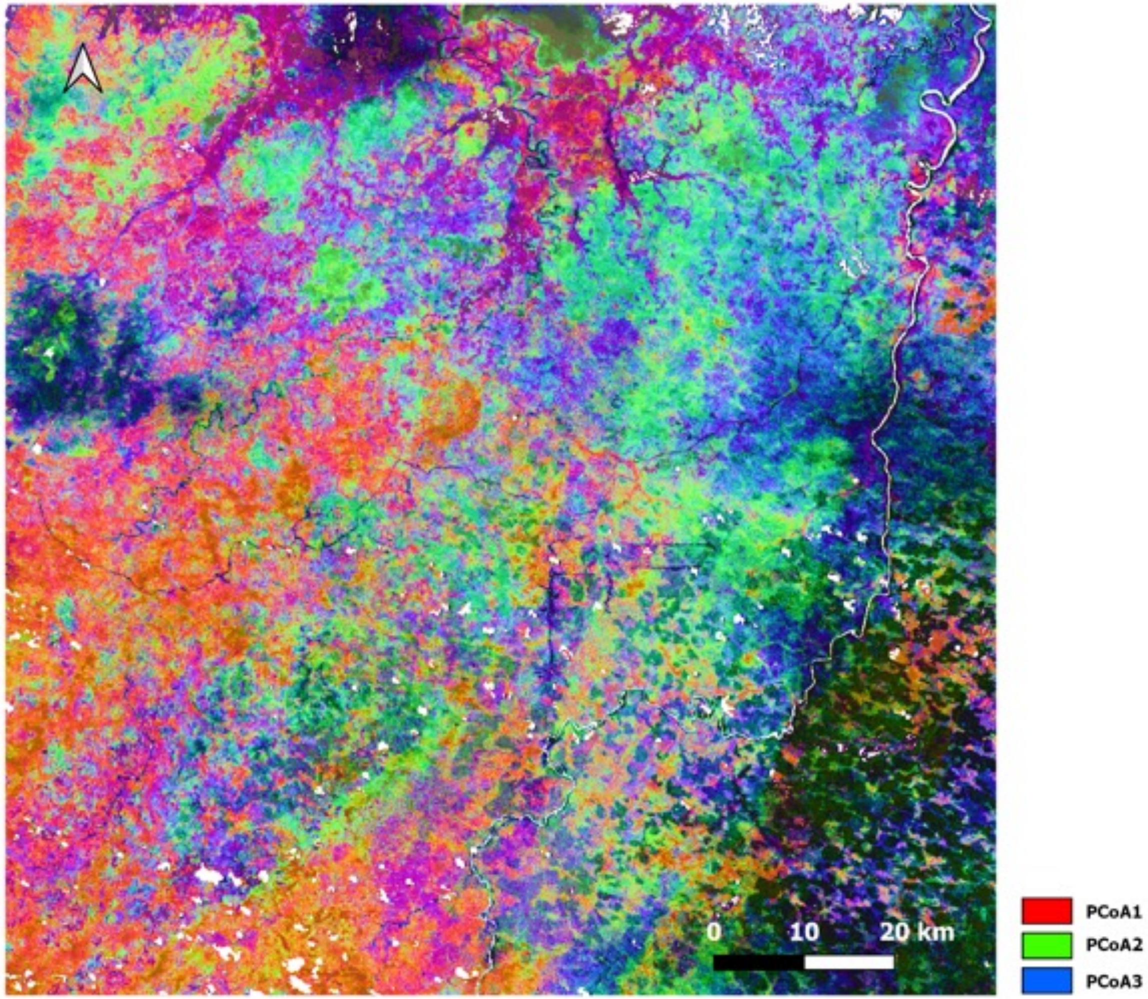


ALPHA & BETA DIVERSITY MAPS

→ Tile 21NWF: « low » cloudiness situation



α-diversity



β-diversity

Spatial resolution = 100 m

