Combining physical modelling and AI for removing sun glint from atmospherically corrected imagery

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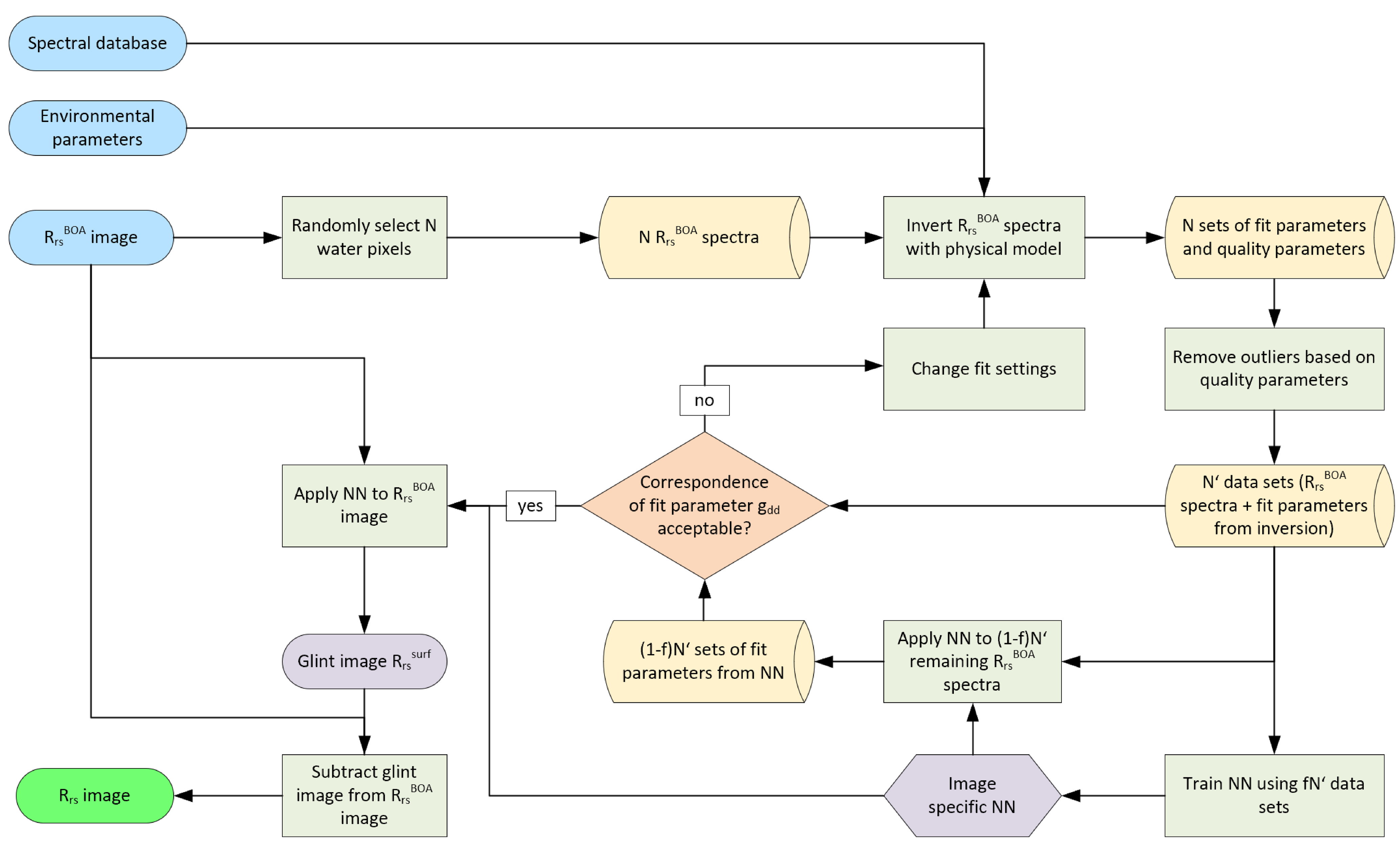


