



RAMI workshop

A beta version of a novel RT simulator tool to simulate reflectance at canopy level

C. Camino, Bolyon C., P. S. A. Beck

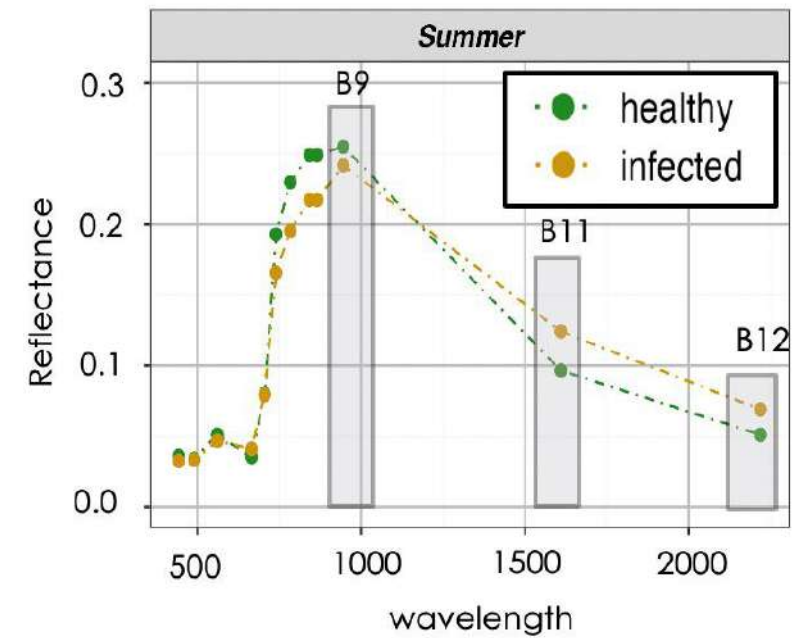
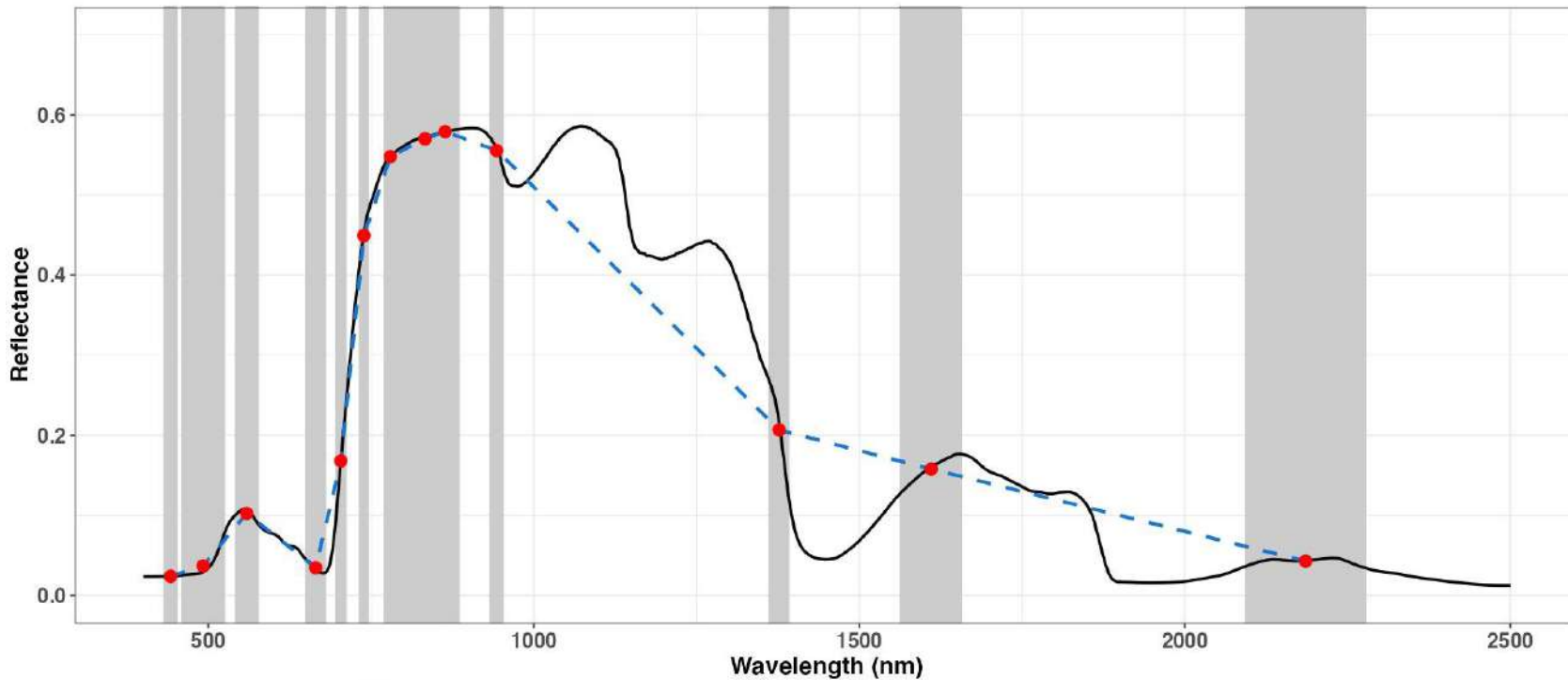
7-9th June, 2023

European Commission (EC), Joint Research Centre (JRC), Ispra, Italia.

Motivation



To contribute to the remote sensing community's understanding of spectral domains.



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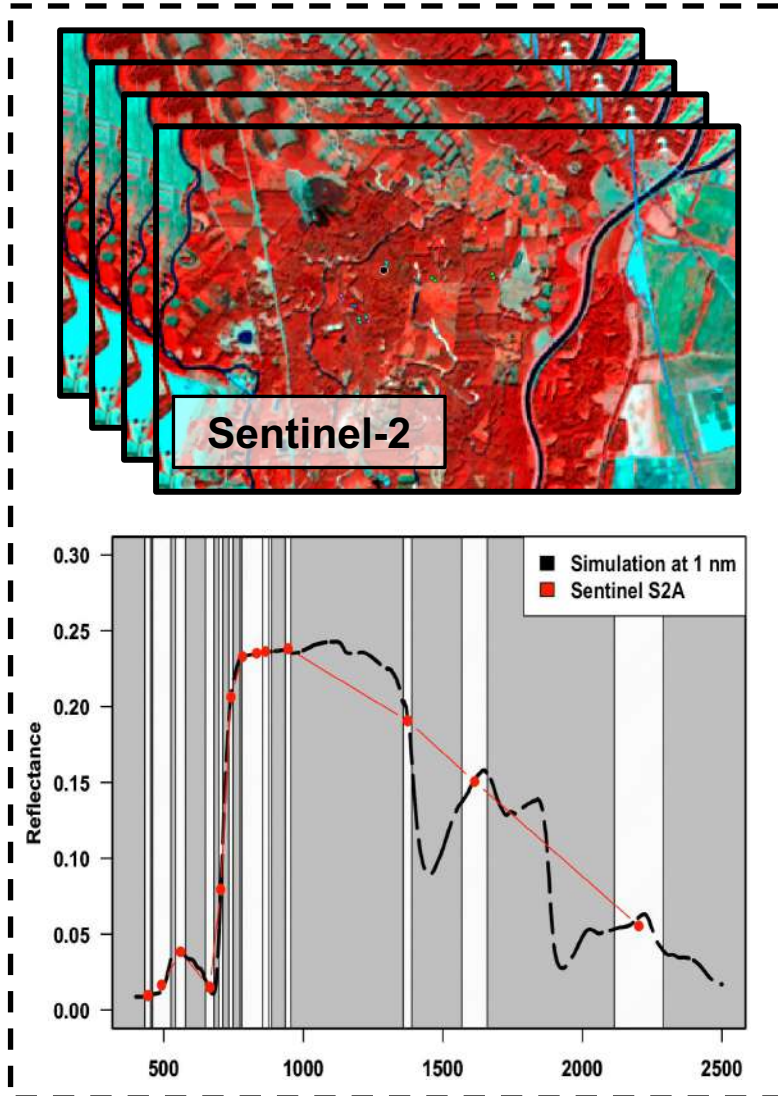
" To make it easier to test RTmodels when studying forest canopies .

