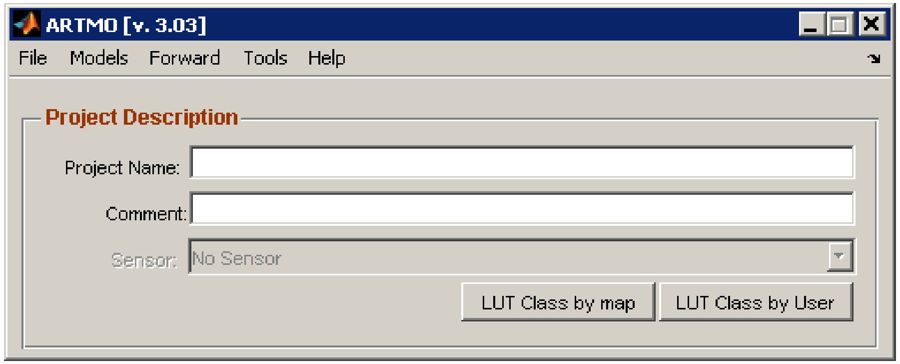
Automated Radiative Transfer Models Operator (ARTMO)

Tutorial: The ARTMO toolbox



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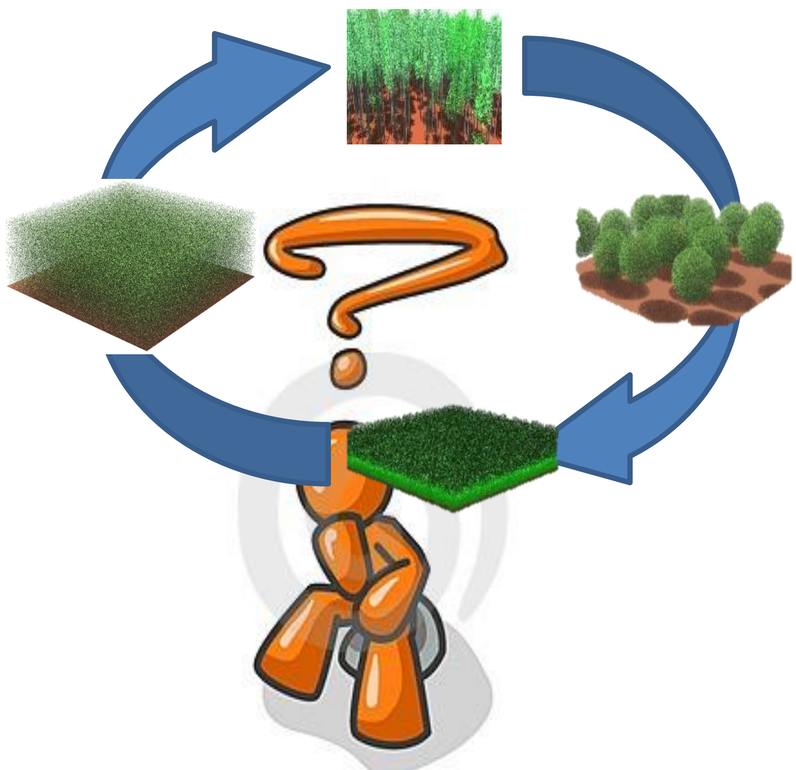
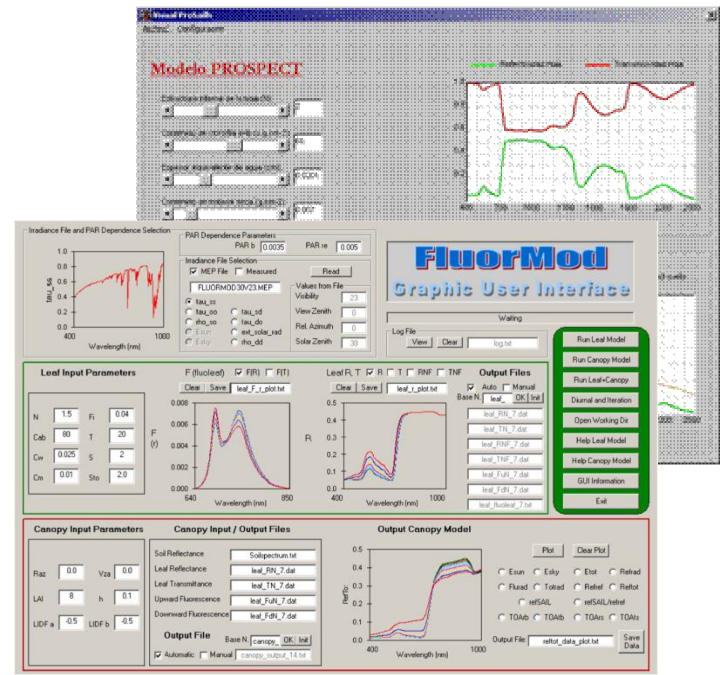
8-12 September 2014 – University of Valencia – Valencia, Spain

RTMs are important tools in EO research but for the broader community these models are perceived as complicated. Only very few of them offer a GUI.

Which RTM to choose?



Only very few of them offer a GUI



(Zarco-Tejada et al., 2006)

- No GUI exists that brings multiple RTMs together in one GUI

- None of existing GUIs provide retrieval strategies for biophysical parameters retrieval .

To fill up this gap:

➢ **To develop a GUI toolbox that:**

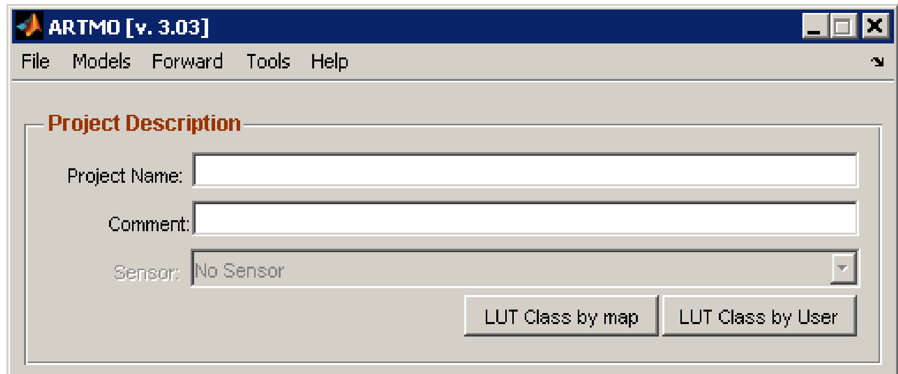
- operates **various RTMs in an intuitive interface**
- provides a comprehensive **visualization** of model outputs
- works both for **multispectral and hyperspectral** data
- enables **to retrieve biophysical parameters** through various retrieval methods
- takes different **land cover classes** into account.

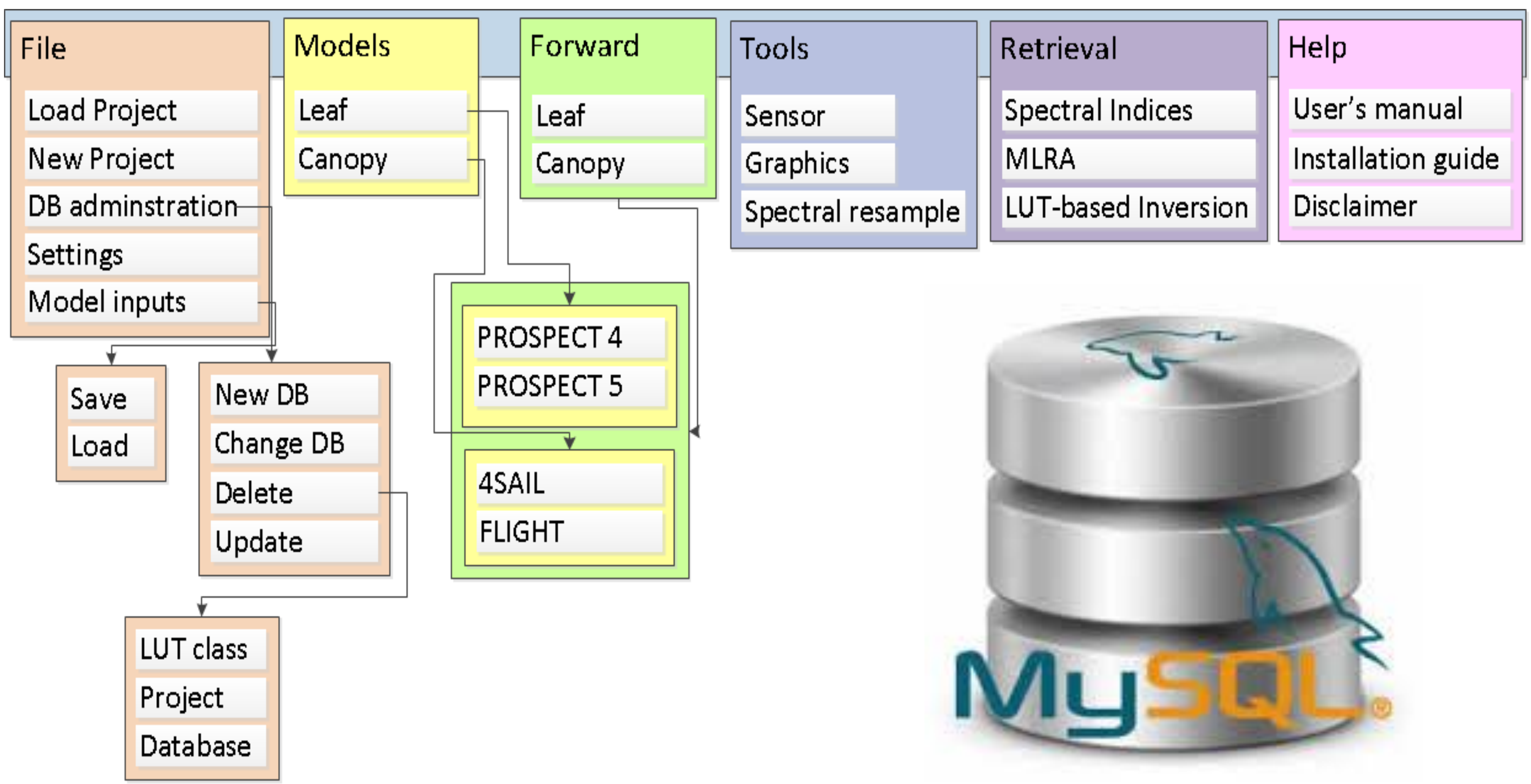
Toolbox for EO applications:

ARTMO:

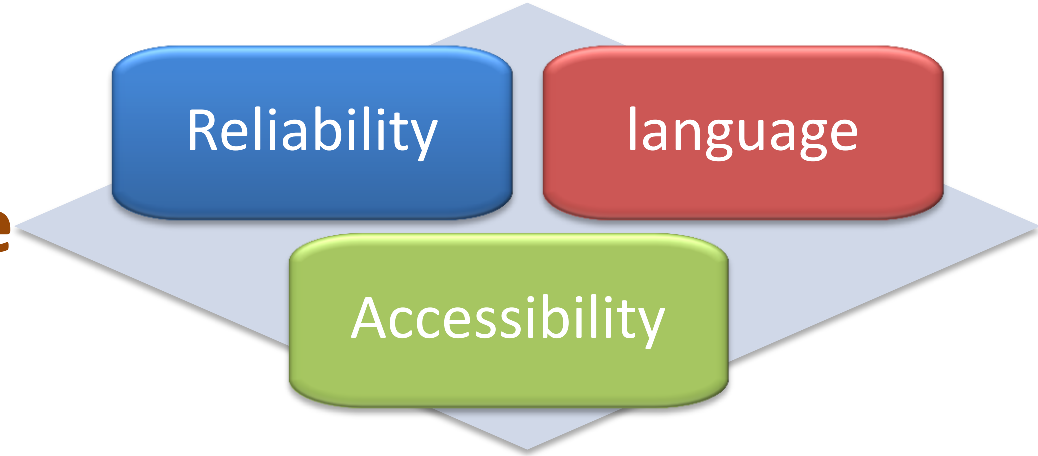
Automated
Radiative
Transfer
Models
Operator

ARTMO v3.03


ARTMO [v. 3.03]
File Models Forward Tools Help
Project Description
Project Name:
Comment:
Sensor:
No Sensor
LUT Class by map
LUT Class by User


File
Load Project
New Project
DB adminstration
Settings
Model inputs
Models
Leaf
Canopy
Forward
Leaf
Canopy
Tools
Sensor
Graphics
Spectral resample
Retrieval
Spectral Indices
MLRA
LUT-based Inversion
Help
User's manual
Installation guide
Disclaimer
Save
Load
New DB
Change DB
Delete
Update
PROSPECT 4
PROSPECT 5
4SAIL
FLIGHT
LUT class
Project
Database