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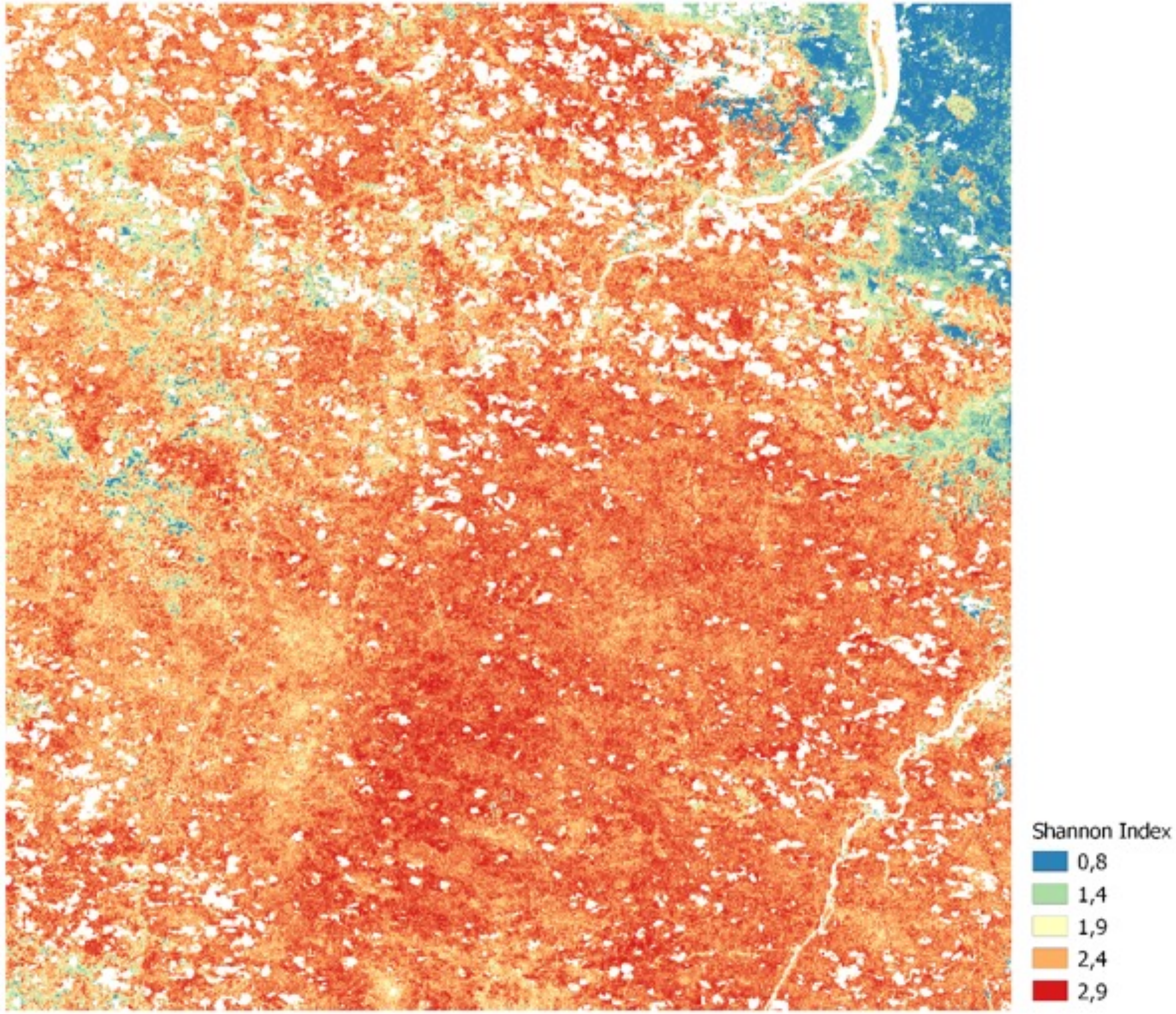
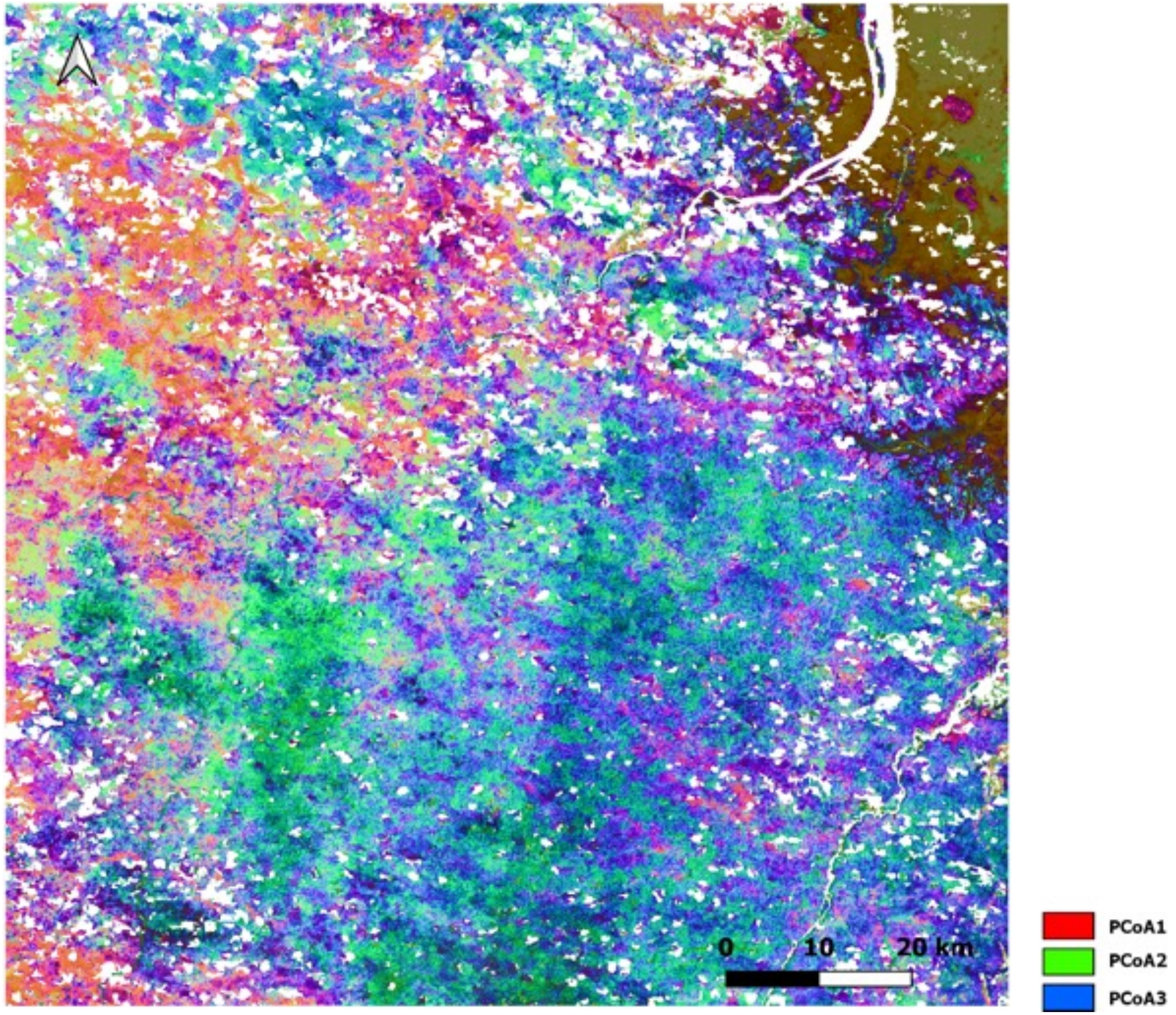
ALPHA & BETA DIVERSITY MAPS

