PROGYSAT
Projet régional d'observation des Guyanes par satellite

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

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3ème Séminaire (séminaire final) – Cayenne, 26-30 juin 2023

CONTEXT OF THE APPLICATION

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

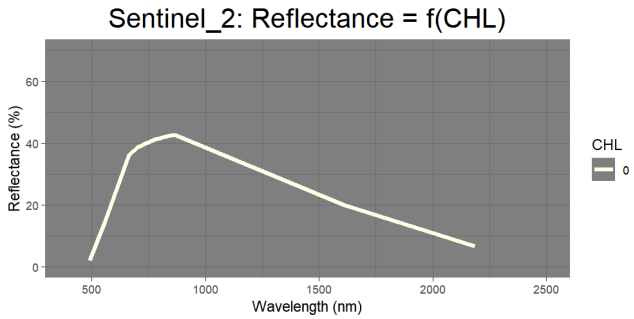
- Increasing capacity for remotely sensed monitoring of tropical ecosystems
  - Satellite constellations acquire data with high temporal frequency: Copernicus, Landsat, Planet…
  - Methodological developments allow taking advantage of this information

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

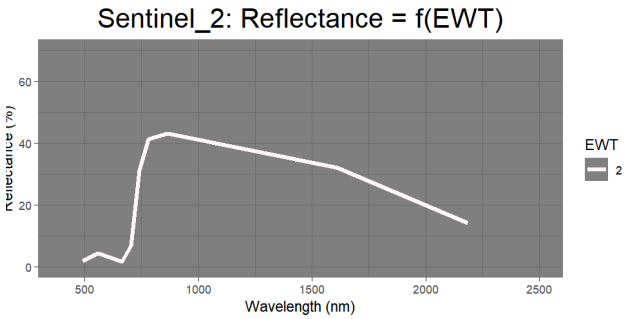
MONITORING TROPICAL FOREST OVER THE GUIANA SHIELD : ASSETS AND CHALLENGES OF OPTICAL IMAGERY

- 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) :

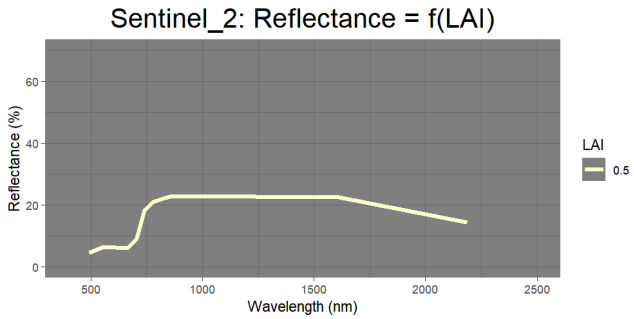
Leaf chlorophyll content



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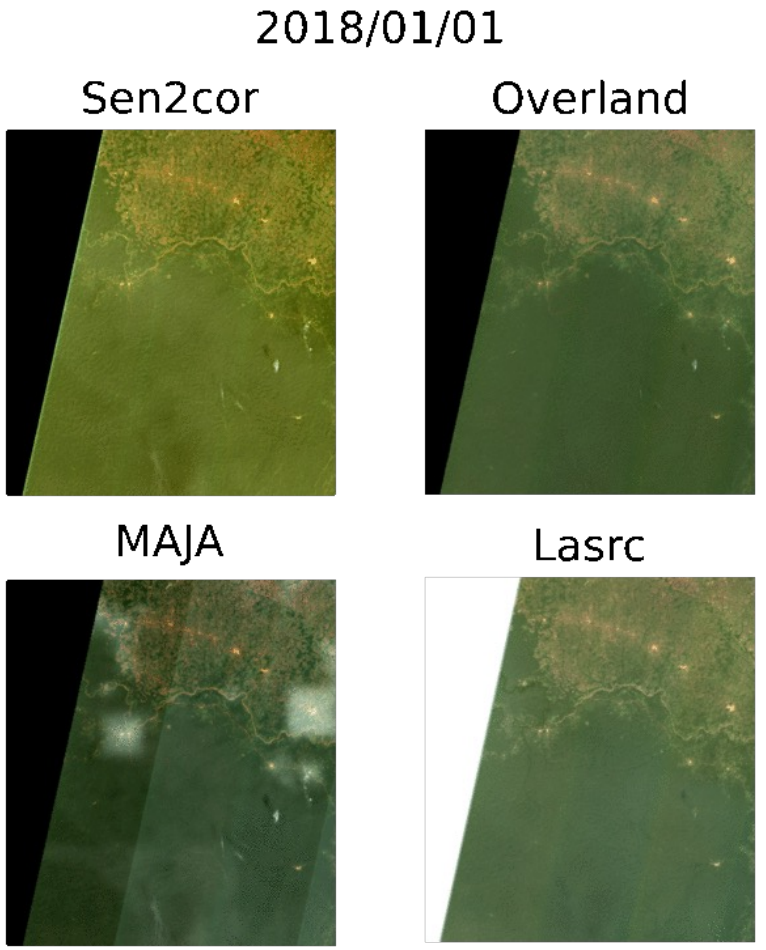
  - Atmospheric correction methods (ACM) do not perform consistently in time



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

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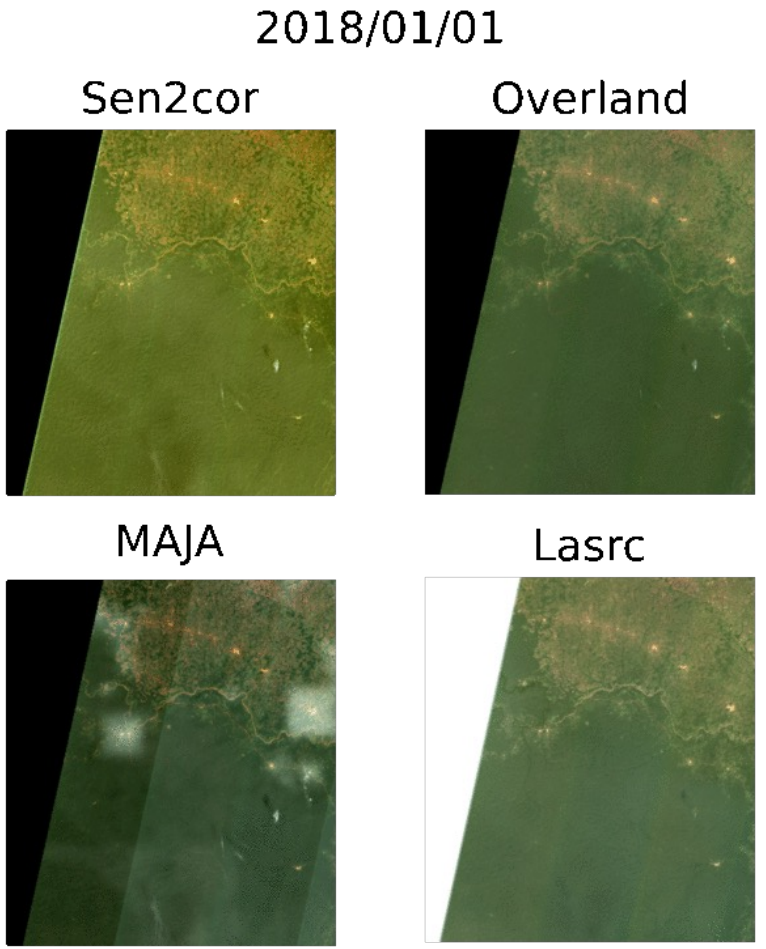
  → **<u>Need to find methods to fill spatial gaps caused by clouds</u>**
  - Atmospheric correction methods (ACM) do not perform consistently in time

  → **<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

Methods in Ecology and Evolution | BRITISH ECOLOGICAL SOCIETY

APPLICATION

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

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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:

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

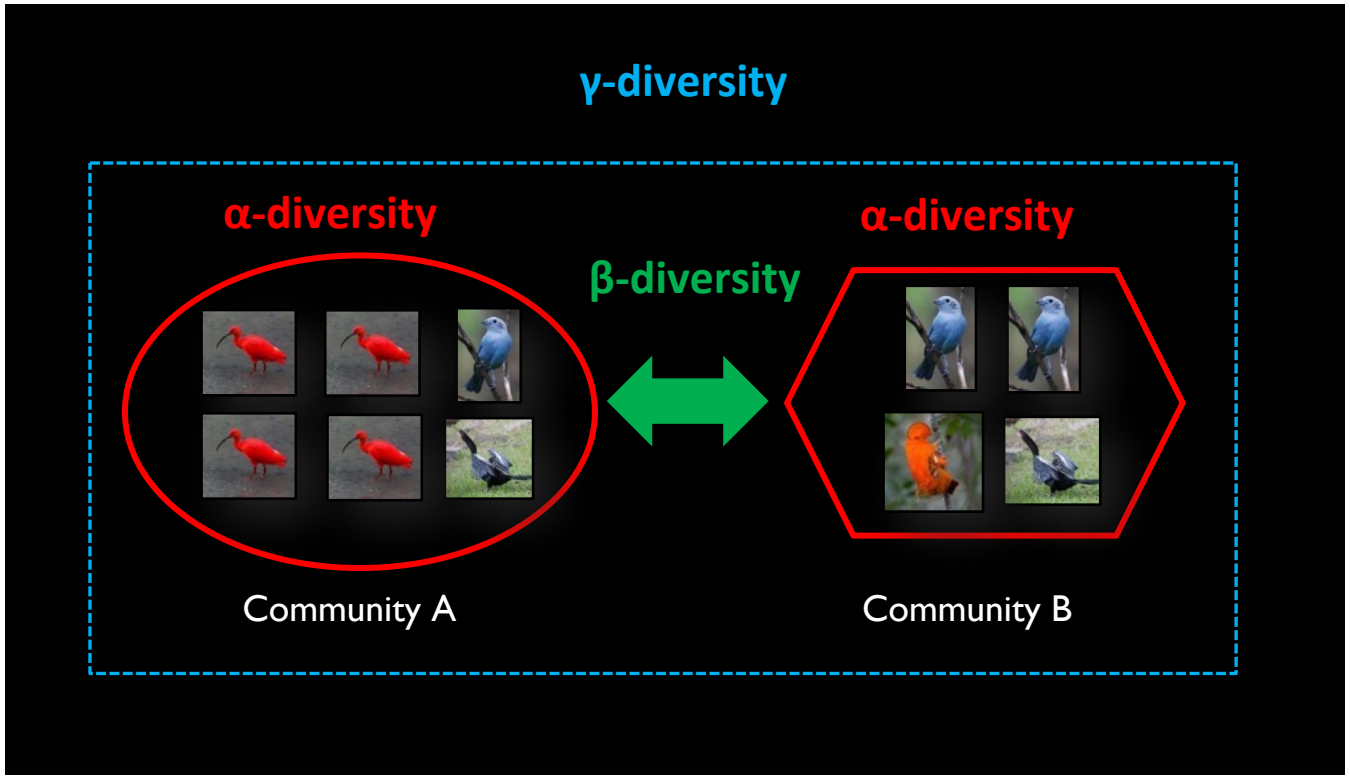
S : Species Richness, the total number of species in the environment

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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  - ***biodivMapR***: map spectral diversity metrics corresponding to α-diversity and β-diversity

Imaging spectroscopy

Multispectral Data

Multisource information

Diversity maps based on spectral diversity:

- ***Functional diversity (Villéger et al., 2008):***
  - FRic: Functional richness
  - FEve: Functional evenness
  - FDiv: Functional divergence
- ***Taxonomic diversity:***
  - α-diversity: Shannon's *H'*, Simpson
  - β-diversity : dissimilarity maps based on Bray Curtis

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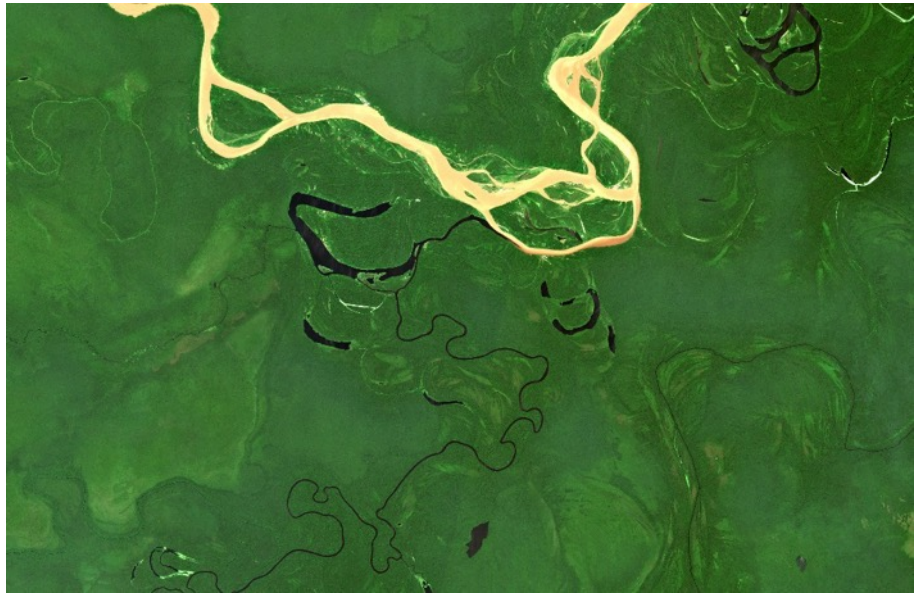

