Glacier Lake Assisted Melting (GLAM)

GLAM BioLith-RT. 3.1 for the GMELT Toolbox

A Bio-Lithological Optical/RT Semi-Analytical Model for Water Components Concentration Retrieval and Lake Energy/Temperature Distribution Simulations

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Overview

- **Absorption coefficient, backscattering coefficient, extinction coefficient, and single backscattering albedo** are **Inherent Optical Properties (IOPs)** of a water body. **Remote Sensing Reflectance (Rrs)** is among the so called **Apparent Optical Properties (AOPs)** of a water system (what is captured by a satellite). The water body composition (physical components such as phytoplankton, detritus, colored dissolved organic matter, and inorganic particles that are present in the water system) influence the IOPs; that along with the incoming light geometric distribution affect the AOPs. Water components concentrations, IOPs, incoming light geometric distribution, and AOPs are linked through mathematical equations called Bio-Lithological Optical/Radiative-Transfer (RT) models [1]

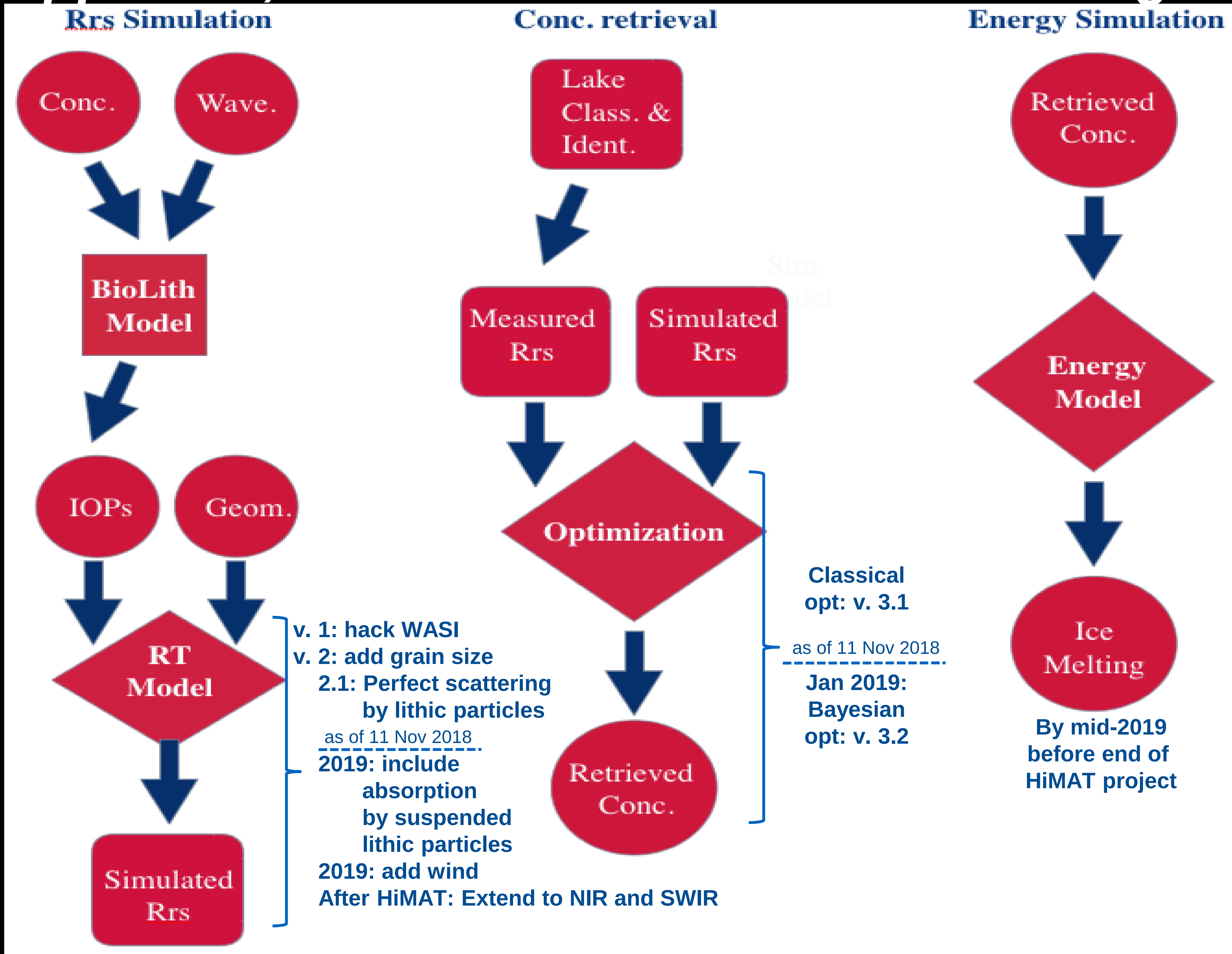
Goals

1. To retrieve the concentration of water components carried into the lakes due to glacier dynamics by using satellite images

2. To use the retrieved physical component concentrations to estimate the amount of energy available in the lakes for the ice melting