→ Tile 22NCK: « high » cloudiness situation



α-diversity



β-diversity

Spatial resolution = 100 m

STEP 3: VALIDATION

- Validation framework from *biodivMapR*
- Discrimination of vegetation « types » or « communities »

→« **Community** »: *in ecology, a group or association of populations of two or more different species occupying the same geographical area at the same time* (Wikipedia)

→We try to identify contrasted communities from spectral diversity maps (expert interpretation)

- Clusters visualization on the PCoA axis (β-diversity) and individual point size (α-diversity)

Spectral Species

Validation plots (communities)

Extract pixels coordinates

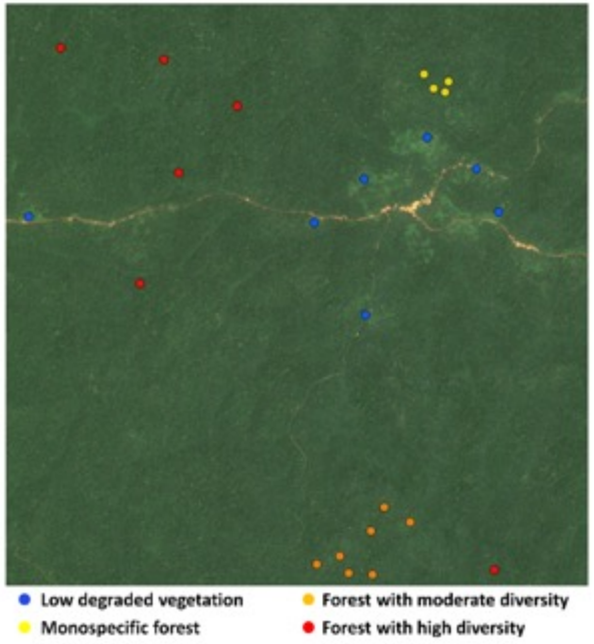
Diversity metrics computing

Shannnon index (image/validation plots)

BC Dissimilarity matrix (image/validation plots)

Ordination method (PCoA)