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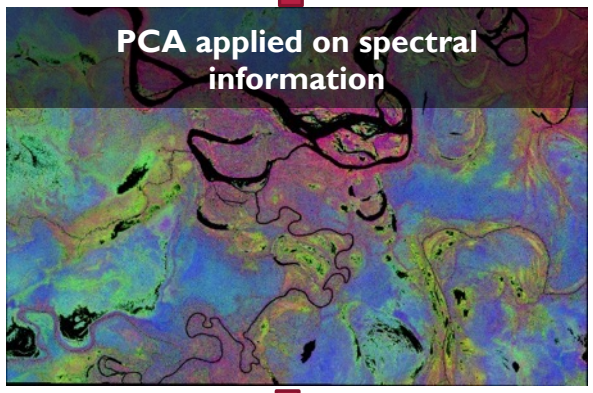
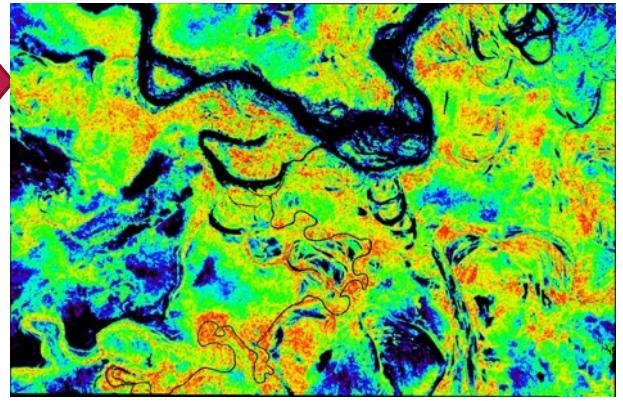
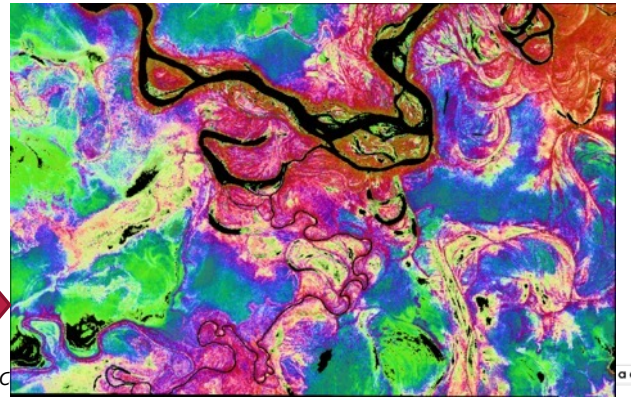
α-diversity map
Species richness
Shannon index
…



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





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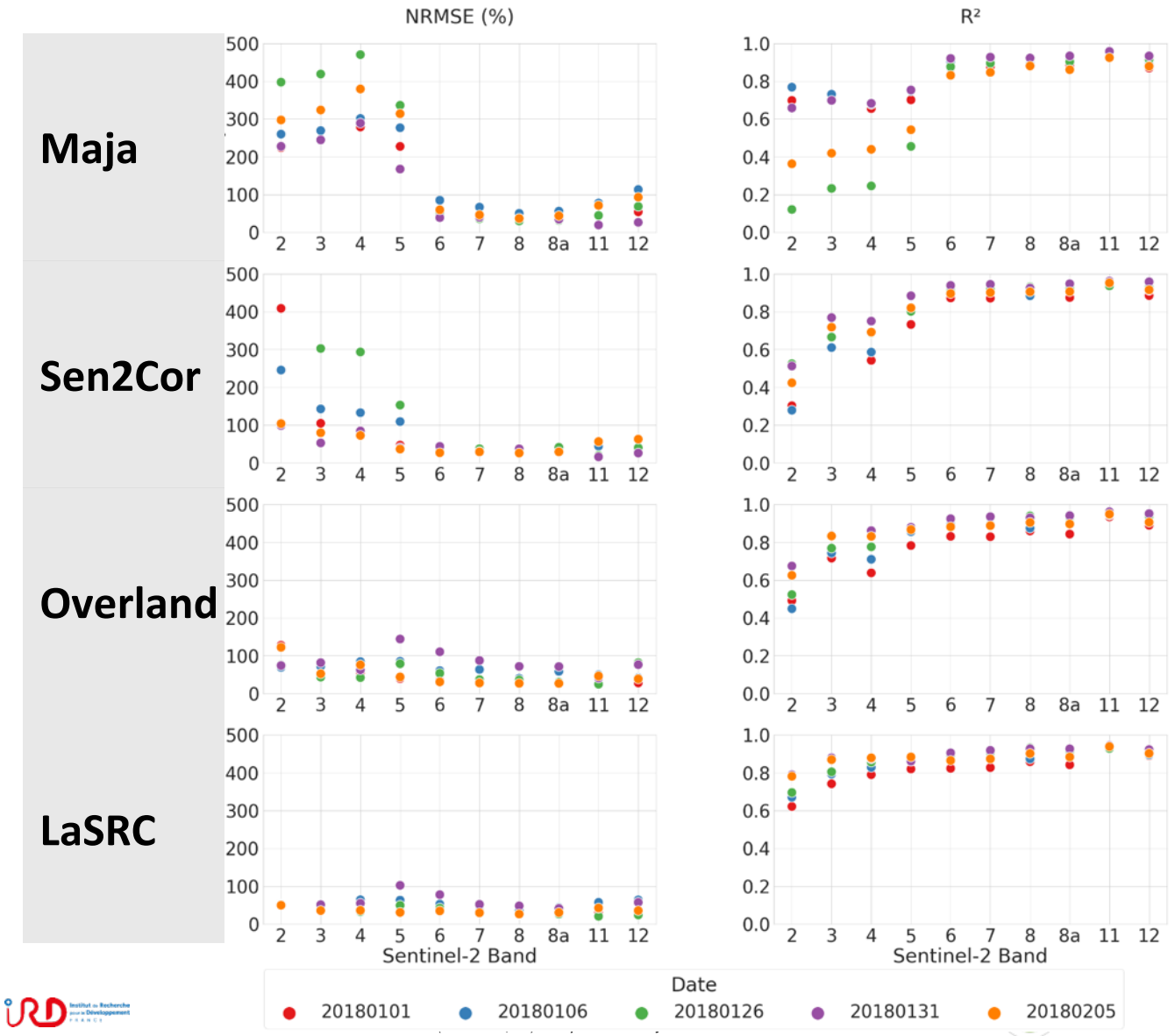
→ How to reduce uncertainty associated with atmospheric corrections ?

→ 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

- TOA correction (reflectances and cloud masks) performed with *sen2lasrc* (de Boissieu, 2022)
- 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

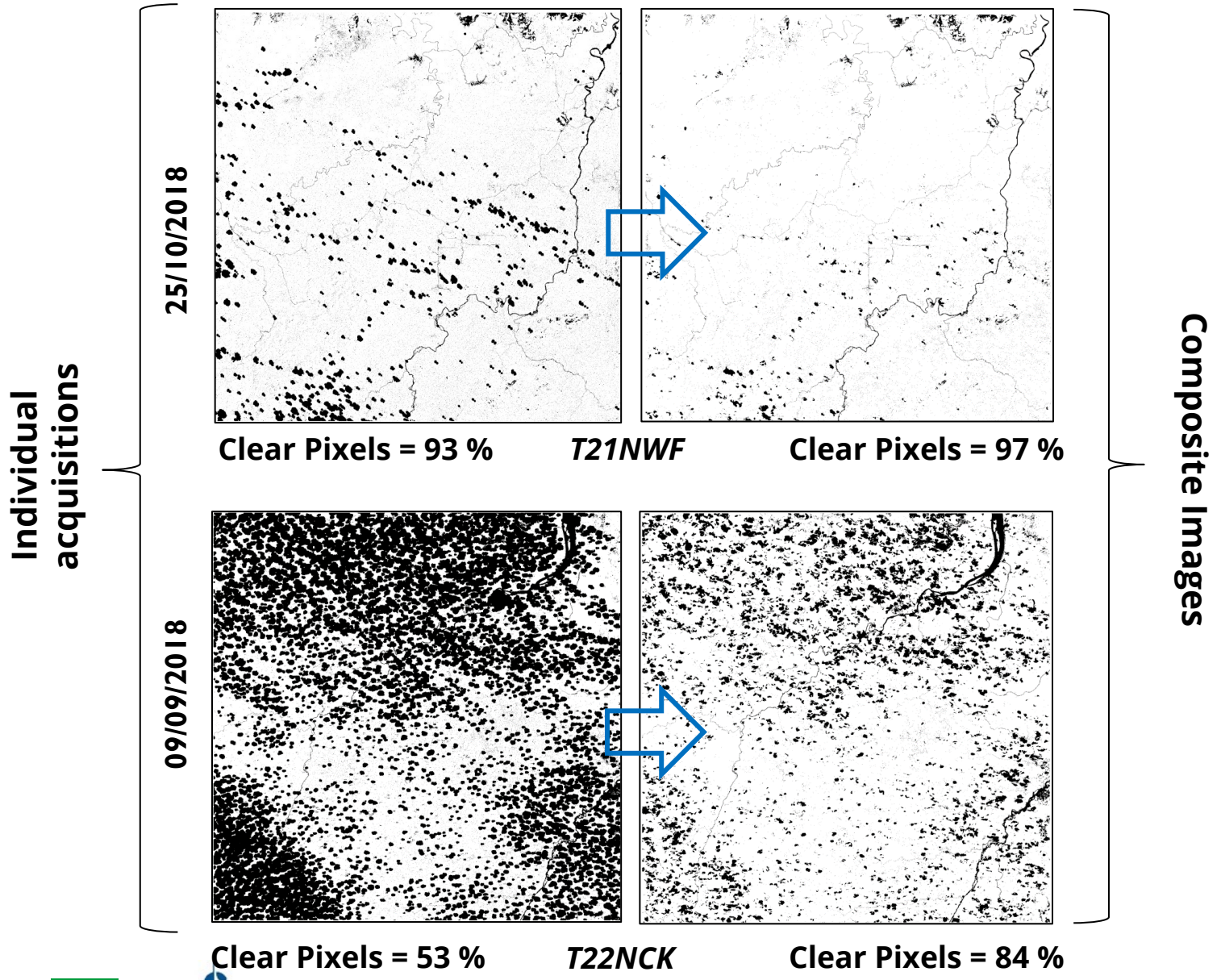
Step 3
Validation with field data

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

MID-TERM REVIEW: COMPOSITE IMAGES

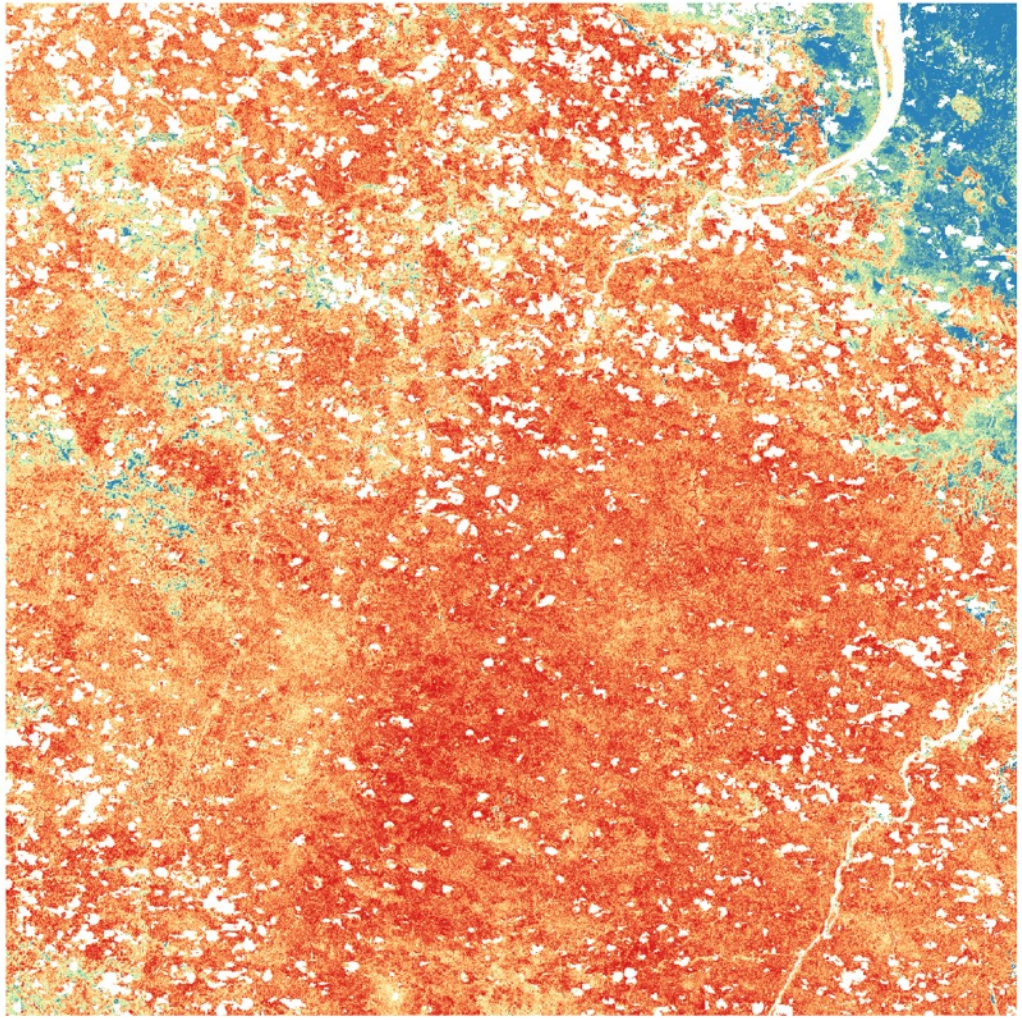
- Tiles with contrasted cloudiness contexts
- **"Best" individual acquisition images *vs* composite image** (Season 2018)

