ARTMO's new Spectral Indices (SI) module for mapping biophysical parameters

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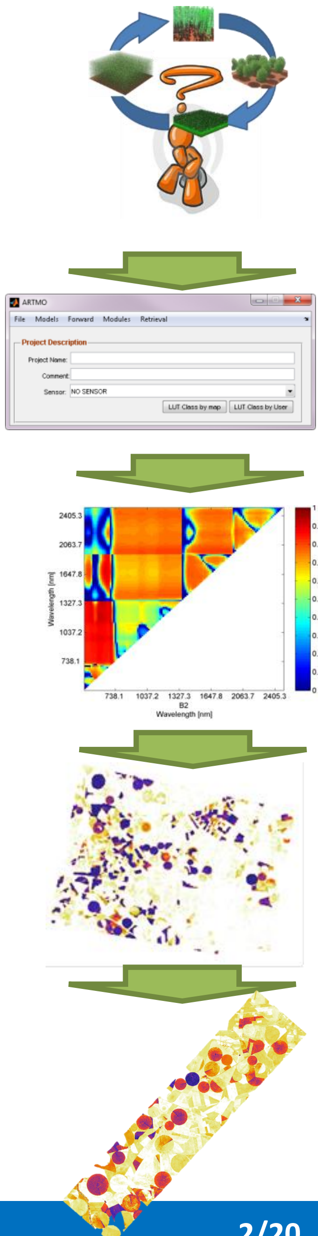
Outlook

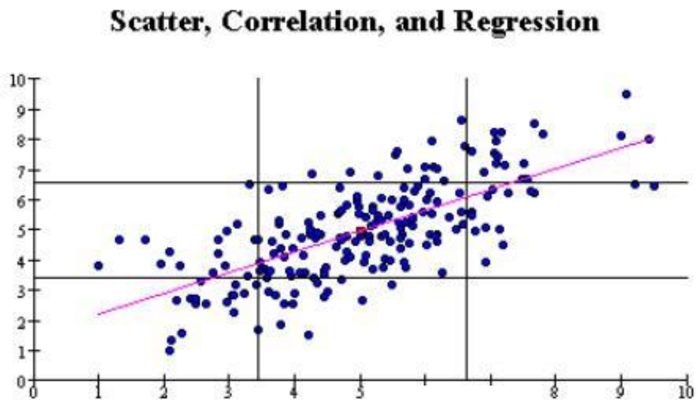
- Background
  - Biophysical parameter retrieval
  - Revisiting spectral indices
  - ARTMO
- SI toolbox
  - SI settings
  - Results tests
  - Retrievals
  - Coupling with RTMs
- Conclusions



Basics biophysical parameter retrieval

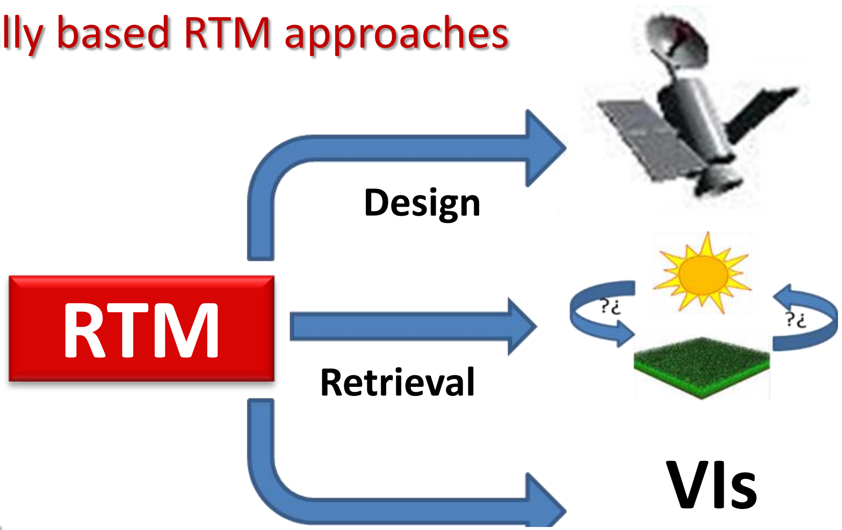
Retrieval of biophysical parameters from optical EO data **always occurs through a model**; e.g. through **statistical models**, through **inversion** of physically-based **radiative transfer models** (RTM), or through **hybrid forms**.

Statistical approaches



VI

Physically based RTM approaches



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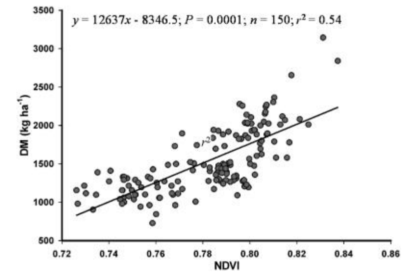
Hybrid forms

Revisiting SIs

- **Parametric regression:** Some constraints introduced
- **Nonparametric regression**: No constraints in developing models (see next presentation)
- **Physically-based approaches**: Inversion of RTMs using parametric or non-parametric inversion techniques.

$$NDVI = \frac{(NIR - red)}{(NIR + red)}$$

Use of **Spectral Indices (SIs)**: example of **parametric** approach



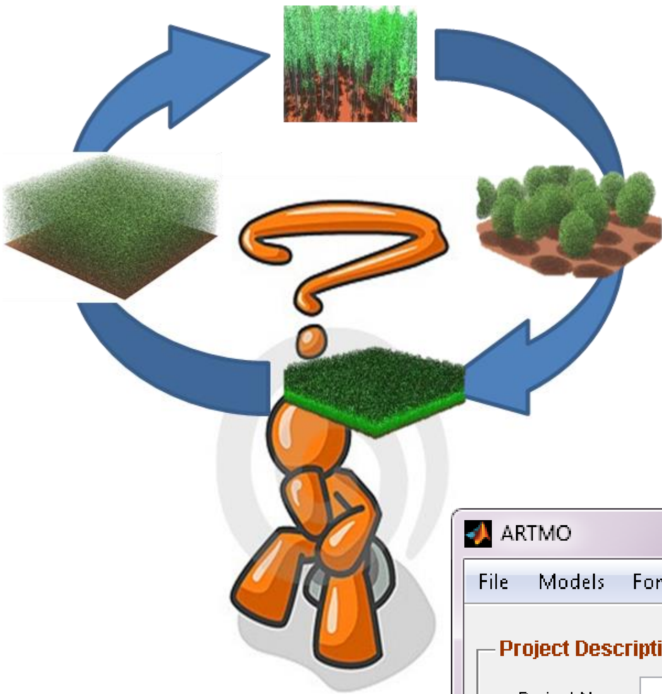
Established SIs (e.g. NDVI) are constrained in 3 ways:

1. **The used bands**: *why red and NIR would be best?*
2. **The formulation**: *why the given formulation would be best?*
3. **The regression**: *why a linear regression would be best?*

Given at three levels **imposing limitations** it can be reasonably assumed that this approach is not optimally exploiting the available information. Especially in view of **hyperspectral data**.