biodivMapR validation plots



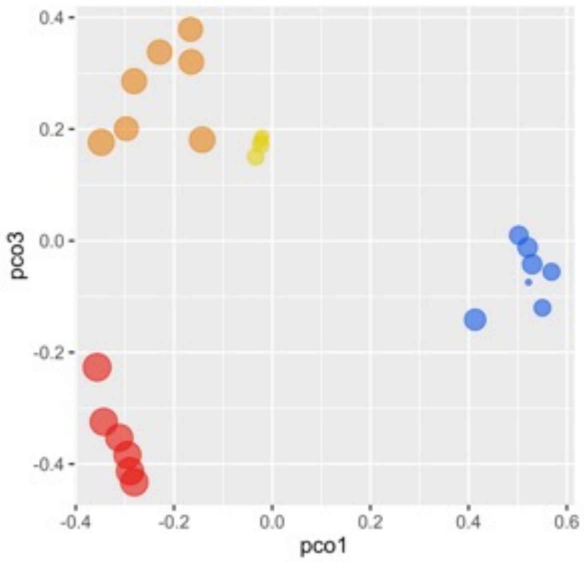


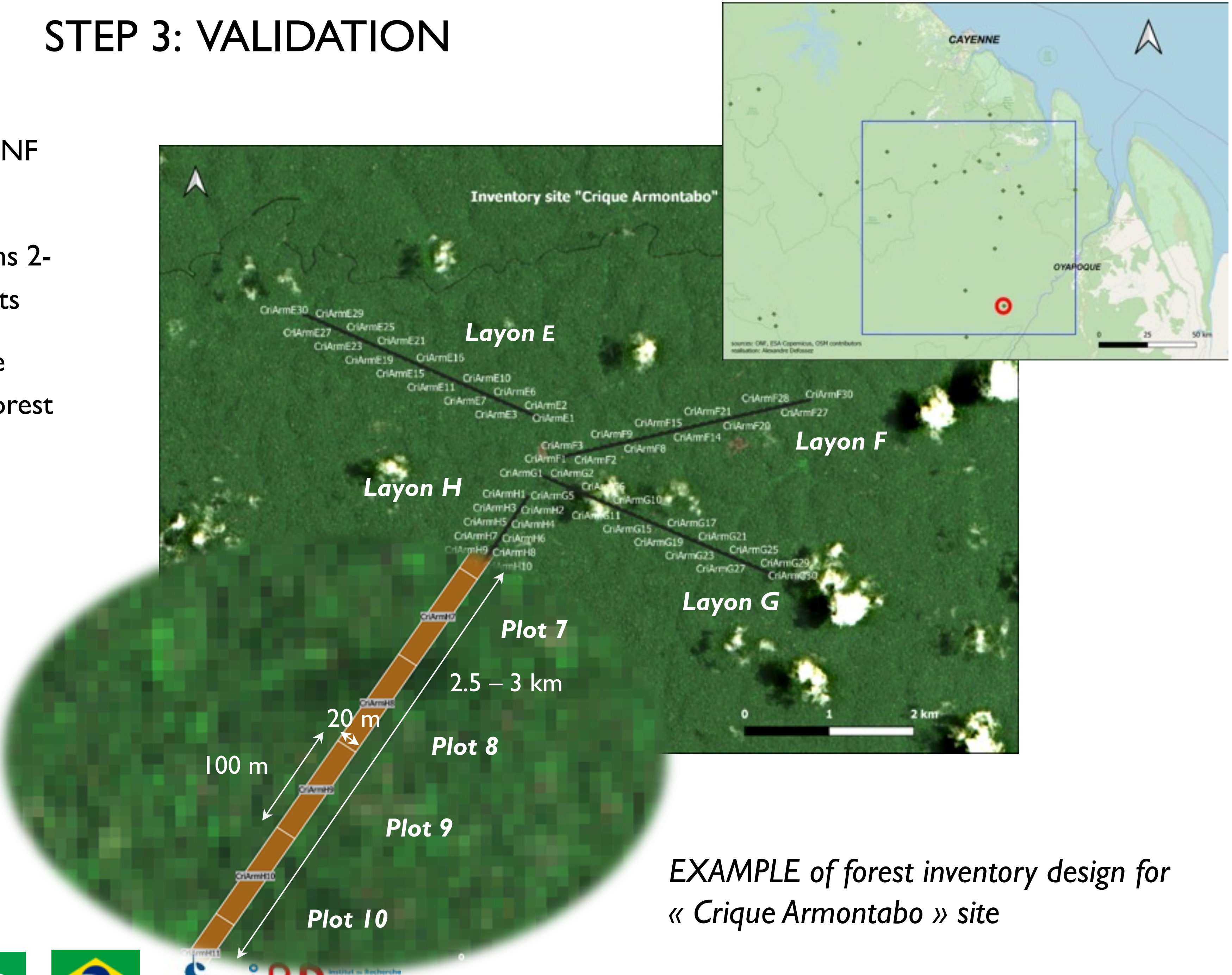
Image and plot from *biodivMapR* tutorial
https://jbferet.github.io/biodivMapR/articles/biodivMapR_08.html

STEP 3: VALIDATION

- Definition of validation plots based on ONF forest inventory network
- In T22NCK : 15 sites → each site contains 2-4 « layons » (transects) with ~ 20-30 plots
- Plots were aggregated by « layon » (same location) and « habitat » (same type of forest habitat)

→ Final set of validation plots :

72 plots with a given habitat type and « layon »