Selection RTMs & programming language



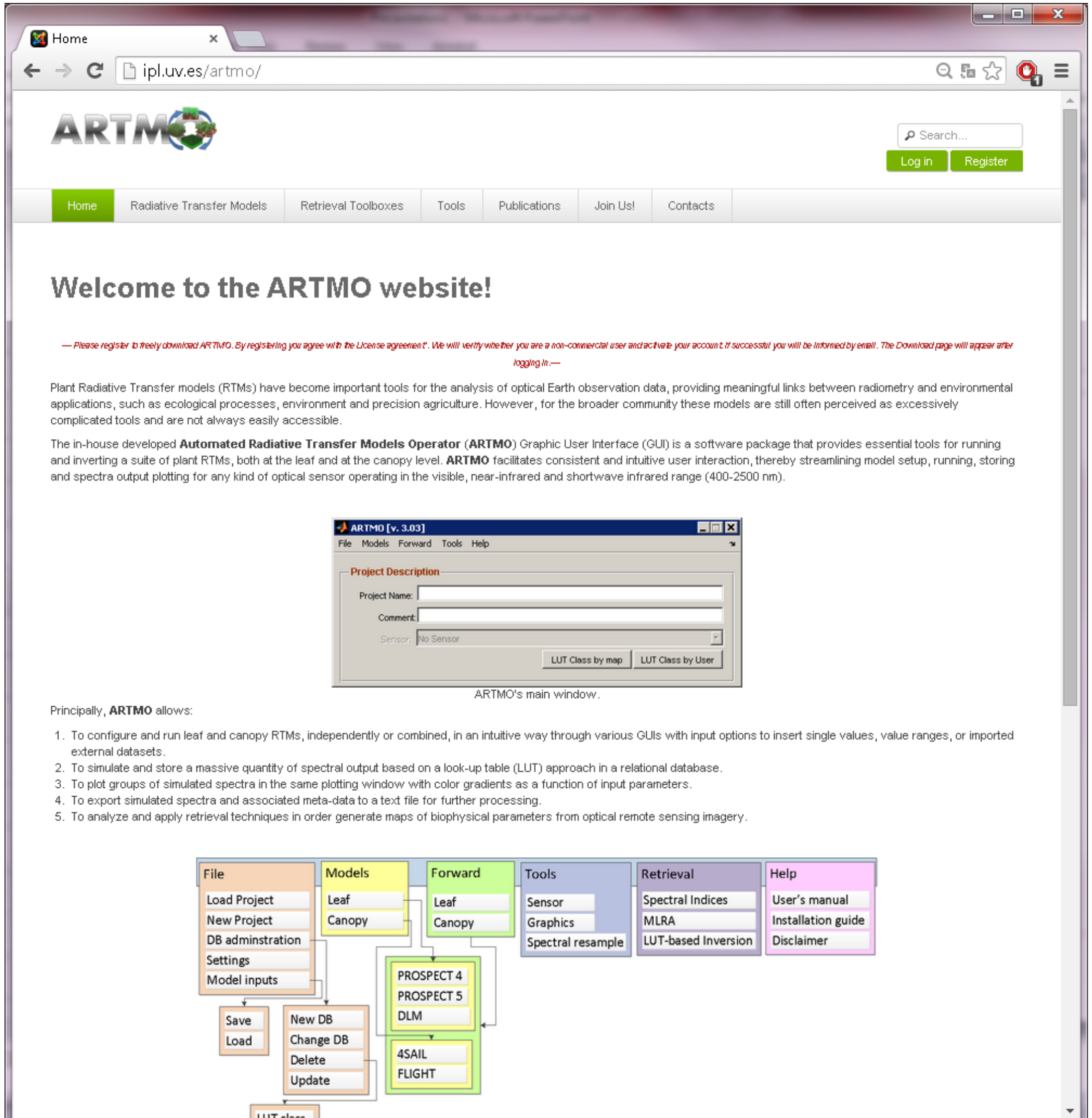
Model	Reference	Source code
PROSPECT-4	Feret et al., 2008	Matlab
PROSPECT-5	Feret et al., 2008	Matlab
DLM	Stuckens et al., 2009	Matlab
4SAIL	Verhoef et al., 2007	Matlab
FLIGHT	North, 1996	Executable file

Leaf RTM
Canopy RTM

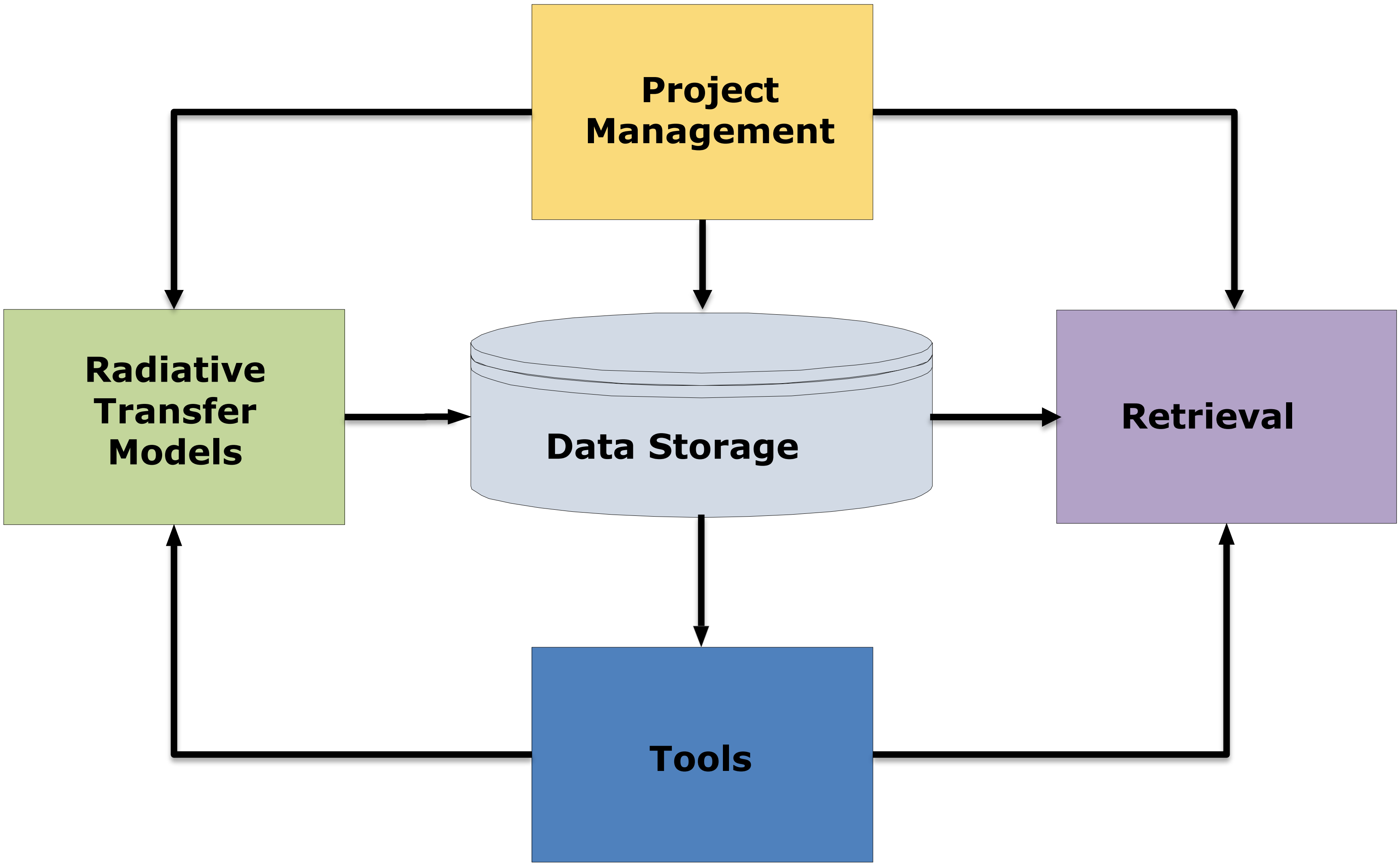
Software packages:

Programming language:	Matlab® (7.9.0.529)
Database:	MySQL® (5.5.8)
Image processing software:	ENVI® 4.5

Website: http://ipl.uv.es/artmo/

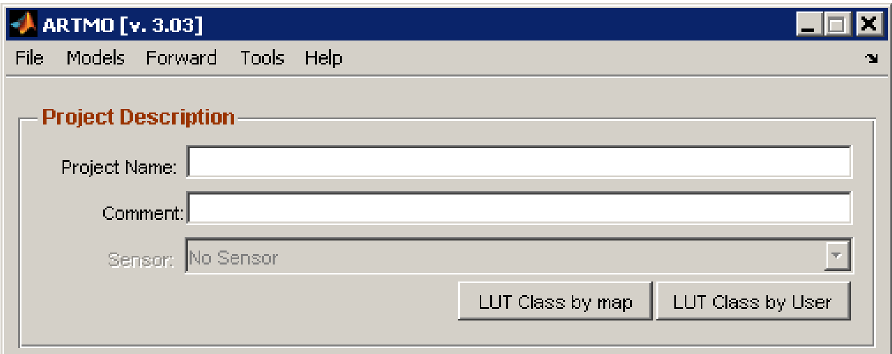


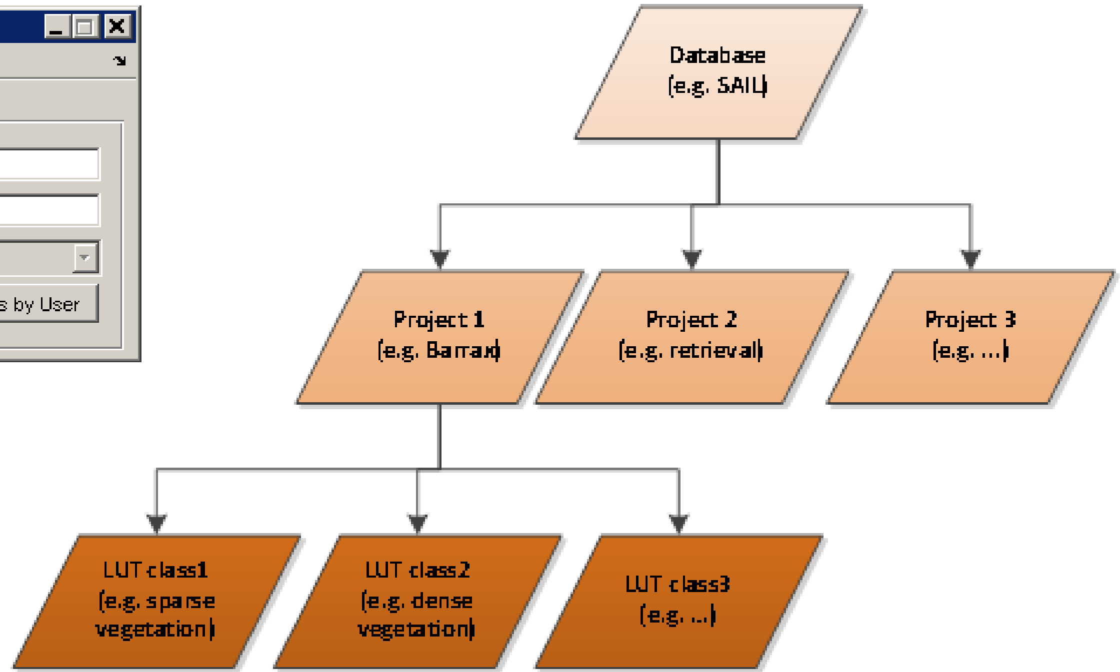
Conceptual architecture ARTMO



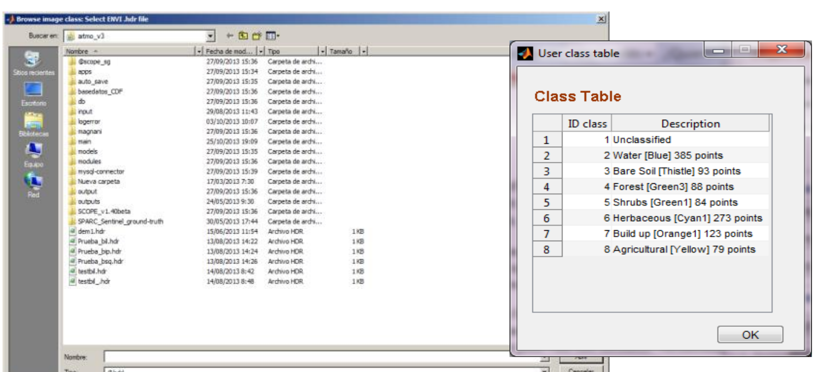
Each individual blocks will be further explained in the following sections.