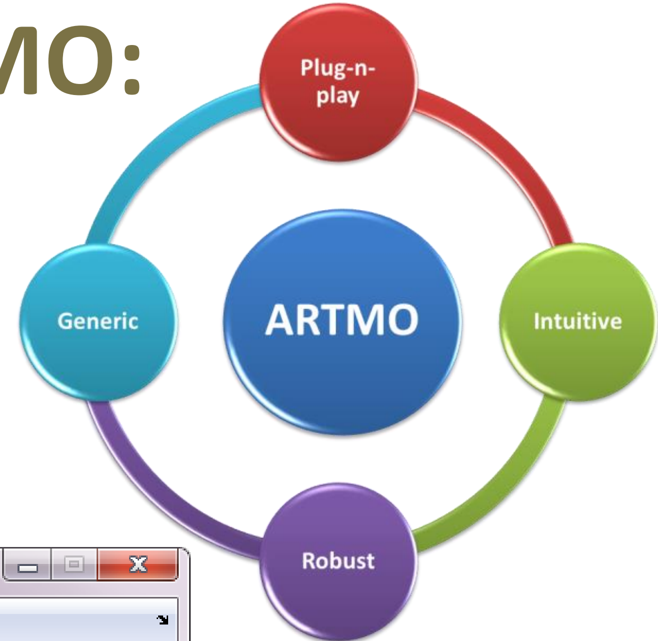
Alternatively, we can also **systematically evaluate and optimize** these 3 types of constraints. For this we developed **ARTMO's Spectral Indices Module**.

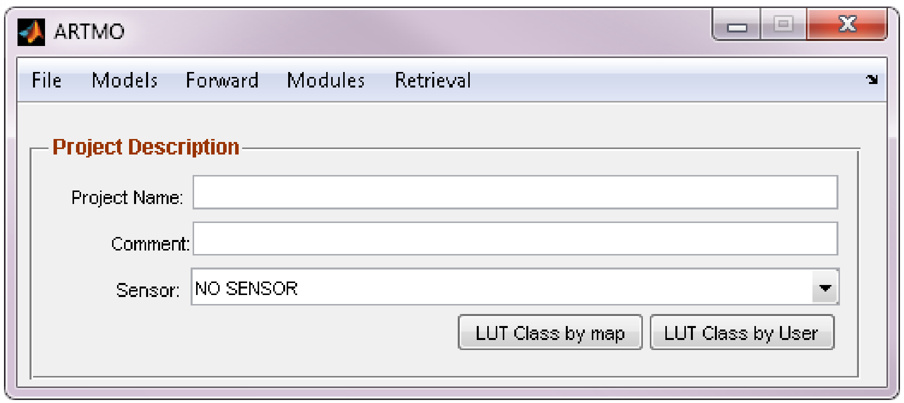
Evaluate performance SI's based on synthetic data vs. field data.



ARTMO:

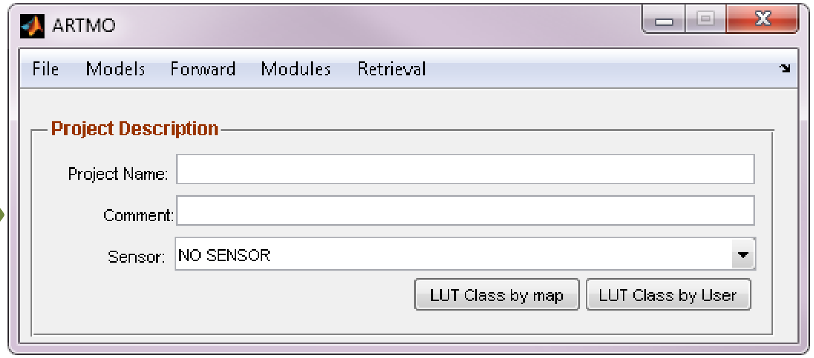
Automated
Radiative
Transfer
Models
Operator





- **Simulations can be done for any sensor in 400-2400 nm range.**
- **Input, output and metadata stored in MySQL running underneath.**
- **Modular design – enables implementation of new modules & Apps**

V3: Modular design



All models and modules can be accessed from the Menu bar

Simulations according to a predefined sensor setting

LUTs can be configured per land cover class or defined by user.

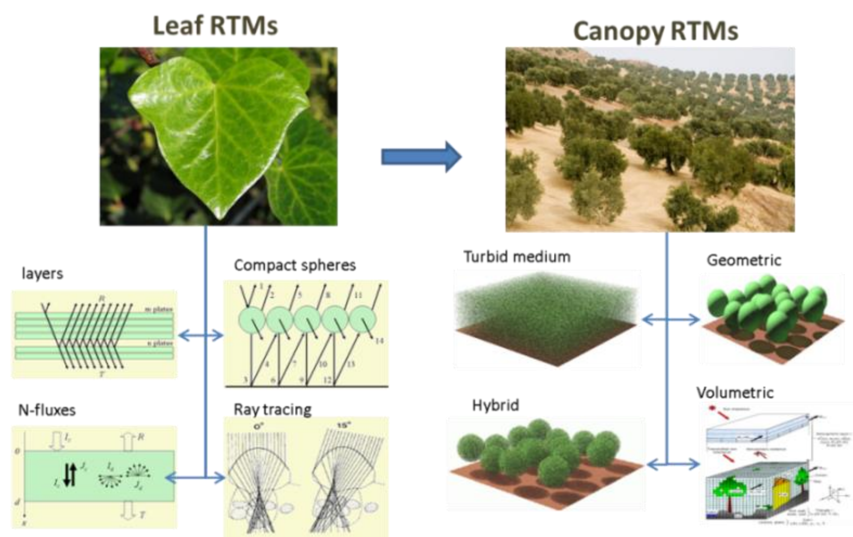
File
- Load Project
- New Project
- DB adminstration
  - New DB
  - Change DB
  - Delete
    - LUT class
    - Project
    - Database
  - Import DB
  - Export DB
  - Analyze DB
- Settings
- Model inputs
  - Save
  - Load

Models
- Leaf
- Canopy
- Combined

Forward
- Leaf
  - PROSPECT 4
  - PROSPECT 5
  - FluorMODleaf
- Canopy
  - 4SAIL
  - FLIGHT
  - FluorSAIL
- Combined
  - SLC
  - SCOPE

Modules
- Sensor
- Graphics

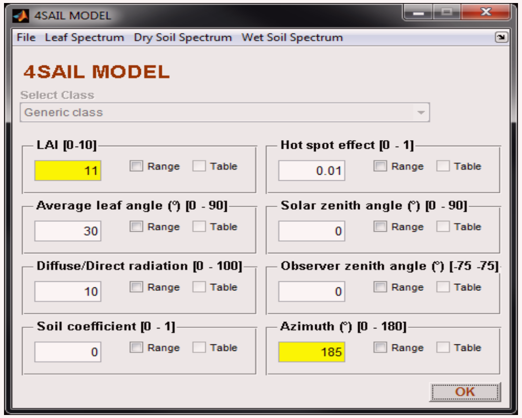
Retrieval
- Spectral Indices
- Machine Learning
- LUT-based Inversion



ARTMO v.3

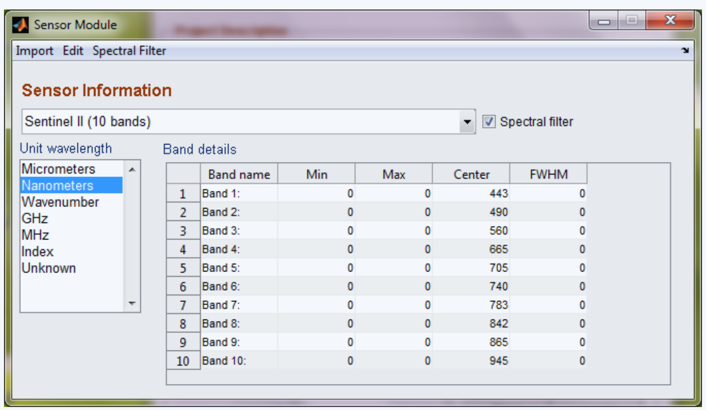
Intuitive GUIs

All models synchronized. Input: single value, range (step/ distribution) or user-defined values



Sensor module

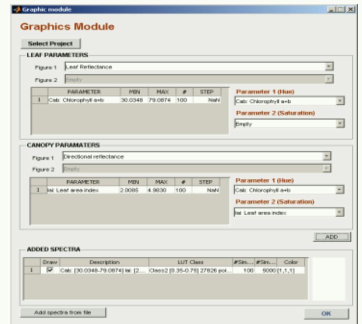
Band settings of any optical sensor can be selected or created.