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

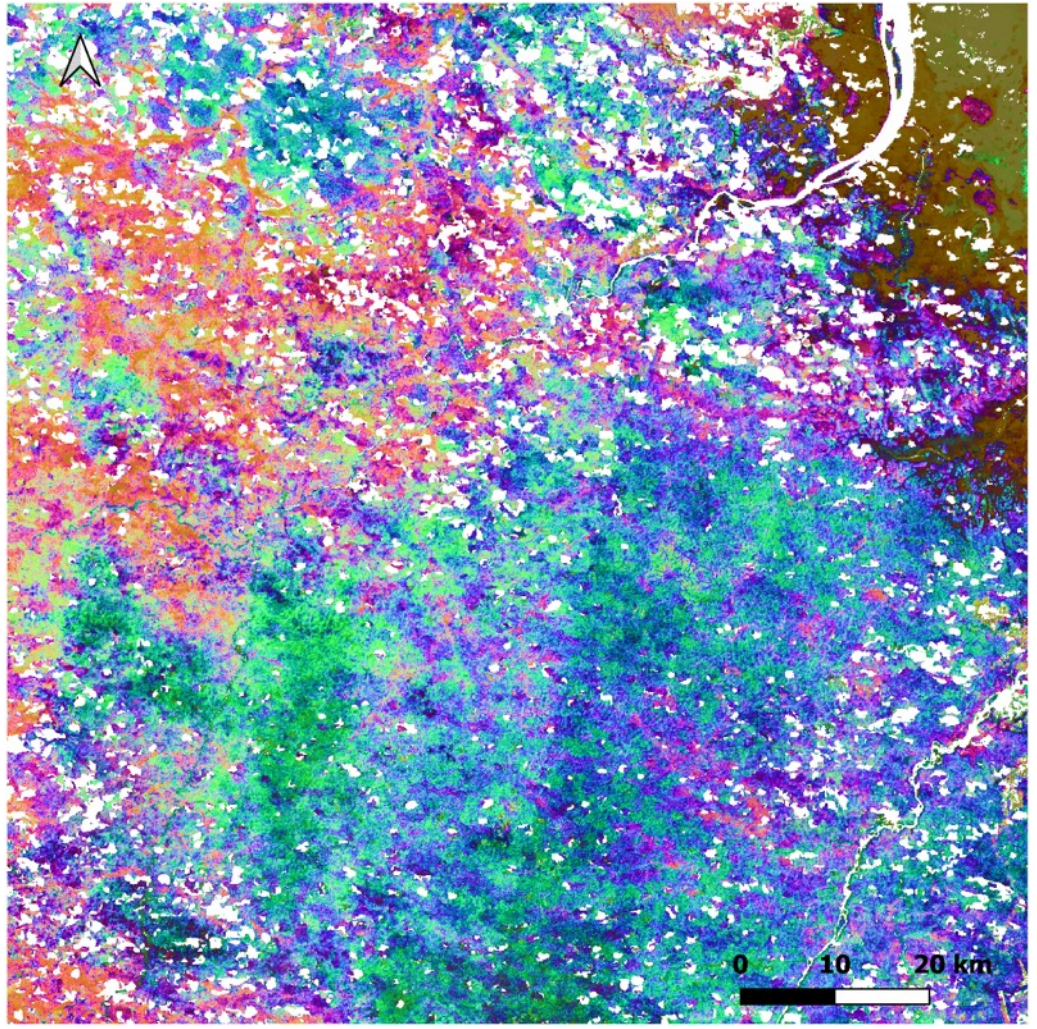


MID-TERME REVIEW: DIVERSITY MAPS AT S2 TILE SCALE

→ Tile 22NCK: « high » cloudiness situation



α-diversity



β-diversity

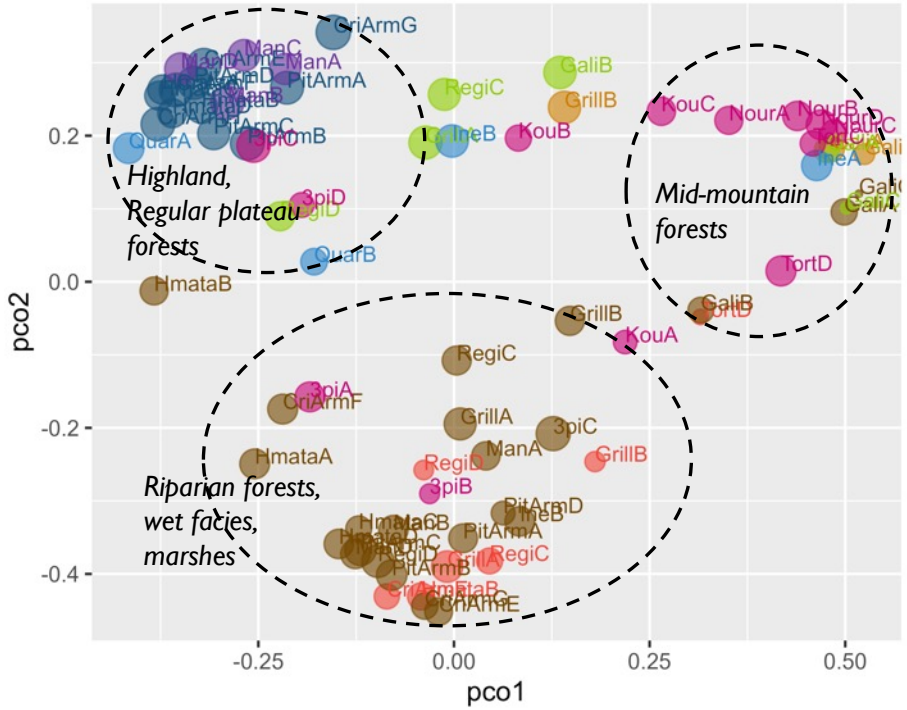
Spatial resolution = 100 m

MID-TERM REVIEW: VALIDATION

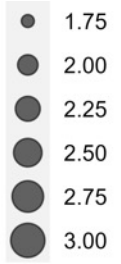
- **Forest inventories** from « Habitats » program of French National Forest Office (ONF):
  - → 42 sites inventoried over French Guiana in 20 main forest habitat types
  - → Inside 22NCK tile extent: 15 sites, each one containing 2-4 « layons » (transects) with ~ 20-30 plots
  - → **72 validation plots with a given habitat type and « layon »**

- Similar habitat types are found in each group → Spectral diversity (β-diversity) allows to discriminate forest communities represented in contrasted habitat types

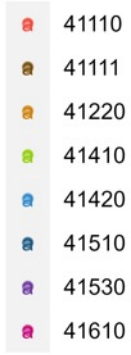
- Topologic precision is a limit to interpretation



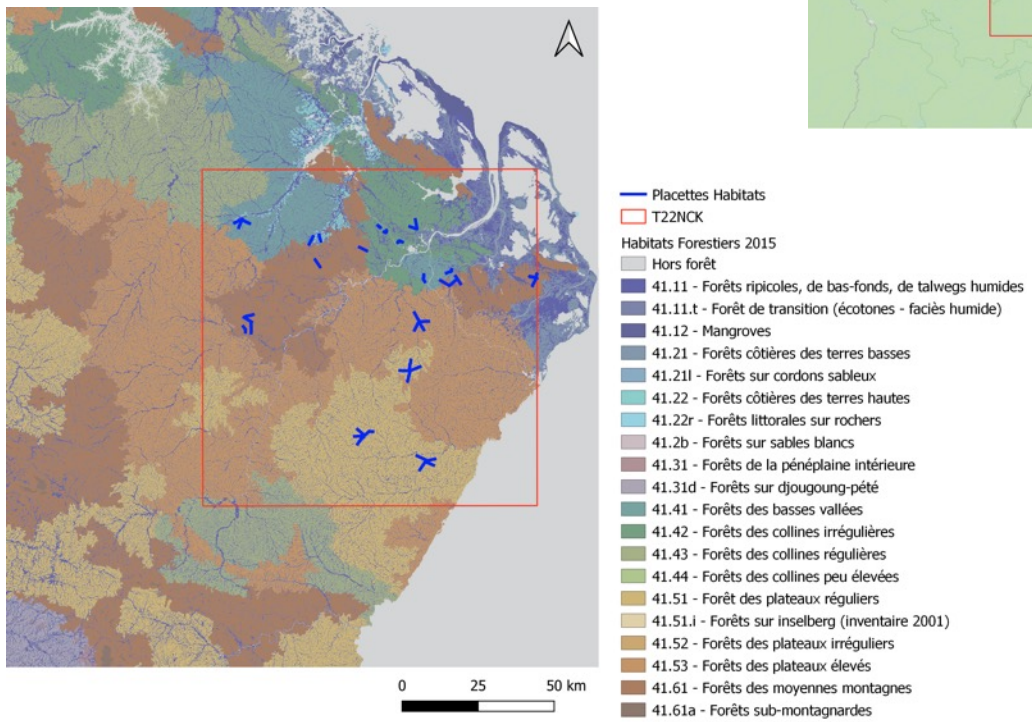
Shannon

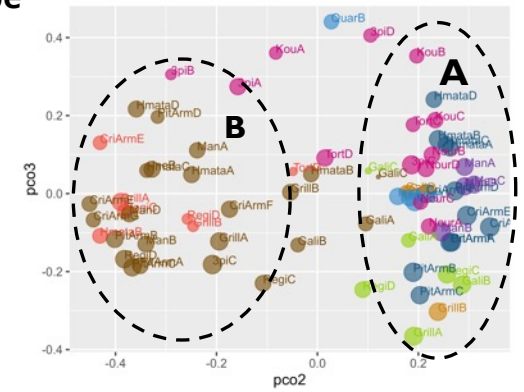


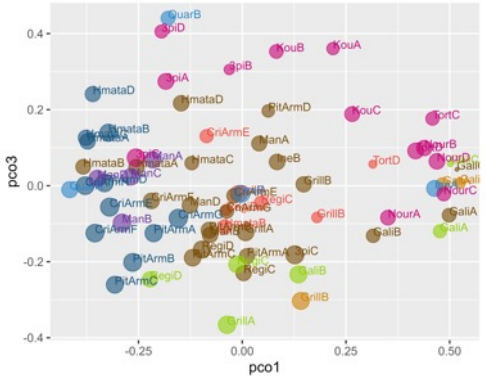
Habitat type



source: Catalogue des Habitats Forestiers de Guyane (ONF)