To make it easier to link spectral features and physiological plant traits.

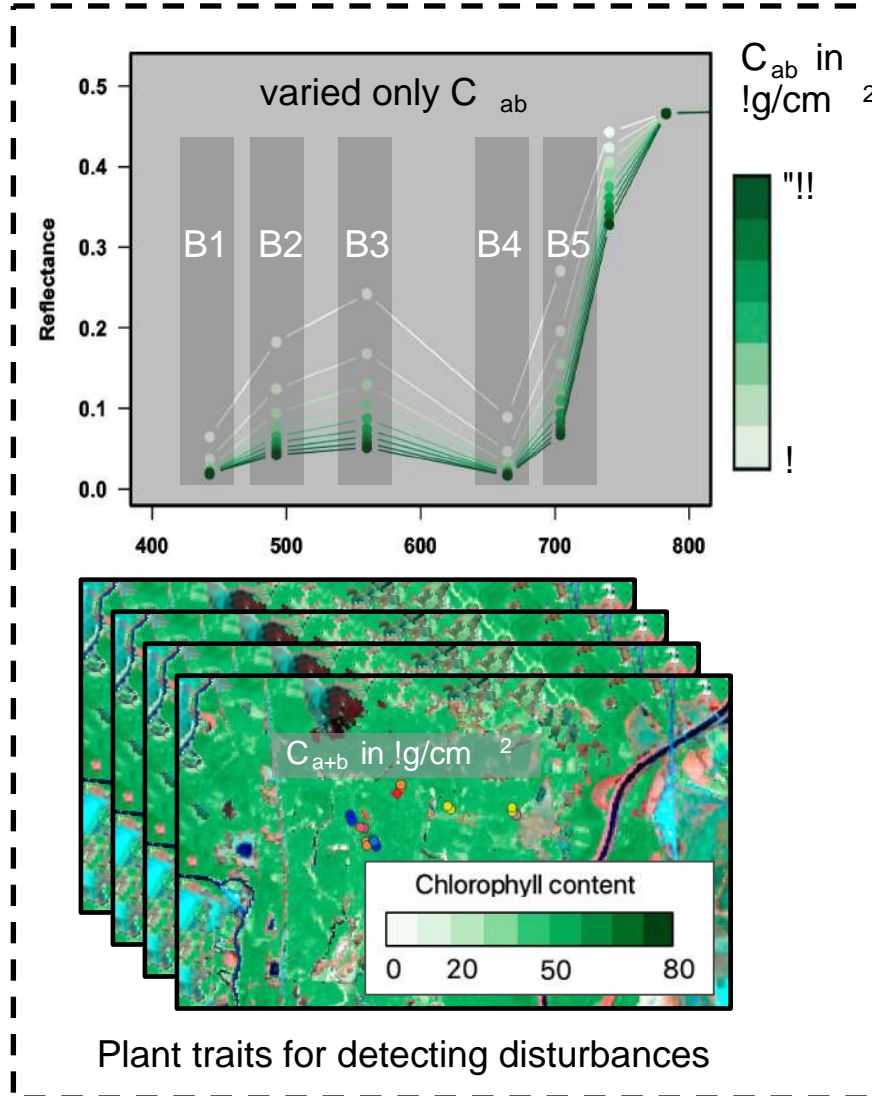
Highly relevant for the the early detection of biotic forest disturbances (e.g., insects and pathogens)

Plant trait -based Forest Health Monitoring

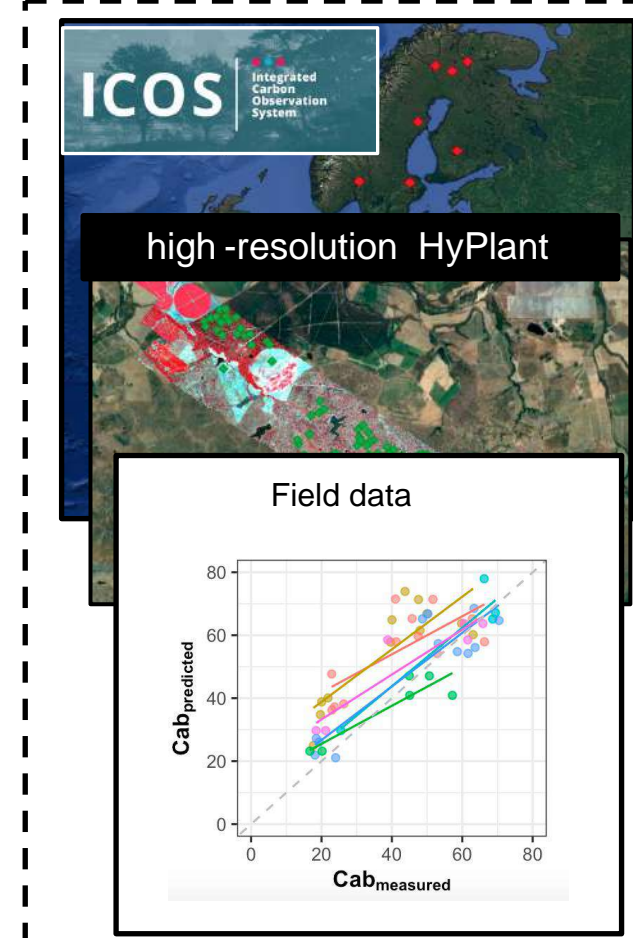
Copernicus



Radiative transfer models

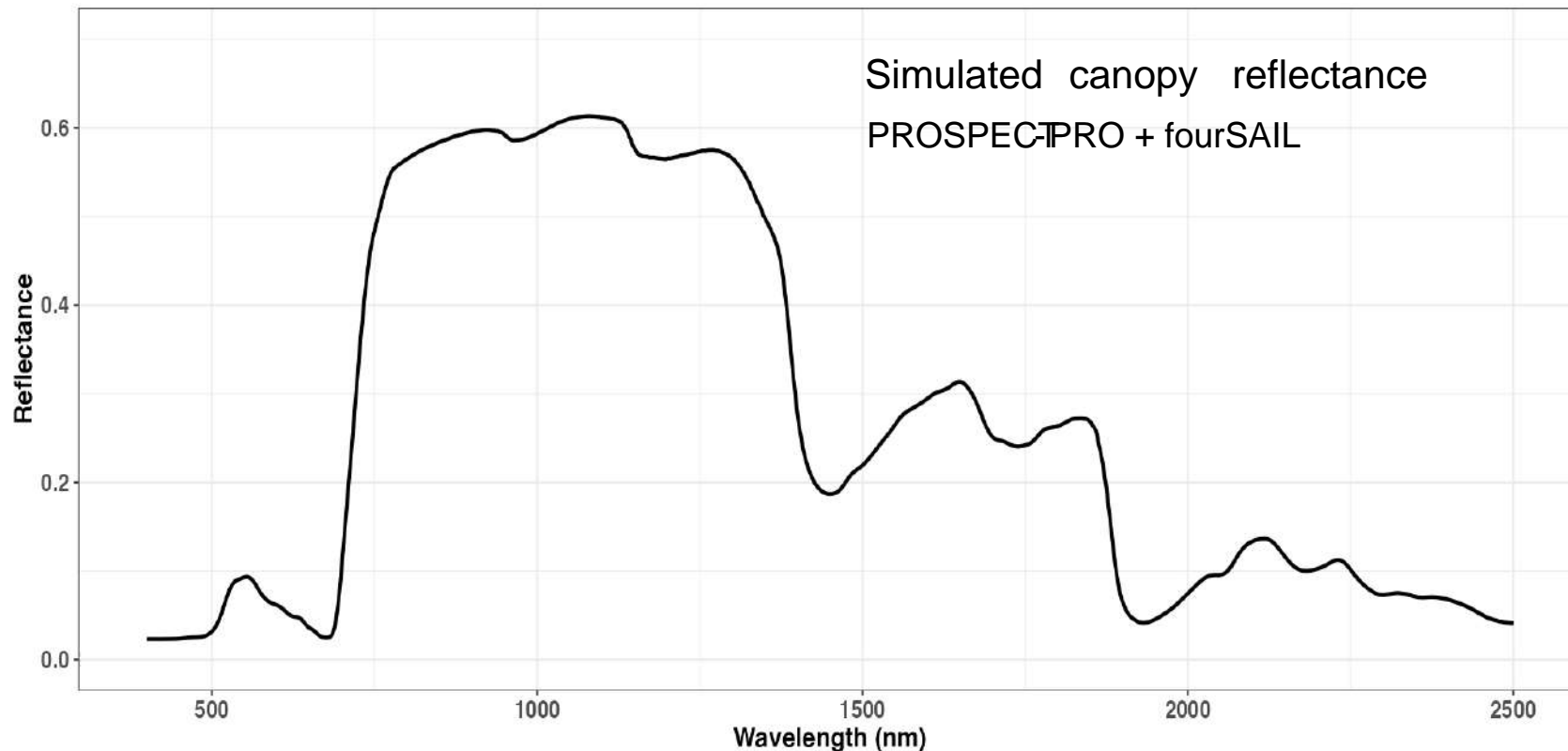


Validation



An online RT reflectance simulator

The RTsimulator is an online framework to model reflectance at canopy scales



Accumulate reflectance spectra

Changes in chlorophyll content on real time

- RT simulator based on:



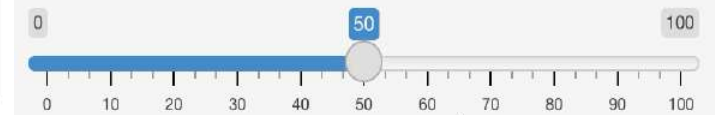
ToolsRTMpackage

SCOPEinRpackage

- Shiny environment

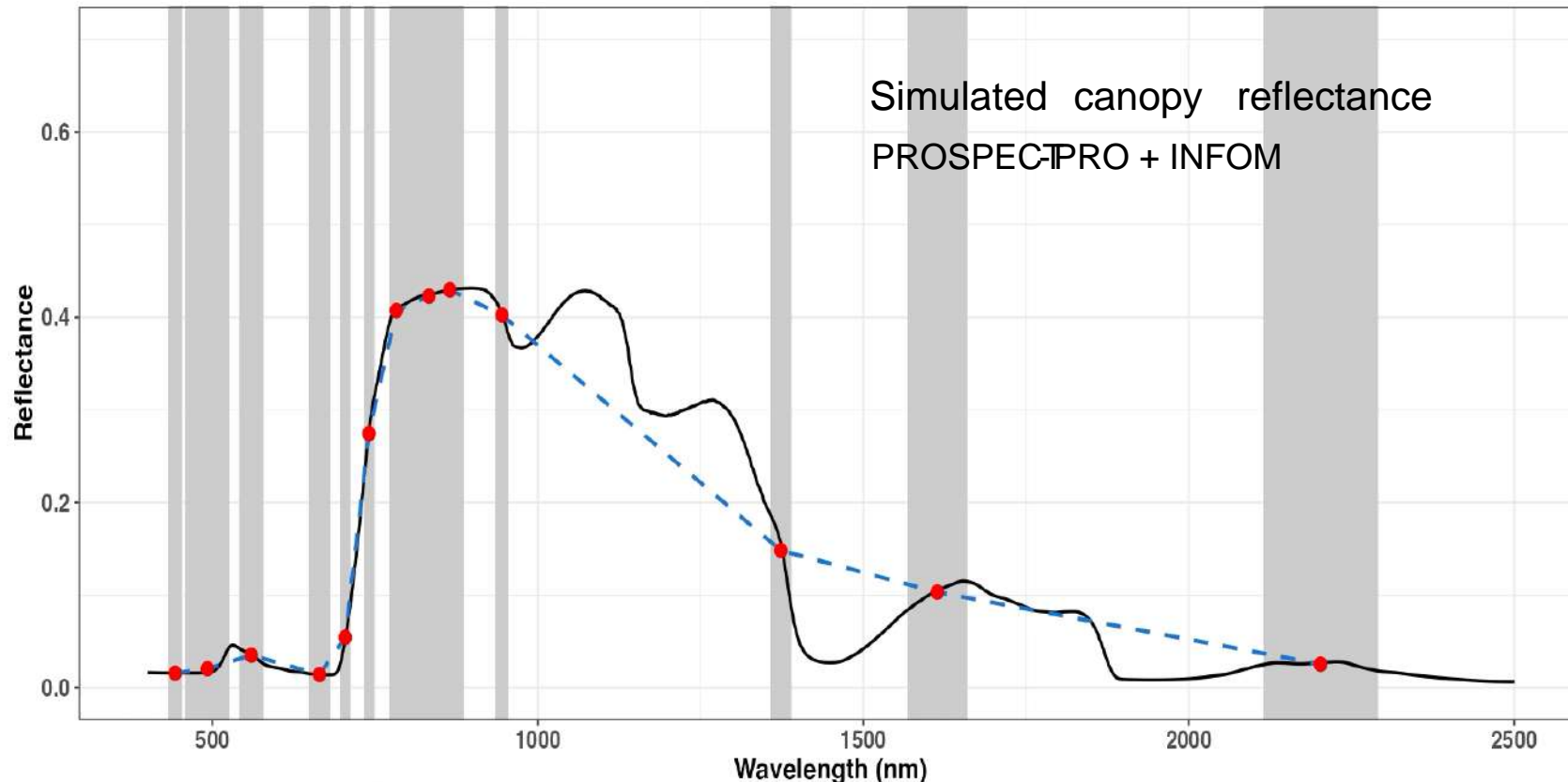
(Web framework for developing web apps using R)

Chlorophyll content ($\mu\text{g cm}^{-2}$)



An online RT reflectance simulator

Effect of plant traits on the canopy reflectance at several spectral resolutions



Accumulate reflectance spectra

Changes in water content on real time

Select satellite sensor:

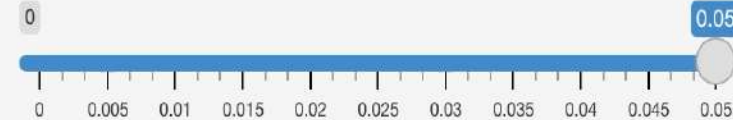
Sentinel2a

Download the reflectance spectrum at selected senso

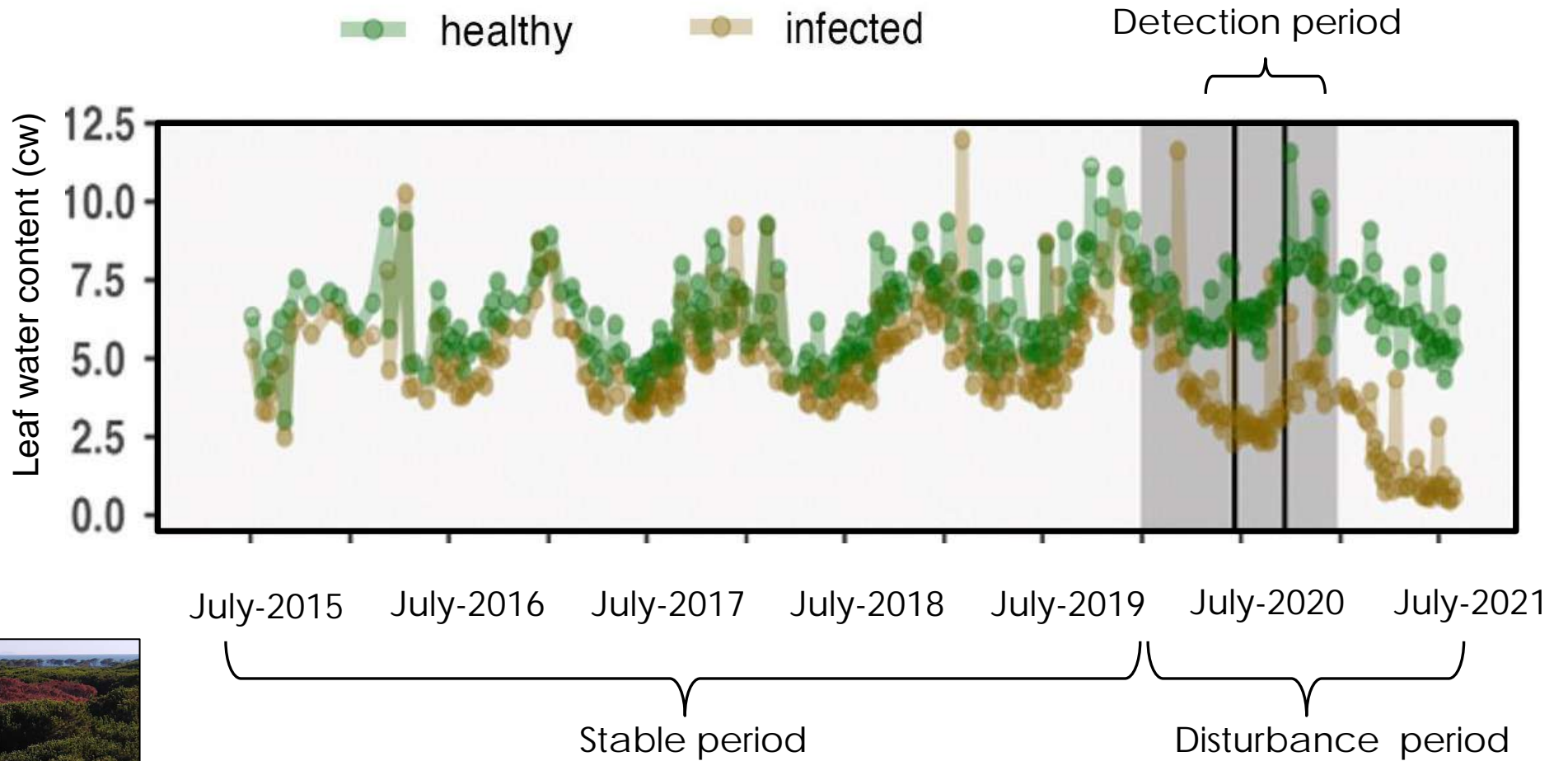
Download spectrum

The selected reflectance spectrum was generated bas

Water content (g cm⁻²)



SWIR for detecting forest disturbances



Predicted Cw: An hybrid ML approach, Sentinel-2 and RT models

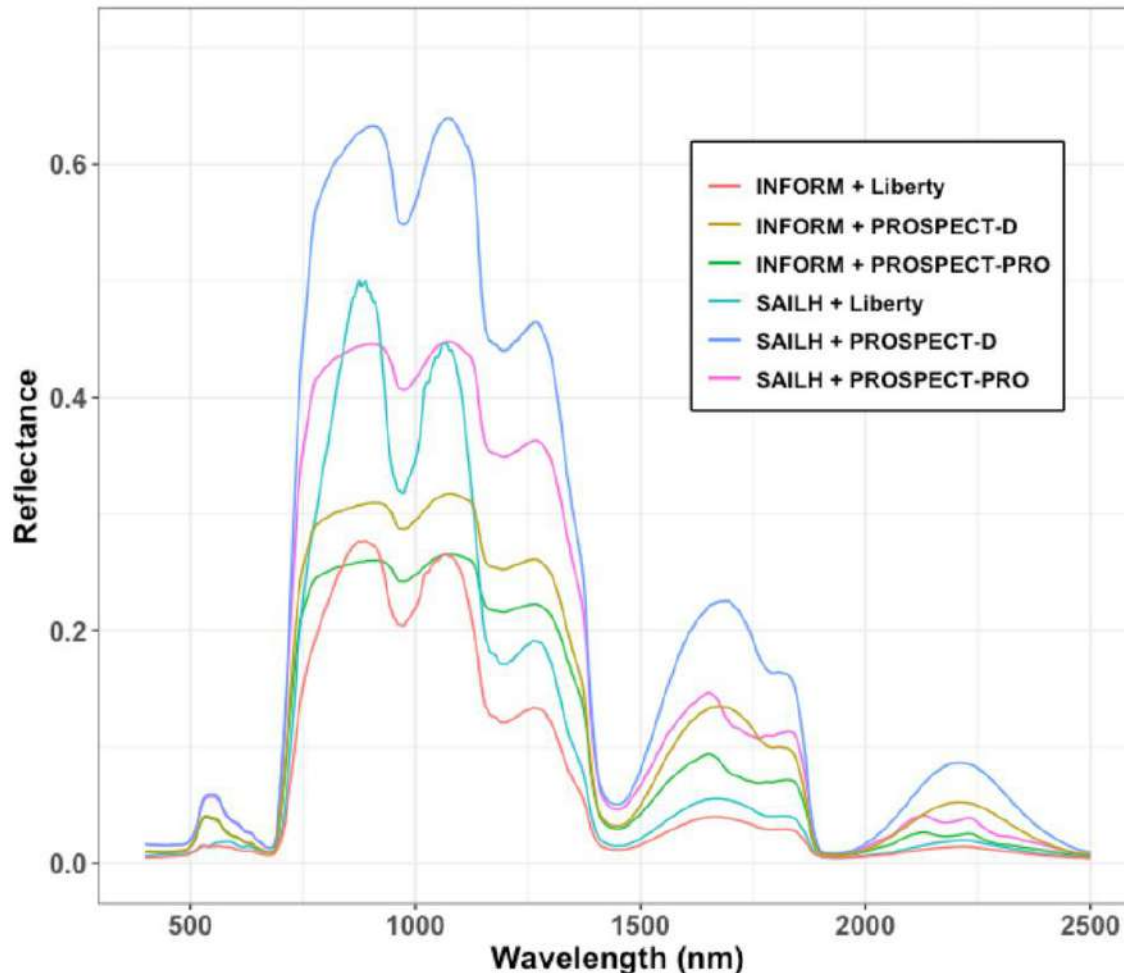
Camino et. al. (2023)





ToolsRTM package

ToolsRTM is a package to simulate reflectance based on several RT models



Leaf models

- Liberty model for conifers canopies.
- PROSPECT model (D and PRO).
- FLUSPECT model (B and CX-B).

Canopy models

- INFORM model.
- fourSAIL model.
- fourSAIL2 model.

Several functions

- Spatial mapping of plant traits.
- LUT generator.
- Inversion methods for plant trait retrievals.



ToolsRTM package

Inversion methods to retrieve plant traits implemented in the ToolsRTMpackage

hybrid ML methods: SVM, NNet, RF, Gradient boosting and Ensemble

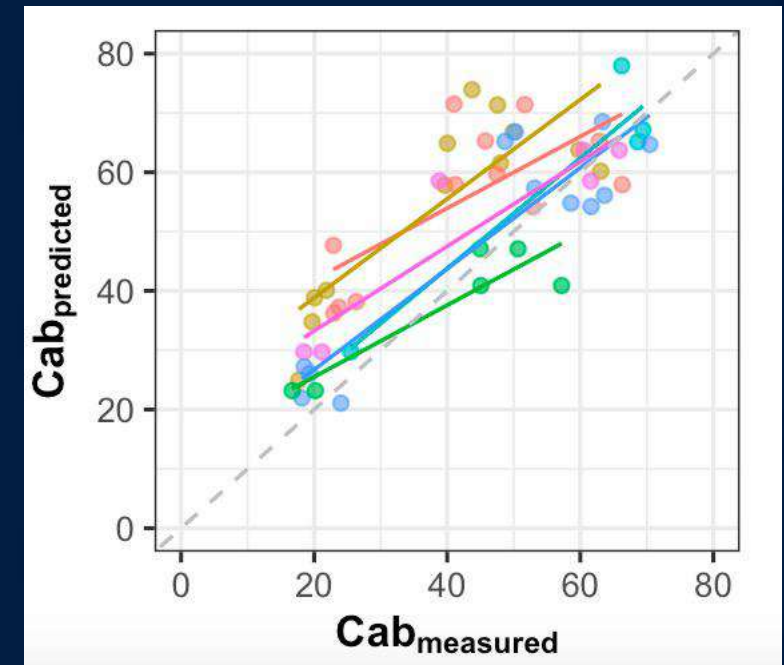
```
ML.preds <- getML.inversion(LUT = LUT.Table,split = 0.8,setseed = 123,input = 'Cab',  
  method = 'SVM', # options: 'SVM','RF','GB','nnet','Ensemble'  
  Field.data = data.field.sb, acron = '_obsv')
```

hybrid ML methods: deep ML models (CNN and hidden layers)

```
model.prep<-getMLmodel(dataset=LUT[,c(depVar[i],inputs.to)], depVar='Cab',model='CNN',  
  optimizer = 'adamax',  
  batch.size=batch.size,n.epochs=n.epochs, save.model=T, path.model='Models/',  
  prop.split=c(0.8,0.2),  
  data.trans='preProcess',method.preProcess='Normalize', depVar.trans=FALSE)
```