ARTMO's hierachical data storage

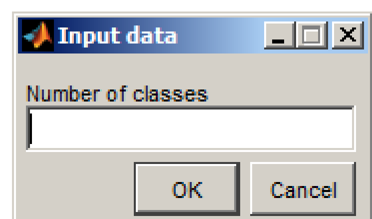


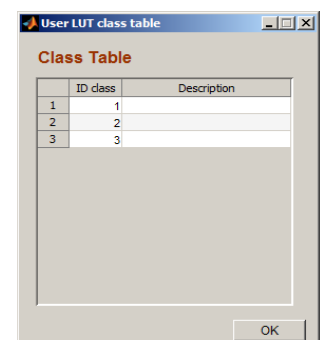


LUT class by map: ENVI .hdr file



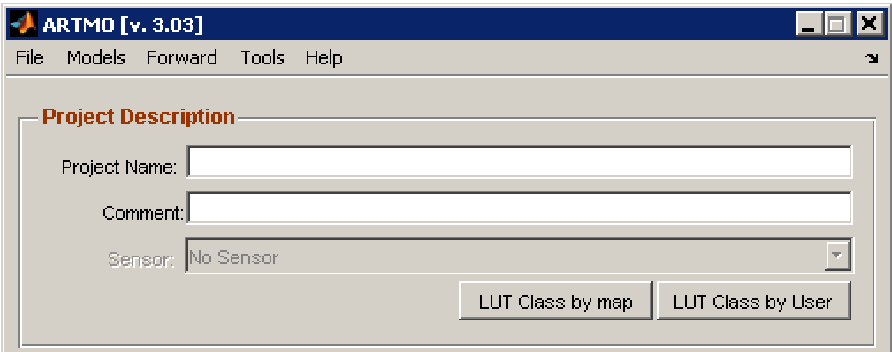
LUT class by User

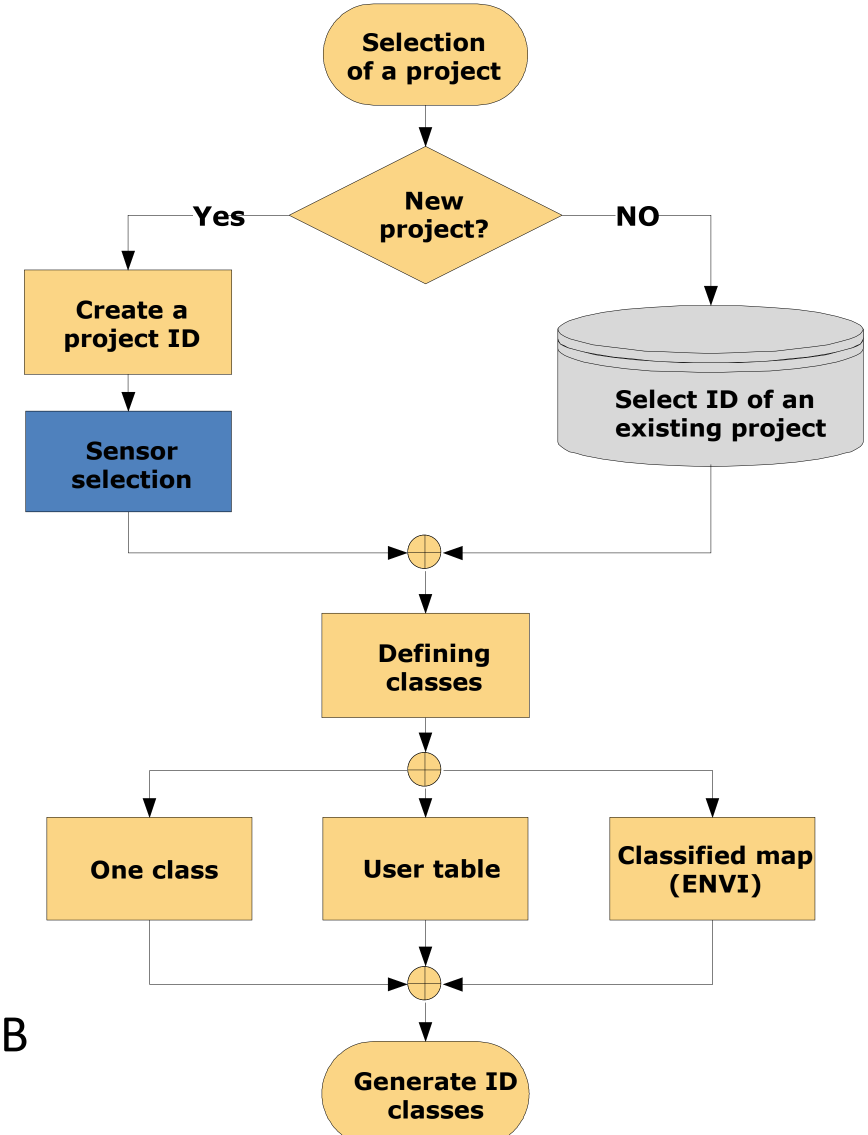




Project Management

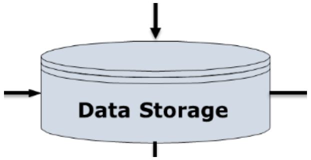
Project management module



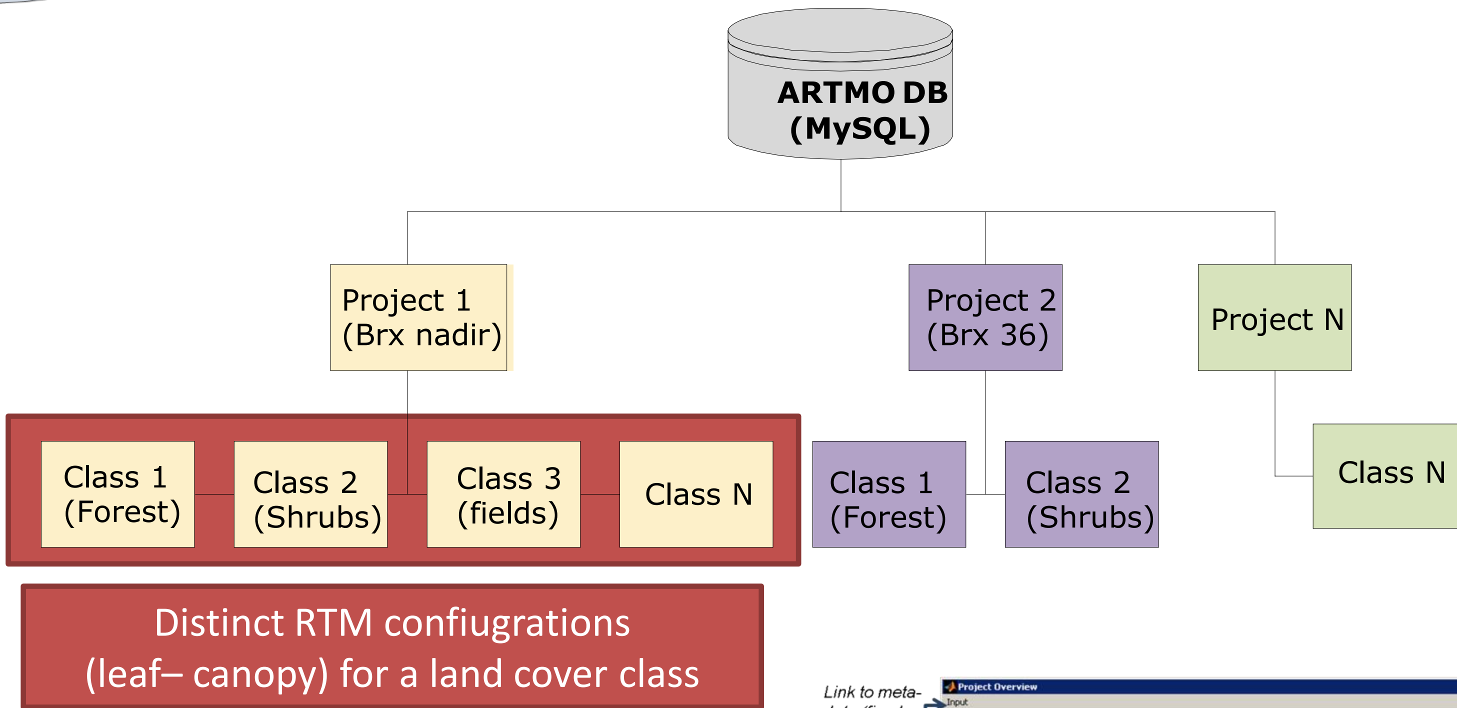


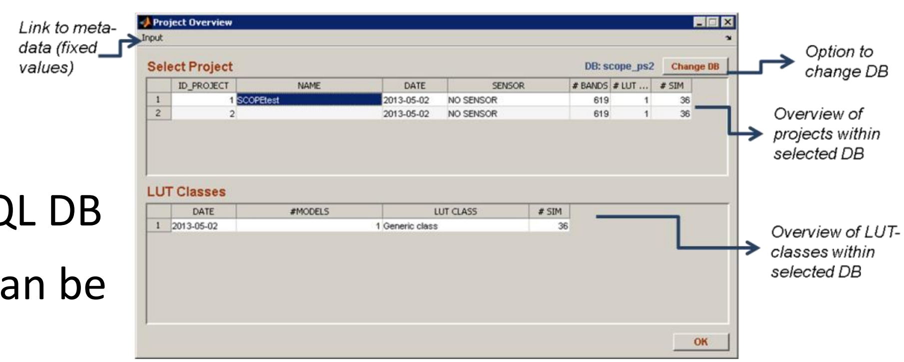
Important features:

- ✓ Load an existing project or create a new one.
- ✓ Select a Sensor
- ✓ Choose whether a proejct should exist of LUT classes.
- ✓ Import/Export DBs, delete class/project/DB



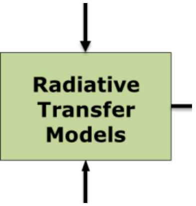
Underneath: MySQL data storage structure



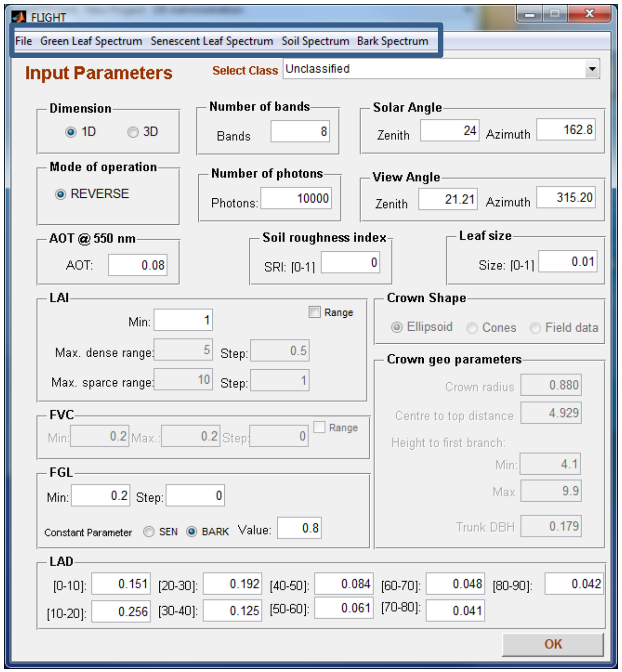


Important features:

- ✓ Input, output and metadata are stored in MySQL DB
- ✓ In 'Project Overview' metadata of all projects can be consulted.
- ✓ LUT casses can be accessed.
- ✓ All fixed input data and ranges of state parameters can be consulted.



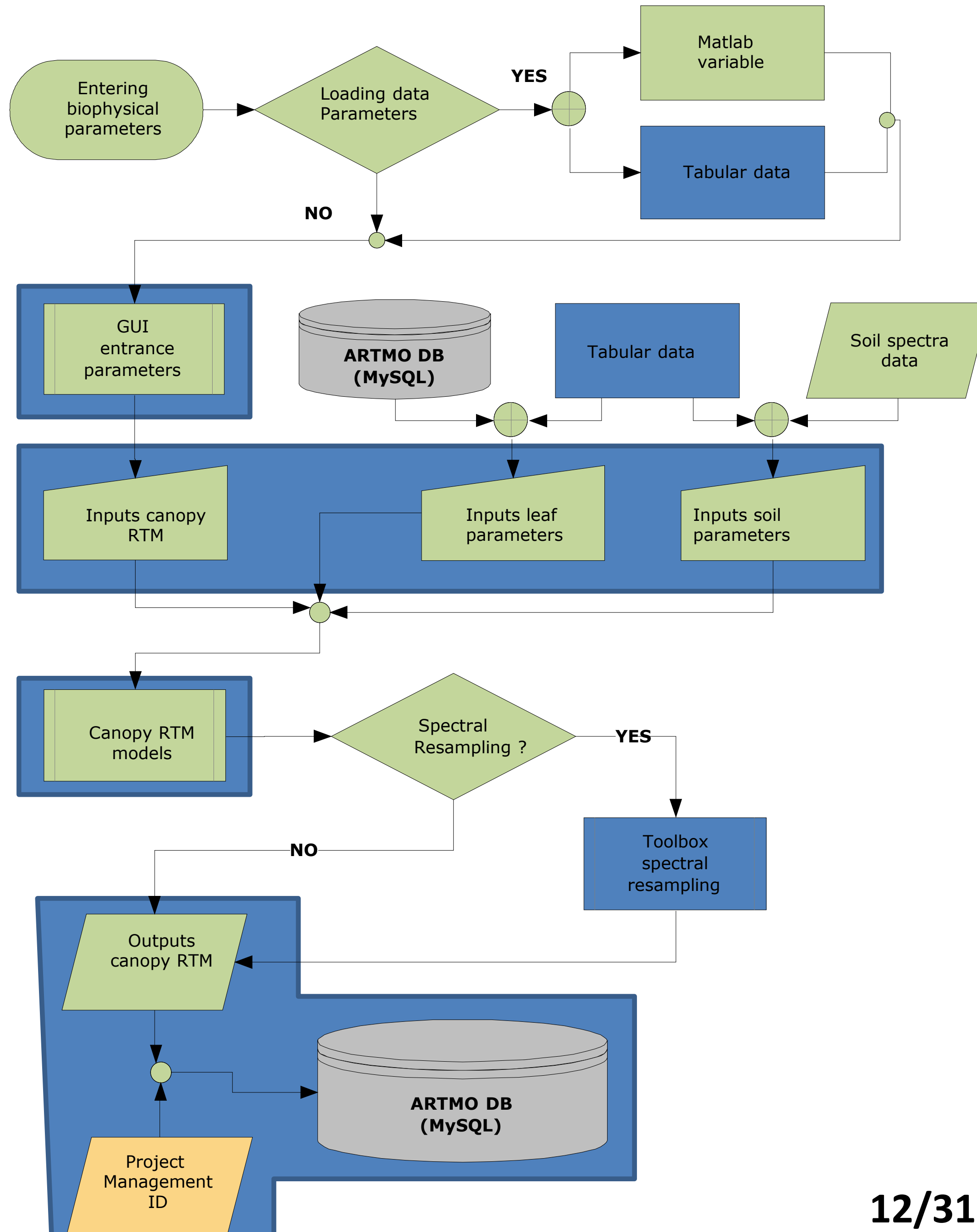
RTM module

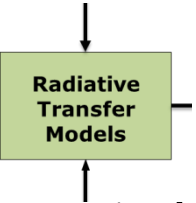


GUI of the model FLIGTH

Important features:

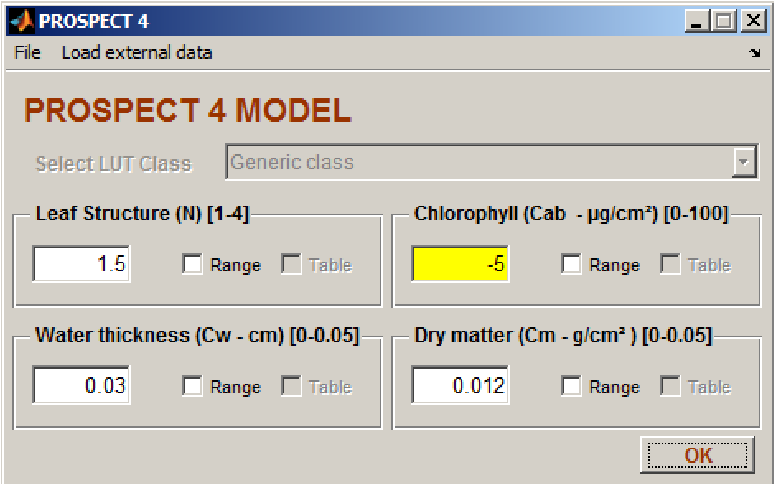
- ✓ Insert a single value
- ✓ Insert user-defined input data
- ✓ Insert a range (stepwise or a distribution)
- ✓ Inset one or multiple spectra



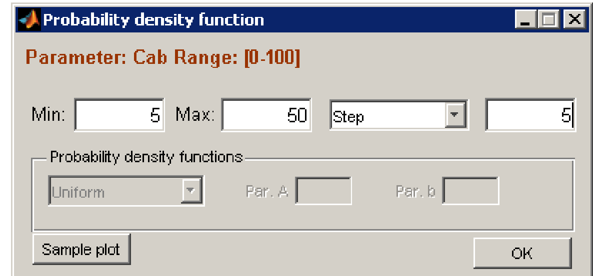


Entering data: PROSPECT-4

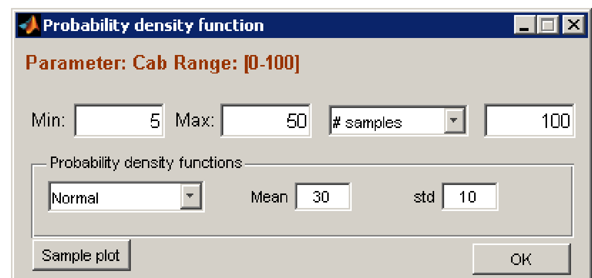
A single value

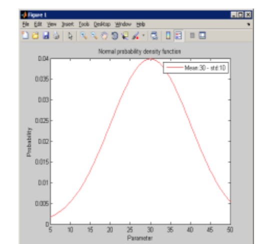


A range of values:
1) steps

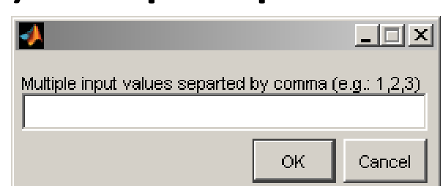


2) distribution: (uniform, normal, Poisson, extreme, Lognormal)