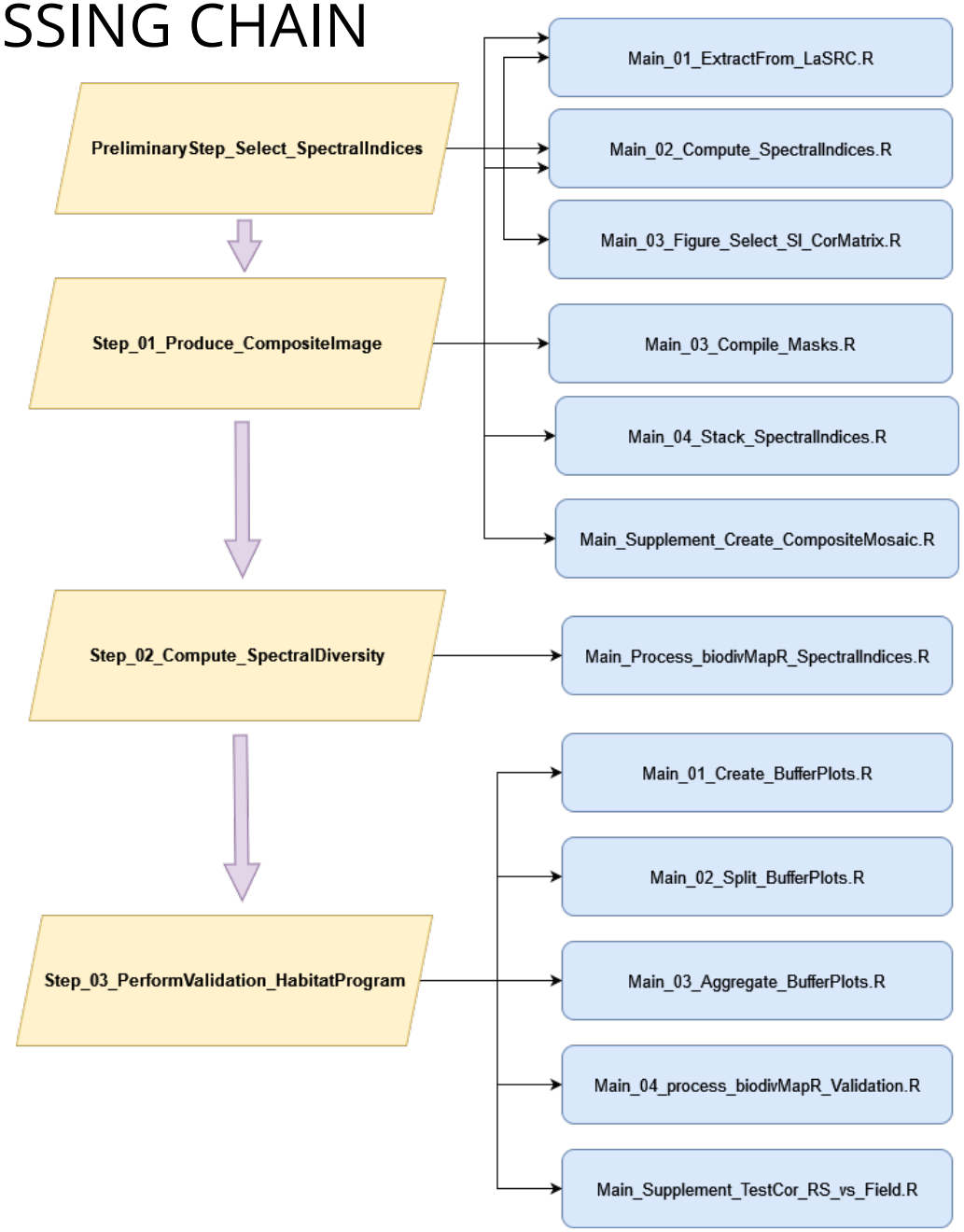




MID-TERM REVIEW: PROCESSING CHAIN

- Process and validate spectral diversity metrics using *biodivMapR* package
- Adapted to the high cloudiness situation within the Guiana Shield
- Intended to provide a complementary layer of information to other mapping products to monitor vegetation
- Some parameters can be modified to target specific vegetation properties *e.g.* change the selection of input spectral indices

- A tutorial specially prepared for PROGYSAT is online to learn how to use *biodivMapR package* in a study zone in Suriname https://jbferet.github.io/biodivMapR/articles/biodivMapR_11.html



WHAT NEXT?

- Spectral index composites based on parcimonious time series still result in missing areas and artifacts.

→ *Does integration over dense S2 time series solve these problems?*

- The classification into forest types provided by the French National Forest Office (ONF) includes different levels. Spectral discrimination may not be as efficient among forest types and sub-types.

→ *Which level of forest type description should be used during validation of RS diversity maps ?*

- Sentinel-2 data can be performed at multiple scales : site, tile, tile mosaic (region/country)

→ *Towards spectral diversity mapping at region scale over the Guiana Shield region: potential and limitations*

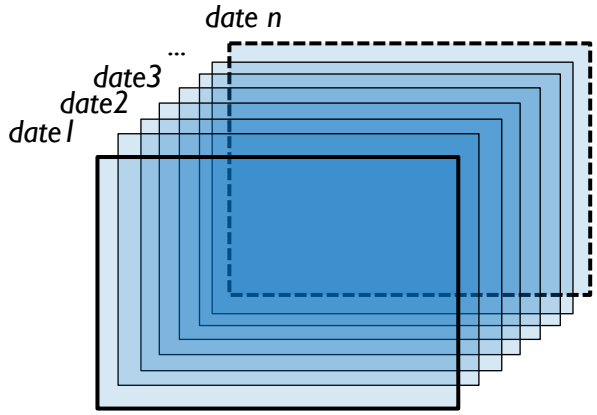
Does integration over dense S2 time series reduce artifacts and missing data?

METHODOLOGICAL FRAMEWORK

Does integration over dense S2 time series reduce artifacts and missing data?

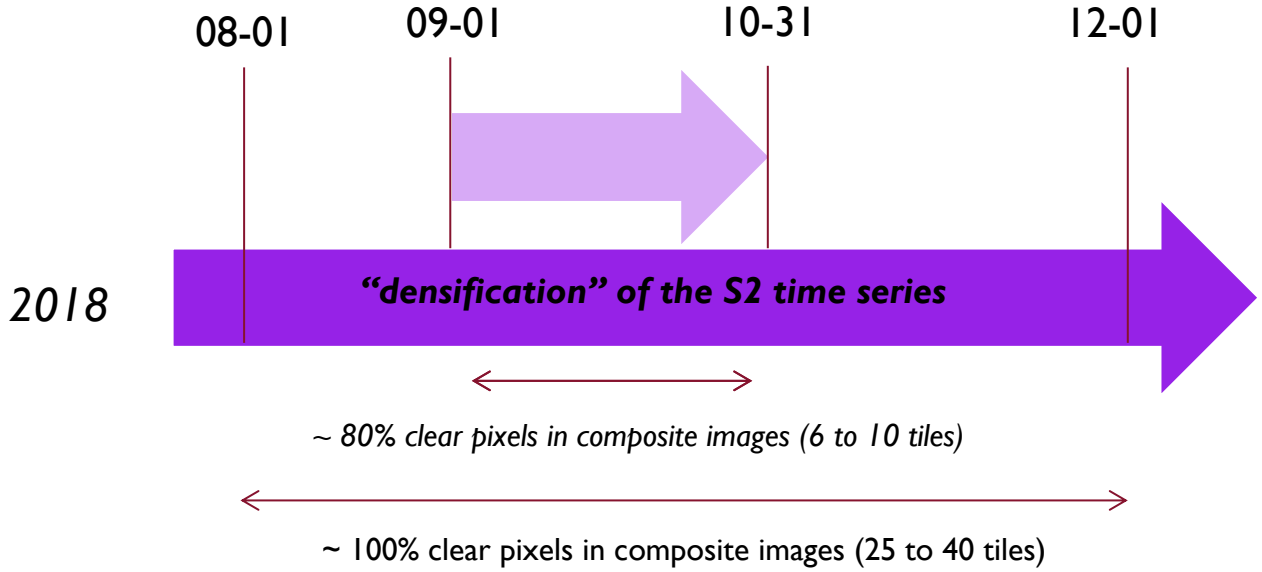
Step 1
Spectral index composite images

- **Climatically & phenologically coherent**
- **Temporally stable**: spectral indices



Step 2
Spectral diversity metrics

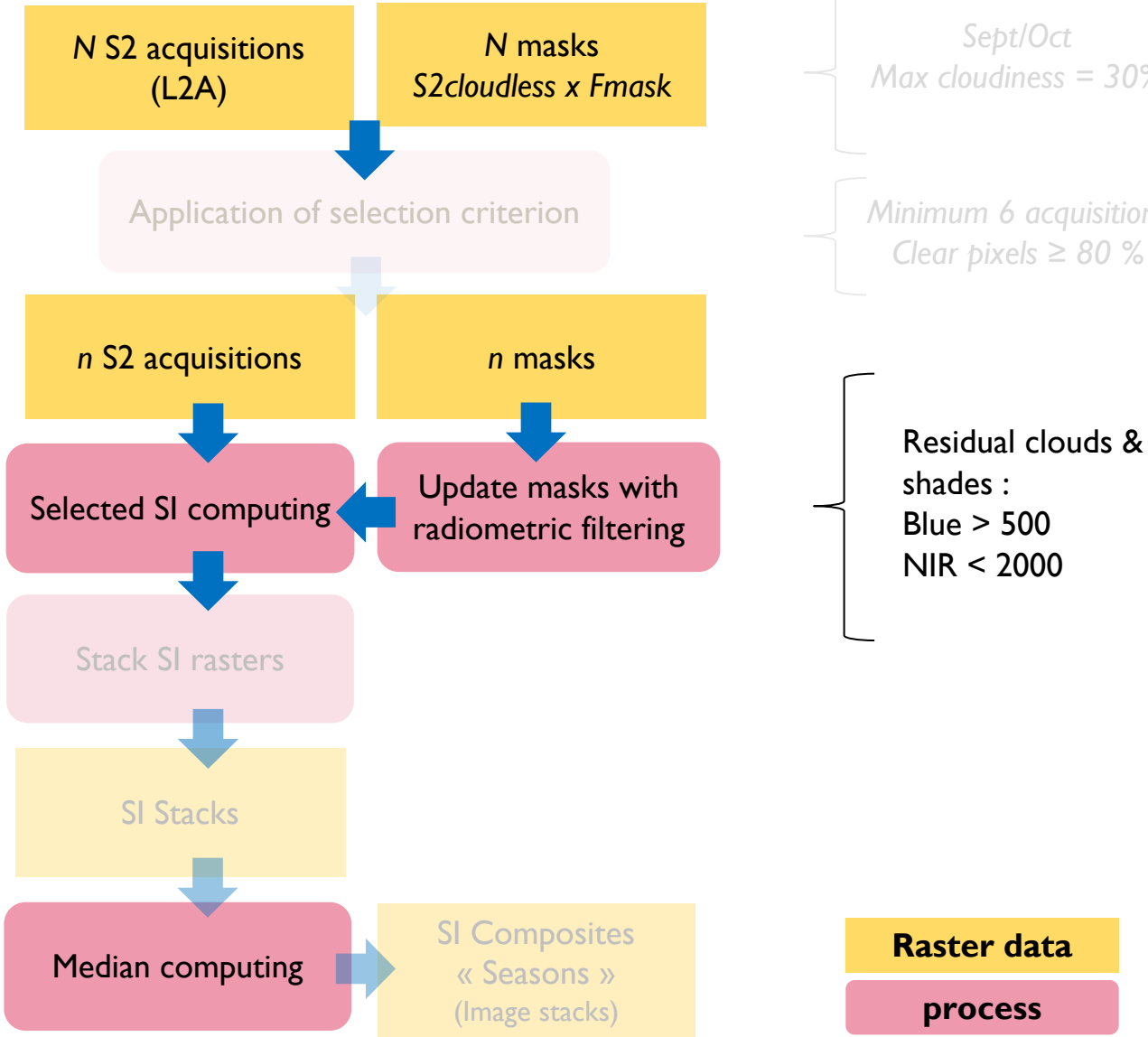
Step 3
Validation with field data



STEP1: PRODUCTION OF COMPOSITE IMAGE

Does integration over dense S2 time series reduce artifacts and missing data?