3. Ice melting hazard estimation via energy simulations

Approach, and GLAM BioLith RT versioning



What GLAM BioLith-RT does

1. **Remote sensing reflectance (Rrs) simulation** via the Bio-Optical\RT models presented in [4,7] **(Forward modeling)**

    - The RT models presented in [4,7] are analytical parameterization of the commercial software Hydrolight

2. **Water component concentrations retrieval** via constrained optimization framework **(Inverse modeling)**

    - Bayesian optimization framework is a better option as it allows to capture the uncertainty in the concentrations to retrieve

What GLAM BioLith-RT will do

1. **Water component concentrations retrieval** via Bayesian optimization framework **(Inverse modeling)-** version 3.2

    - implementation completed, validation in progress

2. **Glacier lakes energy distribution simulation** via RT using the retrieved concentrations **(Forward modeling)**

    - literature review/search in progress

3. **Ice melting rate and hazard** estimation using energy simulations

GLAM BioLith-RT 3.1 package

- In the GLAM BioLith-RT package the user finds several data sets, functions, and scripts to compute the quantities of interest. The most important are the following:

  1. script **main.m** for:

     A. Rrs simulation via the function AOP_Rrs.m given the input select by the user

     B. Water component concentrations retrieval given the observed and the simulated remote sensing reflectance- constrained optimization framework via the function InvModelBioLithRT.m

  2. function **AOP_Rrs.m**: Rrs simulation

  3. function **InvModelBioLithRT.m**: objective function for the optimization problem to concentrations retrieval

- It is up to the user whether use the software only for Rrs simulation (Forward modeling mode) or to retrieve water component concentrations (Inverse modeling mode)

  - The Inverse modeling mode (Forward modeling and Optimization) is the default option. To switch only to the Forward modeling mode the instruction will be given in the next slides

Inverse modeling mode: Input

1. Observed Remote sensing reflectance at different wavelengths
   - The wavelength range allowed is from 400 to 700 nm. Within the allowed range, the user can enter any wavelength desired
2. Case water selection. The user can choose to work with either case-1 or case-2 water (case 1 is seawater, case 2 is lakes or estuarine waters; and turbid glacial lakes are case 2 minus phytoplankton and gelbstoff)
3. View (camera) and Sun angles relative to vertical, in degrees
4. Water component concentrations- phytoplankton (ph), colored dissolved organic matter (CDOM), and suspended particle matter (SPM = the lithic component)
5. Suspended particle matter grain size (default 33.6 μm)- **SPM is considered as perfect scatterer***
6. Selection between deep water or shallow water (when the bottom contribution is not negligible)
7. Bottom depth and areal fraction of bottom surface, when shallow water is selected
8. Quantities related to the remotes sensing reflectance above the water surfaces: irradiance intensities, intensities of light sources, Angstrom exponent, atmospheric pressure, relative humidity, scale height for ozone, scale height of the precipitable water in the atmosphere.

Inverse modeling mode: Output

1. Simulated Rrs (Rrs0) given the water component concentrations - guessed by the user via observed Rrs (Rrs_obs) spectrum analysis

2. Objective function value (Res0) computed w/ Rrs0 versus Rrs_obs

3. Retrieved concentrations (Fitret) and corresponding Objective function value (Res)

4. Simulated Rrs (Rrs_fit) given the retrieved water component concentrations

5. Plot Rrs0, Rrs_fit, and Rrd_obs versus wavelengths (lambda)

Forward modeling mode

- If the **Forward modeling only** is selected then, in main.m:
  A. un-comment from line 121 to 127 (for the Rrs plot)
  B. comment from line 129 to 166 to remove the Inverse modeling mode
- **Input**:
  1. Range of wavelength of interest. The range allowed is from 400 to 700 nm. Within the allowed range, the user can enter any wavelength desired
  2. Case water selection. The user can choose to work with either case-1 or case-2 water
  3. BioLith model selection. So far the user can choose between the models presented in [4] and [7]
  4. View (camera) and Sun angles, in degrees
  5. Water component concentrations and **SPM grain size***
  6. Selection between deep water or shallow water (when the bottom contribution is not negligible)
  7. Bottom depth and areal fraction of bottom surface, when shallow water is selected
  8. Quantities related to the remotes sensing reflectance above the water surfaces: irradiance intensities, intensities of light sources, Angstrom exponent, atmospheric pressure, relative humidity, scale height for ozone, scale height of the precipitable water in the atmosphere.
- **Output**: simulated Rrs (Rrs0)