EXAMPLE of forest inventory design for « Crique Armontabo » site

STEP 3: VALIDATION

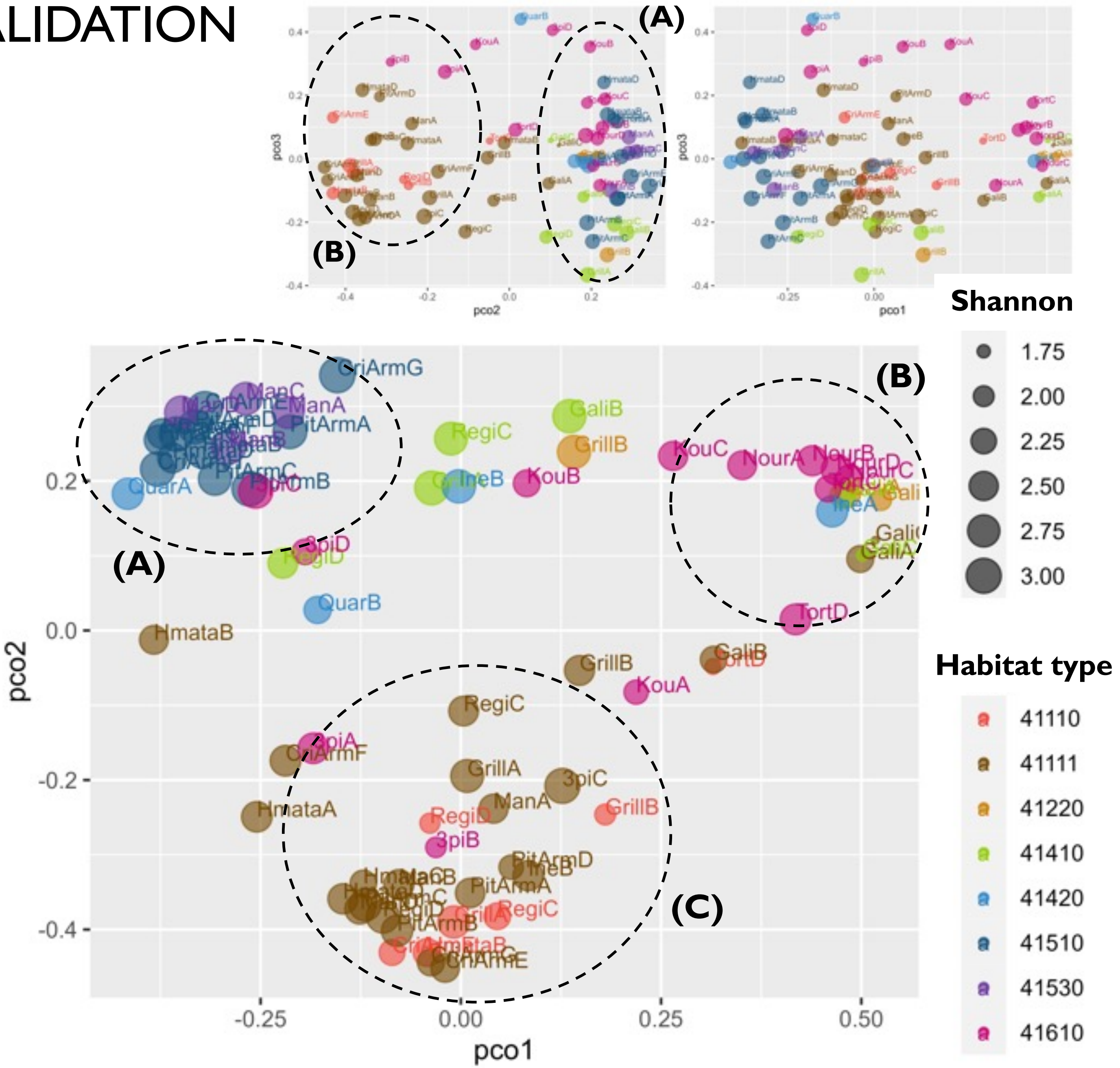
- 3 distinct groups of habitats are observed according to PCoA1 & PCoA2 :

→ A) Regular plateau forests (41510) ; Highland forests (41530)

→ B) Riparian forests, lowland, wet talweg (41110) ; Transitional forest ecotone - wet facies (41111)

→ C) Mid-mountain forests (41610)

- Similar habitat types are found in each group → Spectral diversity (β-diversity) allows to discriminate forest communities represented in contrasted habitat types
- α-diversity does not show specific patterns among habitat types; at this stage, no relation with field data is observed