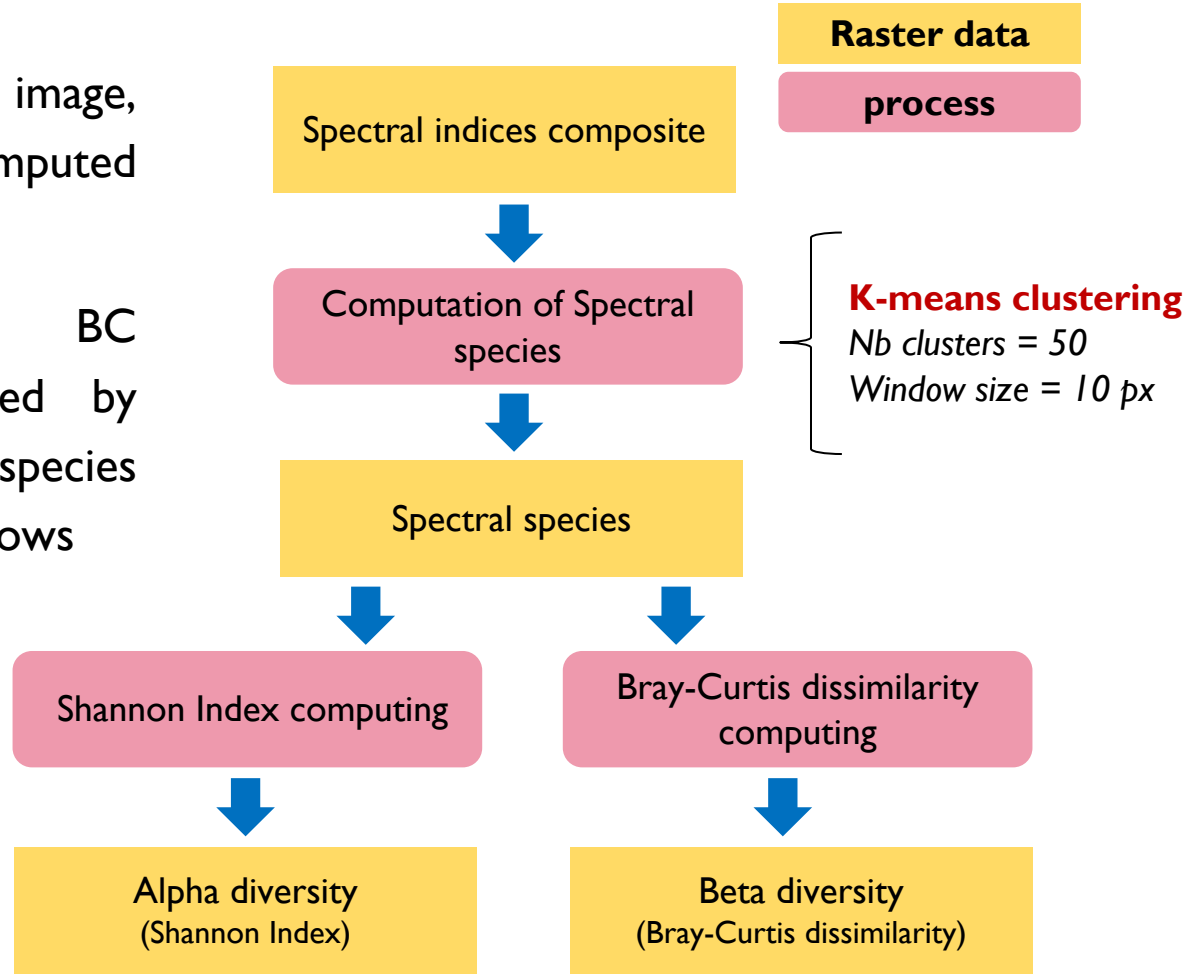
- **All Sentinel-2 acquisitions available downloaded from Aug-01 to Nov-30 to cover dry season & more**
- Mask: cloud, shade & non vegetated pixels
- **Median of NDVI & CR_{SWIR}** is computed for each pixel of the image



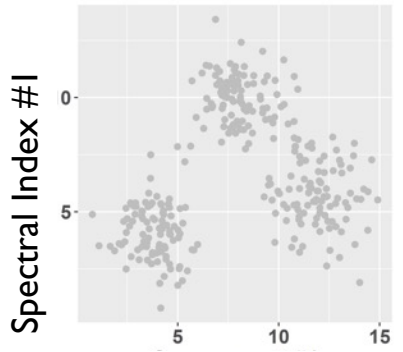
STEP2: MAP SPECTRAL DIVERSITY

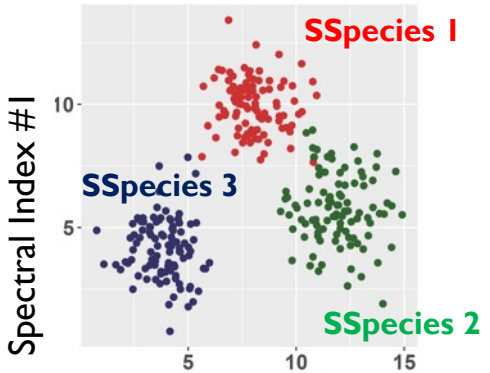
Does integration over dense S2 time series reduce artifacts and missing data?

- From SI composite image, « spectral species » are computed for each pixel
- Shannon index and BC dissimilarity are computed by integrating spectral species distribution over 1 ha windows



Spectral Indices distribution

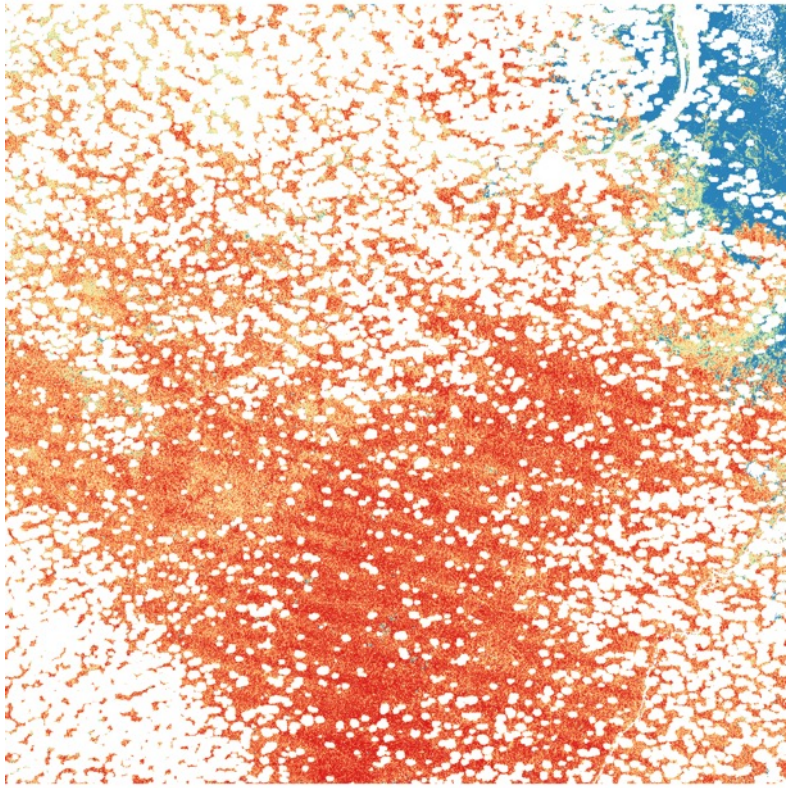


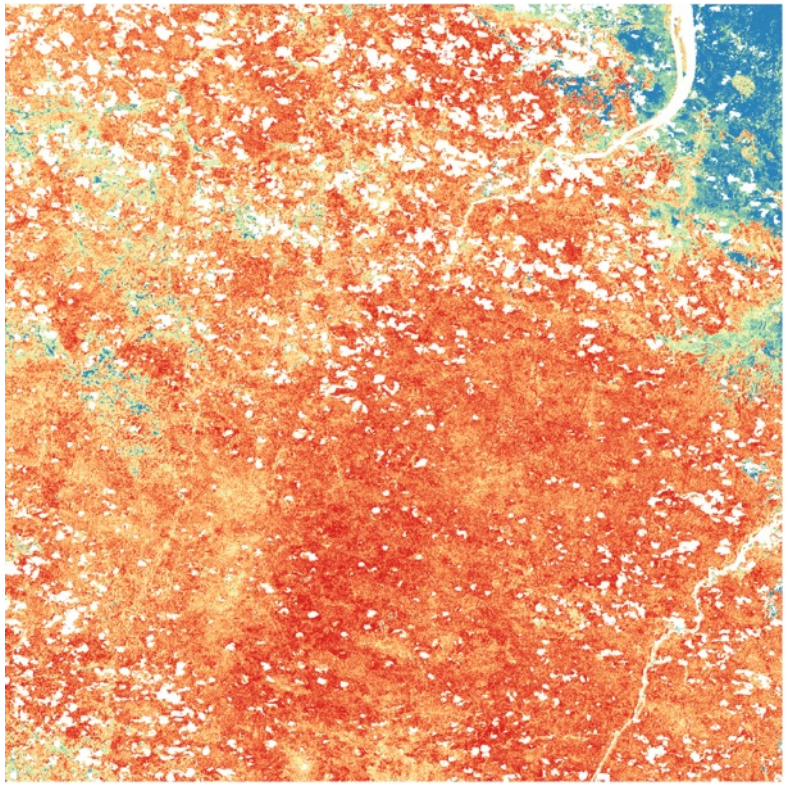


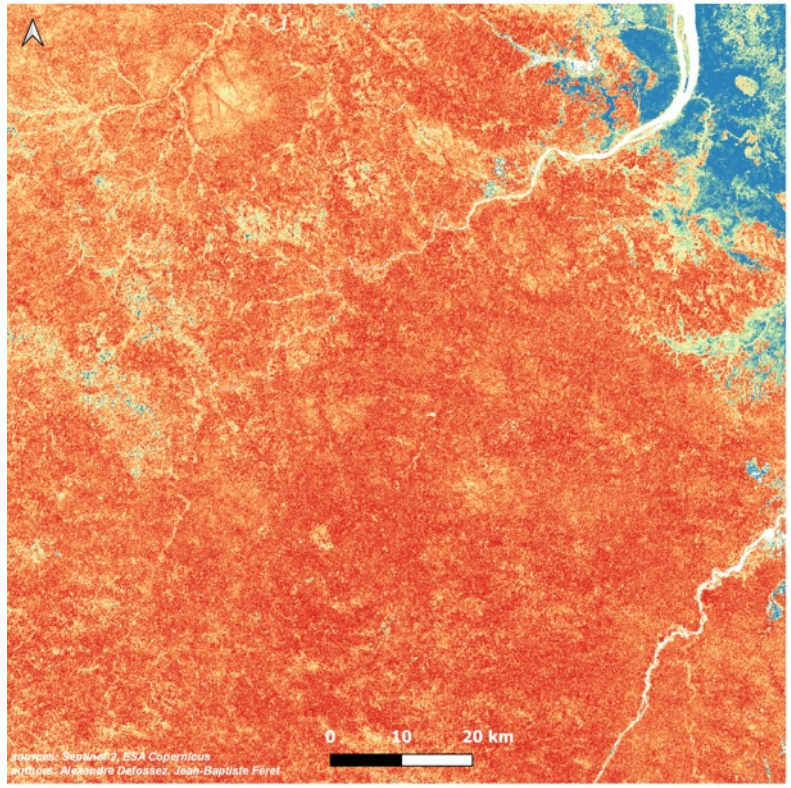
STEP2: MAP SPECTRAL DIVERSITY

Does integration over dense S2 time series reduce artifacts and missing data?