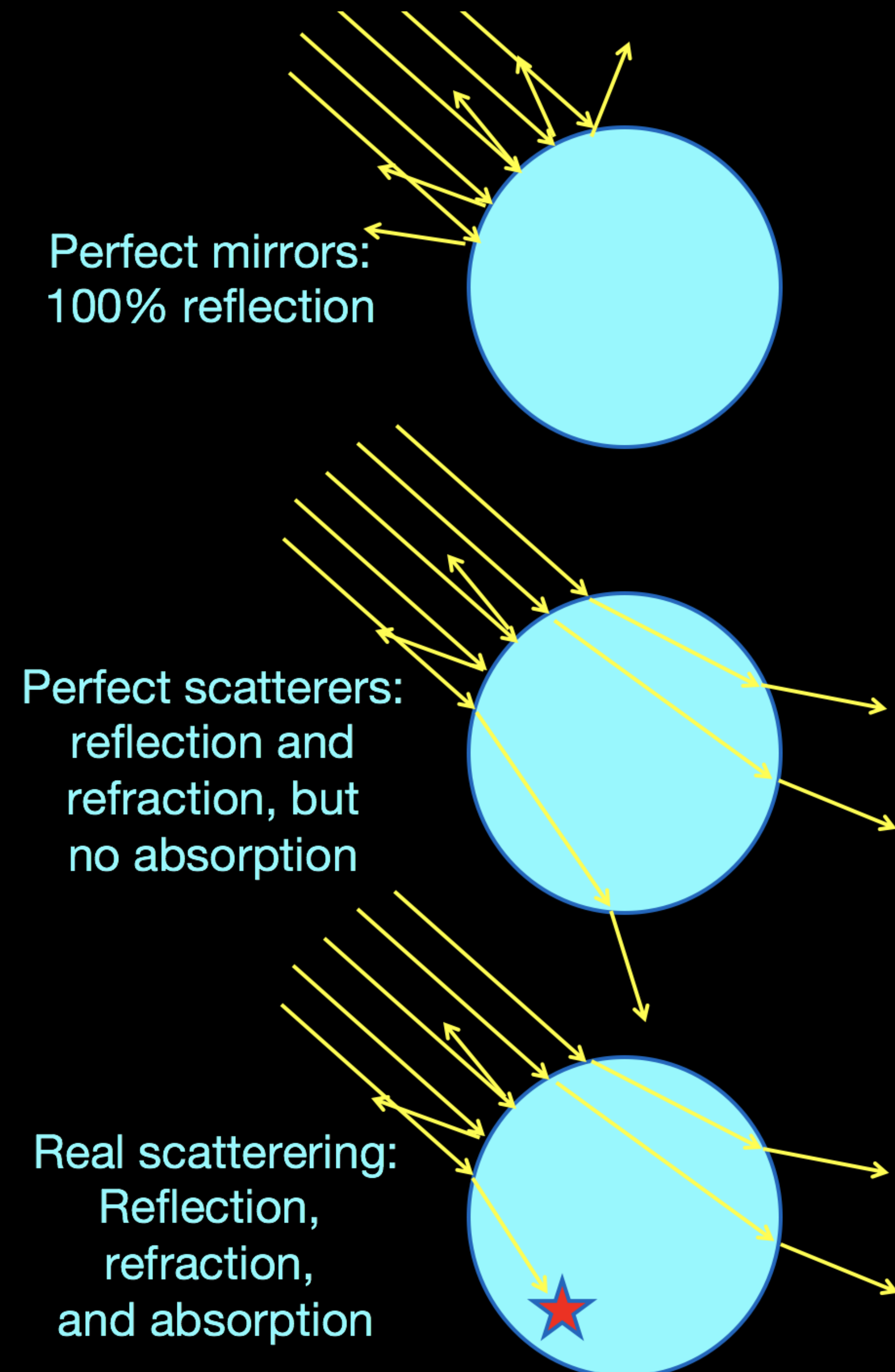
** SPM specific backscattering coefficient*

1. The SPM specific backscattering coefficient (**bbxS**) is modeled as follows, **under the assumption that SPM is a perfect scatterer (no absorption)** [7]:

   - **bbxS= (bbxSW*33.57e-6)/d**

   - d is the grain size - [m]
   - 33.57e-6 [m] is the default grain size [m] - i.e. bbxS=bbxSW when d= 33.57e-6 [m]
   - bbxSW= 0.0086 [m^2/g] is the WASI default value
     - In WASI SPM is considered as perfect scatterer and bbxS is constant between 400 and 800 [nm] wavelength range [4,7]

Perfect mirrors vs. perfect scatterers vs. real scatterers



GLAM BioLith-RT vs WASI

- The software **WASI** [4] was used as a benchmark to test **GLAM BioLith-RT**.
- We compared performances of GLAM BioLith-RT and WASI in simulating the remote sensing reflectance (fwd mode only) for different scenarios, to test GLAM BioLith-RT. In all the cases both GLAM BioLith-RT and WASI were run with the following wavelength range [443; 482; 561; 654] nm (Landsat8 first four bands middle points) and the following inputs:

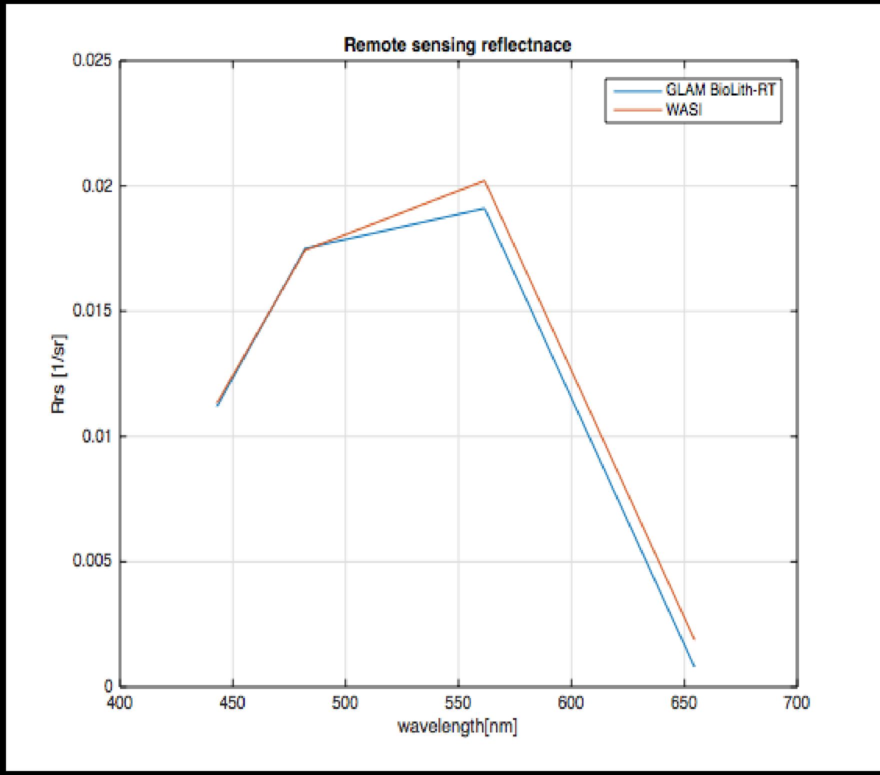
  1. case-2 water, view and sun angle 0 and 40 degrees, pure water, 4 m bottom depth, only sediment in the bottom depth composition, Angstrom exponent= 1.317, atmospheric pressure= 1013.25 mbar, relative humidity=0.60, scale height for ozone= 0.300 cm, scale height of the precipitable water in the atmosphere= 2.500 cm

  2. same as scenario one but with 0.300 mgm^−3 of CDOM

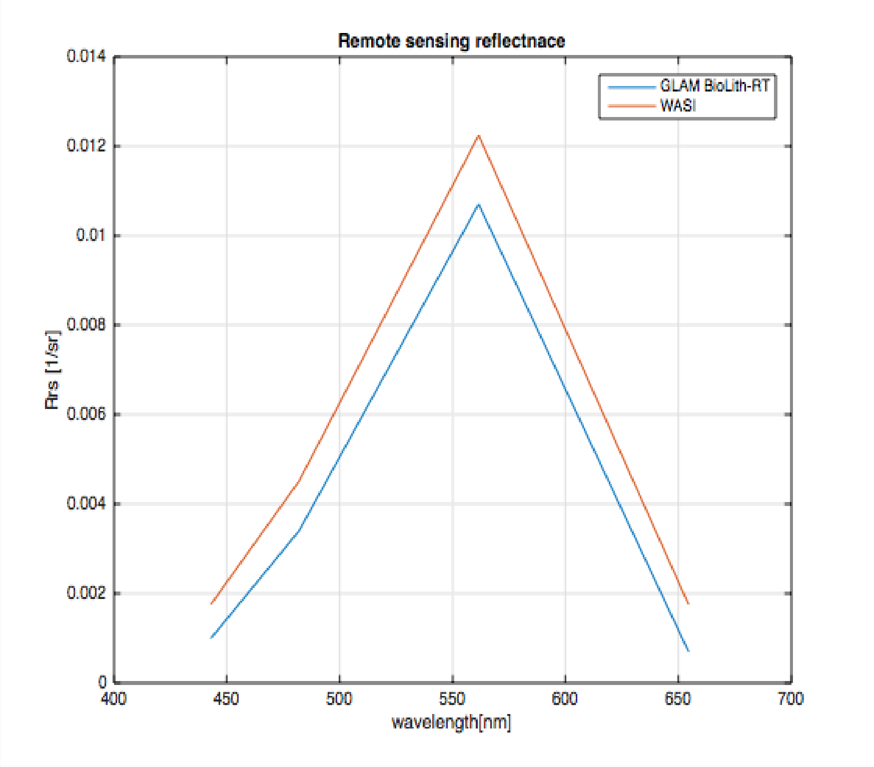
  3. same as scenario one but with 1.000 gm^−3of SPM (w/ default grain size)

- The discrepancies that are negligible are due to slight differences in the remote sensing reflectance above the water surface modeling