CONCLUSION

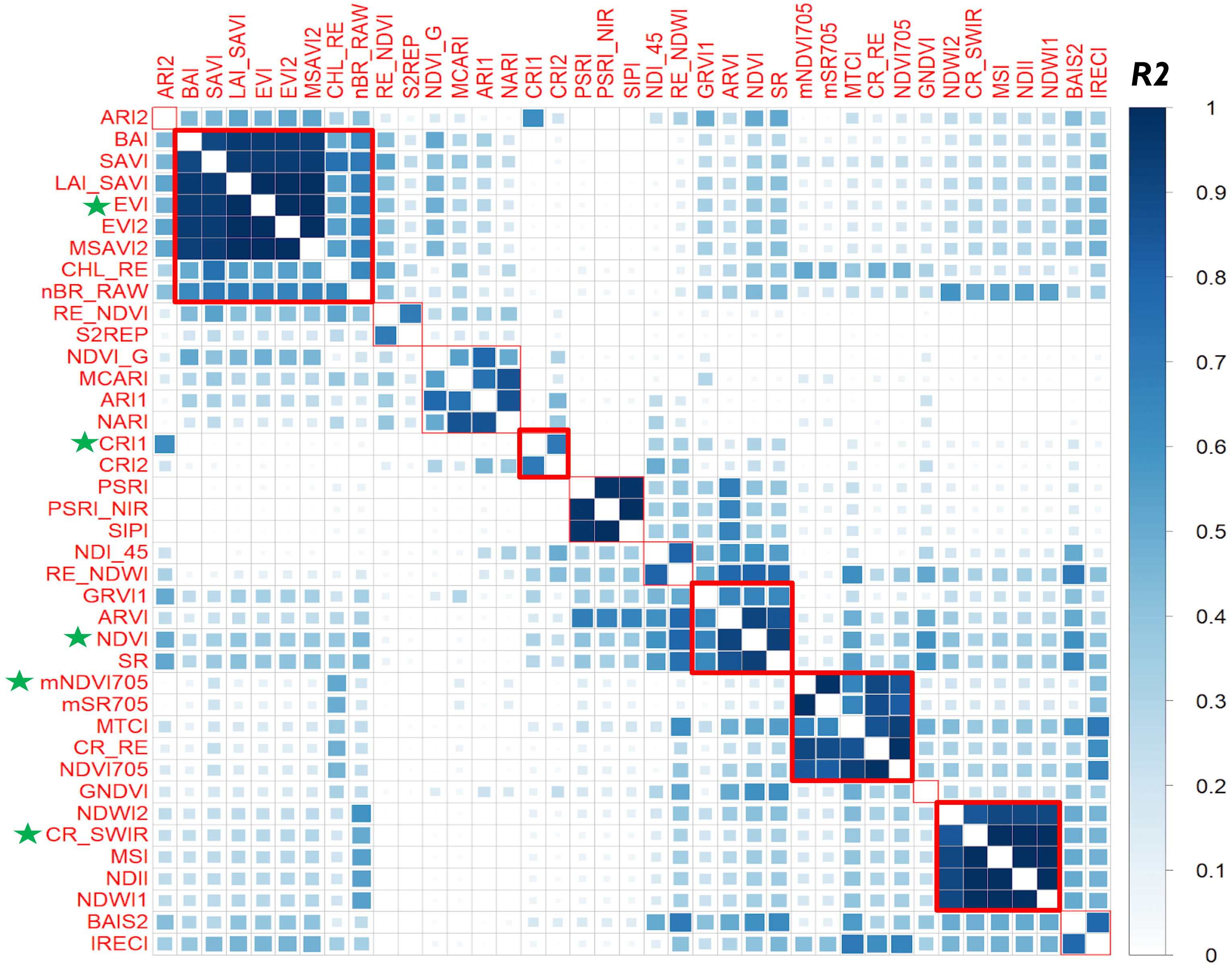
- **Composite images from acquisition obtained during the dry season allow significant increase of data availability over cloudy regions**: relevant for producing images then used as input for *biodivMapR*.
- **The β-diversity image provides original information** about communities spatial distribution, related to contrasted groups of forest habitat types.
- Application & interpretation of *biodivMapR* diversity images will be enlighten by **the definition of which forest caracteristics we are looking for** (taxonomic diversity through « habitat » type, leave biophysical or biochemical properties *e.g.* chlorophyll content, Leaf Area Index, etc.) and **at which geographic scale** (country, bioclimatic-region, natural reserve, *etc.*)
- **Some perspectives for further research**: application of the method to regional scales, differentiate communities through alternative field data (*e.g.* biophysical canopy properties), improve precision of diversity metrics computed from forest inventories…

Thank you for your attention!

SPECTRAL INDICES CORRELATION MATRIX

Indice	Formula
Enhanced Vegetation Index	EVI = 2.5 * ((NIR – RED) / ((NIR) + (6 * RED) - (7.5 * BLUE) + 1))
Carotenoid Reflectance Index 1	CRI1 = (1/510nm) - (1/550nm)
Normalized Difference Vegetation Index	NDVI = (NIR – RED) / (NIR + RED)
modified Red-Edge Normalized Difference Vegetation Index	mNDVI705 = (750 nm - 705 nm) / (750 nm + 705 nm - (2 * 445 nm))
Continuum Removal Short Wave Infra Red	CR_SWIR = 1610 nm / (865 nm + (1610 nm - 865 nm) * (2190 nm - 865 nm) / (2190 nm - 865 nm))

