# Neural Networks for 4th reprocessing

*Technical note of the NNs with interfaces*

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## 1 Introduction

This document describes the neural networks, their interfaces and usage for the 4th reprocessing of MERIS data of case 2 water. It should be used together with the sample program written in *Scilab*.

The procedure has two parts: (1) an alternative atmospheric correction, which computes water leaving reflectances (rho_w) from top of atmosphere reflectances after gaseous and smile correction, and (2) the procedure to compute the inherent optical properties (IOPs) of the water from water reflectances rho_w, their uncertainties and the concentrations of total suspended matter (TSM) and chlorophyll.

The first part includes optionally neural networks to compute the path radiance reflectance (rho_path) and the downwelling and upwelling directed transmittances. The second part includes optionally neural networks to compute the downwelling irradiance attenuation coefficient and the uncertainties of all water products.

A new feature is the surface pressure as input to the atmosphere neural networks to correct for changes of Rayleigh scattering with pressure.

## 2 Overview of the NNs

### 2.1 *Alternative atmospheric correction*

Path to all nets:

```
../nets\richard_atmo_invers29_press_20150125

// rtosa auto NN, auto-associative neural network to detect out of scope TOSA reflectance spectra

aa_rtosa_nn_bn7_9 = nnhs('\rtoa_aaNN7\31x7x31_555.6.net');
```

***// rtosa-rw NN, network to compute water reflectance from tosa reflectance***

*inv_ac_nn9=nnhs('\rtoa_rw_nn3\33x73x53x33_470639.6.net');*

***// rtosa - rpath NN (optional) NN to compute the path radiance reflectance***

*rpath_nn9 = nnhs('\rtoa_rpath_nn2\31x77x57x37_2388.6.net');*

***// rtosa - trans NN (optional)NN to compute downwelling and upwelling transmittance***

*inv_trans_nn = nnhs('\rtoa_trans_nn2\31x77x57x37_37087.4.net');*

Input to all atmosphere nets are:

*// (9.4) )set input to all atmosphere NNs*

*nn_in=[sun_zeni,x,y,z,temperature, salinity, alti_press, log_rtosa];*

*sun_zeni is the sun zenith angle in degrees,*

*x,y,z are the cartesian coordinates of the viewing angle with respect to the sun azimuth,*

*temperature and salinity of the water in degree centigrade*

*alti_press is the atmospheric pressure at ground level in hPa, in case that the pressure correction has been performed already outside the NN, the entry has to be set to standard pressure of 1013.25 hPa.*

*log_rtosa: the natural log of 12 top of atmosphere reflections after gaseous and smile correction (412.3, 442.3, 489.7, 509.6, 559.5, 619.4, 664.3, 680.6, 708.1, 753.1, 778.2, 864.6 nm)*

output of the NNs:

*rtosa auto NN: log_rtosa with 12 bands as the input bands*

*rtosa-rw NN: log_rw with the 12 bands as above*

*rtosa-rpath NN: log_rpath with the 12 bands as above*

*rtosa-trans NN: 24 transmittance bands, sequence (1) transd downwelling transmittance (sun angle, 12 bands) and (2) transu upwelling transmittance (viewing angle 12 bands)*

## 2.2 Water NNs for IOPs, kds, concentrations and uncertainties

*Path to the nets is: ..\nets\coastcolour_wat_20140318*

*// rw-IOP inverse NN*

*inv_nn7=nnhs('\inv_meris_logrw_logiop_20140318_noise_p5_fl\97x77x37_11671.0.net');*

***// IOP-rw forward NN***

*for_nn9b=nnhs('\for_meris_logrw_logiop_20140318_p5_fl\17x97x47_335.3.net');*

***// rw-kd NN, output are kdmin and kd449***

*kd2_nn7 = nnhs('\inv_meris_kd\97x77x7_232.4.net');*

***// uncertainty NN for IOPs***

*unc_biasc_nn1=nnhs('\uncertain_log_abs_biasc_iop\17x77x37_11486.7.net');*

```
// uncertainty NN for adg, atot, btot, kd489 and kdmin
unc_biasc_atotkd_nn=nnhs('\uncertain_log_abs_tot_kd\17x77x37_9113.1.net');
```

input and output of the rw-IOP and rw-kd NN are:

*nn_in_inv=[sun_zeni view_zeni azi_diff temperature salinity log_rw(1:10)];*

*sun_zeni sun: zenith angle, view_zeni: viewing zenith angle and azi_diff, the difference between sun and viewing azimuth, all in degree*

*temperature and salinity of water surface*

*log_rw: the natural log of the water reflectance (not normalized!) for the first 10 bands*

*(412.3, 442.3, 489.7, 509.6, 559.5, 619.4, 664.3, 680.6, 708.1, 753.1).*

*Output of the rw-IOP NN are the natural log of the 5 IOPs ap (pigment), ad (detritus), ag (gelbstoff) absorption coefficient, and bp(particle), bw(white particle) scattering coefficient, all at 443 nm.*

*Output of the rw-kd NN are the natural log of (1)kdmin and (2) kd489.*

*Kd489 is the downwelling irradiance attenuation coefficient at 489 nm and kdmin the downwelling irradiance attenuation coefficient computed from the the three bands of MERIS with minimum kd values.*

input and output of the IOP-rw forward NN

*nn_in_for=[sun_zeni view_zeni azi_diff_deg temperature salinity log_iops_nn1];*

*here log_iops_nn1 is the ouput of rw-IOP inverse NN, i.e. the natural log of the 5 IOPs ap (pigment), ad (detritus), ag (gelbstoff) absorption coefficient, and bp(particle), bw(white particle) scattering coefficient, all at 443 nm.*

*Output is the natural log of the water reflectance rho_w at the 10 spectral bands (s. above).*

Input and output of the uncertainty NN for IOPs

*input are the natural logs of the 5 iops ap (pigment), ad (detritus), ag (gelbstoff) absorption coefficient, and bp(particle), bw(white particle) scattering coefficient, all at 443 nm.*

*Output are the differences between the natural logs of the IOPs of the simulation and the corresponding logs of the IOPs as output of the NN*

Input and output of the uncertainty NN for adg, atot, btot, kd489, kdmin

*input are the natural logs of the 5 iops ap (pigment), ad (detritus), ag (gelbstoff) absorption coefficient, and bp(particle), bw(white particle) scattering coefficient, all at 443 nm.*

*Output are the differences between the natural logs of adg, atot, btot, kd489, and kdmin of the simulation and the corresponding logs as output of the NN.*

# 3 Computational steps

*(s. also scilab program)*

All NNs are initiated in step2 of the program.

TOSA means here top of atmosphere after gaseous and smile correction. In the example program the reflectances are only corrected for ozone and water vapour (wv only for band 9). No smile correction is performed in this example. The pressure correction with respect to Rayleigh scattering is included in the NN for the range 800 – 1040 hPa.

## 3.1 Out of scope test of TOSA reflectance

First step of the procedure is to check if the TOSA reflectance spectrum after gaseous and smile correction is within the scope of the training data set (s. step 9.4). For this purpose an auto-associative NN is used. The output of this NN are the natural logs of the tosa reflectances, which are compared with the input tosa reflectances. The ratio between all corresponding bands of both spectra are computed and the spectral bands with minimum and maximum ratio are determined. The bands with the minimum ratio is inverted and the maximum of both, the maximum and the inverted minimum, is used as a measure of the out of scope degree. The flag is set if the minimum is below or the maximum above a pre-defined threshold. Presently these thresholds are 0.95 and 1.05 respectively.

Another flag (out of range flag) is set (or could be "ored" with the out of scope flag), if any of the input variables is outside the range of the training data set of the atmosphere neural networks (step 9.6.2). For this purpose the minima and maxima of all input variables are retrieved from the NN.