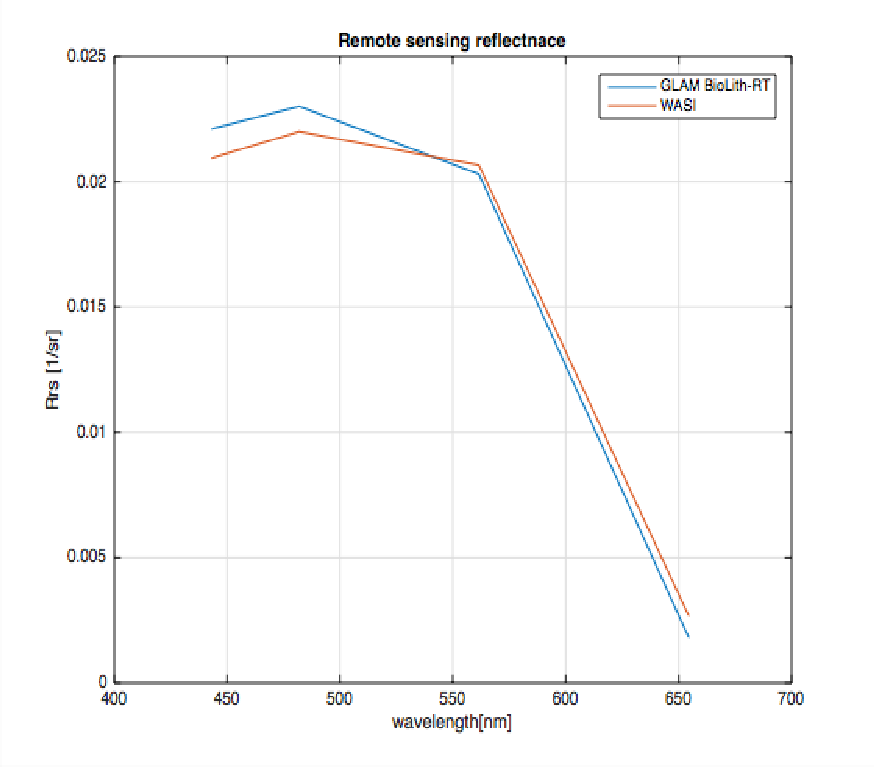
GLAM BioLith-RT vs WASI (continued)