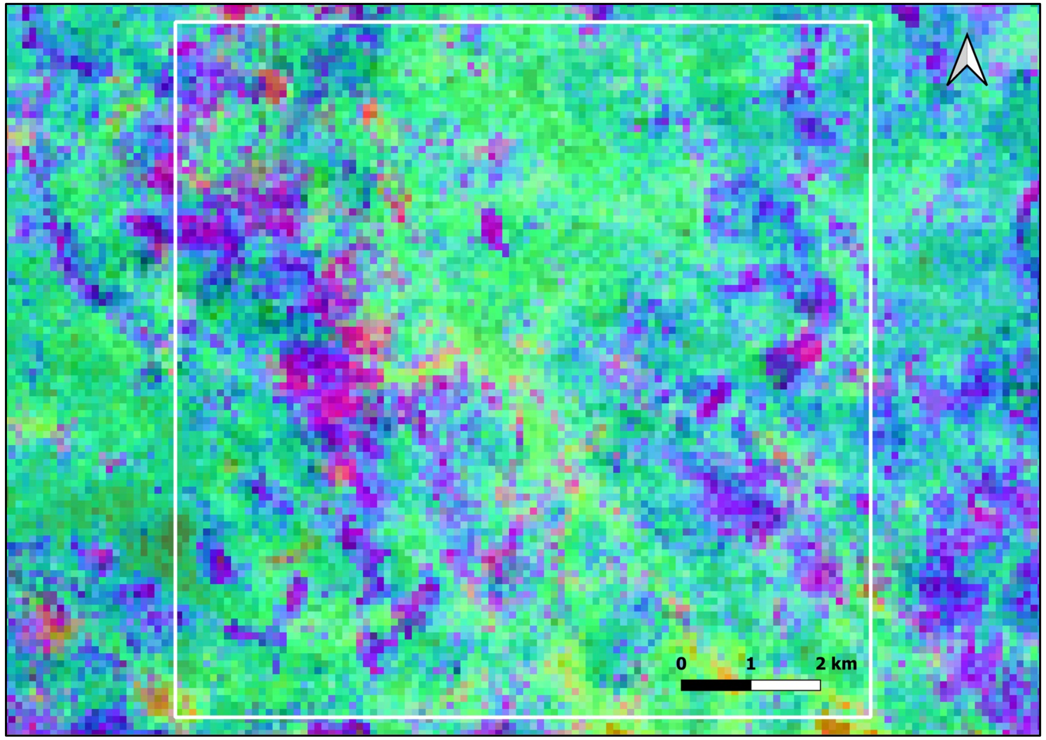
SPECTRAL INDICES CORRELATION MATRIX



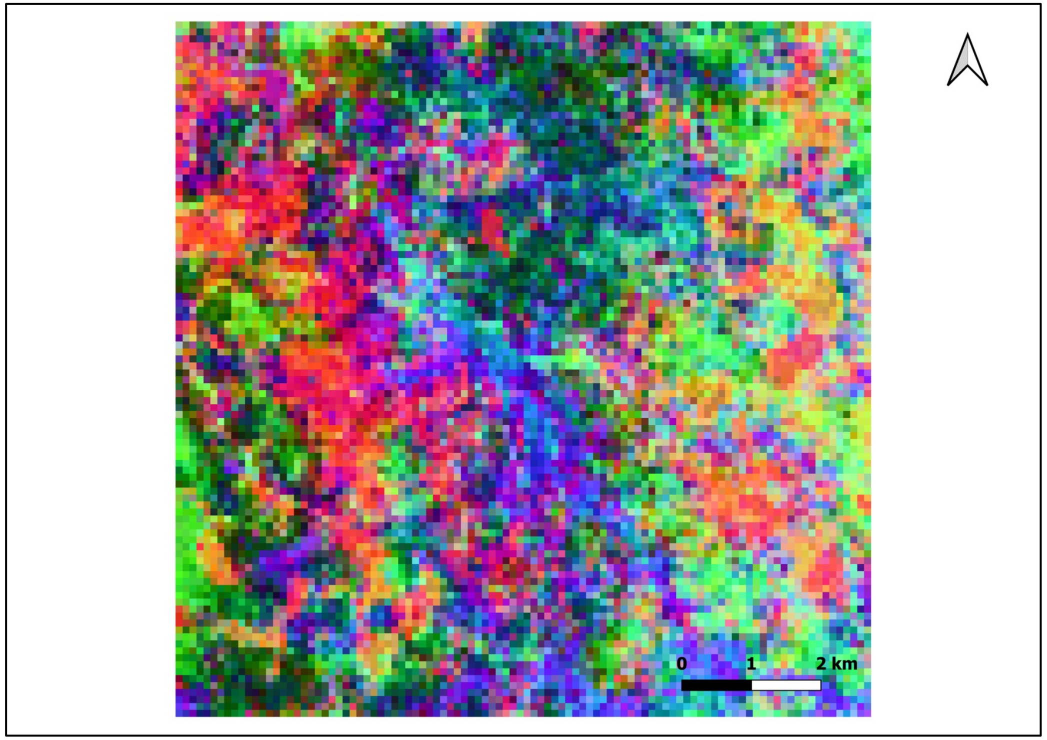
WHICH GEOGRAPHICAL SCALE FOR WHICH APPLICATION?