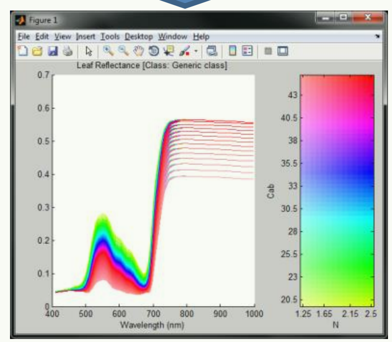


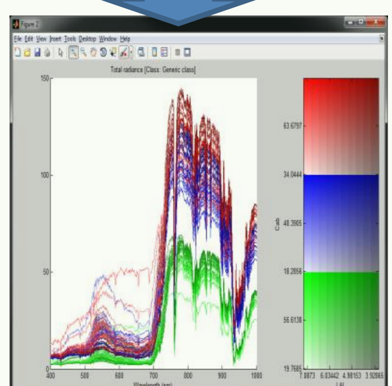
When a sensor is selected then all output data is directly resampled to that band settings. This facilities sensitivity studies and retrievals

Graphics module

A sub-selection of a LUT-class can be made. Output can be plotted as a function of 1 or 2 parameters. Output can be exported.



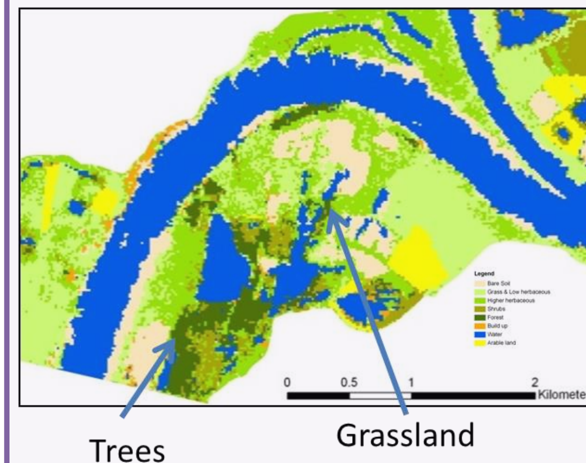


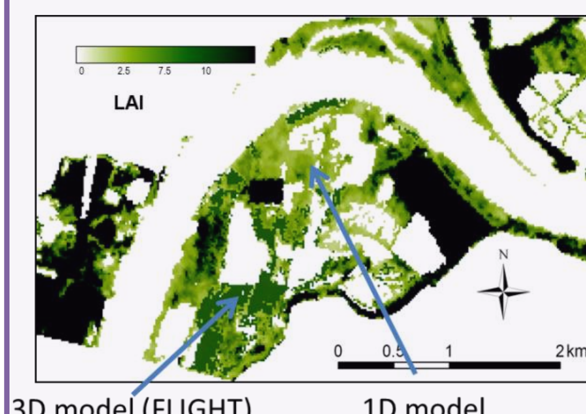


Class–based concept

All retrieval approaches can be set class-based. When a classified map is provided, then per land cover class a different retrieval strategy can be developed.

Input: **Land cover map**





SI toolbox

Spectral Indices Module

Load images & class | Input | SI Settings | Test SIs | Retrieval | Tools

Load Image & Class
- Load Image
- Load Class

Input
- RTM data
  - Select project
  - Edit settings
- User data

SI setting

Test SIs
- Load test
- New test

Retrieval

Tools
- Save
- Load
- Test database
  - Rename
  - Delete
- Add spectral index
- Add function fittings
- View map

When loading a land cover map then retrieval strategies can be optimized per class.

Input data can come either from RTMs, from field observations or from both.

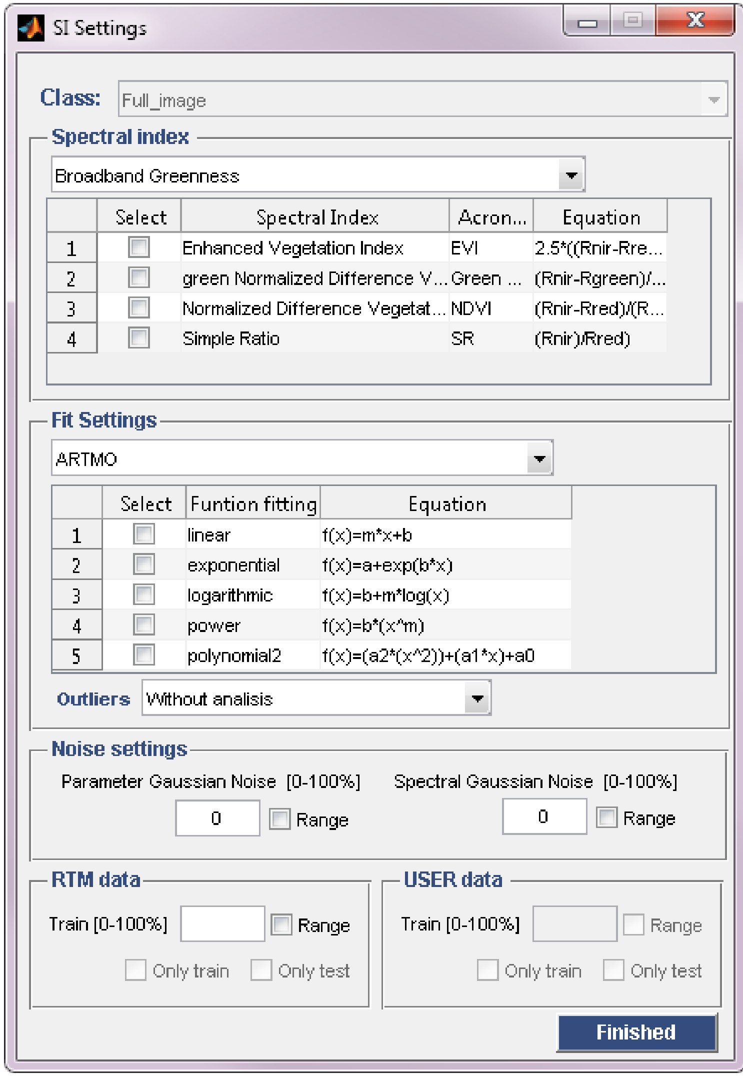
In '**SI setting**' multiple SIs, curve fittings and regularization options can be selected.

In **Test SIs,** run tests with the predefined strategies or load an existing test

In **Retrieval** manually set up a **SI retrieval strategy** or select an earlier evaluated strategy.

In tools new indices and curve fittings can be inserted or loaded.

Spectra Index settings

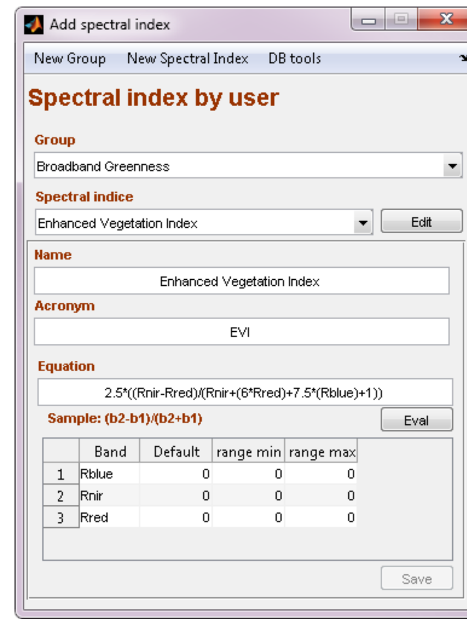


If active, configure per land cover class.