## 3.2 Computation of the water reflectance

The next step is the computation of the water leaving radiance reflectance rho_w (step 9.9), which is Lw/Ed*PI. Note: it is the directional reflectance, not normalized.

## 3.3 Optional computation of the path radiance reflectance and transmittances

An alternative way to compute the water reflectance is provided by computing the path radiances (step 9.7) and the downwelling and upwelling transmittances (step 9.8). This option is not used here.

## 3.4 Water neural networks

These include all NNs after the atmospheric correction. It is also the start, when the standard atmospheric correction of MEGS is used.

### 3.4.1 Computation of the IOPs and tests

The 5 IOPs, i.e. ap (pigment absorption coefficient), ad (detritus absorption coefficient), ag (gelbstoff absorption coefficient), bp (particle scattering coefficient), and bw (white particle scattering coefficient), are computed in step 9.10.1.

The IOPs are then used to compute the water reflectance with the forward NN (step 9.11). These reflectances are compared with the reflectances from the atmospheric correction in step 9.12.

The parameter, which is used here to test out of scope conditions, is the slope between band 2 (443 nm) and band 5 (560 nm). If the ratio of the 2 slopes, i.e. of the spectra after atmospheric correction and as output of the forwardNN, is outside a predefined threshold, a flag is triggered (step 9.12). Optionally the ratio is provided as a quality parameter to the user.

Another flag is set, if the input values to the NN are outside the minima – maxima range (step 9.10.2).

### 3.4.2 Optional computation of the downwelling irradiance coefficients

The downwelling irradiance coefficients kd490 and kdmin are computed with one NN in step 9.13.

### 3.4.3 Computation of combined IOPs and concentrations of TSM and chlorophyll

(step 9.14) The absorption coefficients of detritus (ad) and gelbstoff (ag) are not only treated as 2 independent components but also as two absorption components with similar spectral properties but with two different spectral exponents, which bracket the absorption coefficient of any humic material in the water. Thus, both are combined and provided as the absorption coefficient of adg (detritus+gelbstoff), which is one of the three standard products. The same happens with the scattering coefficient of standard (bp) and white particles (bw), which are combined to btot, which is then converted to TSM (total suspended matter) by multiplying btot by 1.73.

The pigment absorption is converted into chlorophyll concentration [mg m-3] by:

$$\langle chl.\rangle = 21.0 * ap^{1.04}$$

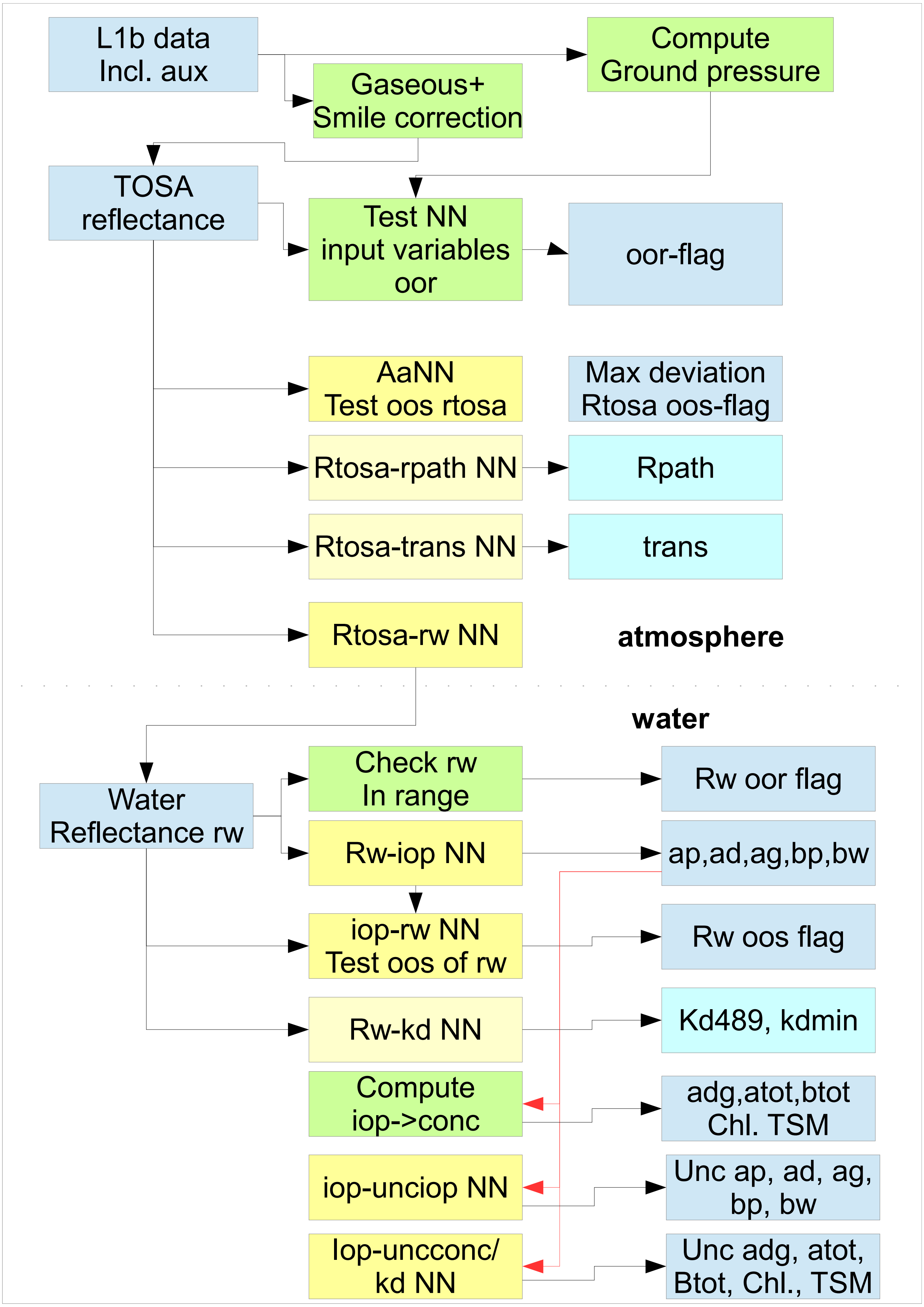
### 3.4.4 Computation of uncertainties

The uncertainties of IOPs are computed in step 9.15. The uncertaintyNN is trained with the IOPs as input and the differences between the natural logs of the simulated IOPs and the output of the inverse NN as output, thus they are a function of the 5 IOPs.

To convert this estimate of relative uncertainty into absolute quantities, the difference 1-ratio is multiplied with the corresponding retrieved IOP.

For determining the uncertainties of the combined IOPs and of the kds as special uncertainty NN was trained with the combined parameters and kds and is used in step 9.16 in the same way as the IOP uncertainties. The uncertainties of chlorophyll and TSM are derived from the uncertainty of *ap* and of *btot* respectively by converting these with the corresponding factors (s. above).

The overall flow is visualized in Fig. 1.



L1b data
Incl. aux
Compute
Ground pressure
Gaseous+
Smile correction
TOSA
reflectance
Test NN
input variables
oor
oor-flag
AaNN
Test oos rtosa
Max deviation
Rtosa oos-flag
Rtosa-rpath NN
Rpath
Rtosa-trans NN
trans
Rtosa-rw NN
atmosphere
water
Water
Reflectance rw
Check rw
In range
Rw oor flag
Rw-iop NN
ap,ad,ag,bp,bw
iop-rw NN
Test oos of rw
Rw oos flag
Rw-kd NN
Kd489, kdmin
Compute
iop->conc
adg,atot,btot
Chl. TSM
iop-unciop NN
Unc ap, ad, ag,
bp, bw
Iop-uncconc/
kd NN
Unc adg, atot,
Btot, Chl., TSM