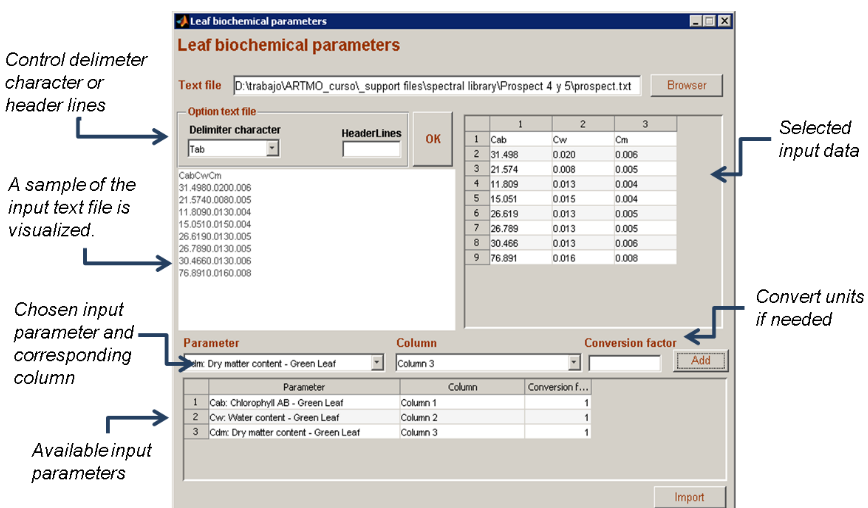




3) Multiple input values



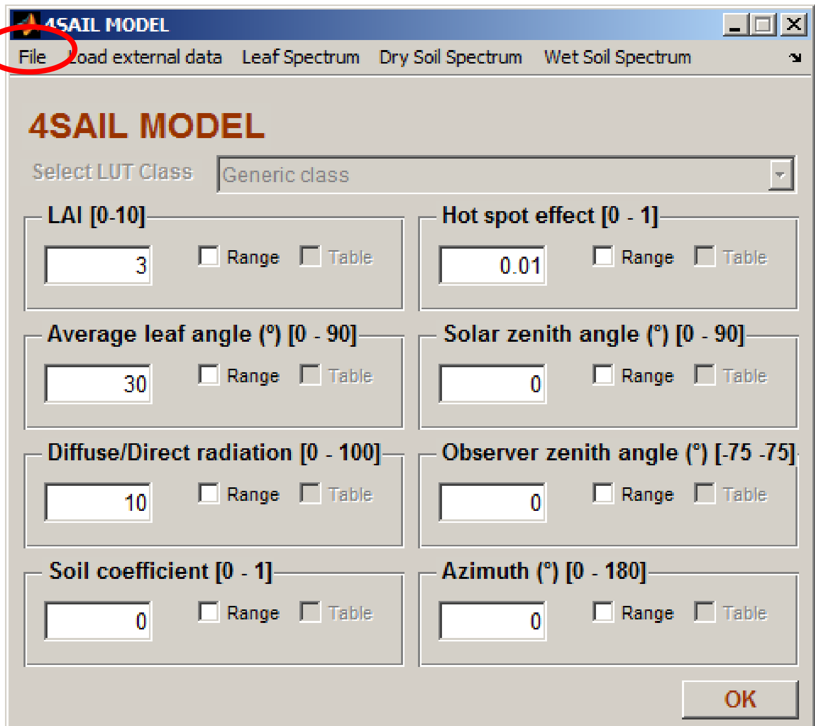
Recorded user data (e.g. field data)

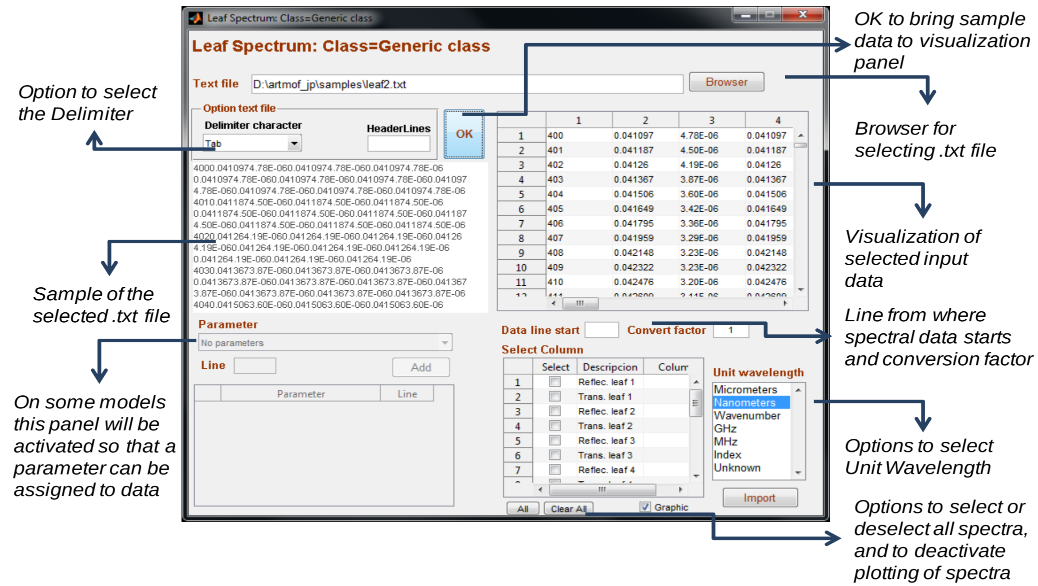


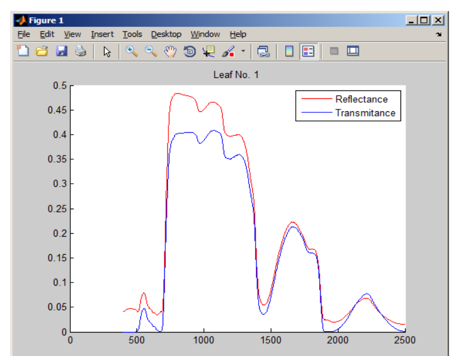
Radiative Transfer Models

Entering data: SAIL

When not coupled with a leaf reflectancemodel (e.g. PROSPECT) then leaf reflectance and transmittance data needs to be entered.

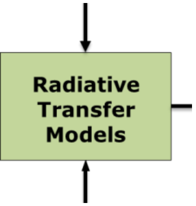




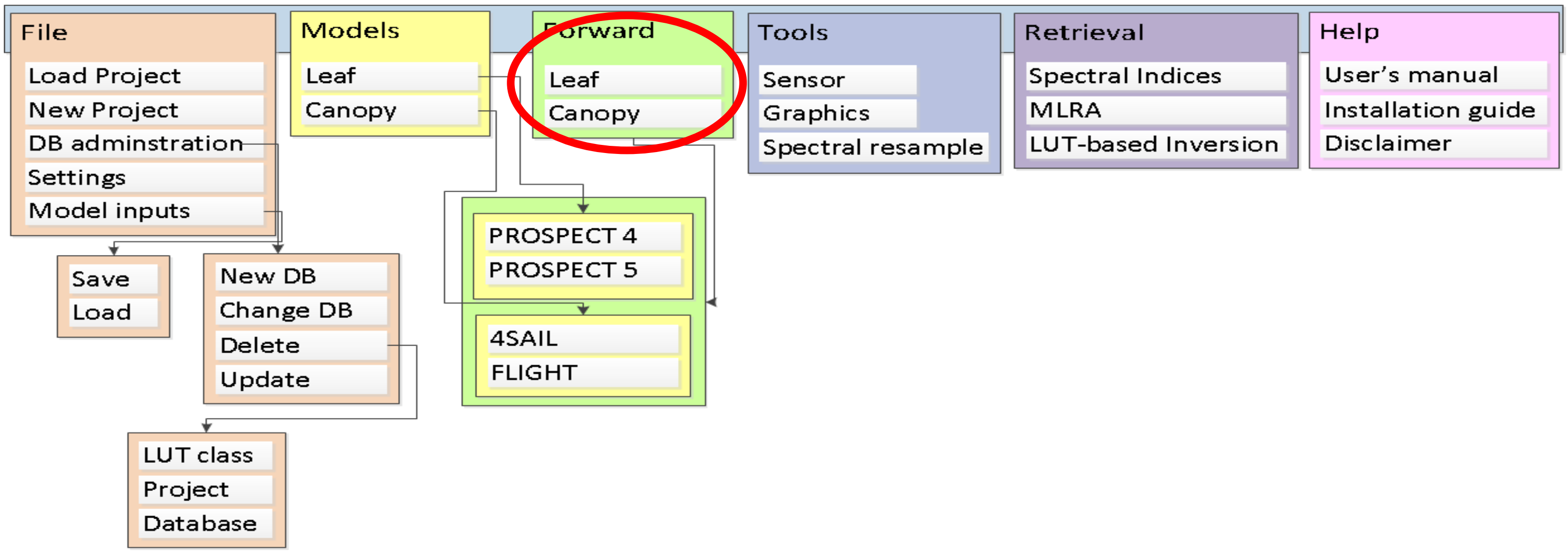


File

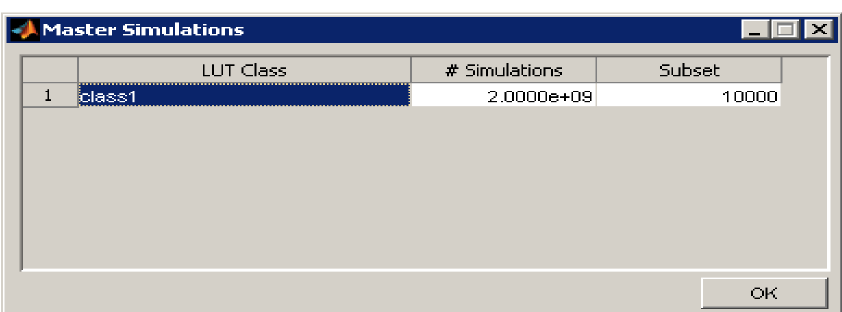
- **Save**: Save the input settings.
- **Load**: Load earlier saved input settings.

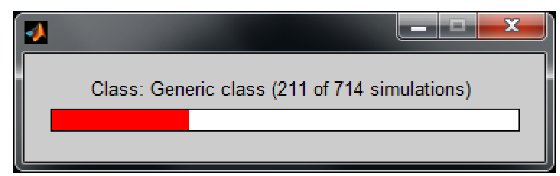


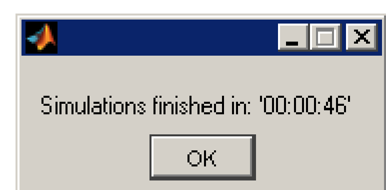
Forward running simulations



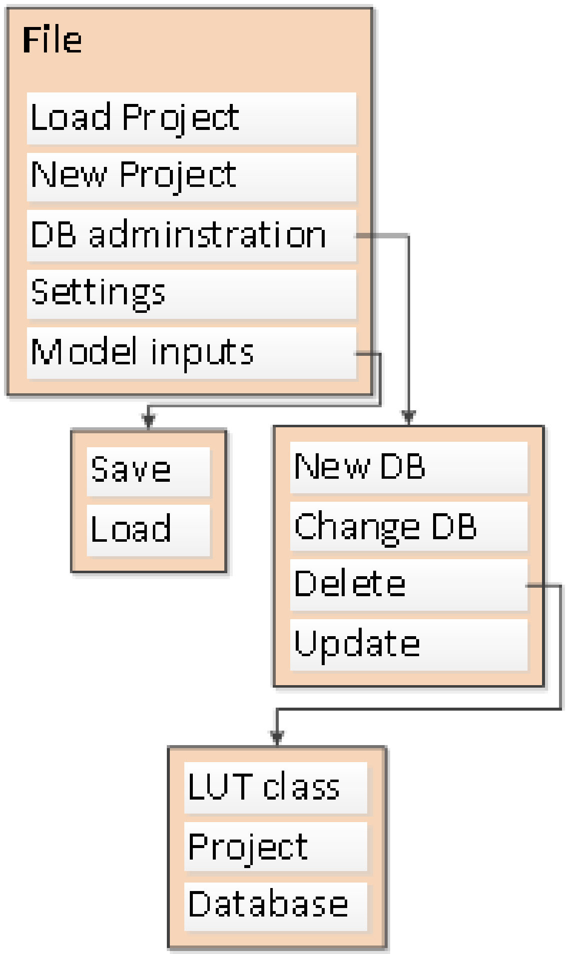
- In Forward the configured models can selected, combined (in case of leaf + canopy) and run.
- Since all posible combinations are calculated, the LUT blows up exponentially. It therefore possible to select a random subset.