Select an Index group

By default:
- **Broadband greenness**
- **Narrowband greenness**
- **Leaf pigment (carotenoids, anthocyanins,…)**
- **Water**
- **….**

Select one or multiple indices



Select one or multiple curve fittings

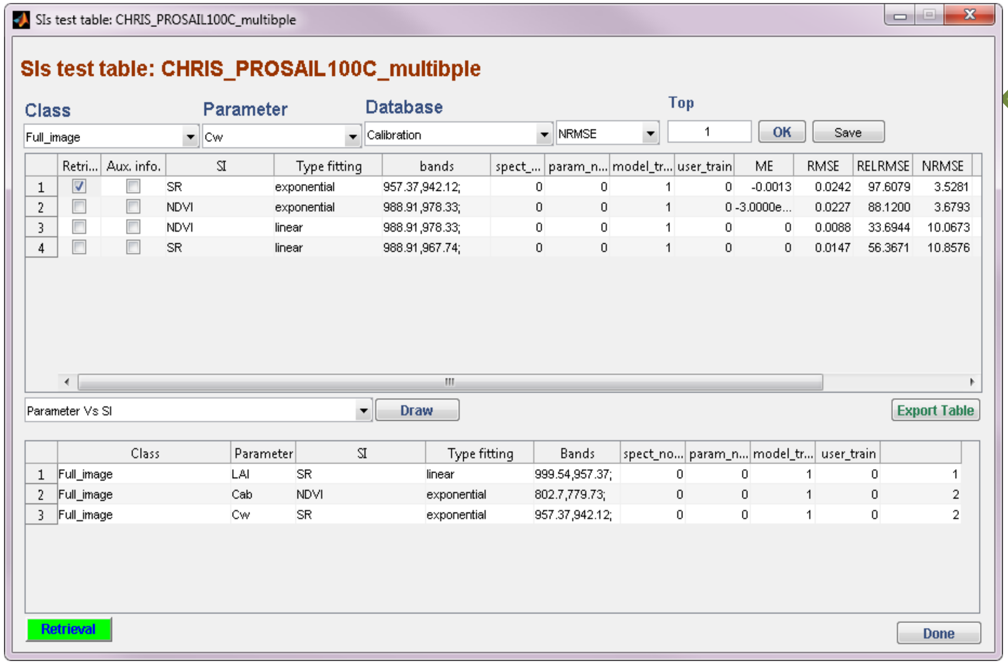
In tools, new curve fittings can be added.

Options to add noise

Option to mix RTM with field observations

In tools, new index group or SI can be added or imported.

Results test



	Retri...	Aux. info.	SI	Type fitting	bands	spect_...	param_n...	model_tr...	user_train	ME	RMSE	RELRMSE	NRMSE
1	☑	☐	SR	exponential	957.37,942.12;	0	0	1	0	-0.0013	0.0242	97.6079	3.5281
2	☐	☐	NDVI	exponential	988.91,978.33;	0	0	1	0	-3.0000e...	0.0227	88.1200	3.6793
3	☐	☐	NDVI	linear	988.91,978.33;	0	0	1	0	0	0.0088	33.6944	10.0673
4	☐	☐	SR	linear	988.91,967.74;	0	0	1	0	0	0.0147	56.3671	10.8576

	Class	Parameter	SI	Type fitting	Bands	spect_no...	param_n...	model_tr...	user_train	
1	Full_image	LAI	SR	linear	999.54,957.37;	0	0	1	0	1
2	Full_image	Cab	NDVI	exponential	802.7,779.73;	0	0	1	0	2
3	Full_image	Cw	SR	exponential	957.37,942.12;	0	0	1	0	2

Results can be organized according to land cover class, parameter, cal/val, and statistical output

Overview of results. Here, best results per SI andcurve fitting

Options to plot all kinds of output and export results

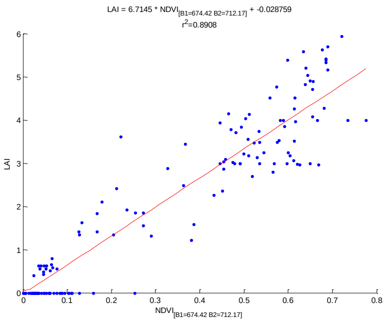
Selected strategies appear here and can be transported to the Retrieval module.

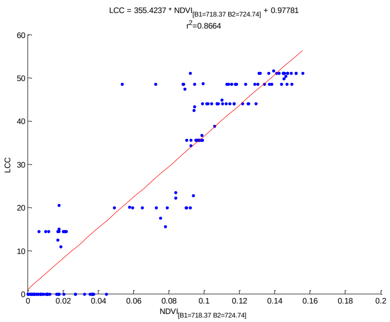
Outputs:

- Curve fitting
- 1:1

Matrices:

- Correlation
- Calibration
- Validation





Data:

SPARC campaign, Barrax, Spain

Field data:

- **LCC** measured with **CCM-200**
- **LAI** measured with LiCor LAI-2000

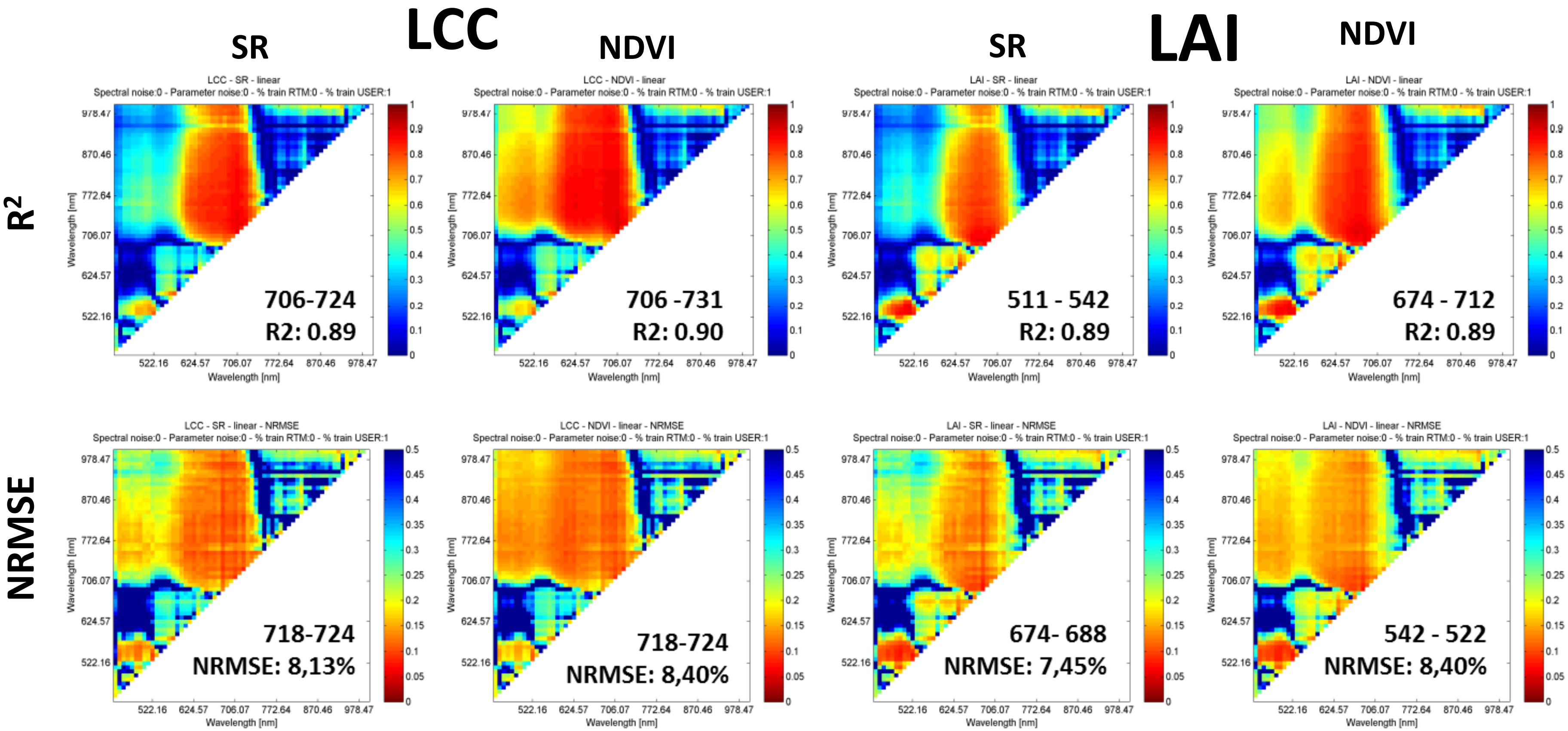
Spectral data:

- **CHRIS mode 1** (62 bands; 34m) nadir spectra
- **HyMap** (5 m resolution;
- 125 bands ; 450-2500 nm

Case studies

SPARC- CHRIS: Impact of Co/Ca, bands & formulation

100% calibration – linear regression

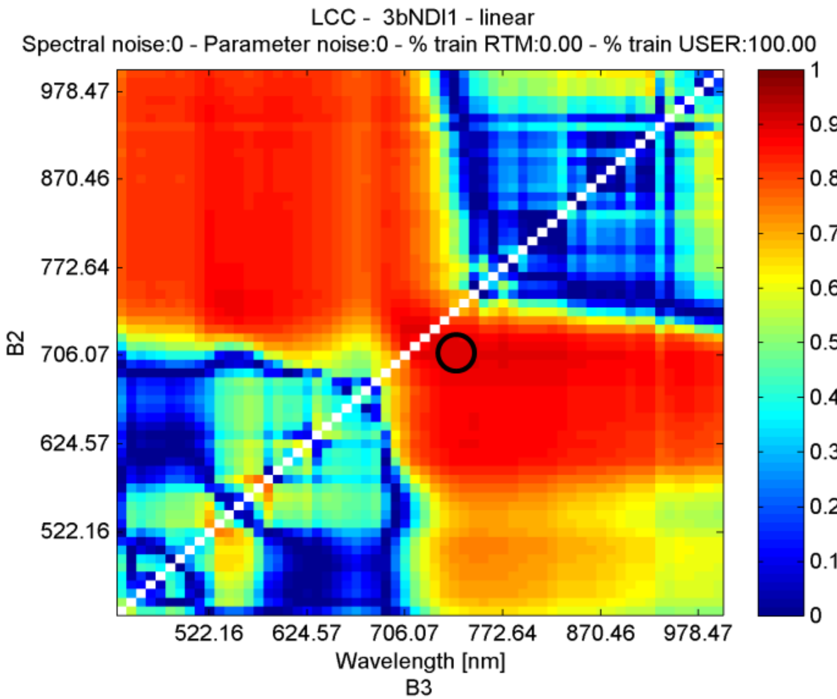


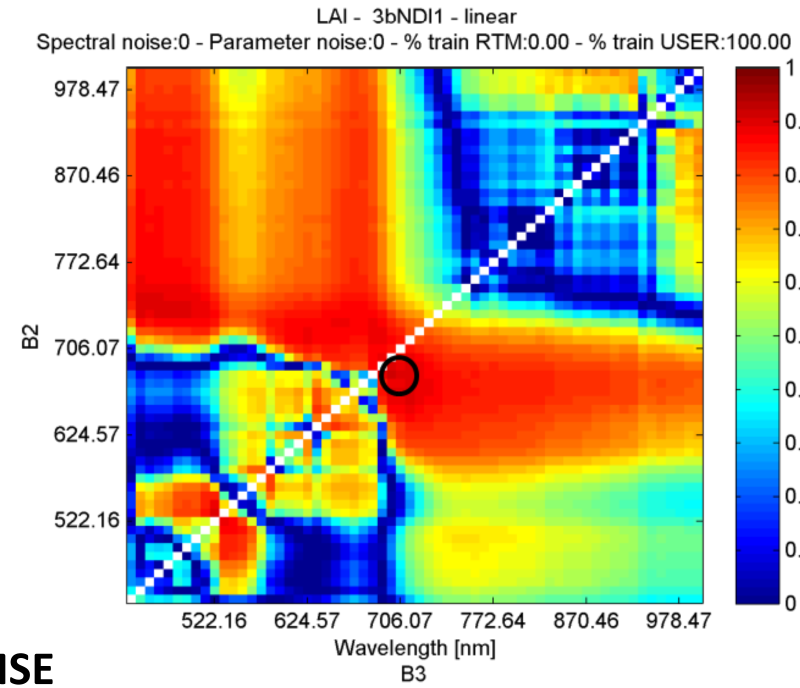
- **SR & NDVI results alike**
- Most sensitive bands in **red edge**, but also in **PRI** region
- **Correlation/calibration results can differ**

GMES 10% threshold

3-band NDI= (b3-b1)/(b3+b2)

LCC – 441 nm fixed R^2 Correlation matrices   **LAI** – 410 nm fixed





R^2

SI	Parameter	Band combination	R2	2-band
3-band NDI	**LCC**	**441 – 706- 731**	**0.91**	**0.90 (NDVI)**
	LAI	**410 – 688- 700**	**0.91**	**0.90 (NDVI)**

NRMSE

SI	Parameter	Band combination	NRMSE [%]	2-band
3-band NDI	LCC	718– 725 - 738	8.25	**8.13** (SR)
	LAI	522– 553- 674	**6.73**	7.45 (SR)

- **3-band SIs can indices further improve accuracies**
- **Best band combinations depend also on chosen output statistic**
- **Other formulations probably further improve accuracies. Up to 4 different bands can be analyzed.**