Traditional methods based on a merit function (e.g., RMSE)

```
inv.RMSE<-ToolsRTM::InversionOpt(rfl.sensor=rfl.sensor,  
  rfl.prosail=rfl.prosail,  
  LUT=LUT,  
  wave=wave.vnir.swir,  
  n=nSamples,  
  method='merit-RMSE',  
  nOpt=100)
```



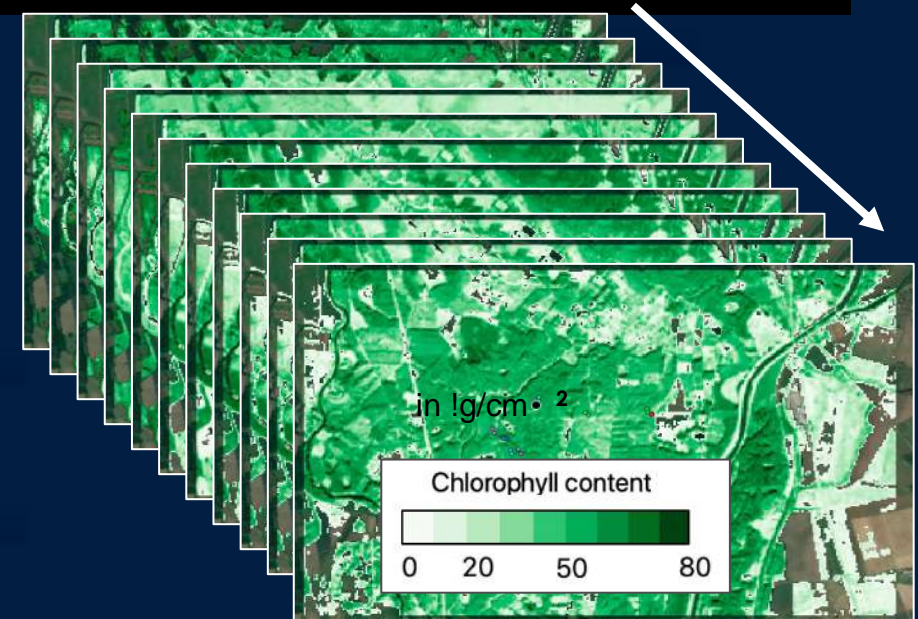


ToolsRTM package

Spatial mapping of plant traits by coupling RTmodels and Sentinel-2

Integrating RT with Sentinel-2 for getting spatial maps based on the best correlated spectral indicator

```
spatial.maps<-getSpatialTrait(rasterFiles = files.sensor[i],  
                             ForestLayer = path.with.forest.mask,  
                             Sensor='Sentinel2a',saveFile = path.export,  
                             proj = 3035,  
                             shapeLayer = paths.with.shape,  
                             model.ML = model.nne$Cab$model,  
                             trait = 'Cab',factorR=factorSE)
```



LUT generator functions

- Generate random inputs for each RT model

- Normal or uniform distribution

- Correlation between traits

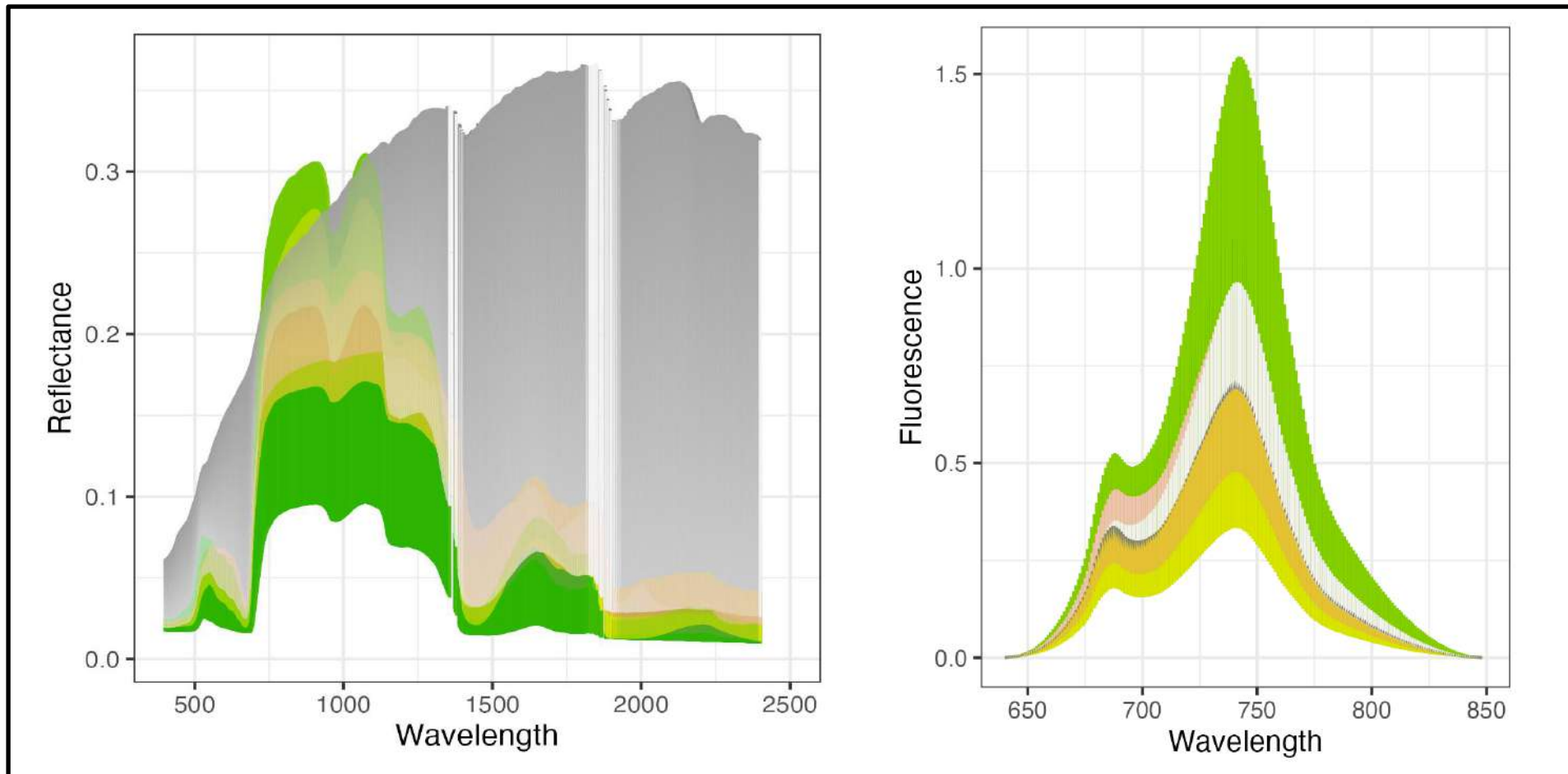
- LUT + Sims adapted to specify sensors



SCOPEinR package

SCOPEinR is a package to simulate reflectance using the SCOPE model

SCOPE Soil Canopy Observation, Photochemistry and Energy fluxes radiative transfer model





SCOPEinR package

Running the SCOPE model in R

Configure main options for SCOPE and get LUTs

```
# 1. Get options for running SCOPE model  
options<-read.table('input/setoptions.csv',header=T, sep=',')  
SCOPEinR::data.opts  
e.g., estimate fluorescence ; vertical profiles, adding soil spectrum, É
```