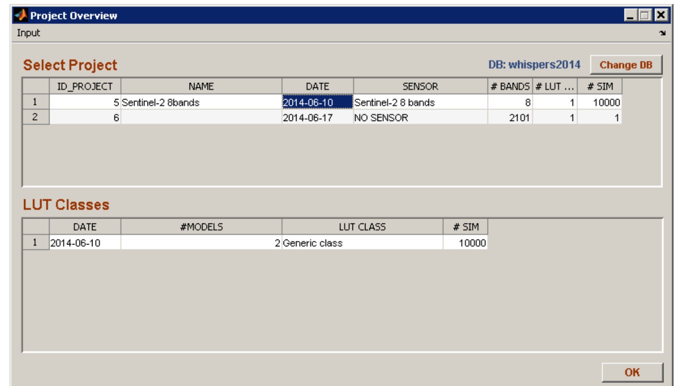




ARTMO's file settings

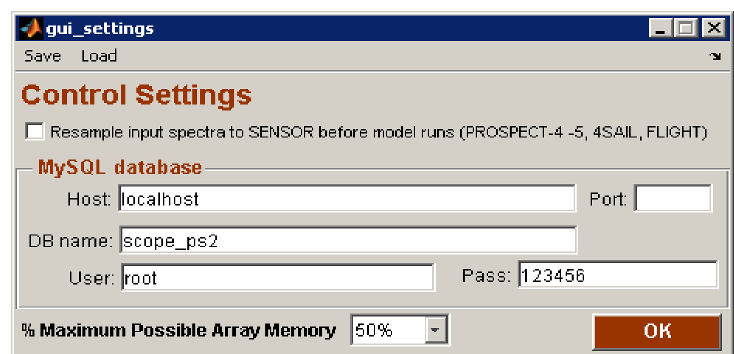


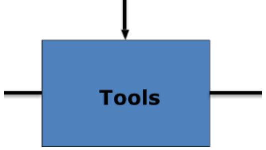
Delete a Project or a LUT-class



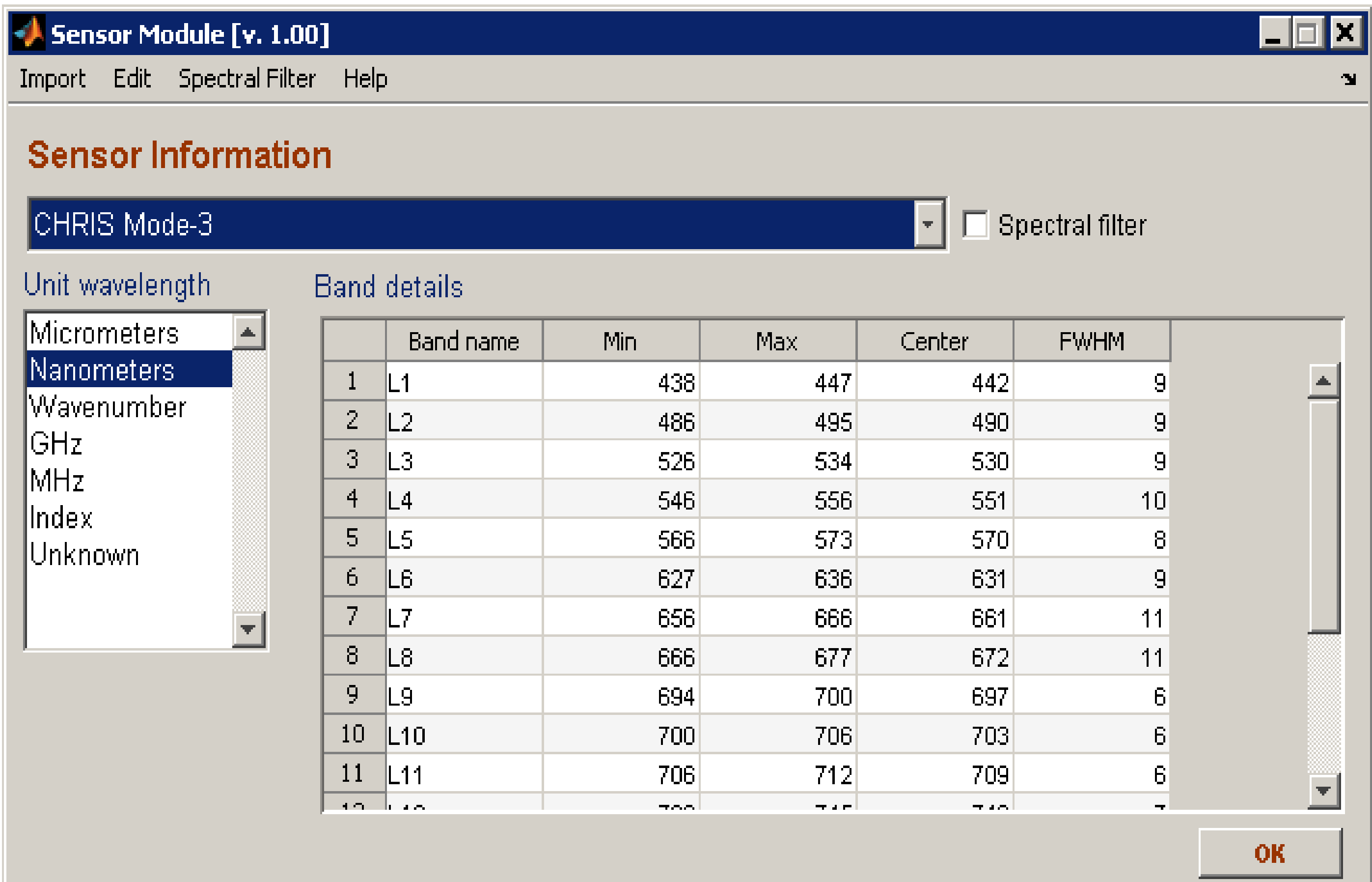
Delete a DB

Setttings: manage connection with MySQL

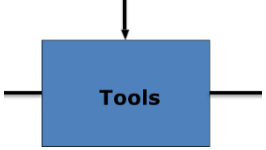




SENSOR TOOL



	Band name	Min	Max	Center	FWHM
1	L1	438	447	442	9
2	L2	486	495	490	9
3	L3	526	534	530	9
4	L4	546	556	551	10
5	L5	566	573	570	8
6	L6	627	636	631	9
7	L7	656	666	661	11
8	L8	666	677	672	11
9	L9	694	700	697	6
10	L10	700	706	703	6
11	L11	706	712	709	6

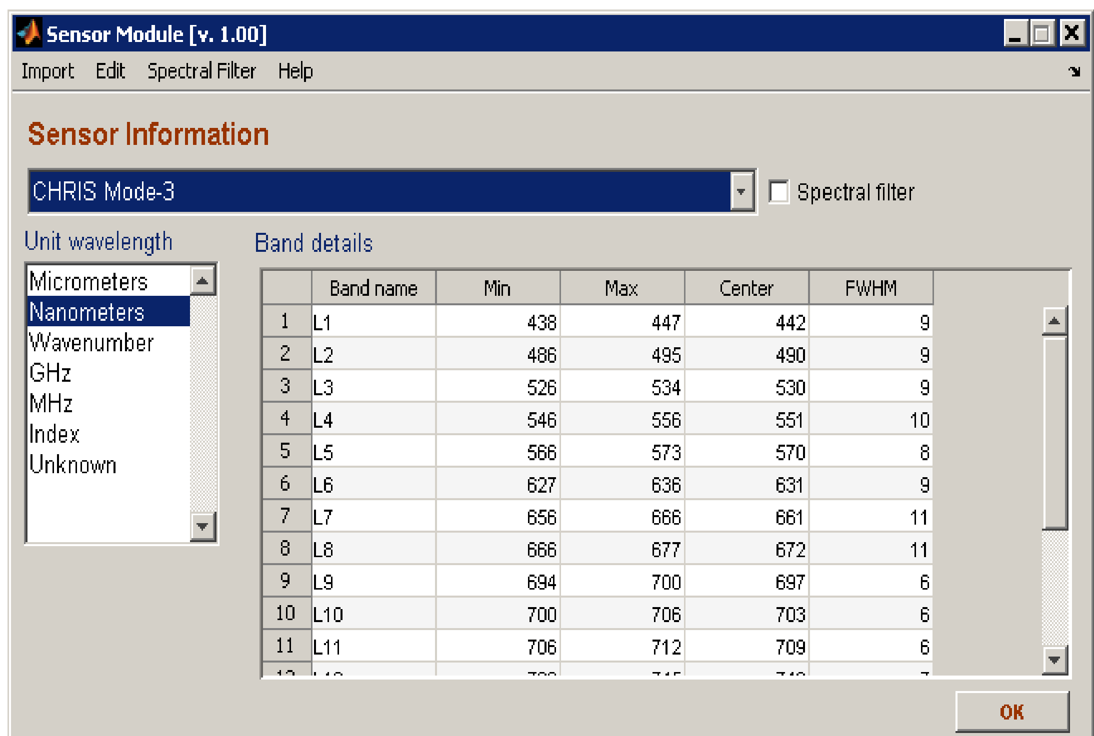


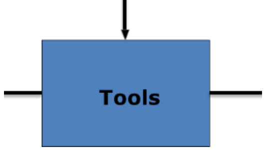
Sensor:

The Sensor tool enables configuring the band settings of a specific sensor. Once configured, radiative transfer models (RTMs) can then **generate outputs according to the band settings of a chosen sensor**.

The user can either **import sensor band settings or define its own sensor configurations**. In principle, any kind of band settings can be defined, but it is recommended to stay within the range that is covered by most models, i.e. 400-2400 nm.

- New sensor settings can be imported by clicking on the ‘**Import**’ button in the top bar.
- Existing band settings can be modified or new ones can be added by clicking on the ‘**Edit**’ button.
- Also a spectral filter of a sensor can be imported or viewed by clicking on the ‘**Spectral Filter**’ button.





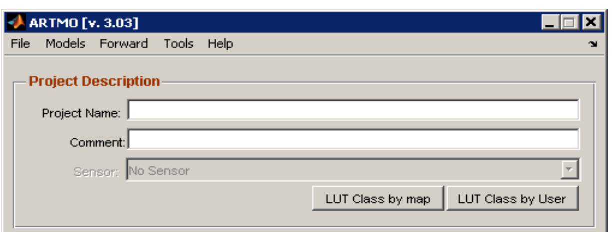
Available sensors:

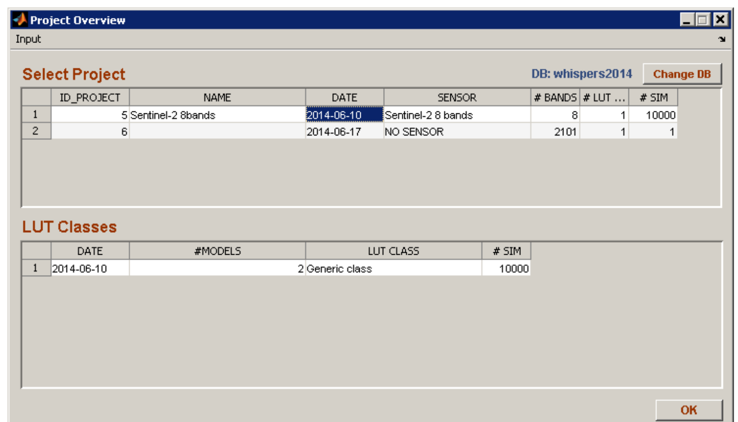
When having the Sensor tool implementedinto ARTMO, then the following sensor band settings will be by default available when creating a new DB:

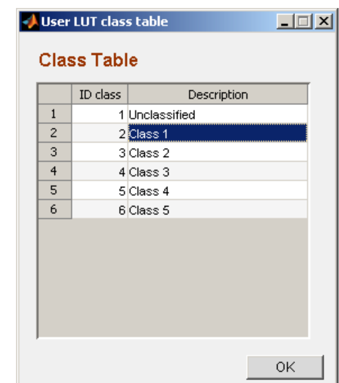
- Landsat 7 TM
- Landsat 7 ETM+
- SPOT-4 VMI
- SPOT-4 HRVIR
- CHRIS Mode-3
- MODIS
- MERIS
- Sentinel-2
- Sentinel-3 OLCI
- Sentinel-3 SLSTR

Step 1 – Defining a project

1. In Matlab Command window type: **artmo**
2. Create a new project – check also 'Load Project'
3. Select a sensor
4. Check the settings options
5. Check the 'Class' options

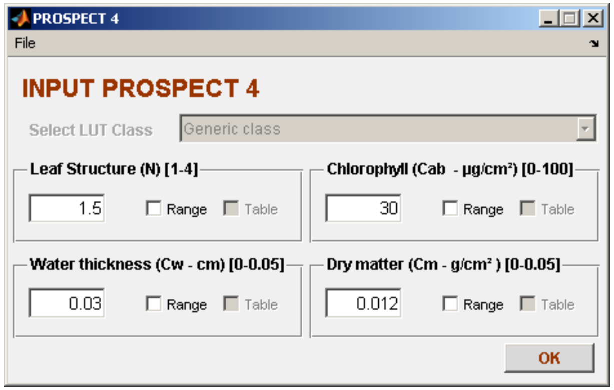






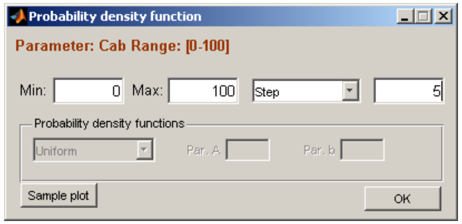
- ✓ Create a project (e.g. Barrax) with CHRIS 62 bands sensor
- ✓ Load a classified map to enable multiple LUT-classes:

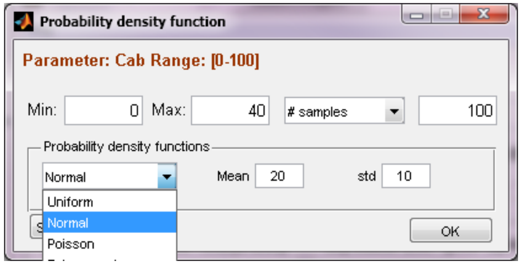
Step 2 – filling in the LUT

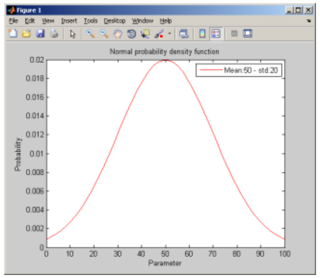


Leaf model PROSPECT-4

- 3 ways to fill in the LUT
  1. A single value
  2. Selecting a range – multiple options:
     1. According to a step
     2. According to a distribution (uniform, normal, Poisson, extreme, Lognormal)







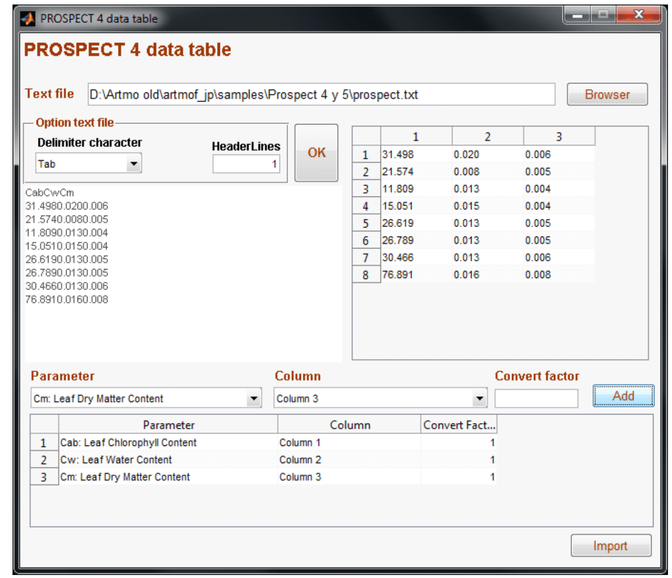
  3. Inputting a range: File > Load Data Table

     (see next slide)