α-diversity







Individual acquisition (minimum cloud cover):
09/09/2018

Composite #1:
Sept-Oct 2018

Composite #2:
Aug-Nov 2018

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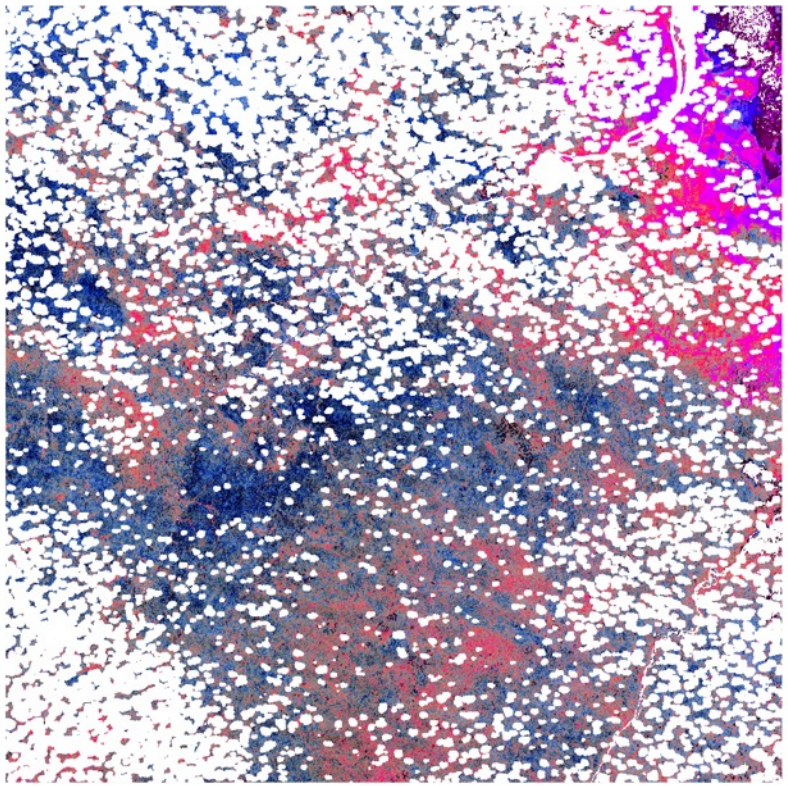
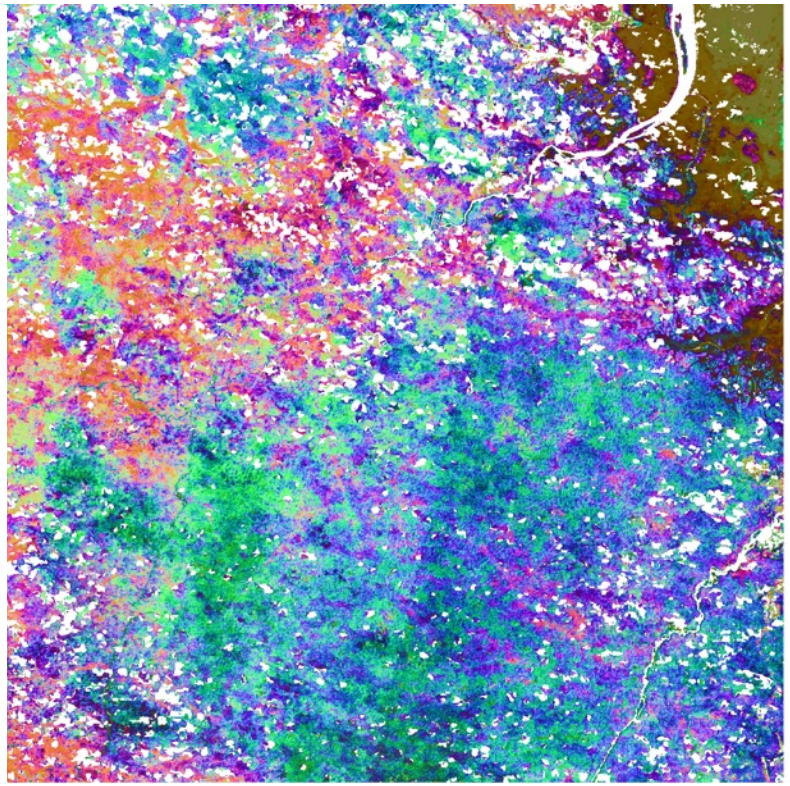
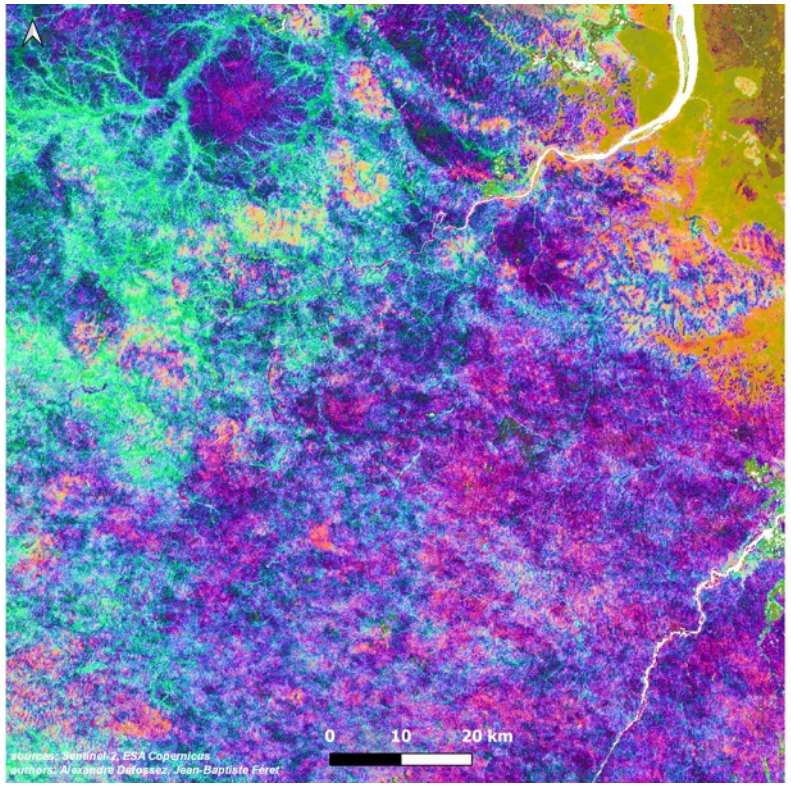
STEP2: MAP SPECTRAL DIVERSITY

Does integration over dense S2 time series reduce artifacts and missing data?

β-diversity







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Which level of forest type description should be used during validation of RS diversity maps?

METHODOLOGICAL FRAMEWORK

Which level of forest type description should be used during validation of RS diversity maps?

Step 1

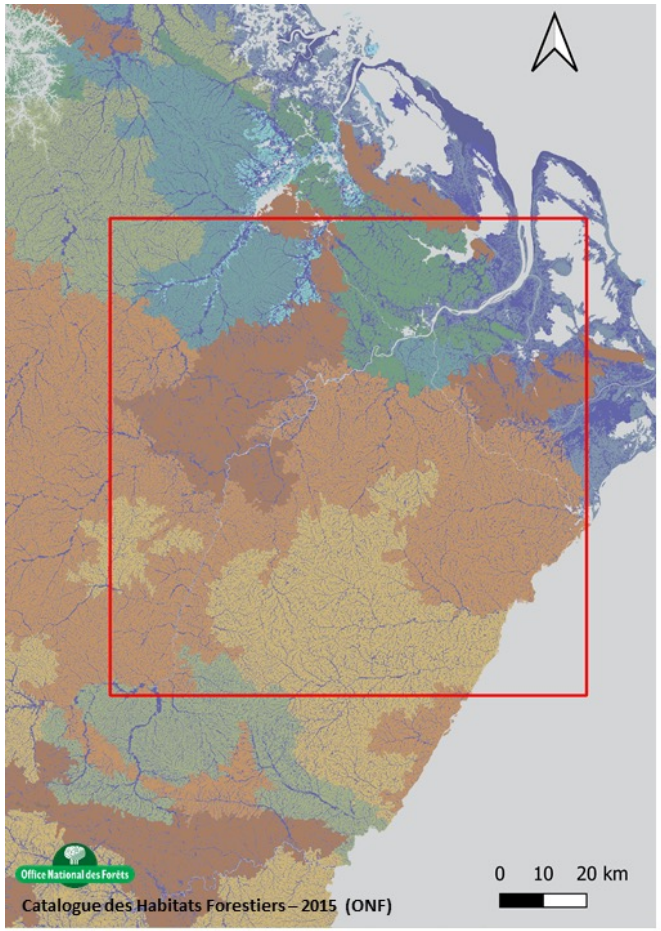
Spectral index composite images

Step 2

Spectral diversity metrics

Step 3

Validation with field data



T22NCK_SpatialExtent
Habitats_Forestiers_2015
Hors forêt
41.11 - Forêts ripicoles, de bas-fonds, de talwegs
41.11.t - Forêt de transition (écotones - faciès hun
41.12 - Mangroves
41.21 - Forêts côtières des terres basses
41.21l - Forêts sur cordons sableux
41.22 - Forêts côtières des terres hautes
41.22r - Forêts littorales sur rochers
41.2b - Forêts sur sables blancs
41.31 - Forêts de la pénéplaine intérieure
41.31d - Forêts sur djougoung-pété
41.41 - Forêts des basses vallées
41.42 - Forêts des collines irrégulières
41.43 - Forêts des collines régulières
41.44 - Forêts des collines peu élevées
41.51 - Forêt des plateaux réguliers
41.51.i - Forêts sur inselberg (inventaire 2001)
41.52 - Forêts des plateaux irréguliers
41.53 - Forêts des plateaux élevés
41.61 - Forêts des moyennes montagnes
41.61a - Forêts sub-montagnardes


Les mangroves de bord de mer sont constituées de palétuvier gris (*Languncularia germinans*) sur les bancs de vase les plus récents et de palétuvier blanc (*Avicennia racemosa*) à l'arrière de ces formations.


Collines Est Dégrad Clémancin sur la crique Sparouine.


Montagnes de la Trinité.

METHODOLOGICAL FRAMEWORK

Which level of forest type description should be used during validation of RS diversity maps ?

Generic habitat	Main habitat	Particular habitat	Habitat description
41.1	**41.110**	/	Riparian forests, lowland, wet talweg
41.1	**41.111**	/	Transitional forest ecotone - wet facies
41.2	**41.220**	/	Coastal upland forests with goupi and manil swamp
41.4	**41.410**	/	Forests of low river valleys wapa and red maho forests
41.4	**41.420**	/	Irregular hill forests forests with mahos, wapa and amaranth
41.5	**41.510**	/	Regular plateau forest with moni, angélique and patawa
41.5	**41.530**	/	High plateau forests with angélique, moni and bita tiki
41.6	**41.610**	/	Mid-mountain forests with moni and yayamadous
41.5 to 41.6	/	**46.421**	Lowland forests on lateritic armour
41.5 to 41.6	/	**46423**	Lowland forests on inselberg
41.1	/	**4A**	Swamp forests
41.4 to 41.6	/	**3E**	Cambrouses

Corine Land Cover typology (appart from particular habitats)

Mid-mountain forest (Montagne de la Trinité)

Riparian forests, lowland, wet talweg

image source: Catalogue des habitats forestiers de Guyane (ONF)

STEP3: VALIDATION

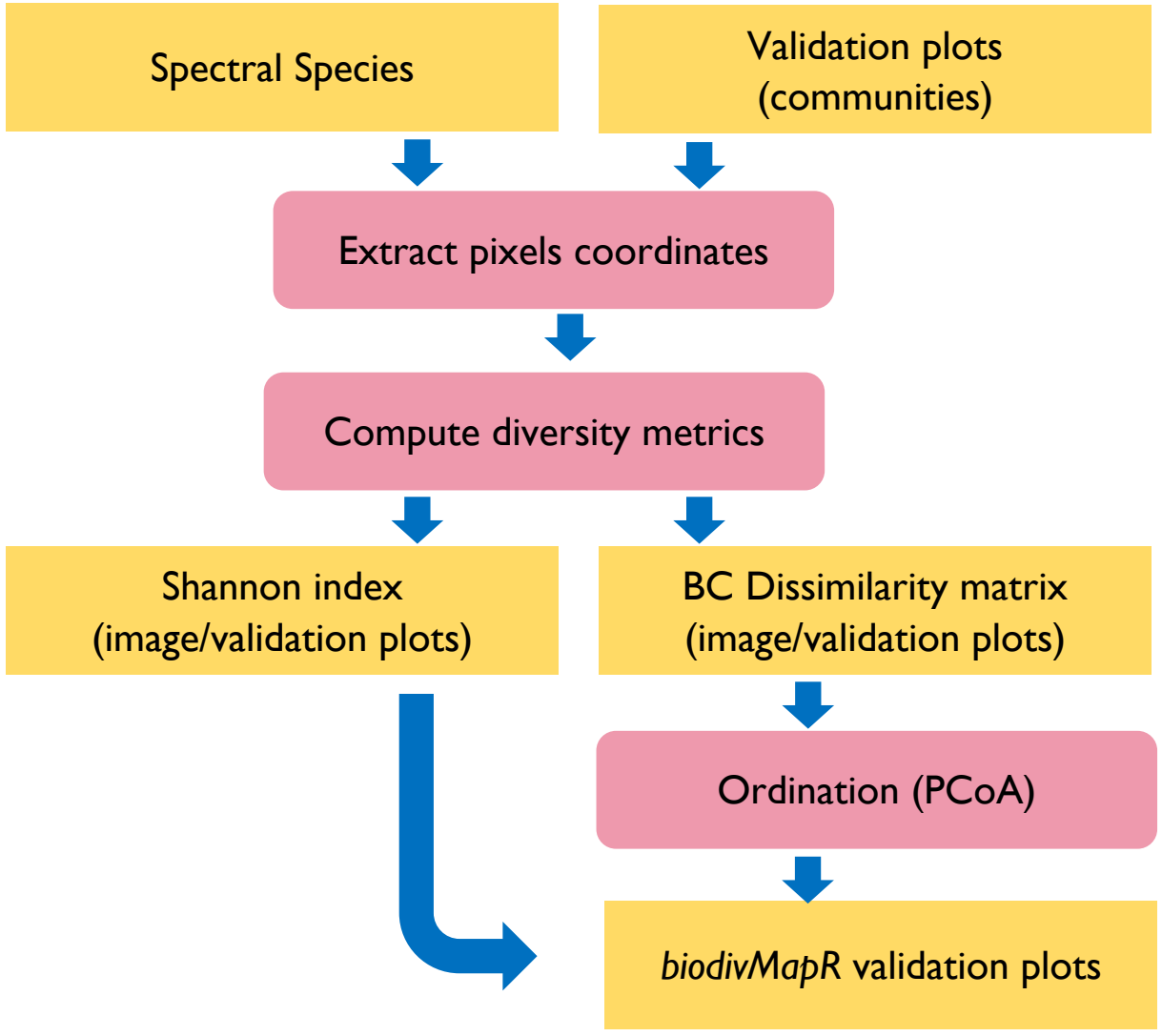
Which level of forest type description should be used during validation of RS diversity maps ?