→ Complexity of β-diversity patterns for a given area is relative to the number of pixels used to determine the "spectral species"
→ In larger scales, we observe a **« dilution » effect**

Full tile



Reduced zone (10km²)



Example with T21NWF

EXPLORATION OF CORRELATIONS: IMAGES *VS* INVENTORIES

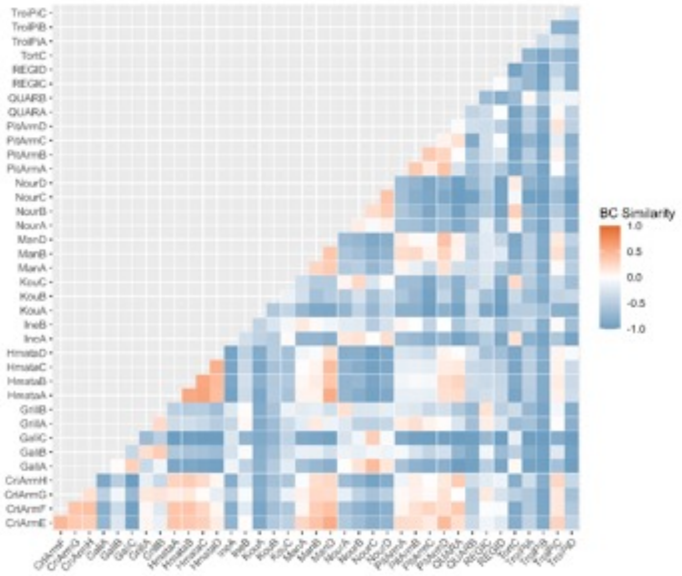
→ *Validation plots aggragated by « layon » (T22NCK – Season 2018)*

Mantel test	**Observation**	**P-value**	**Std. Obs.**	**Expectation**	**Variance**
	0.5	*1e-04*	*5.83*	*0.0001*	*0.007*

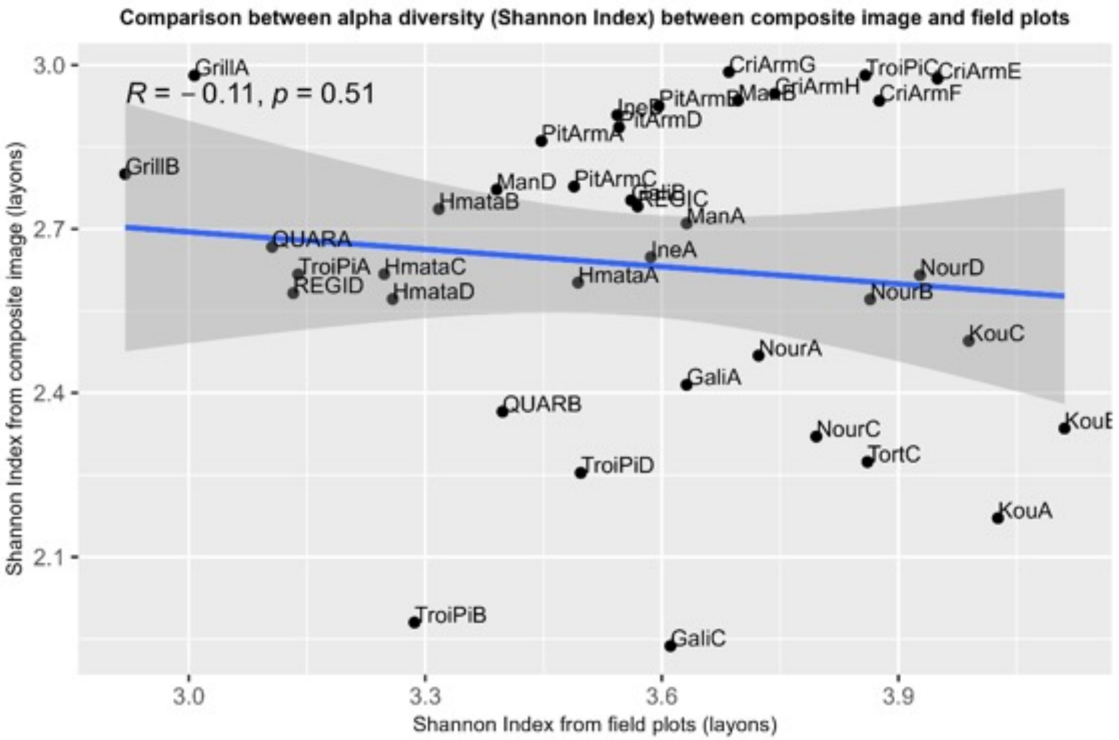
→ **β-diversity:** dissimilarity matrices from the composite image and the forest inventories are positively correlated

Forest inventories

Composite image



Similarity matrices (Bray-Curtis)



Correlation test	**Pearson's r**	**Spearman's ρ**
	-0.11 (pval = 0.50)	*-0.087 (pval = 0.60)*

→ **α-diversity**: lack of correlation between diversity estimated from forest inventories and from the composite image