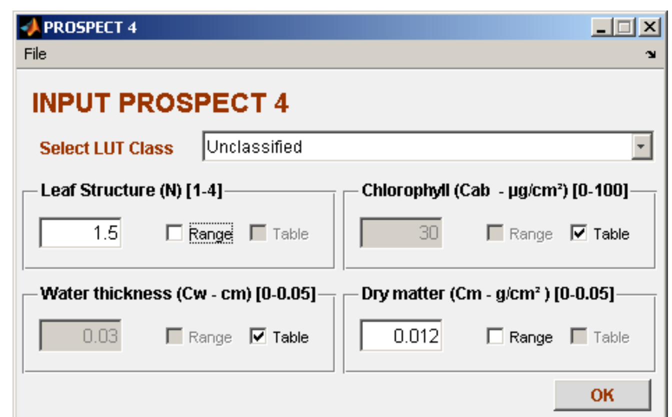
Inputting user-defined data (e.g. coming from field data)

2 options to insert user data:

1. Combined multiple parameters: Multiple columns can be assigned to different parameters



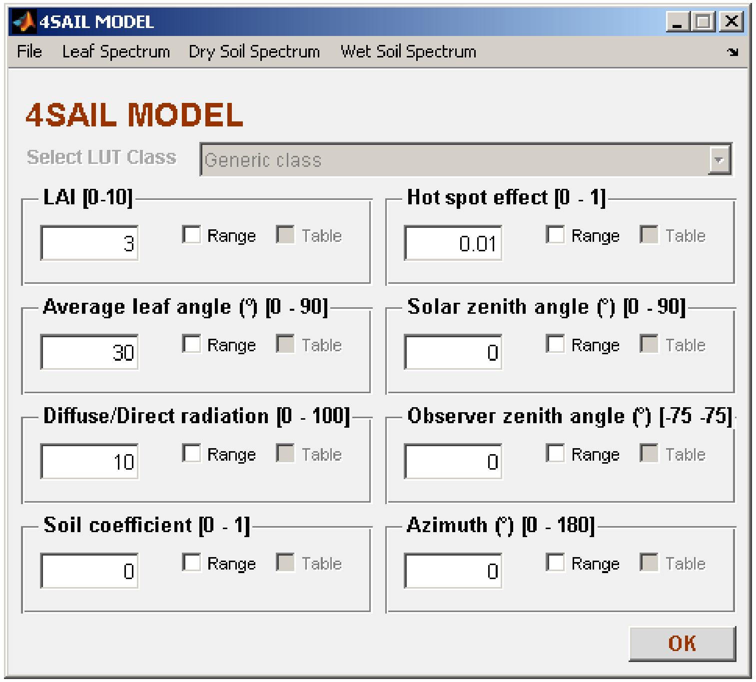
2. Building up LUTs by combining mulitple tables.



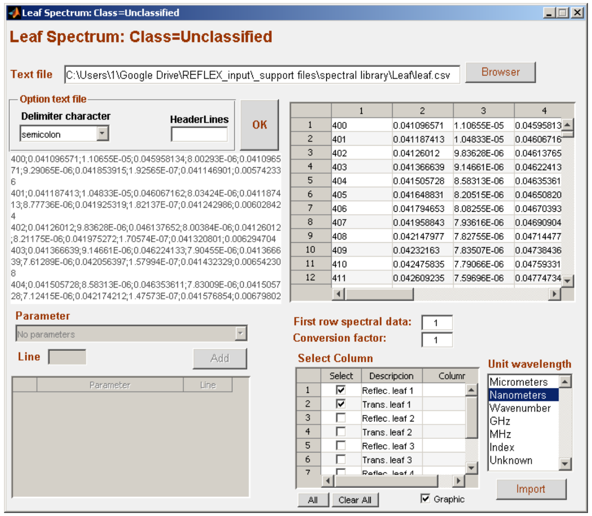
✓ Try out different input combinations

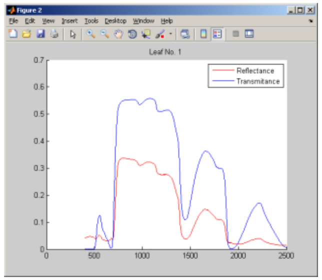
Filling in a canopy model: 4SAIL

- Filling in 4SAIL: single or multiple values
- Soil spectra is required. Default spectra are provided or own spectra can be inserted.
- When not coupled with a leaf model then leaf spectra is required.

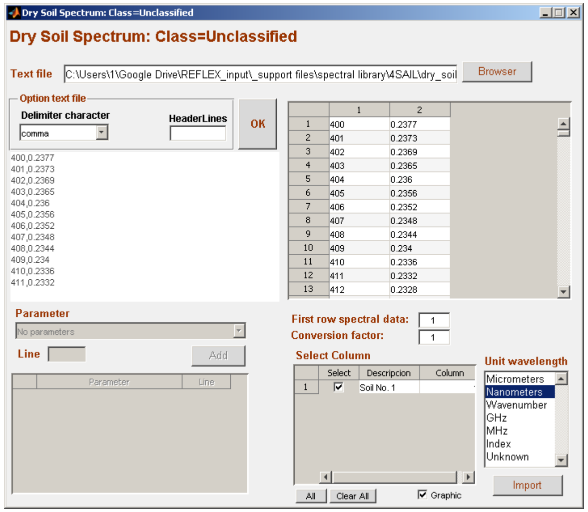


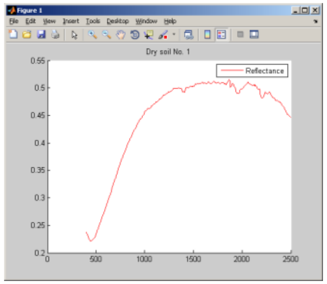
Input leaf spectra (refl. & trans)





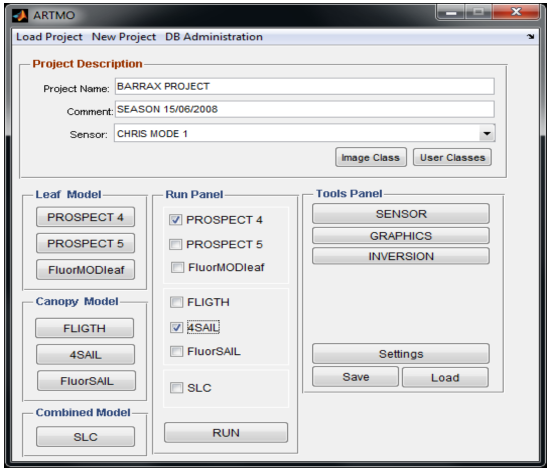
Input soil spectra (refl.)

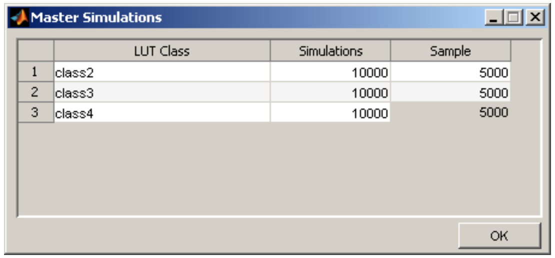




Filling in PROSPECT-4 + 4SAIL

When models are parameterized they turn active in the main window and can then be selected. By clicking on ‘Run’ a GUI appears where for each LUT class a random subselection can be defined.



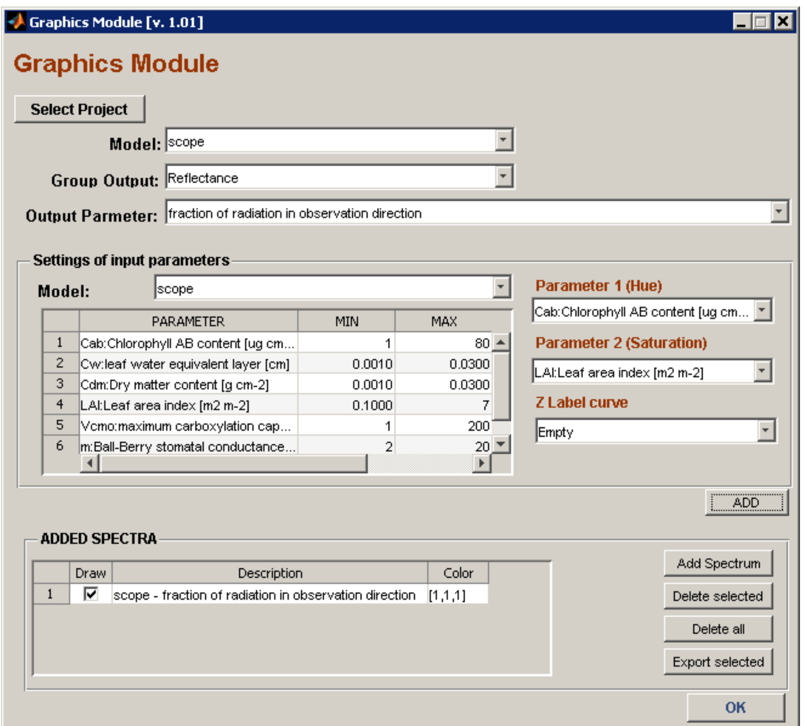


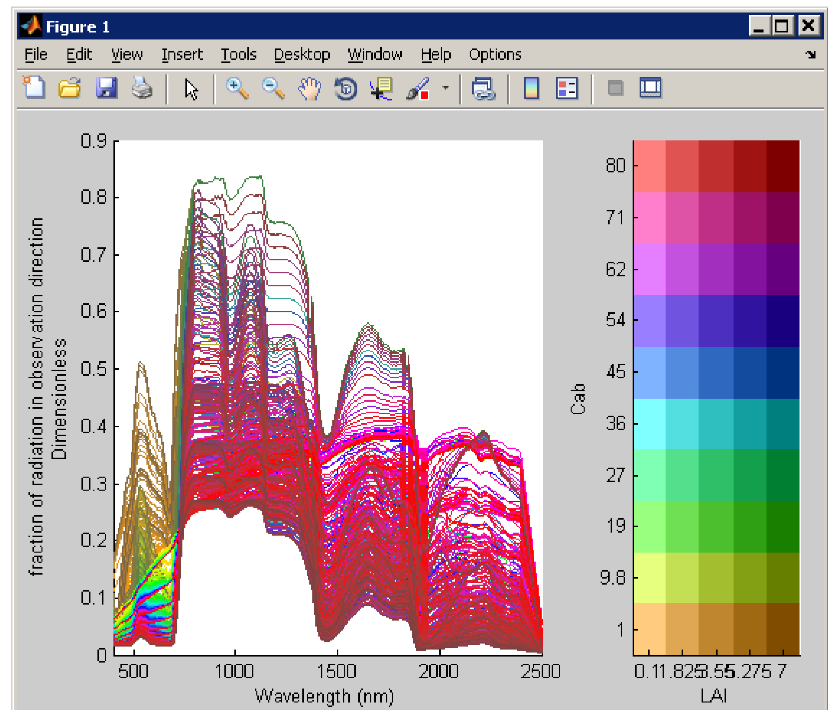
	Model Parameters	Units	Range	Distribution
Leaf parameters: PROSPECT-4				
N	Leaf structure index	unitless	1.3-2.5	Uniform
Chl	Leaf chlorophyll content	[μg/cm^2]	5-75	Gaussian (μ: 35, SD: 30)
C_m	Leaf dry matter content	[g/cm^2]	0.001-0.03	Uniform
C_w	Leaf water content	cm	0.002-0.05	Uniform
Canopy variables: 4SAIL				
LAI	Leaf area index	[m^2/m^2]	0.1-7	Gaussian (μ: 3, SD: 2)
ALA	Average leaf angle	[º]	40-70	Uniform
α_{soil}	Soil scaling factor	unitless	0-1	Uniform
HotS	Hot spot parameter	[m/m]	0.05-0.5	Uniform
skyl	Diffuse incoming solar radiation	[fraction]	0.05	-
θ_s	Sun zenith angle	[º]	22.3	-
θ_v	View zenith angle	[º]	20.19	-
ϕ	Sun-sensor azimuth angle	[º]	0	-

- ✓ Fill in PROSPECT-4 and 4SAIL according to acceptable ranges. Make sure to have a broad range for Chl and LAI (e.g. Gaussian).
- ✓ Repeat parameterization for the different LUT classes.
- ✓ Click on ‘Run’ and select random subset of each LUT class, e.g. 5000 each.