Scenario 1



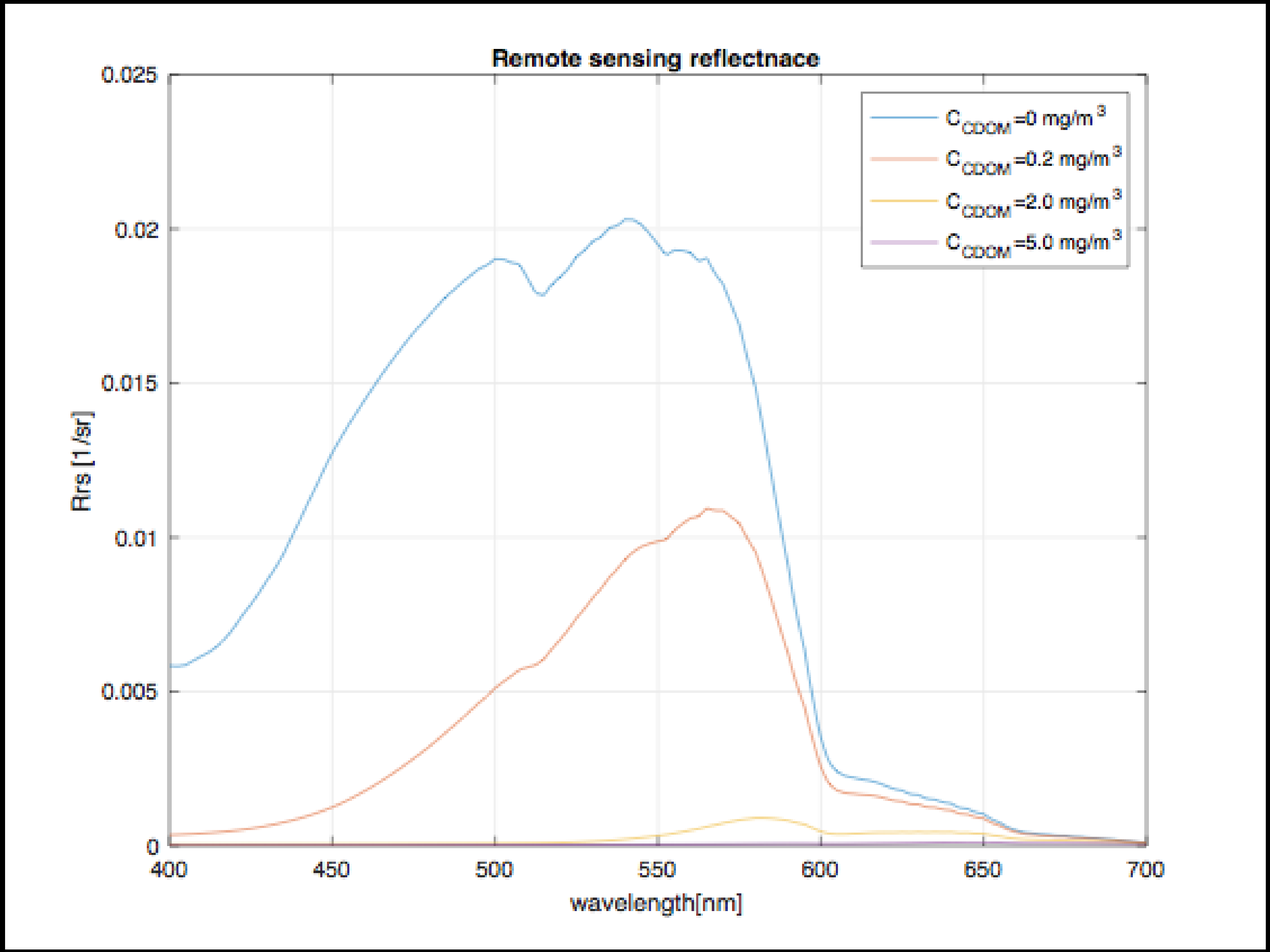
Scenario 2



Scenario 3

Forward modeling mode: example w/ CDOM variation

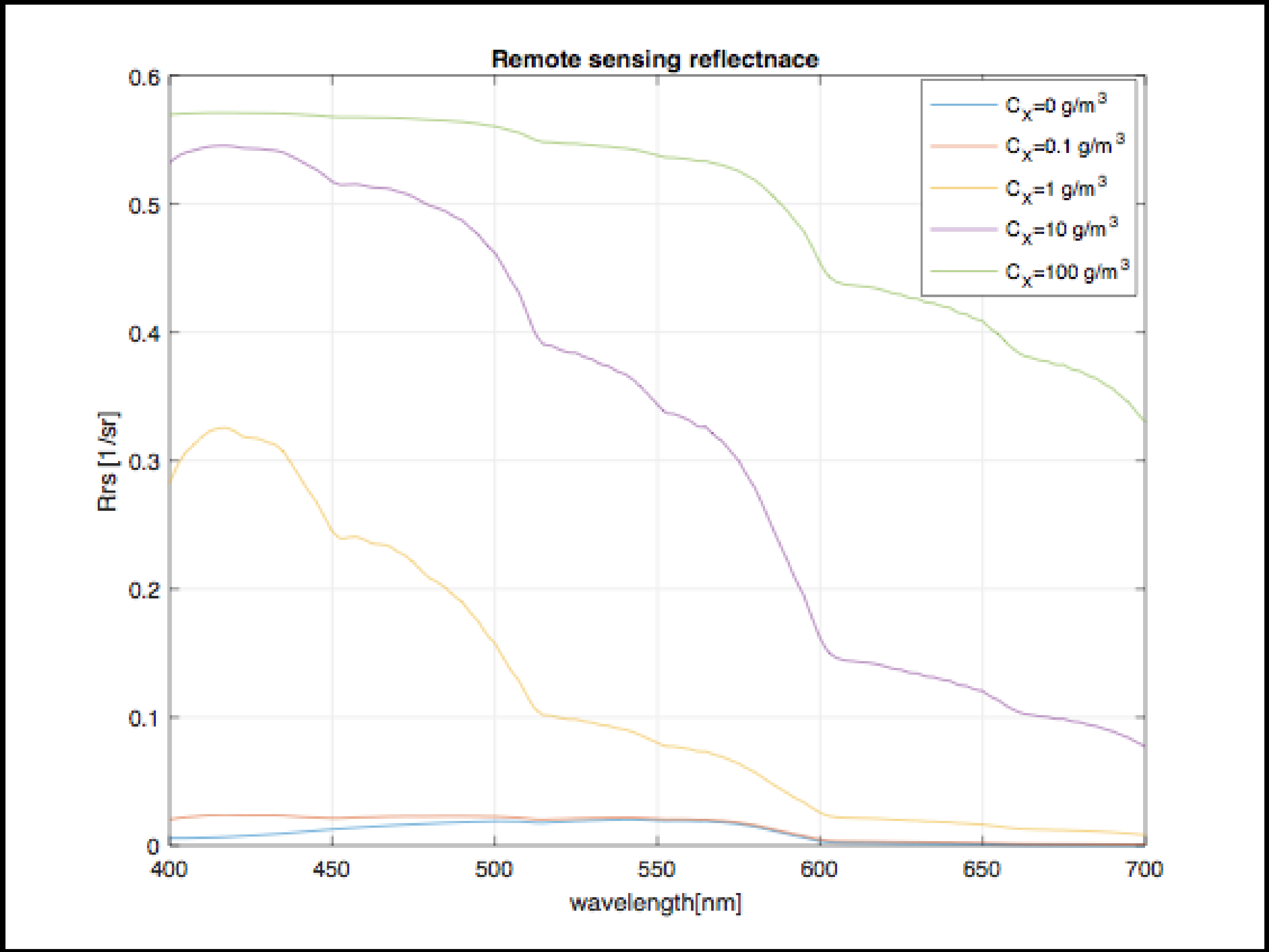
- Simulation of Rrs for four different scenarios:
  1. pure water
  2. water and 0.3 mg/m^3 of CDOM
  3. water and 2.0 mg/m^3 of CDOM
  4. water and 5.0 mg/m^3 of CDOM
- As expected via increasing the CDOM concentration, the pick shifts towards higher wavelengths and the water becomes darker



Forward modeling mode: example w/ SPM concentration variation

Here the variable amount of SPM is approximated as idealized perfect scatterers of constant grain size. Discrete absorptions are due to the water component.