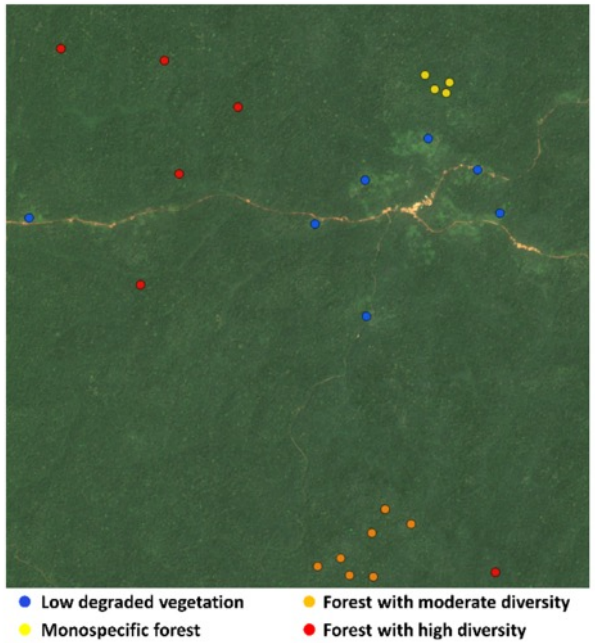
- Validation framework from *biodivMapR*
- Discrimination between vegetation « types » or « communities »

→« **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)





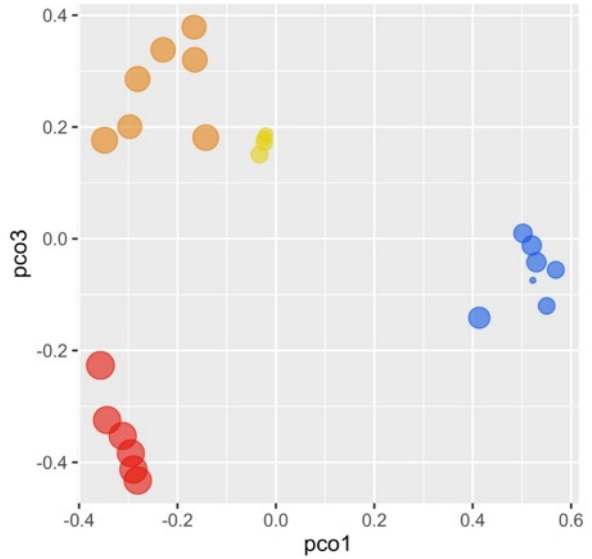


Image and plot from *biodivMapR* tutorial *https://jbferet.github.io/biodivMapR/articles/biodivMapR_08.html*

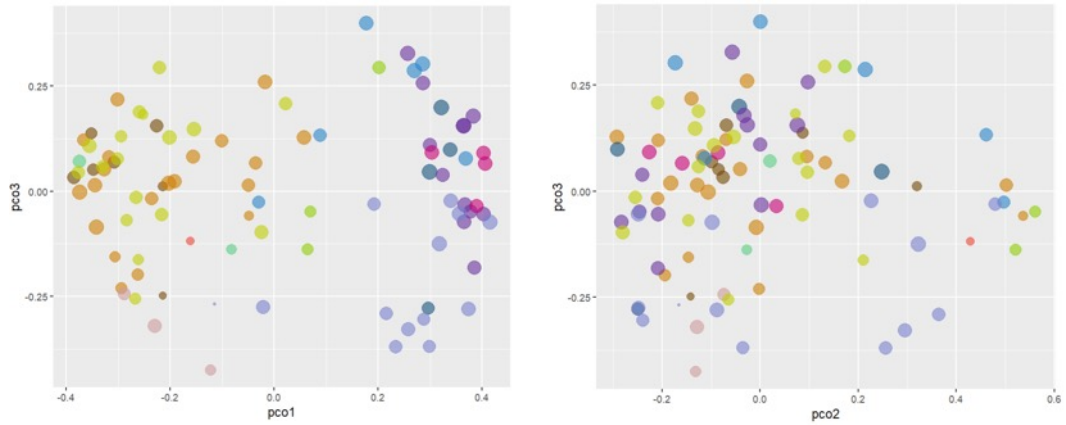
STEP 3: VALIDATION

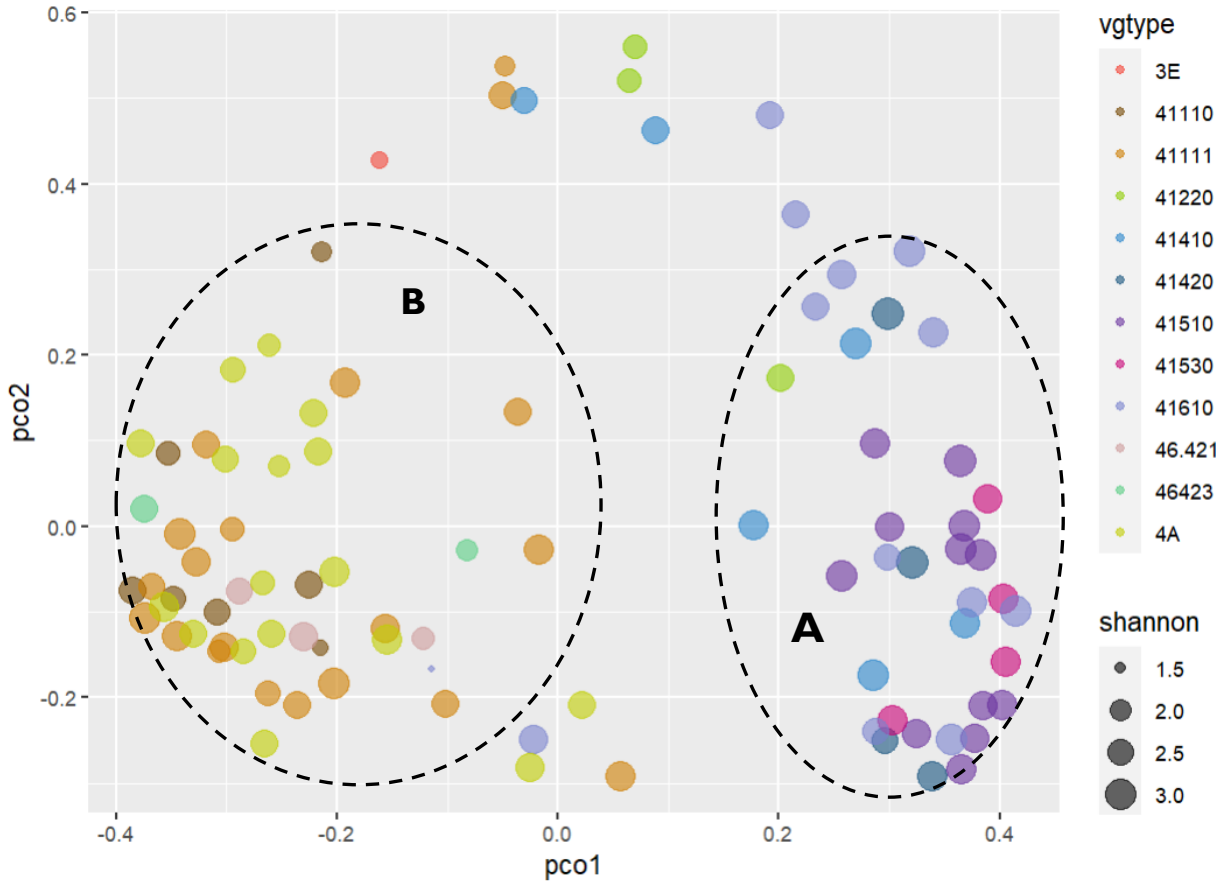
Which level of forest type description should be used during validation of RS diversity maps ?

- Two distinct groups of forest habitats are observed according to the first axis of the Principal Coordinates Analysis (PCoA):

→ A) Regular plateau forests (41510) ; Highland forests (41530), Mid-mountain forests (41610) ; Irregular hill forests forests (41420)

→ B) Riparian forests, lowland, wet talweg (41110) ; Transitional forest ecotone - wet facies (41111) ; **Swamp forests (4A) ; Lowland forests on lateritic armour (46.421), Lowland forests on inselberg (46.423)**





- Similar habitat types are found inside A and B groups → Spectral diversity (β-diversity) allows to discriminate 2 ensembles of forest habitats associated with **specific topography (A) or wet environment (B)**
- **Swamp forests (4A) show coherent β-diversity patterns**
- **More plots would be needed to assess the potential specificity of lowland forests (46.421, 46.423)**

- α-diversity does not show specific patterns among habitat types; at this stage, no relation with field data is observed

PROGYSAT
Projet régional d'observation des Guyanes par satellite

Towards spectral diversity mapping at region scale over the Guiana Shield region: potential and limitations

METHODOLOGICAL FRAMEWORK: REGIONAL MOSAIC

Towards spectral diversity mapping at region scale over the Guiana Shield region: potential and limitations

Step 1

Spectral index composite images

n tiles

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Spectral diversity metrics

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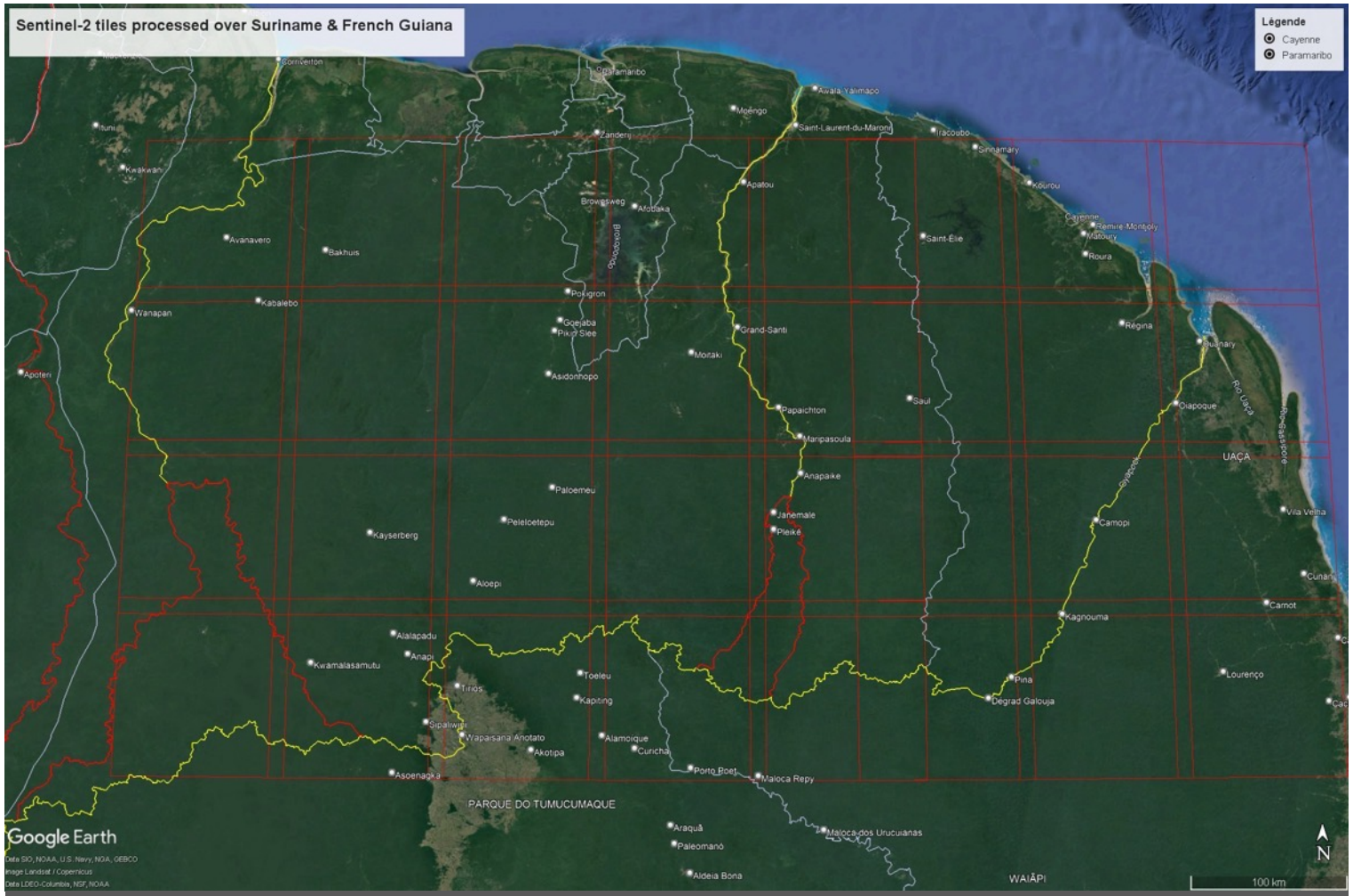
Computation (40 cores, 700 Gb RAM)

download S2 & LaSRC : **2 days**

Produce SI mosaic: **1 day**

apply biodivMapR: **1 day**

→ Cloud computing & data catalog



Time series processed for 32 Sentinel-2 tiles over Suriname, French Guiana & part north of Amapa