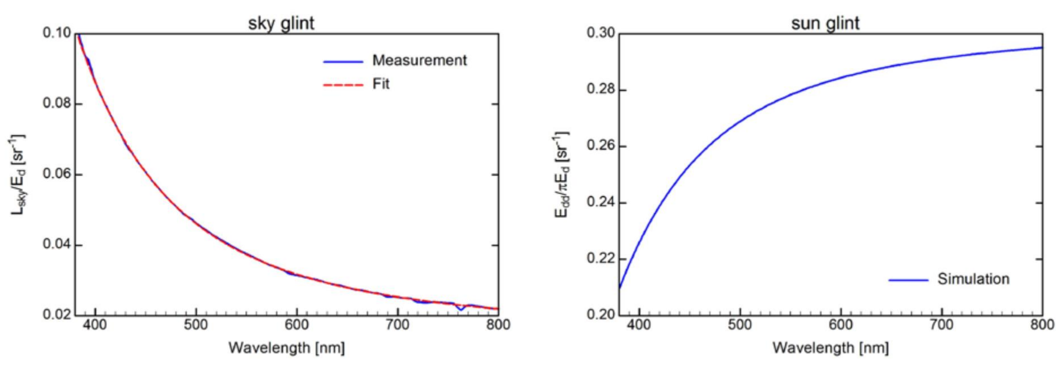
Flow chart illustrating the computation and correction of glint from an atmospherically corrected image. N water pixels are inverted using a physical model. Pixels which cannot be fitted reasonably (outliers) reduce N to N′ ≤ N. A fraction f of the N′ data sets is used to train a NN, the remaining (1–f) N′ data sets serve for validation.

Physical model

The irradiance model of Gregg and Carder (1990) is adopted to decompose the sky radiance reflected at the water surface (L_{sky}) into a direct component from the sun (E_{dd}; sun glint) and two diffuse components caused by Rayleigh (E_{dsr}) and aerosol (E_{dsa}) scattering (sky glint):

$$L_{sky}(\lambda) = g_{dd}\, E_{dd}(\lambda) + g_{dsr}\, E_{dsr}(\lambda) + g_{dsa}\, E_{dsa}(\lambda).$$

The E's are computed using analytic equations. The g's are the relative contributions of the E's to the illumination of a pixel. $g_{dsr} = 1/\pi$ and $g_{dsa} = 1/\pi$ is set, approximating isotropic sky radiance, while g_{dd} is determined for each pixel by inverse modelling.



Typical spectra of sky glint and sun glint.

The water surface reflects a fraction ρ_L of L_{sky}. Normalizing with the downwelling irradiance (E_d) yields the glint in reflectance units sr^{-1}:

$$R_{rs}^{surf}(\lambda) = \rho_L \frac{L_{sky}(\lambda)}{E_d(\lambda)}.$$

Atmospheric correction of satellite imagery over water provides the sum of R_{rs}^{surf} and remote sensing reflectance (R_{rs}) at bottom of atmosphere (BOA):

$$R_{rs}^{BOA}(\lambda) = R_{rs}(\lambda) + R_{rs}^{surf}(\lambda).$$

Hence, the corrected image in units of R_{rs} is obtained by subtracting R_{rs}^{surf} from R_{rs}^{BOA}.