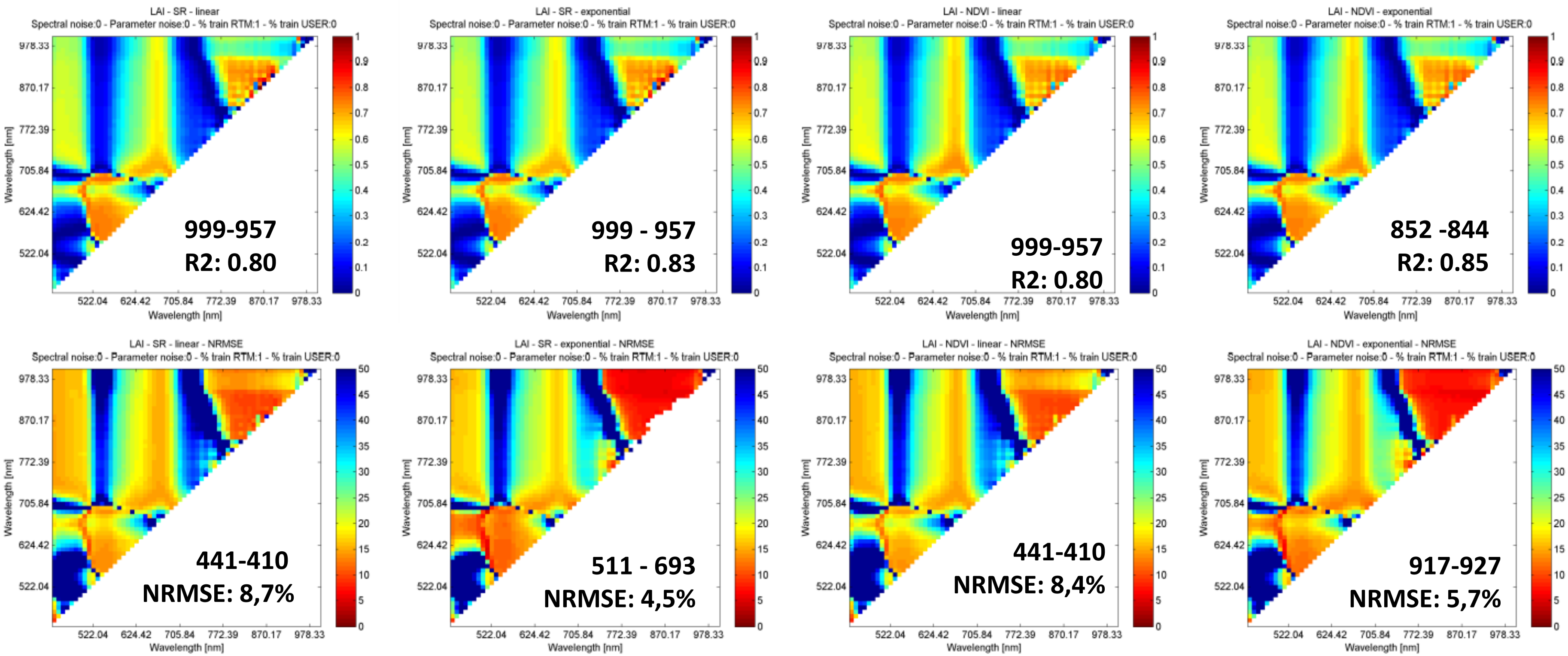
Laboratorio de Procesado de Imágenes

PROSAIL – CHRIS - LAI: Impact of curve fitting

100% calibration – 10000 random simulations

SR: linear | Exponential — NDVI: linear | Exponential

R^2 / NRMSE

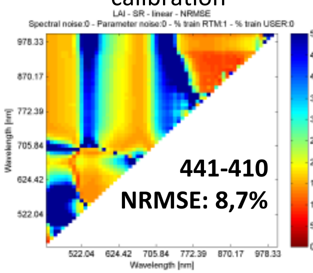


- SR and NDVI alike. Curve fitting can play an important role.
- Best band combinations depend also on chosen output statistic.
- Note that PROSAIL results differ from results based on field data.

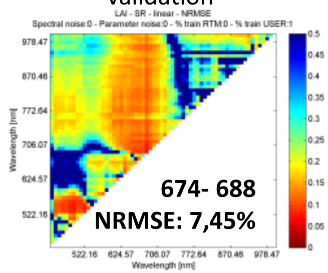
LAI - Calibrated by PROSAIL, validated by SPARC dataset

100% calibration – 10000 random simulations

calibration

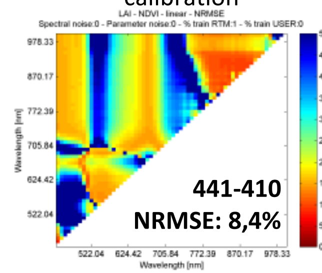


validation

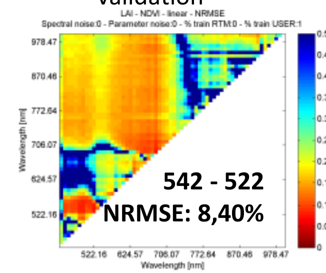


SR

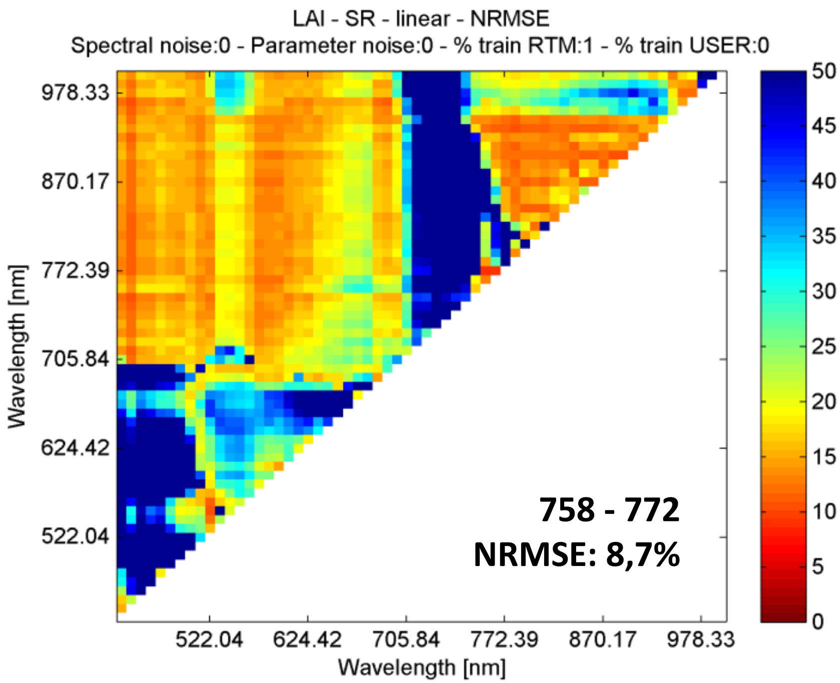
calibration

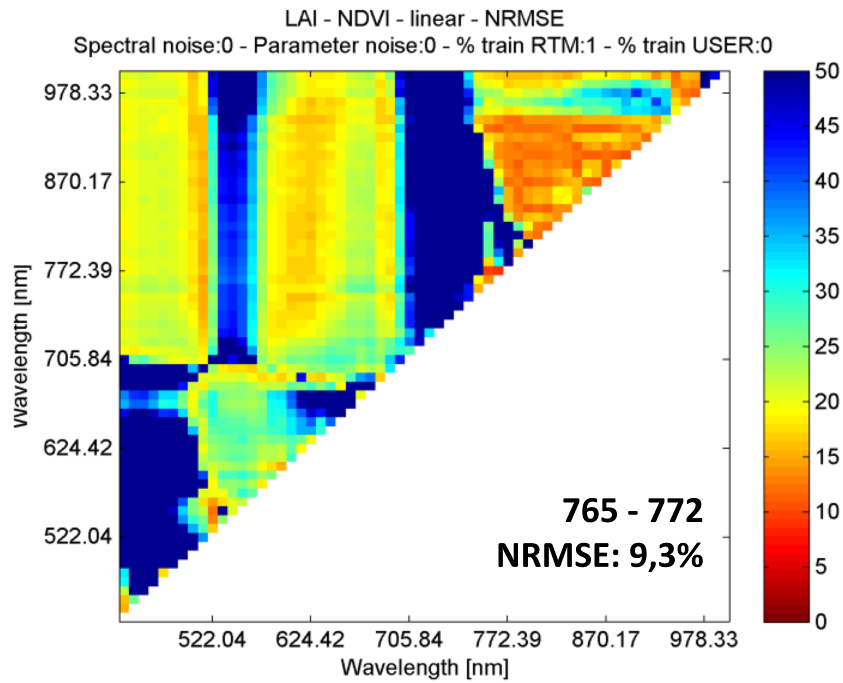


validation



NDVI





Results rather good. Be careful when relying only on RTM data. NIR region most successful.