ALPHA DIVERSITY: REGIONAL MOSAIC

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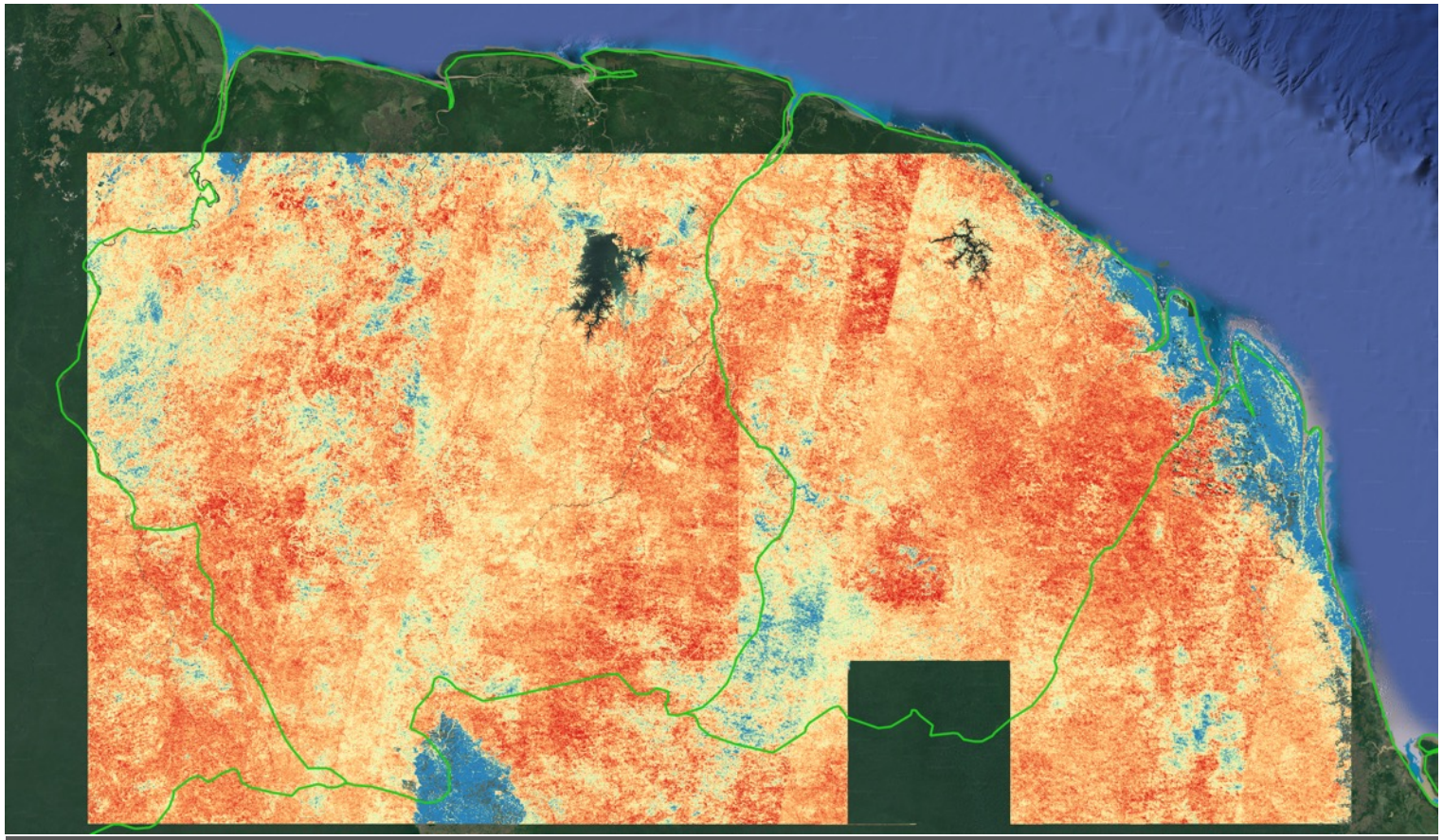

Need to account for sensor artifacts and directional effects of S2 data

BETA DIVERSITY: REGIONAL MOSAIC

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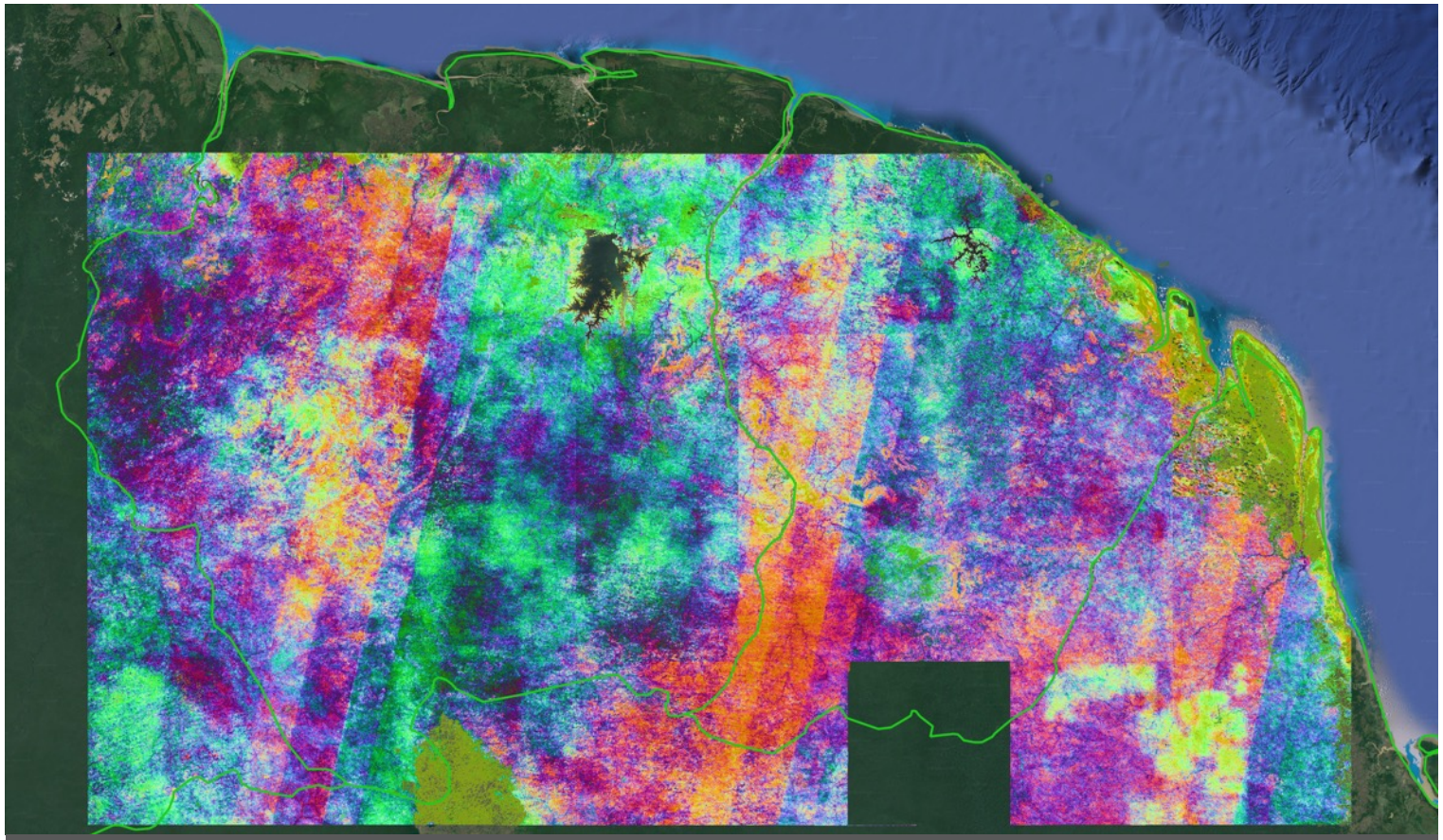
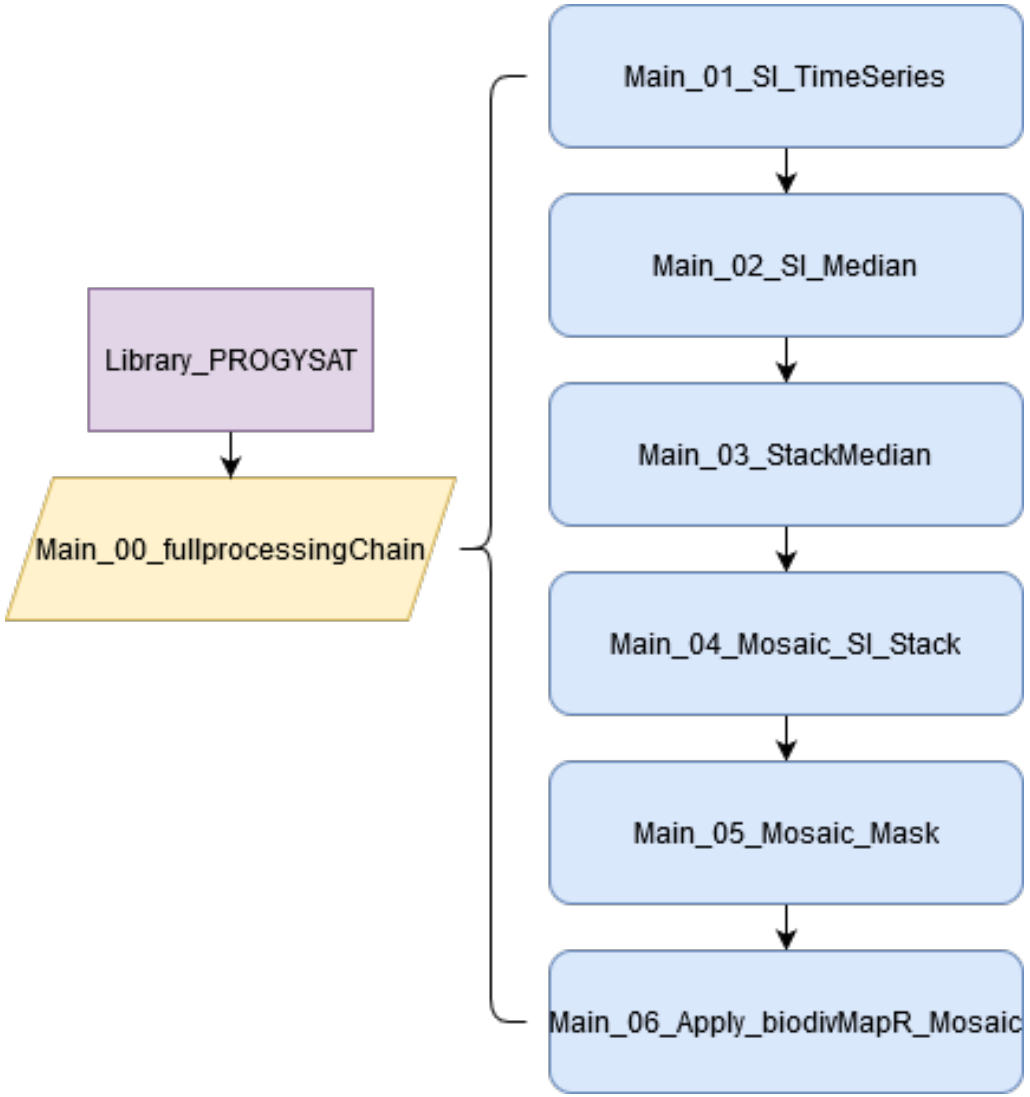


Need to account for sensor artifacts and directional effects of S2 data

UPADATED PROCESSING CHAIN (IN DEVELOPMENT)

- Dense Sentinel-2 time-series (gap filling)
- Perform regional mosaics
- Optimised computing time (parallelisation)



CONCLUSION & PERPSECTIVES

- We propose an **automated processing chain for downloading Sentinel-2 data and mapping forest biodiversity** indicators (Python and R languages).

- **An updated version of the processing chain is currently being developed**, enabling **denser time series** and the construction of a **mosaics**, with **optimization for parallel computing** and HPC.

- A promising **agreement between forest inventory data in French Guiana and biodiversity indicators** at the scale of a Sentinel-2 tile was observed, however…

  … *correction of BRDF and sensor artifacts needs improvements (large-scale mosaics, swath edge)*

  … *fusion of Sentinel-2 data with SAR could improve the accuracy of biodiversity indicators.*

  … *validation needs consolidation based on botanical inventories and exchanges with ecologists*

MAIN PROJECT DELIVERABLES

✓ Stable version of the processing chain based on *biodivMapR* package

… soon available on GitLab / GitHub repositories.

✓ A report detailing the method and the results of the field validation for the French National Forest Office research and development department.

✓ An **online tutorial** on how to use the *biodivMapR* package, with an example of a study area in Suriname (will be presented Thursday 29th in our workshop).

https://jbferet.github.io/biodivMapR/articles/biodivMapR_11.html

Thank you for listening!