AI

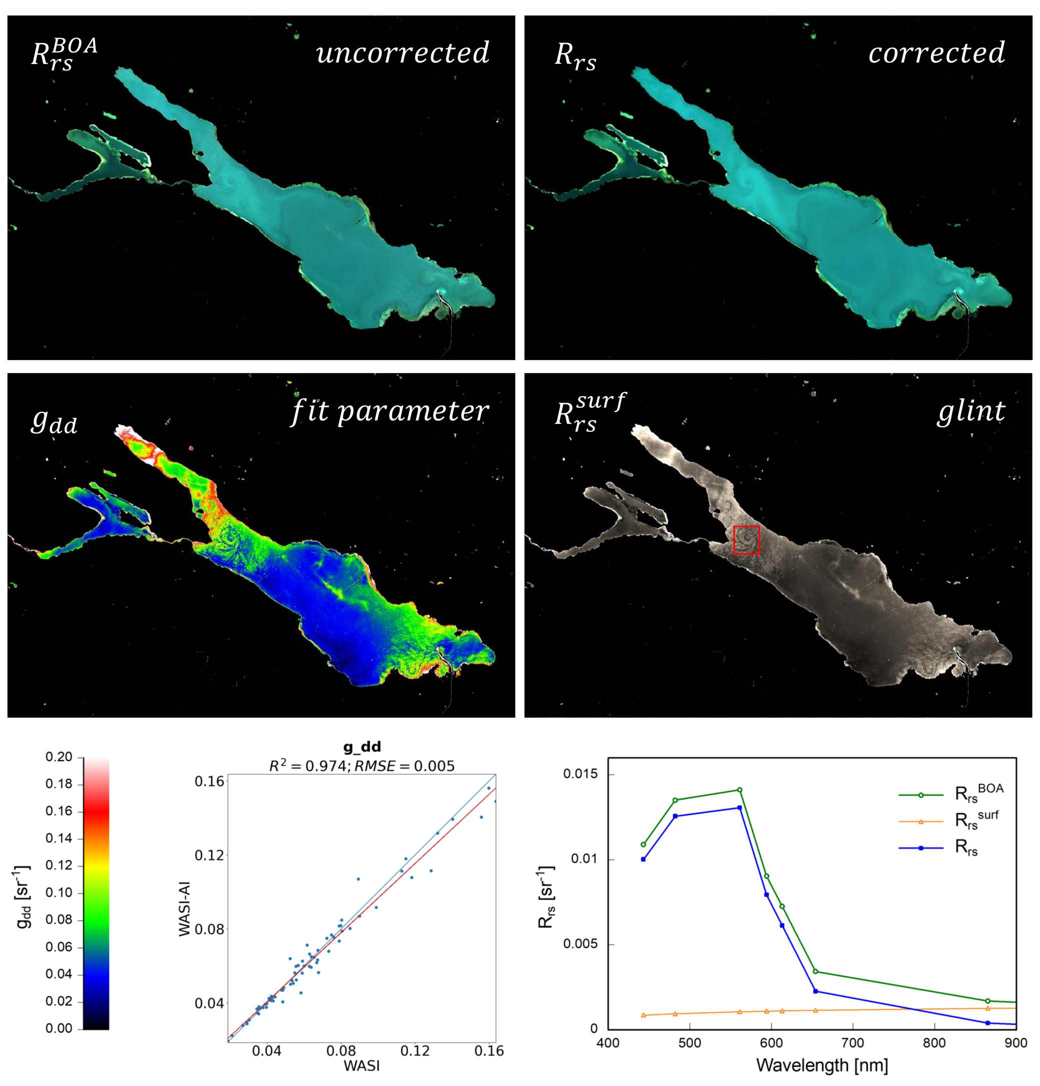
Around 800 pixels are inverted with the physical model, then the spectra together with the fit parameter g_{dd} are used to train a neural network (NN). This image specific NN is applied to all water pixels to get R_{rs}.