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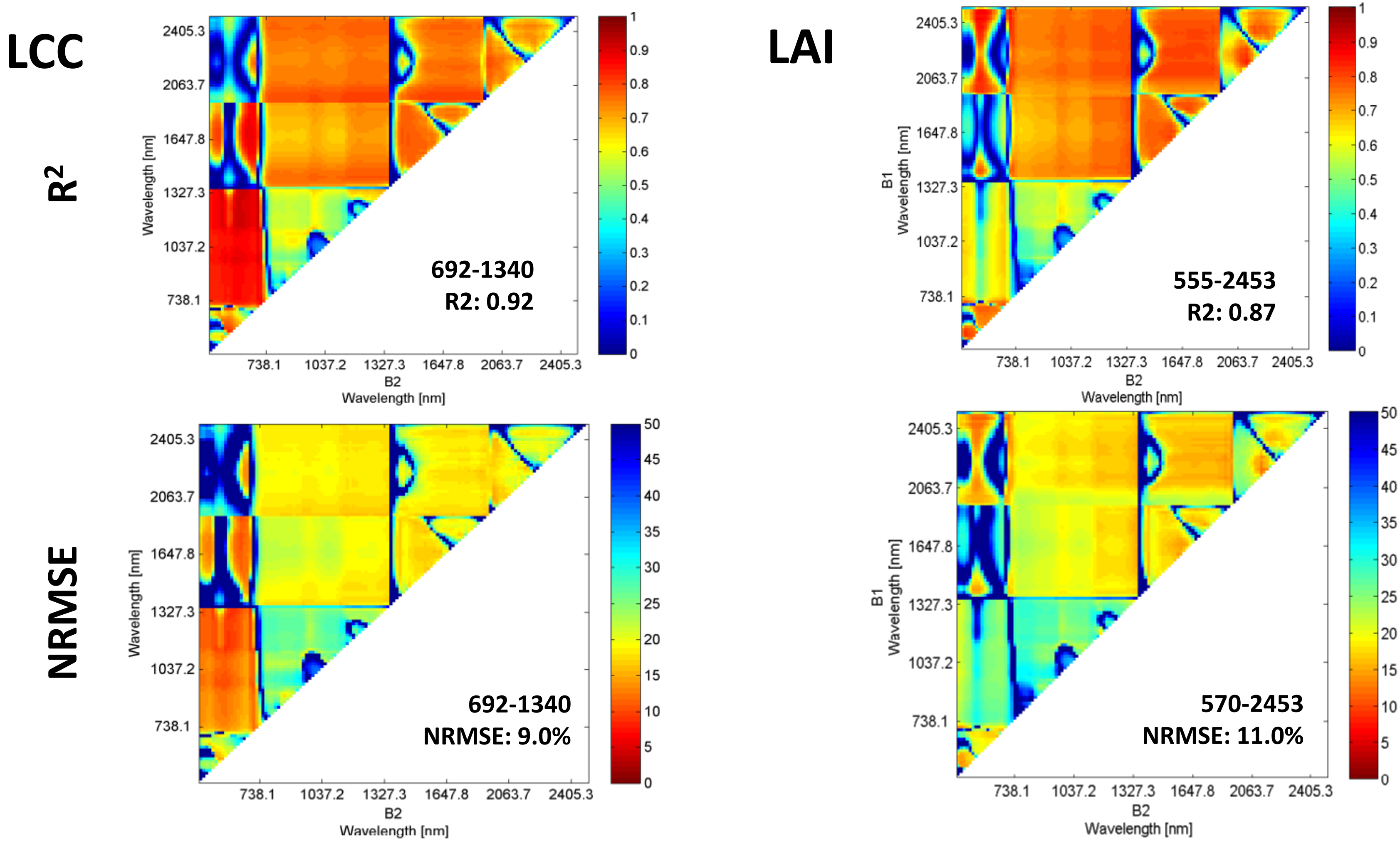
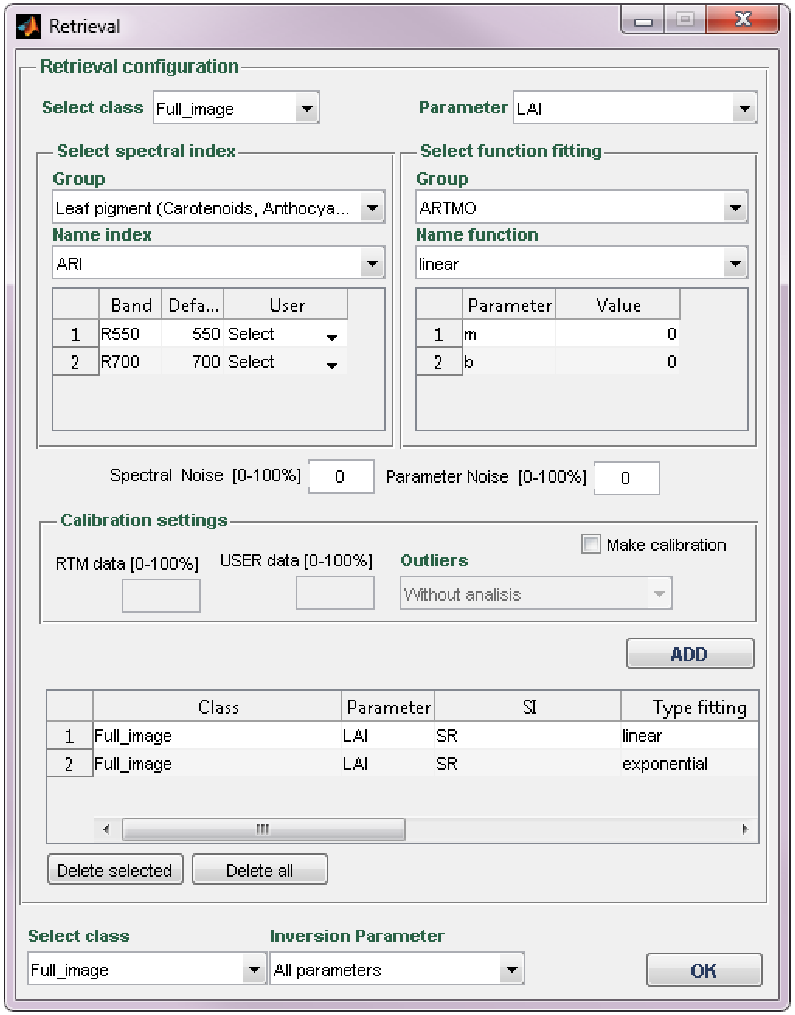
HyMap [450-2500 nm]

100% calibration – linear regression



The full range matters. Best results using bands in visible and SWIR (1340, 2453 nm).