Get the LUT with main inputs for simulations

```
# 2. get LUT table  
N.Samples = 500  
LUT <-getLUT.SCOPE(inputLUT=inputLUT,nLUT=N.Samples)  
## get correlation between traits  
LUT <- getCor(n_inputs = 2 ,setseed = n_seed,distribution = 'Uniform',nLUT = N.Samples, rho = 0.20,  
              Varnames = c('LIDFa','LIDFb'),MinRange = c(-0.5,-0.5), MaxRange = c(0.2,0.2))
```



SCOPEinR package

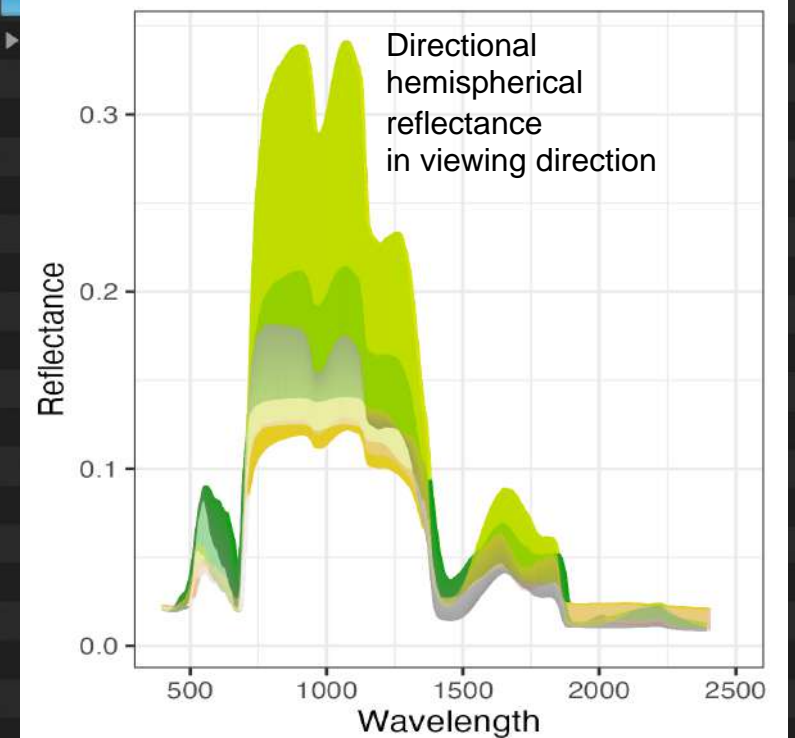
Running the SCOPE model in R

Run the SCOPE model

```
# 3. Run the SCOPE model  
db.sim <- get.SCOPE(LUT=LUT, n.LUT = N.Samples, options.SCOPE=options,  
  optipar=SCOPEinR::optipar2021.Pro.CX,  
  leaf.model='fluspect-CX', canopy.model='fourSAIL',  
  get.outputs = 'ALL', get.plots = F)
```

Save the main outputs and generate additional plots

```
# 4. Save main outputs  
get.SCOPE.outputs(data.sim = db.sim, N.sims=N.Samples, LUT=LUT, path.out = 'outs/',  
  get.more.inputs=c('refl', 'lidf', 'LIDFb', 'Ft_Fo', 'rdo'),  
  get.plots=T)  
  
## 5. Get additional plots  
get.SCOPE.plots(path.files=subdirectories[6], plant.trait=traits, get.plots='reflectance')
```



On-the-fly RT Simulations of canopy reflectance

Online reflectance simulator Interactive ToolsRTM SCOPE model LUT generator Monitoring plant pests References

Select RT models:

Leaf Model: PROSPECT-PRO

Canopy Model: INFORM

leaf parameters:

Chlorophyll content ($\mu\text{g cm}^{-2}$): 15.5

Carotenoid content ($\mu\text{g cm}^{-2}$): 11.2

Anthocyanin content ($\mu\text{g cm}^{-2}$): 2

Cbrown: 0.2

mesophyll structure parameter: 1.6

Canopy reflectance Inputs References About ToolsRTM

Interactive reflectance

Accumulate reflectance spectra

Select satellite sensor: Sentinel2a

Download the reflectance spectrum at selected sensor resolution with main plant traits:

[Download spectrum](#)

The selected reflectance spectrum was generated based on plant traits and canopy parameters showed in the following tables:

Plant traits values used for the selected leaf model:

Main R packages:



- ToolsRTMpackage

Dependencies:

- Shiny package

- hsdar package



On-the-fly RT Simulations with the SCOPE model

Online reflectance simulator Interactive ToolsRTM SCOPE model LUT generator Monitoring plant pests References

Select RT models:

Leaf Model:
FLUSPECT-B-Cx

Canopy Model:
fourSAILH

leaf parameters :

Fluorescence quantum efficiency (fqe)
0 0.02 0.05

Chlorophyll content ($\mu\text{g cm}^{-2}$)
0 50 100

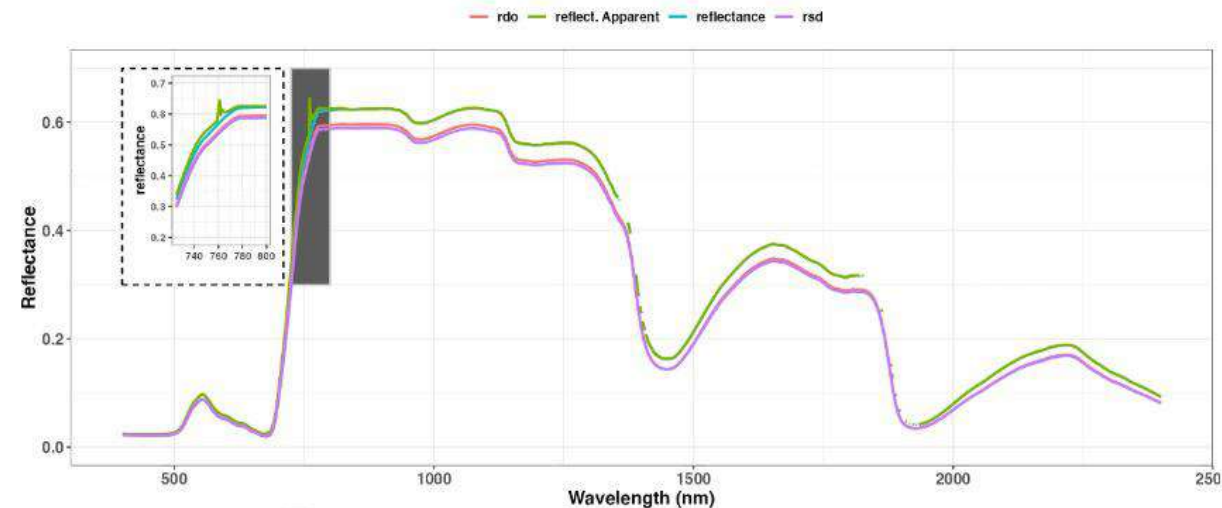
Carotenoid content ($\mu\text{g cm}^{-2}$)
0 20 40

Anthocyanin content ($\mu\text{g cm}^{-2}$)
0 2 7

Leaf Senescence
0.01 1

Reflectance **Fluorescence** Radiance About SCOPEinR

Interactive reflectance



Accumulate reflectance spectra

Select satellite sensor:

SCOPE

Download the reflectance spectrum at selected sensor resolution with main plant traits:

Download reflectance

The selected reflectance spectra were generated based on plant traits and canopy parameters showed in the following tables:

Main R packages:



- SCOPEinRpackage

Dependencies:

- Shiny package

- hsdar package



On-the-fly RT Simulations with the SCOPE model

Online reflectance simulator Interactive ToolsRTM SCOPE model LUT generator Monitoring plant pests References

Reflectance **Fluorescence** Radiance About SCOPEinR

Interactive reflectance

Future implementations

- Update RT models with the incoming versions.
- Inter-comparison module for RT models.
- Global sensitive analysis for each input (LUT).
- Improve the Web interface.
- Adding additional plots on demand.