- Simulation of Rrs for four different scenarios:
  1. pure water
  2. water and 0.1 g/m^3 of SPM, d=3.36 μm
  3. water and 1.0 g/m^3 of SPM, d=3.36 μm
  4. water and 10.0 g/m^3 of SPM, d=3.36 μm
  5. water and 100.0 g/m^3 of SPM, d=3.36 μm
- As expected via increasing the SPM concentration, w/ fixed SPM grain size, the water becomes brighter



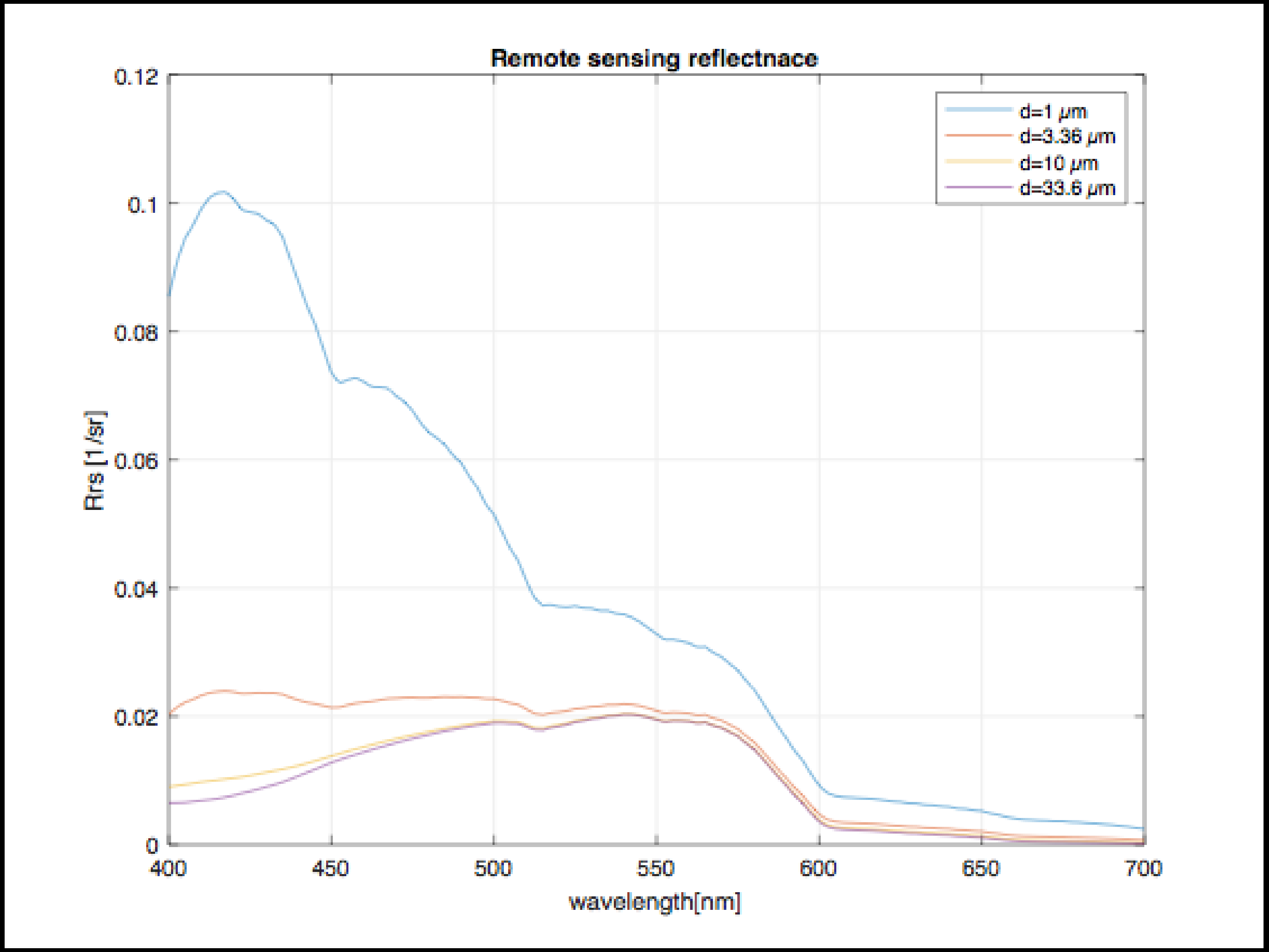
Forward modeling mode: example w/ SPM grain size variation

Here the constant amount of SPM is approximated as idealized perfect scatterers.
Discrete absorptions are due to the water component.