Retrieval



Manual options

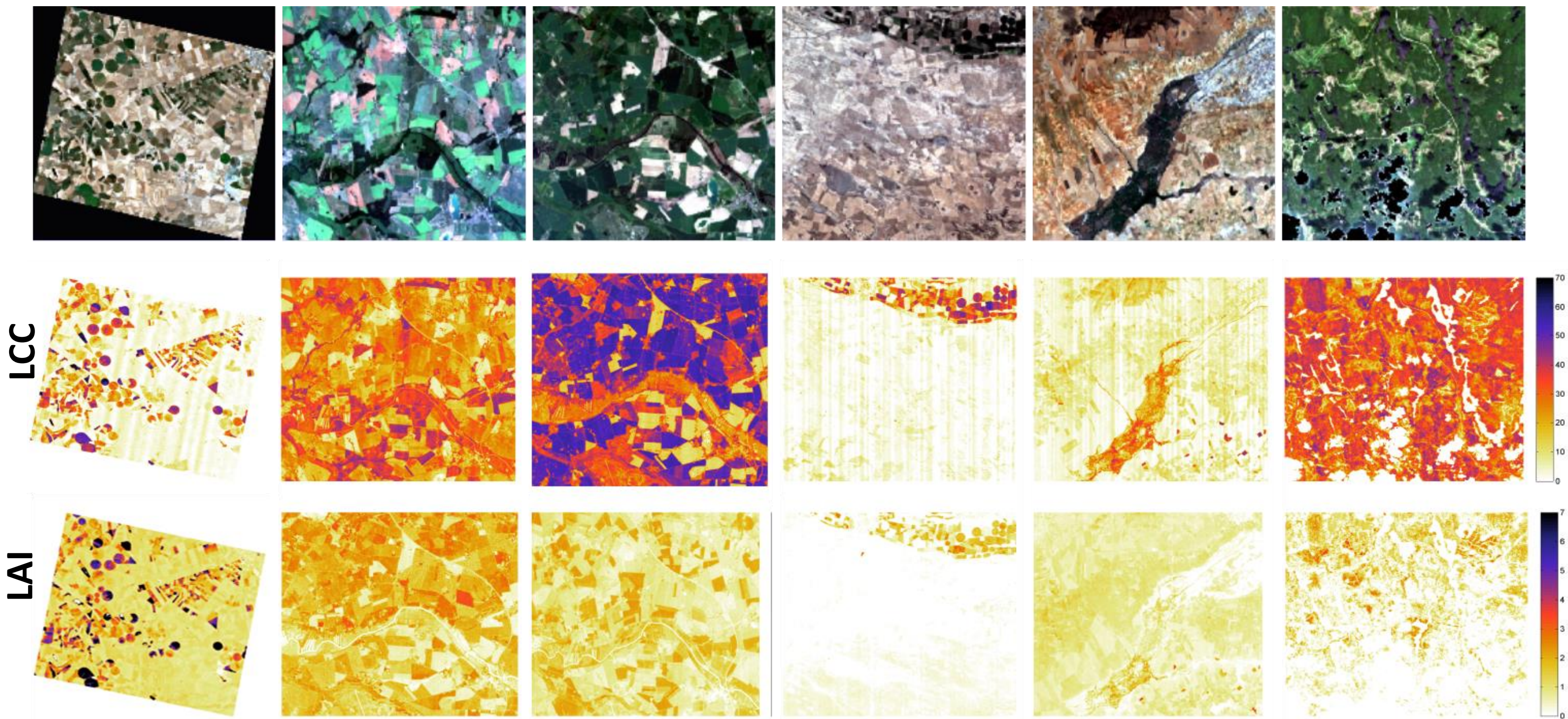
- Options to select land cover class and parameter.
- Options to select a spectral index and a curve fitting.
- Options to add noise, select Cal/val distribution and remove outliers

Selected strategies.

Plotting options

Best evaluated strategies (3-band SI) applied to CHRIS

Barrax Aug 09 | **Demmin May 06** | **Demmin June 06** | **Monegros July 04** | **Tablas Aug 09** | **Salldbury May 06**



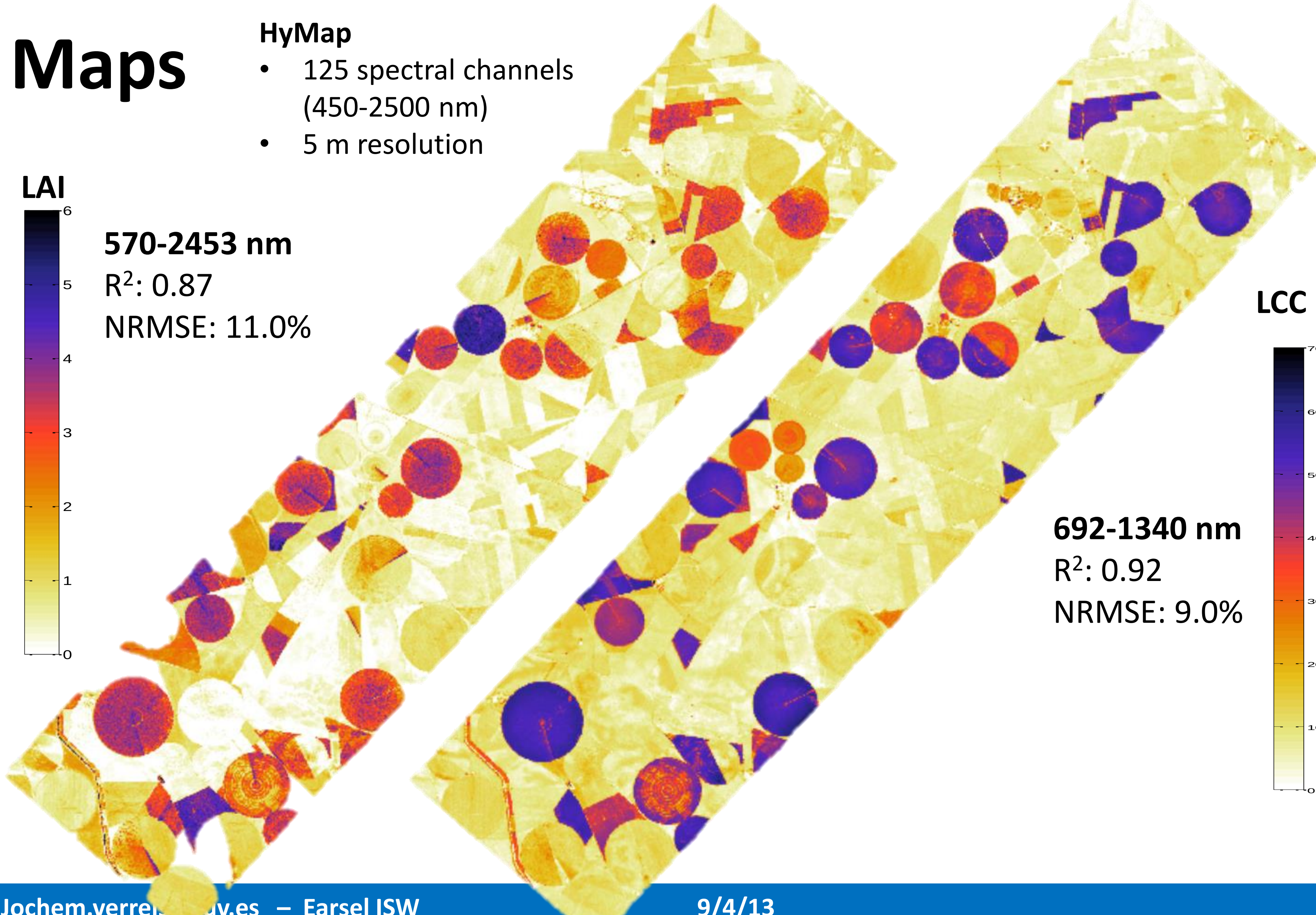
Portability is questionable:

- Striping effects, inconsistencies took place.
- Uncertainties are missing

Maps

HyMap

- 125 spectral channels (450-2500 nm)
- 5 m resolution



570-2453 nm
R^2: 0.87
NRMSE: 11.0%

692-1340 nm
R^2: 0.92
NRMSE: 9.0%

Conclusions

- **Spectral indices by default a sub-optimal approach.** Not only because of only **few bands** used, but also because of **formulation** and **parametric regressors**.
  - NDVI bands not necessarily best
  - NDVI formulation not necessarily best
  - Linear regression not necessarily best

- **ARTMO's SI Module** facilitates **systematic analysis of SIs**.

- **Alternative formulations** (e.g. with more bands) and alternative **curve fitting** can lead to improved results.

- **RTM-evaluated SIs not best for applying to images.**

Thanks

Availability

ARTMO is work in progress - beta version

- Accessible at Valencia University under our supervision.

- Matlab programmers are encouraged to write their own apps. In turn, a copy can be given.
  - Atmospheric models
  - BRDF apps
  - Temporal domain
  - classifiers

- Public available after publication (will take some time – so far unsuccessful)