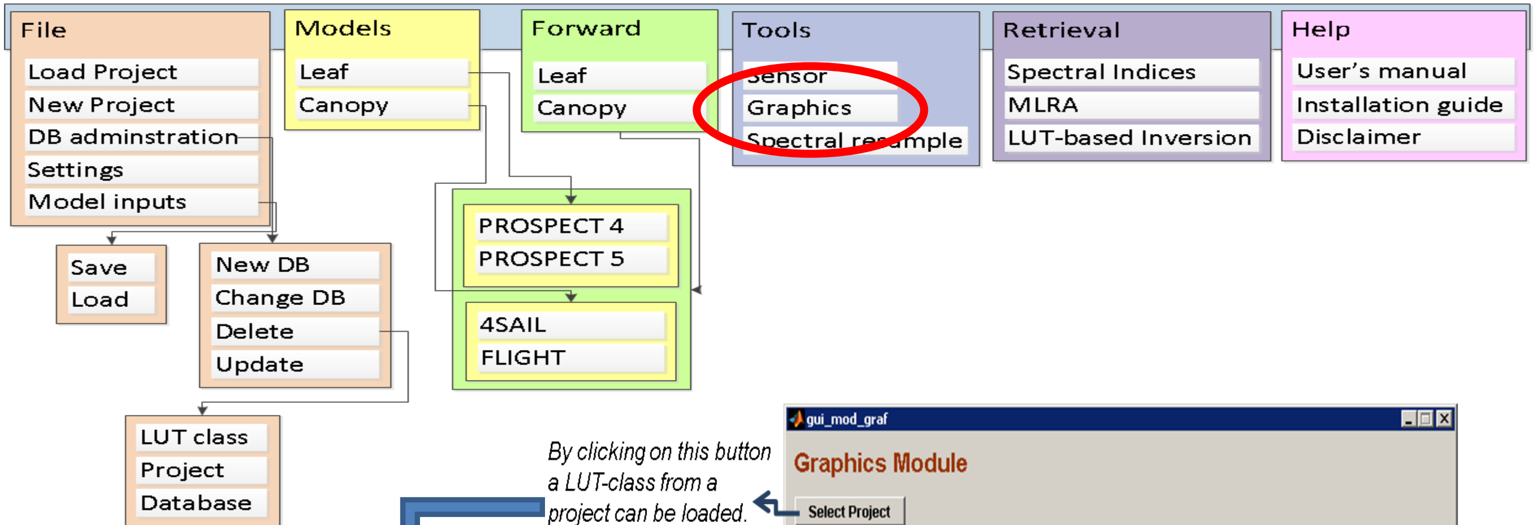
Graphics v1.01 toolbox

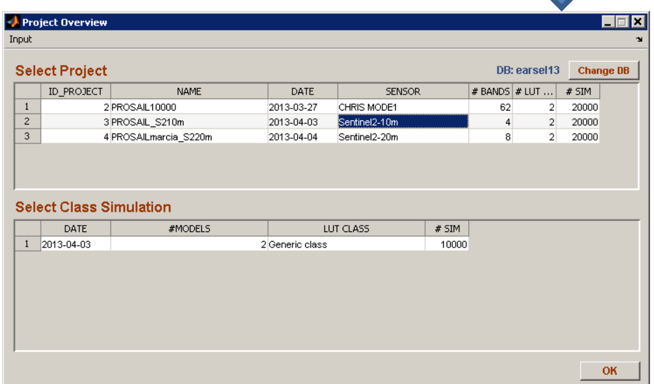
Tutorial





Graphics





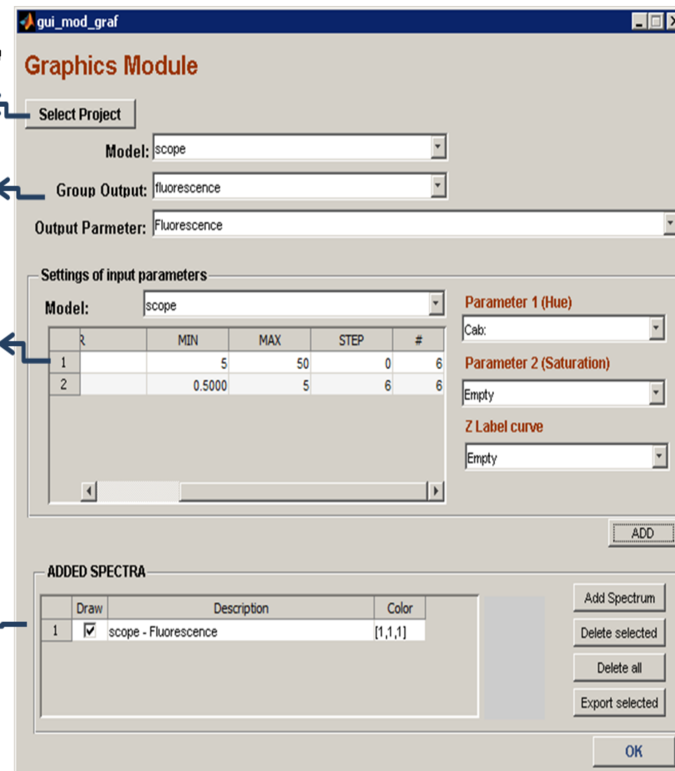
Only a LUT class can be selected, but spectral outputs of multiple LUT classes can be plotted within same plotting window.

By clicking on this button a LUT-class from a project can be loaded.

Select the model, group output and output model.

Overview of range parameters of chosen model.

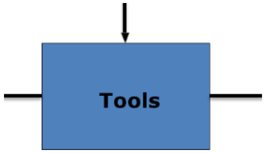
Overview of selected spectral groups.



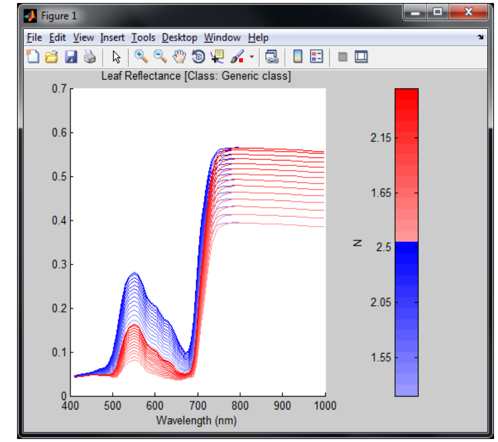
Options to visualize the impact of parameters according to color gradients.

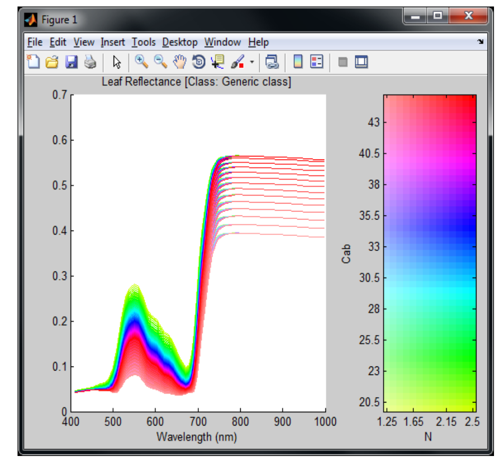
Add selected spectral group to plotting panel.

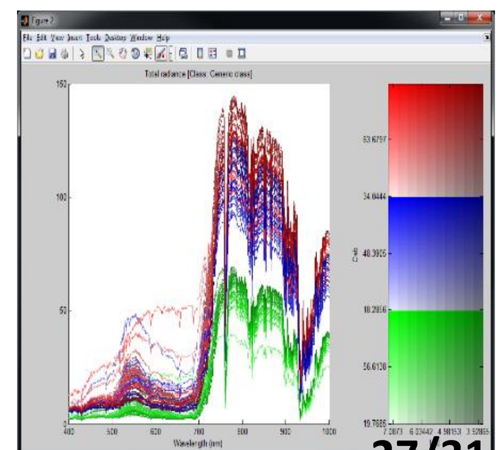
Options to add external spectrum, export and delete spectral groups .



Plotting examples



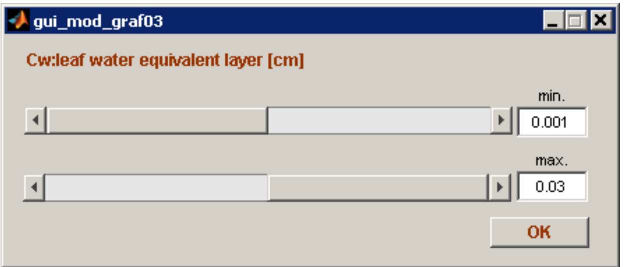




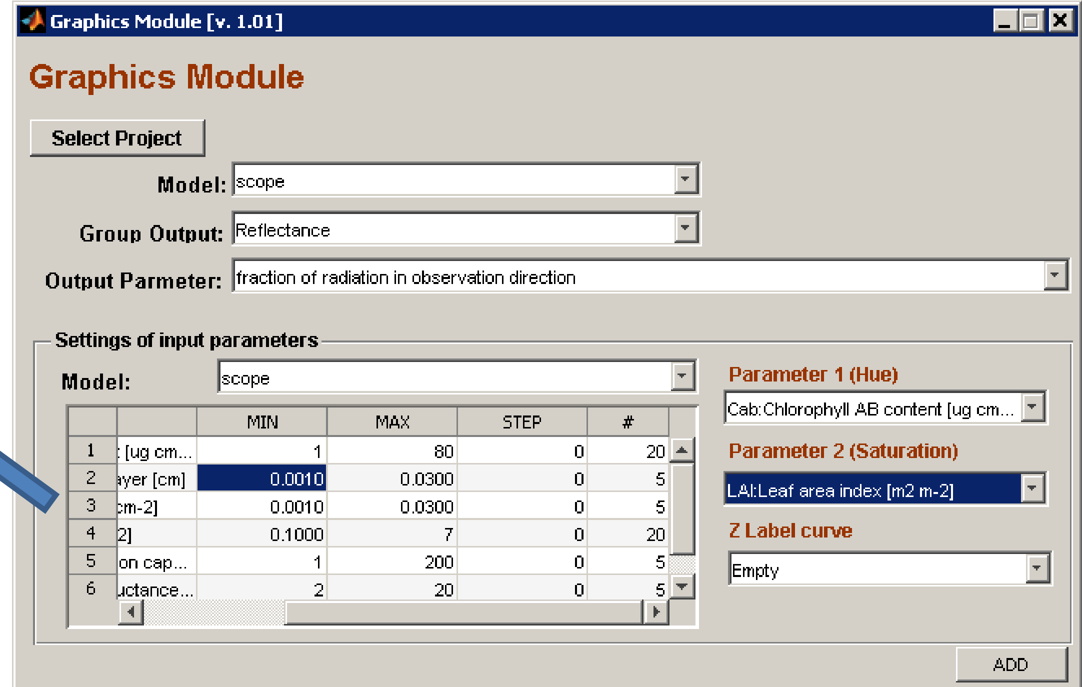
Important features:

- ✓A group of spectra can be plotted according to one color range related to 1 parameter.
- ✓Multiple groups can be added to the same plotting panel.
- ✓A group of spectra can also be added to 2 parameters, 1 as color hue and 1 as color saturation.
- ✓External spectra can be added.
- ✓The ‘Graphics’ module allows exporting spectra to a *.txt* file.

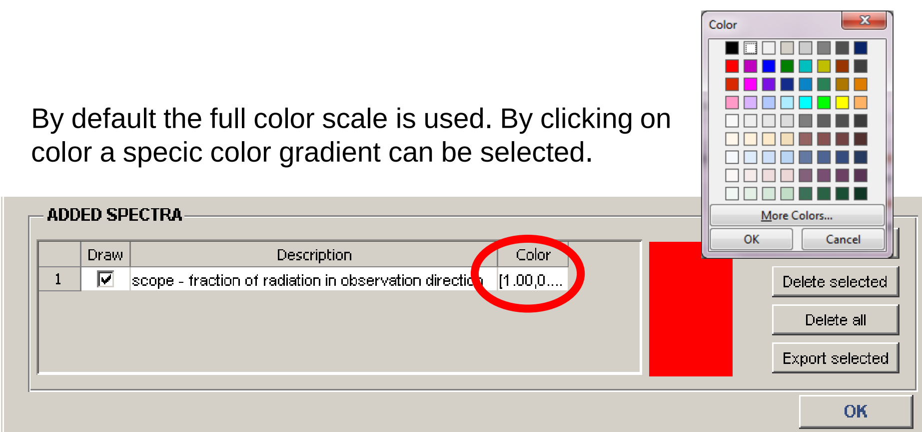
Graphics

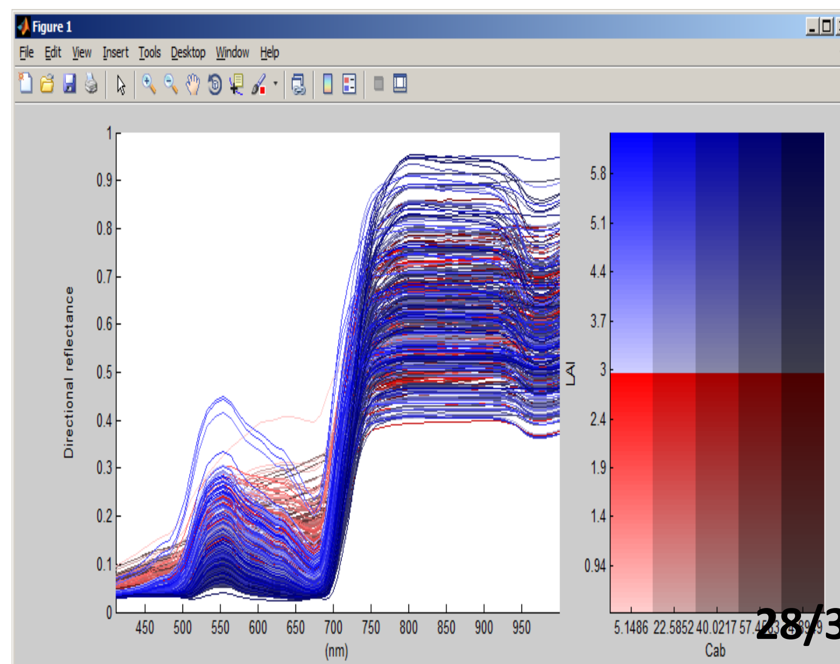


A subselection of the LUT can be plotted. Output spectra can be plotted as a function of color.



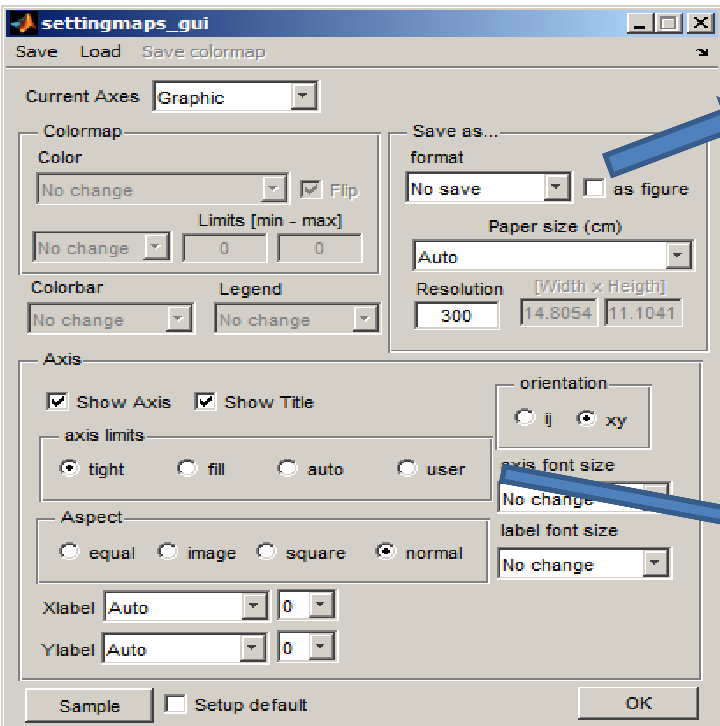
By default the full color scale is used. By clicking on color a specic color gradient can be selected.