Select RT models:

Leaf Model:
FLUSPECT-B-Cx

Canopy Model:
fourSAILH

leaf parameters :

Fluorescence quantum efficiency (fqe)
0 0.02 0.05

Chlorophyll content ($\mu\text{g cm}^{-2}$)
0 50 100

Carotenoid content ($\mu\text{g cm}^{-2}$)
0 20 40

Anthocyanin content ($\mu\text{g cm}^{-2}$)
0 2 7

Leaf Senescence
0.01 1

Download the reflectance spectrum at selected sensor resolution with main plant traits:

[Download reflectance](#)

The selected reflectance spectra were generated based on plant traits and canopy parameters showed in the following tables:

Main R packages:



- SCOPEinRpackage

Dependencies:

- Shiny package

- hsdar package



LUT generator for specific satellite sensor

Online reflectance simulator Interactive ToolsRTM SCOPE model LUT generator ▾ Monitoring plant pests References ▾

Select a leaf RT Model:
PROSPECT-D ▾

Select a canopy RT Model:
INFORM ▾

Select sensor for resampling resolution:
RTM ▾

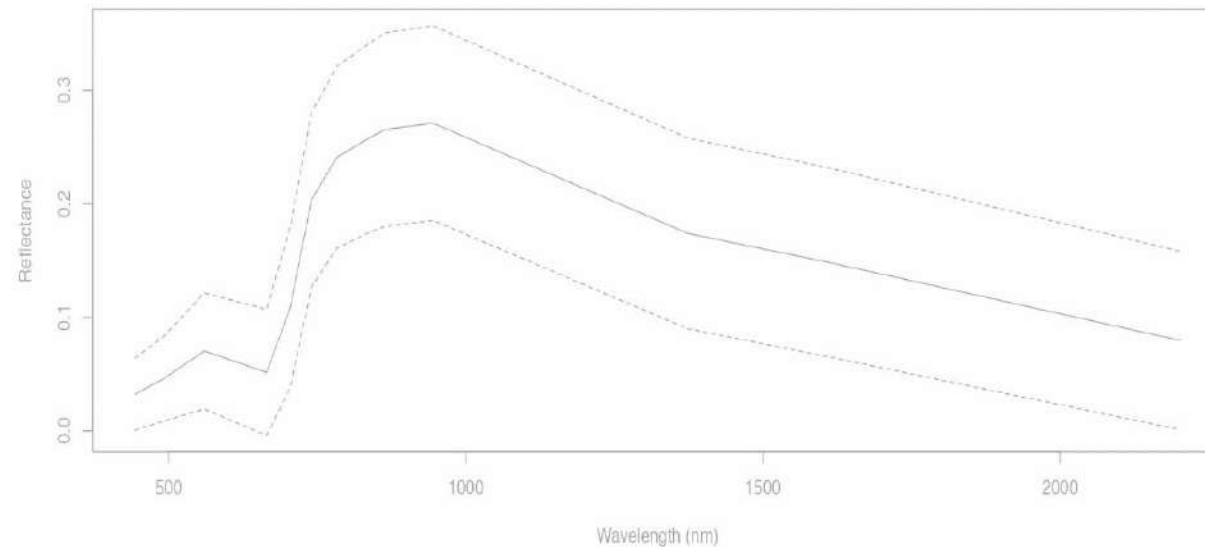
Number of samples:
100

maximum LUT to 20,000 simulations

random seed:
1234

Random seed parameter for repeatability
 accumulative LUTs

Simulated average reflectance



Generate the LUT

Download

Main R packages:



- SCOPEinRpackage
- ToolsRTMpackage

Dependencies:

- Shiny package
- hsdar package

LUT generator for specific satellite sensor

Online reflectance simulator Interactive ToolsRTM SCOPE model **LUT generator** Monitoring plant pests References

Select a leaf RT Model:
PROSPECT-PRO

Select a canopy RT Model:
fourSAILH

Select sensor for resampling resolution:
RTM

Number of samples:
100
maximum LUT to 20,000 simulations

random seed:
1234
Random seed parameter for repeatability

accumulative LUTs

Simulated average reflectance

Future implementations

- Incorporate the SCOPE model.
- Additional distribution functions for selected inputs.
- Selection of the range for each input.
- Correlation between plant traits.
- ML inversions for deriving plant traits.
- Traditional inversion methods.

Main R packages:



- SCOPEinRpackage
- ToolsRTMpackage

Dependencies:

- Shiny package
- hsdar package

Monitoring forest disturbances with RT models

Online reflectance simulator Interactive ToolsRTM SCOPE model LUT generator **Monitoring plant pests** References

Fungus detection at SR2

Select a time period:

2020-01-01 to 2020-12-31

Maximum Cloud Coverage (%):

2 100

0 10 20 30 40 50 60 70 80 90 100

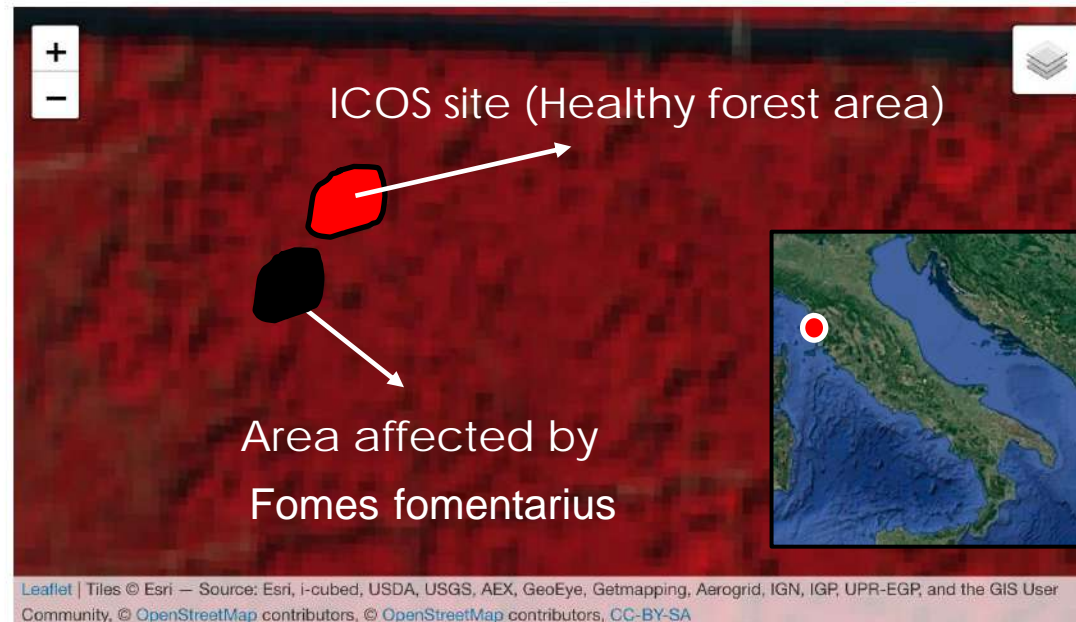


Map **Spectral plot** Spectral Time Series San Rossore info Ideas

Interactive map

Get spectral information

(If checkbox is activate, click on the map for generating time series)



Main R packages:



- SCOPEinRpackage
 - ToolsRTMpackage
- Dependencies:
- Shiny package
 - rgee package

Study case : In the surrounding forest areas of ICOS flux tower in San Rossore, Italy.



Monitoring forest disturbances with RT models

Fungus detection at SR2

Select a time period:
2020-01-01 to 2020-12-31

Maximum Cloud Coverage (%):
2 100

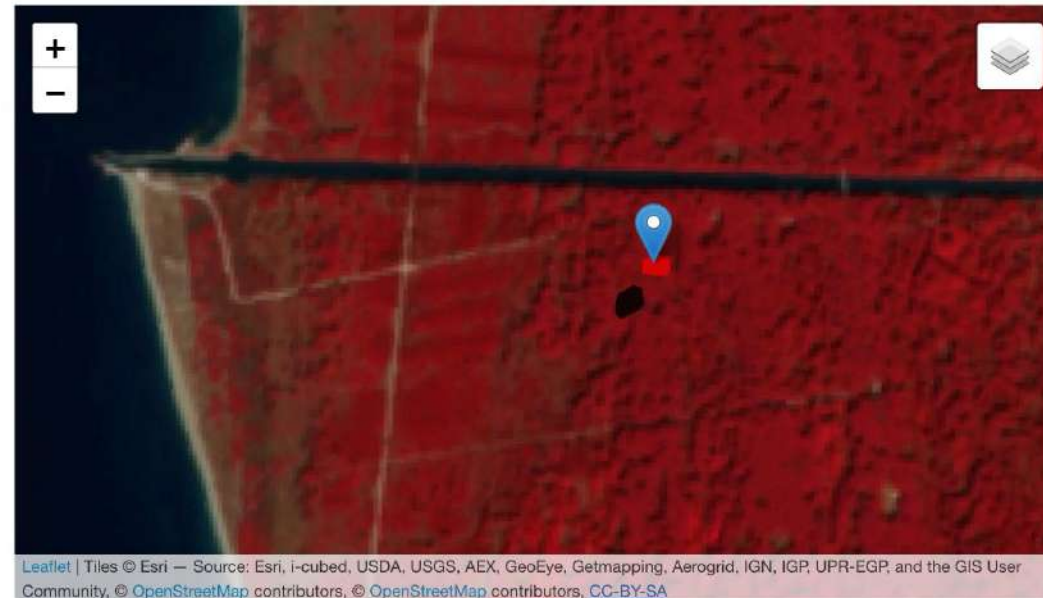
Base Map
Select a base map:
Sentinel-2

Coordinates:
[1] "Lat: 43.73 Long: 10.29"