Implementation in WASI

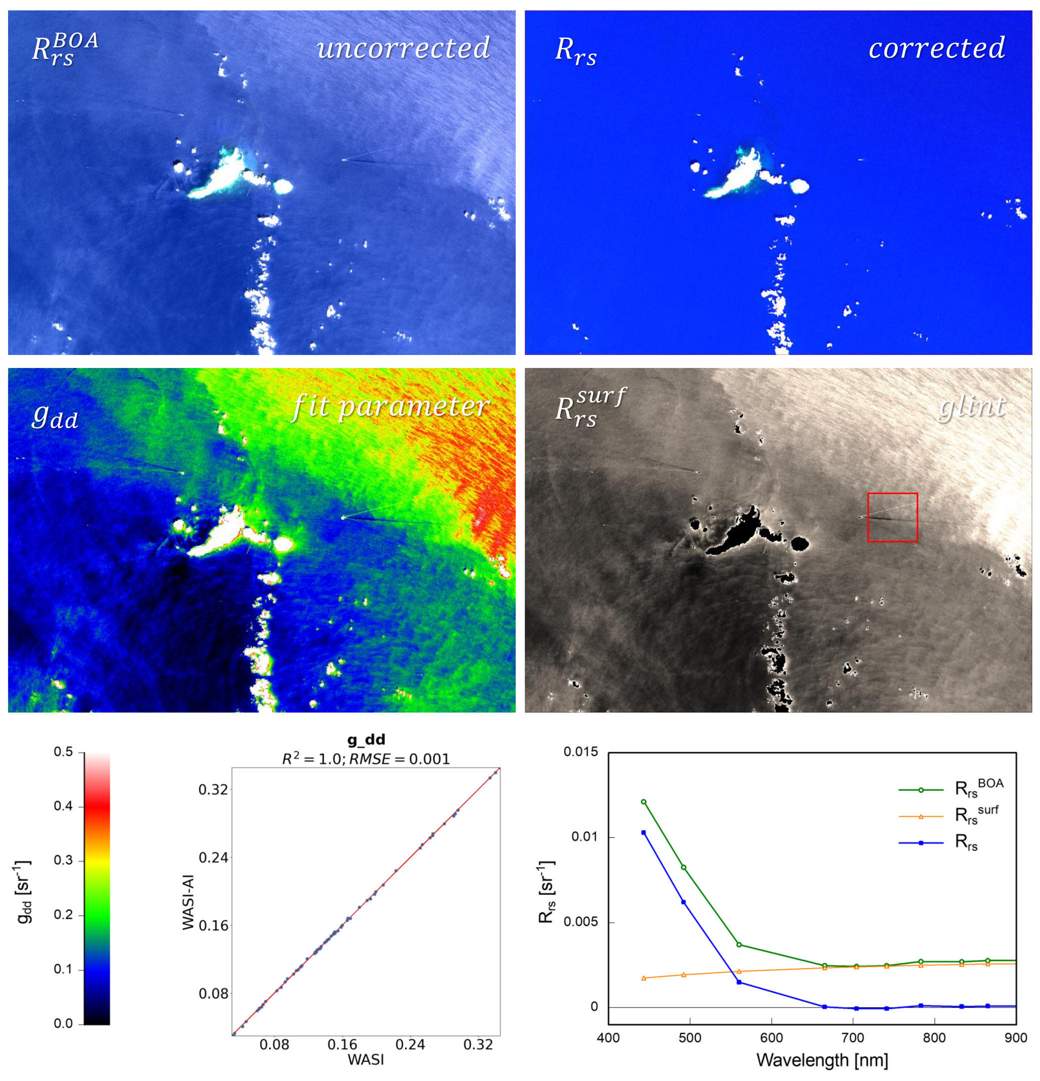
The method is implemented in version 7 of the software WASI. Download:

https://ioccg.org/resources/software/

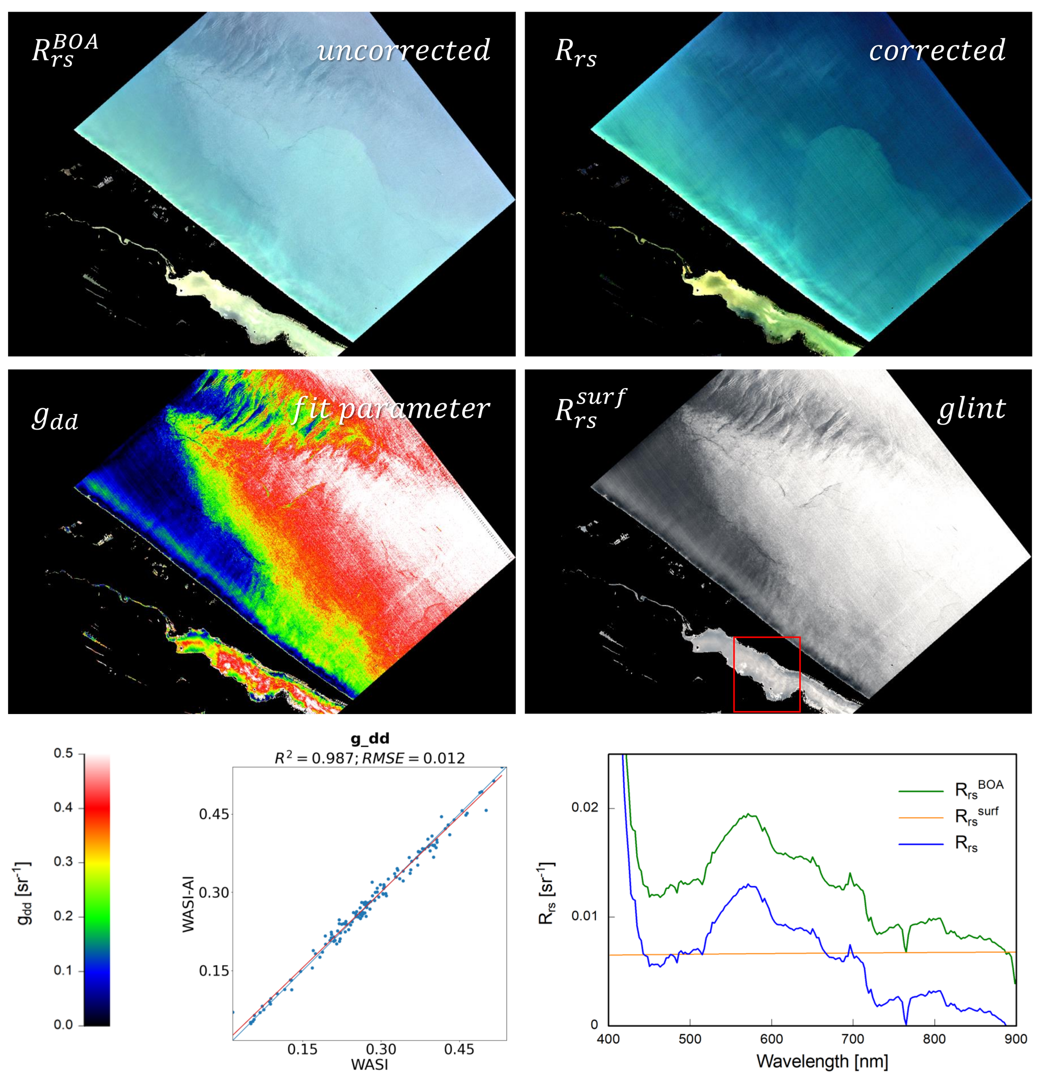
Examples



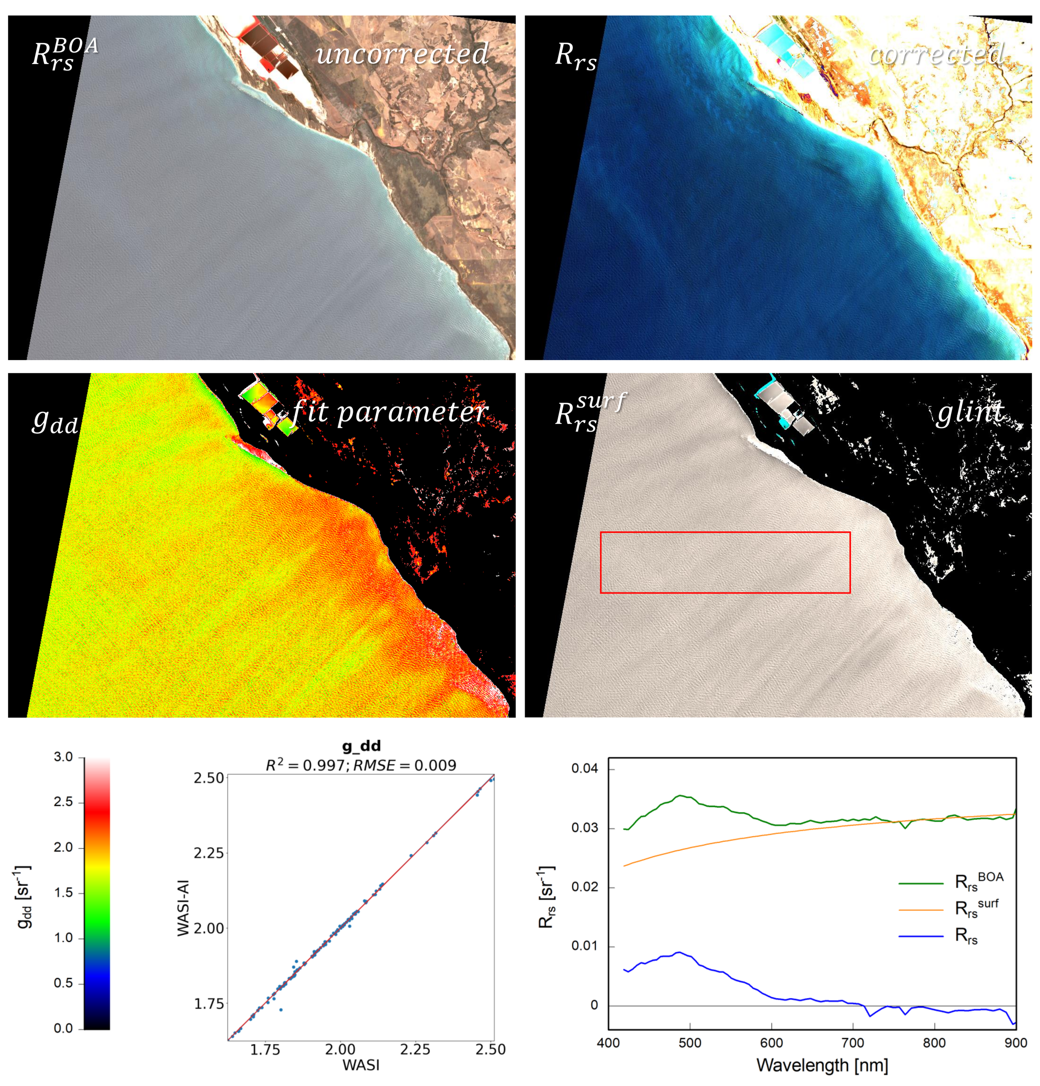
Landsat-9 image from Lake Constance, Germany/Austria /Switzerland, 2022-08-02. Little sun glint. The spectra R_{rs}^{BOA}, R_{rs}^{surf}, R_{rs} are averages from the area marked in the glint image.



Sentinel-2A image from Ventotene and Santo Stefano islands, Italy, 2023-06-26. Medium sun glint. The glint patterns caused by waves disappear completely, including the waves from ships.



DESIS image from Tam Giang Lagoon, Vietnam, 2023-05-03. High sun glint. Subtracting the bright glint image makes sensor artifacts (stripes) in the dark ocean visible.



EnMAP image from Western Australia, 2024-01-27. Extreme sun glint. The grayish appearence of the recorded image is caused by the very bright, slightly reddish glint overlaying dark blue water.