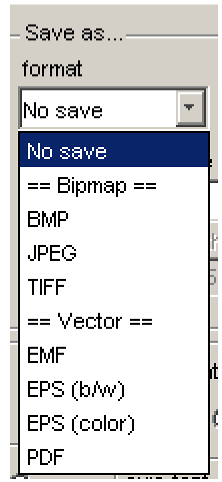


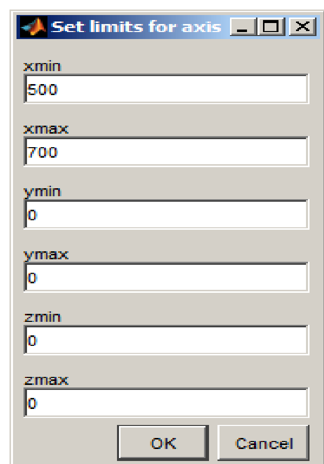


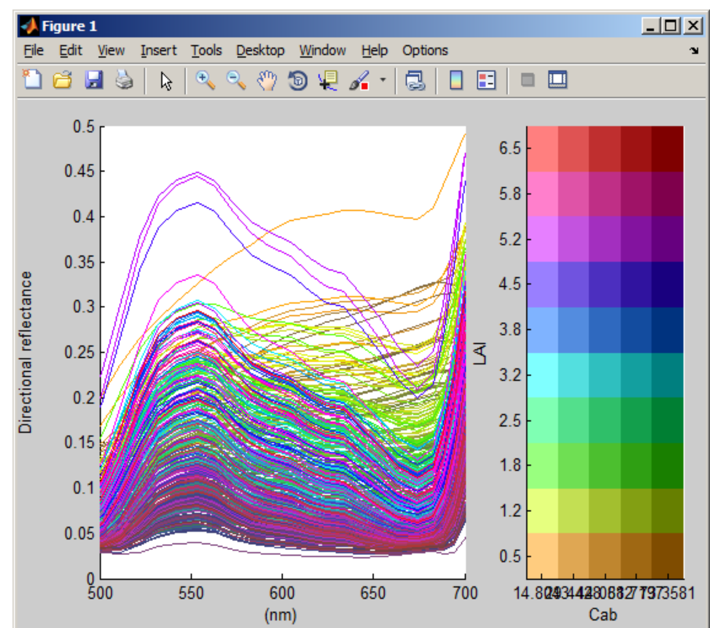
Plotting options

Graphs can be saved into various formats. As such, their space is optimized, i.e. with a minimum of white space around the graph.



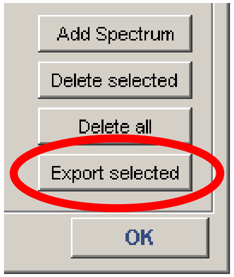


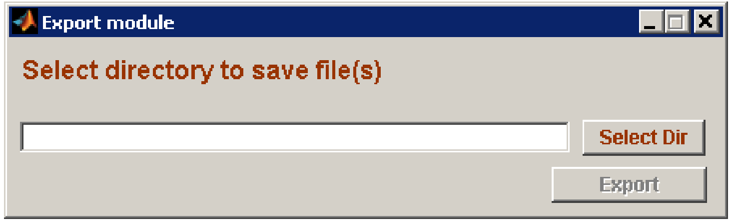




By reducing the Axes a subselection of the spectral output can be visualized.

Export graphics



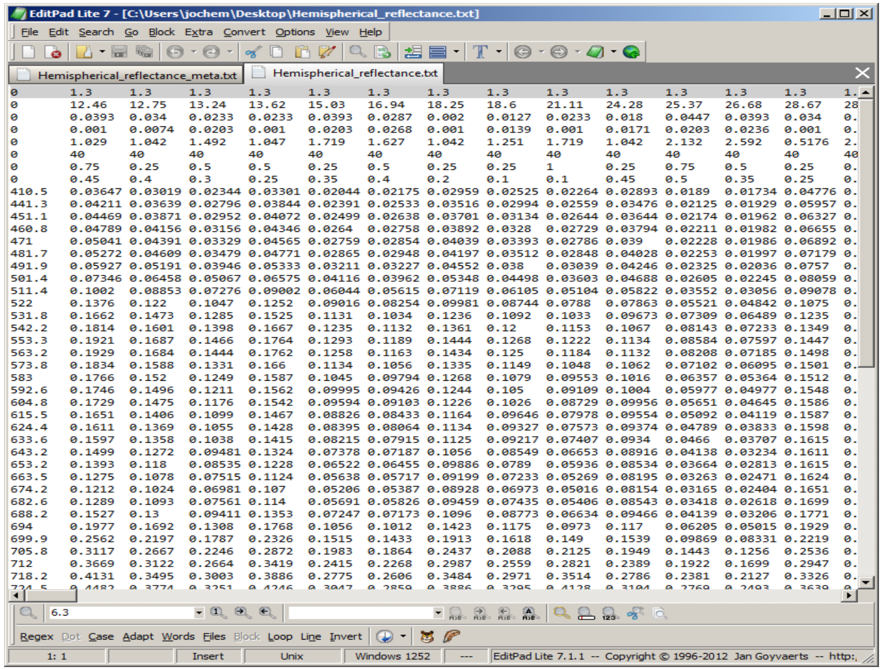


The Graphics module enables exportation of selected simulations to a text file for further use.

Two files are created:

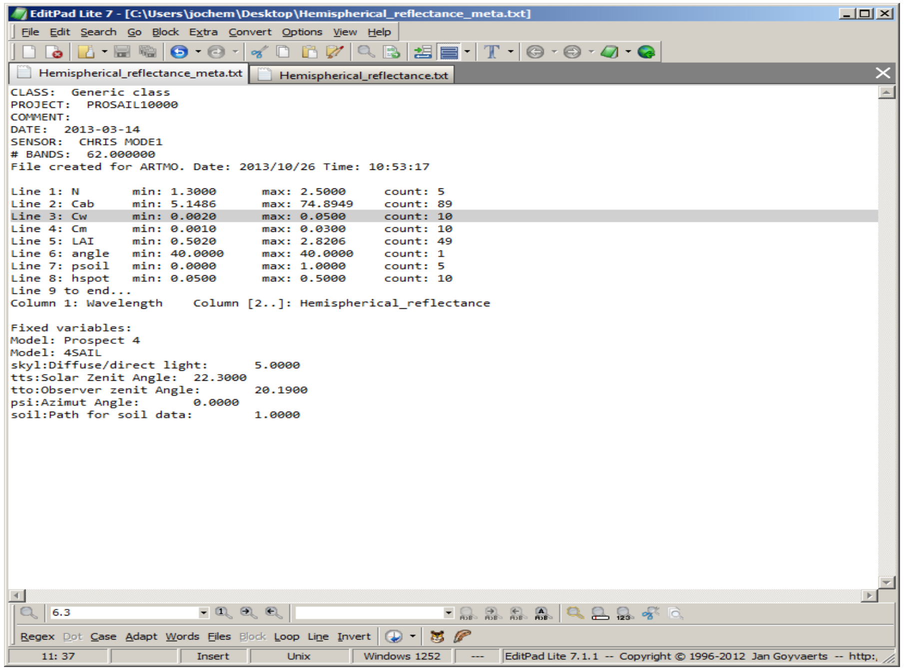
1. **Spectral data** including ranging variables on top of the spectral outputs
2. **Associated metadata** including a description of how data is organized and fixed variables

Spectral data



0	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.
0	12.46	12.75	13.24	13.62	15.03	16.94	18.25	18.6	21.11	24.28	25.37	26.68	28.67	28
0	0.0393	0.034	0.0233	0.0233	0.0393	0.0287	0.002	0.0127	0.0233	0.018	0.0447	0.0393	0.034	0.
0	0.001	0.0074	0.0203	0.001	0.0203	0.0268	0.001	0.0139	0.001	0.0171	0.0203	0.0236	0.001	0.
0	1.029	1.042	1.492	1.047	1.719	1.627	1.042	1.251	1.719	1.042	2.132	2.592	0.5176	2.
0	40	40	40	40	40	40	40	40	40	40	40	40	40	40
0	0.75	0.25	0.5	0.5	0.25	0.5	0.25	0.25	1	0.25	0.75	0.5	0.25	0.
0	0.45	0.4	0.3	0.25	0.35	0.4	0.2	0.1	0.1	0.45	0.5	0.35	0.25	0.
410.5	0.03647	0.03019	0.02344	0.03301	0.02044	0.02175	0.02959	0.02525	0.02264	0.02893	0.0189	0.01734	0.04776	0.
441.3	0.04211	0.03639	0.02796	0.03844	0.02391	0.02533	0.03516	0.02994	0.02559	0.03476	0.02125	0.01929	0.05957	0.
451.1	0.04469	0.03871	0.02952	0.04072	0.02499	0.02638	0.03701	0.03134	0.02644	0.03644	0.02174	0.01962	0.06327	0.
460.8	0.04789	0.04156	0.03156	0.04346	0.0264	0.02758	0.03892	0.0328	0.02729	0.03794	0.02211	0.01982	0.06655	0.
471	0.05041	0.04391	0.03329	0.04565	0.02759	0.02854	0.04039	0.03393	0.02786	0.039	0.02228	0.01986	0.06892	0.
481.7	0.05272	0.04609	0.03479	0.04771	0.02865	0.02948	0.04197	0.03512	0.02848	0.04028	0.02253	0.01997	0.07179	0.
491.9	0.05927	0.05191	0.03946	0.05333	0.03211	0.03227	0.04552	0.038	0.03039	0.04246	0.02325	0.02036	0.0757	0.
501.4	0.07346	0.06458	0.05067	0.06575	0.04116	0.03962	0.05348	0.04498	0.03603	0.04688	0.02605	0.02245	0.08059	0.
511.4	0.1002	0.08853	0.07276	0.09002	0.06044	0.05615	0.07119	0.06105	0.05104	0.05822	0.03552	0.03056	0.09078	0.
522	0.1376	0.122	0.1047	0.1252	0.09016	0.08254	0.09981	0.08744	0.0788	0.07863	0.05521	0.04842	0.1075	0.
531.8	0.1662	0.1473	0.1285	0.1525	0.1131	0.1034	0.1236	0.1092	0.1033	0.09673	0.07309	0.06489	0.1235	0.
542.2	0.1814	0.1601	0.1398	0.1667	0.1235	0.1132	0.1361	0.12	0.1153	0.1067	0.08143	0.07233	0.1349	0.
553.3	0.1921	0.1687	0.1466	0.1764	0.1293	0.1189	0.1444	0.1268	0.1222	0.1134	0.08584	0.07597	0.1447	0.
563.2	0.1929	0.1684	0.1444	0.1762	0.1258	0.1163	0.1434	0.125	0.1184	0.1132	0.08208	0.07185	0.1498	0.
573.8	0.1834	0.1588	0.1331	0.166	0.1134	0.1056	0.1335	0.1149	0.1048	0.1062	0.07102	0.06095	0.1501	0.
583	0.1766	0.152	0.1249	0.1587	0.1045	0.09794	0.1268	0.1079	0.09553	0.1016	0.06357	0.05364	0.1512	0.
592.6	0.1746	0.1496	0.1211	0.1562	0.09995	0.09426	0.1244	0.105	0.09109	0.1004	0.05977	0.04977	0.1548	0.
604.8	0.1729	0.1475	0.1176	0.1542	0.09594	0.09103	0.1226	0.1026	0.08729	0.09956	0.05651	0.04645	0.1586	0.
615.5	0.1651	0.1406	0.1099	0.1467	0.08826	0.08433	0.1164	0.09646	0.07978	0.09554	0.05092	0.04119	0.1587	0.
624.4	0.1611	0.1369	0.1055	0.1428	0.08395	0.08064	0.1134	0.09327	0.07573	0.09374	0.04789	0.03833	0.1598	0.
633.6	0.1597	0.1358	0.1038	0.1415	0.08215	0.07915	0.1125	0.09217	0.07407	0.0934	0.0466	0.03707	0.1615	0.
643.2	0.1499	0.1272	0.09481	0.1324	0.07378	0.07187	0.1056	0.08549	0.06653	0.08916	0.04138	0.03234	0.1611	0.
653.2	0.1393	0.118	0.08535	0.1228	0.06522	0.06455	0.09886	0.0789	0.05936	0.08534	0.03664	0.02813	0.1615	0.
663.5	0.1275	0.1078	0.07515	0.1124	0.05638	0.05717	0.09199	0.07233	0.05269	0.08195	0.03263	0.02471	0.1624	0.
674.2	0.1212	0.1024	0.06981	0.107	0.05206	0.05387	0.08928	0.06973	0.05016	0.08154	0.03165	0.02404	0.1651	0.
682.6	0.1289	0.1093	0.07561	0.114	0.05691	0.05826	0.09459	0.07435	0.05406	0.08543	0.03418	0.02618	0.1699	0.
688.2	0.1527	0.13	0.09411	0.1353	0.07247	0.07173	0.1096	0.08773	0.06634	0.09466	0.04139	0.03206	0.1771	0.
694	0.1977	0.1692	0.1308	0.1768	0.1056	0.1012	0.1423	0.1175	0.0973	0.117	0.06205	0.05015	0.1929	0.
699.9	0.2562	0.2197	0.1787	0.2326	0.1515	0.1433	0.1913	0.1618	0.149	0.1539	0.09869	0.08331	0.2219	0.
705.8	0.3117	0.2667	0.2246	0.2872	0.1983	0.1864	0.2437	0.2088	0.2125	0.1949	0.1443	0.1256	0.2536	0.
712	0.3669	0.3122	0.2664	0.3419	0.2415	0.2268	0.2987	0.2559	0.2821	0.2389	0.1922	0.1699	0.2947	0.
718.2	0.4131	0.3495	0.3003	0.3886	0.2775	0.2606	0.3484	0.2971	0.3514	0.2786	0.2381	0.2127	0.3326	0.

Associated metadata




```
CLASS:  Generic class
PROJECT:  PROSAIL10000
COMMENT:
DATE:  2013-03-14
SENSOR:  CHRIS MODE1
# BANDS:  62.000000
File created for ARTMO. Date: 2013/10/26 Time: 10:53:17

Line 1: N       min: 1.3000      max: 2.5000      count: 5
Line 2: Cab     min: 5.1486      max: 74.8949     count: 89
Line 3: Cw      min: 0.0020      max: 0.0500      count: 10
Line 4: Cm      min: 0.0010      max: 0.0300      count: 10
Line 5: LAI     min: 0.5020      max: 2.8206      count: 49
Line 6: angle   min: 40.0000     max: 40.0000     count: 1
Line 7: psoil   min: 0.0000      max: 1.0000      count: 5
Line 8: hspot   min: 0.0500      max: 0.5000      count: 10
Line 9 to end...
Column 1: Wavelength    Column [2..]: Hemispherical_reflectance

Fixed variables:
Model: Prospect 4
Model: 4SAIL
skyl:Diffuse/direct light:      5.0000
tts:Solar Zenit Angle:  22.3000
tto:Observer zenit Angle:       20.1900
psi:Azimut Angle:       0.0000
soil:Path for soil data:        1.0000
```

Excercise

✓ Make some plottings from earlier simulated LUT classes.
✓ Export your plotting to a text file.