Interactive map

Get spectral information

(If checkbox is activate, click on the map for generating time series)



Main R packages:



- SCOPEinRpackage
 - ToolsRTMpackage
- Dependencies:
- Shiny package
 - rgee package



Study case : In the surrounding forest areas of ICOS flux tower in San Rossore, Italy.

Monitoring forest disturbances with RT models

Online reflectance simulator Interactive ToolsRTM SCOPE model LUT generator ▾ Monitoring plant pests References ▾

Fungus detection at SR2

Select a time period:

2020-01-01 to 2020-12-31

Maximum Cloud Coverage (%):

2 100

Base Map

Select a base map:

Sentinel-2 ▾

Coordinates:

[1] "Lat: 43.73 Long: 10.29"

Map Spectral plot Spectral Time Series San Rossore info Ideas

Interactive map

Get spectral information

(If checkbox is activate, click on the map for generating time series)

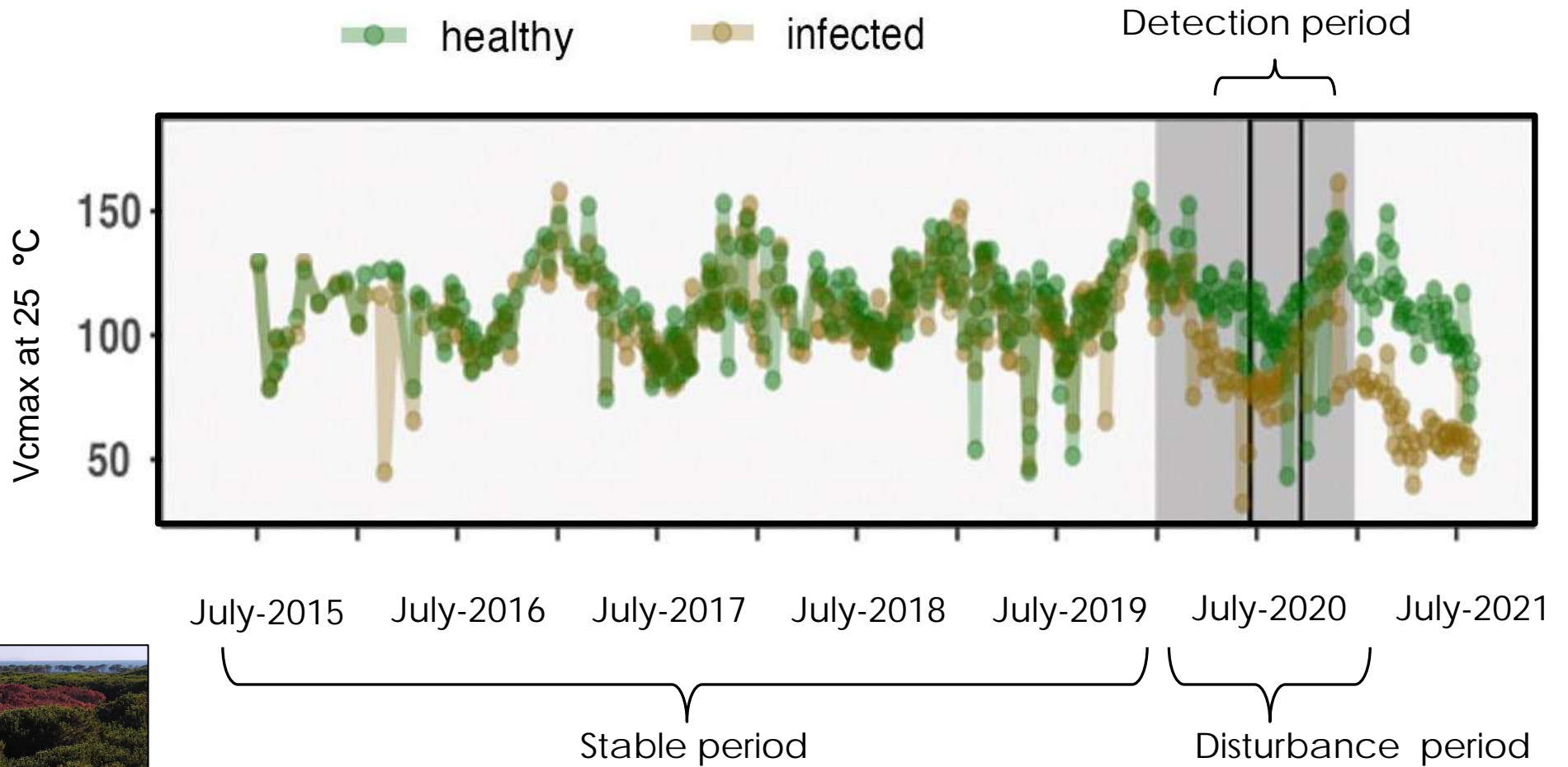


Main R packages:



- SCOPEinRpackage
 - ToolsRTMpackage
- Dependencies:
- Shiny package
 - rgee package

V_cmax for forest disturbance monitoring



Camino et. al. (2023)

Monitoring forest disturbances with RT

Online reflectance simulator Interactive ToolsRTM SCOPE model LUT generator ▾ **Monitoring plant pests** References ▾

Fungus detection at SR2

Select a time period:

2020-01-01 to 2020-12-31

Maximum Cloud Coverage (%):

2 100

Base Map

Select a base map:

Sentinel-2

Coordinates:

[1] "Lat: 43.73 Long: 10.29"

Map Spectral plot Spectral Time Series San Rossore info Ideas

Interactive map

Get spectral information

(If checkbox is activate, click on the map for generating time series)

Future implementations

- Intercomparison of time series.
- Integrate pre-trained ML model.
- Selection of RT models and plant traits.
- A complex and dynamic interface.

Main R packages:



- SCOPEinRpackage
 - ToolsRTMpackage
- Dependencies:
- Shiny package
 - rgee package

Conclusions

!

RTTools for monitoring the physiological traits of forests using biophysical models is crucial to develop accurate methods for the early detection of pest epidemics .

"

Integrating RT models and satellite imagery is needed to support forest health monitoring activities in near-real-time .

#

Our online RTSimulator supports the use of RT models to understand the spectral response of plant traits changes related to forest disturbances .

Next steps

1 Establish collaborations with model developers (YOU) and model users

2 Publish the RTsimulator with the R packages by the end of the year .

Add useful functionalities and additional RTmodels .



Thanks for your attention !

Contact: Carlos.Camino-Gonzalez@ec.europa.eu

Special thanks to main authors of RT models:

SCOPEmodel:

- Yang et al., (2020) and Van der Tol et al. (2009, 2014)

FLUSPECTmodel:

- Vilfan et al., (2016; 2018)

PROSPECTmodel:

- Jacquemoud et al., (1990); Feret et al. (2017, 2021)

Liberty model:

- Dawson et al., (1998); Di Vittorio et al., (2009).

FourSAIL & fourSAIL2models:

- Verhoef & Bach H, 2007, (2016; 2018)
- Verhoef et al., (2007)

INFORM model:

- Atzberger (2000) and Schlerf et al., (2006)