- Simulation of Rrs for four different scenarios:

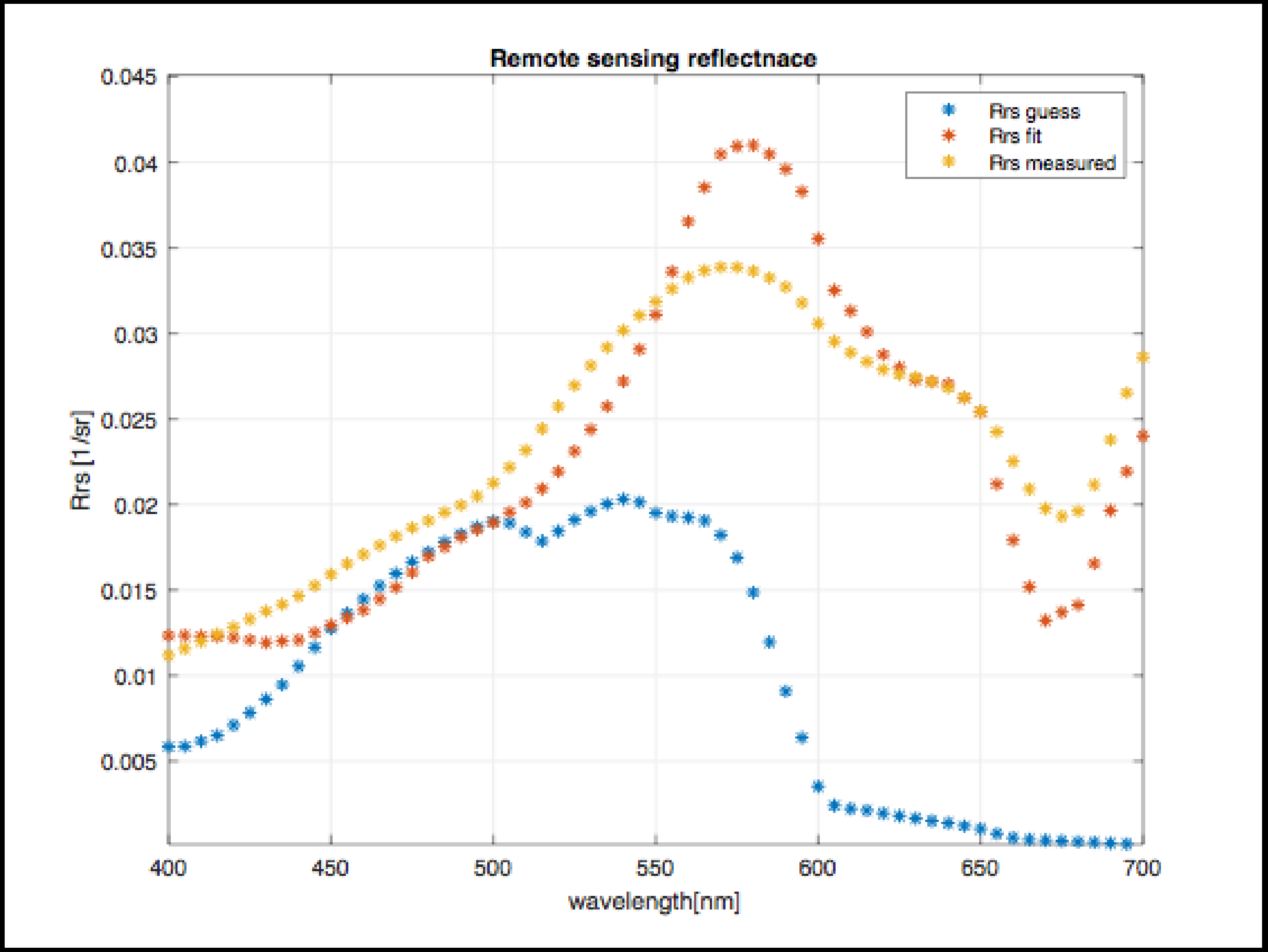
  1. pure water
  2. water and 0.1 g/m^3 of SPM, d= 1 μm
  3. water and 0.1 g/m^3 of SPM, d= 3.36 μm
  4. water and 0.1 g/m^3 of SPM, d= 10 μm
  5. water and 0.1 g/m^3 of SPM, d= 33.6 μm

- As expected via decreasing the SPM grain size, w/ fixed SPM concentration-, the pick shifts towards lower wavelengths and the water becomes brighter



Inverse modeling mode: example

- **Assumption** of pure water to compute Rrs0 (Rrs guess)
  - obj. fun. Res0= 0.0166
- **Retrieval**:
  - C(ph)=83.1842 [mg/m^3]
  - C(CDOM)= 0.4162 [mg/m^3]
  - C(SPM)= 32.8626 [mg/m^3]- default grain size
  - Res=8.1663x10^(-04)



Notes and Acknowledgments

- GLAM BioLith-RT has been being developed primarily for educational and research use

- The input spectra used in GLAM BioLith-RT are the ones available in the software WASI package

- **We would like to sincerely thank Dr. Peter Gege for the fantastic job done with WASI. Thanks to Dr. Gege's software and its detailed user manual it has been possible for us to develop and test GLAMBioLith-RT**

References

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