Critical loads for eutrophication and acidification for European terrestrial ecosystems;

A project that supplied the UBA CCE with a flexible and well documented background data base for critical loads

Gert Jan Reinds, Max Posch, Jaap Slootweg

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Aim of the project

- Construct a database and software in R to compute critical loads for eutrophication (by Nitrogen) and acidification (by Nitrogen and Sulphur) for terrestrial ecosystems in Europe.
- Reporting of the background data used (maps, tables), the computational rules implemented to derive some of the data (e.g. transfer functions between soil type and soil characteristics) and of the procedures that compute the critical loads.
- ‘Validate’ this database and its results

Workpackages

- WP 1: Data compilation and assessment
- WP 2: Calculation of steady state critical load for eutrophication and acidification
- WP 3: Evaluation of the results
- WP 4: Final report and presentation

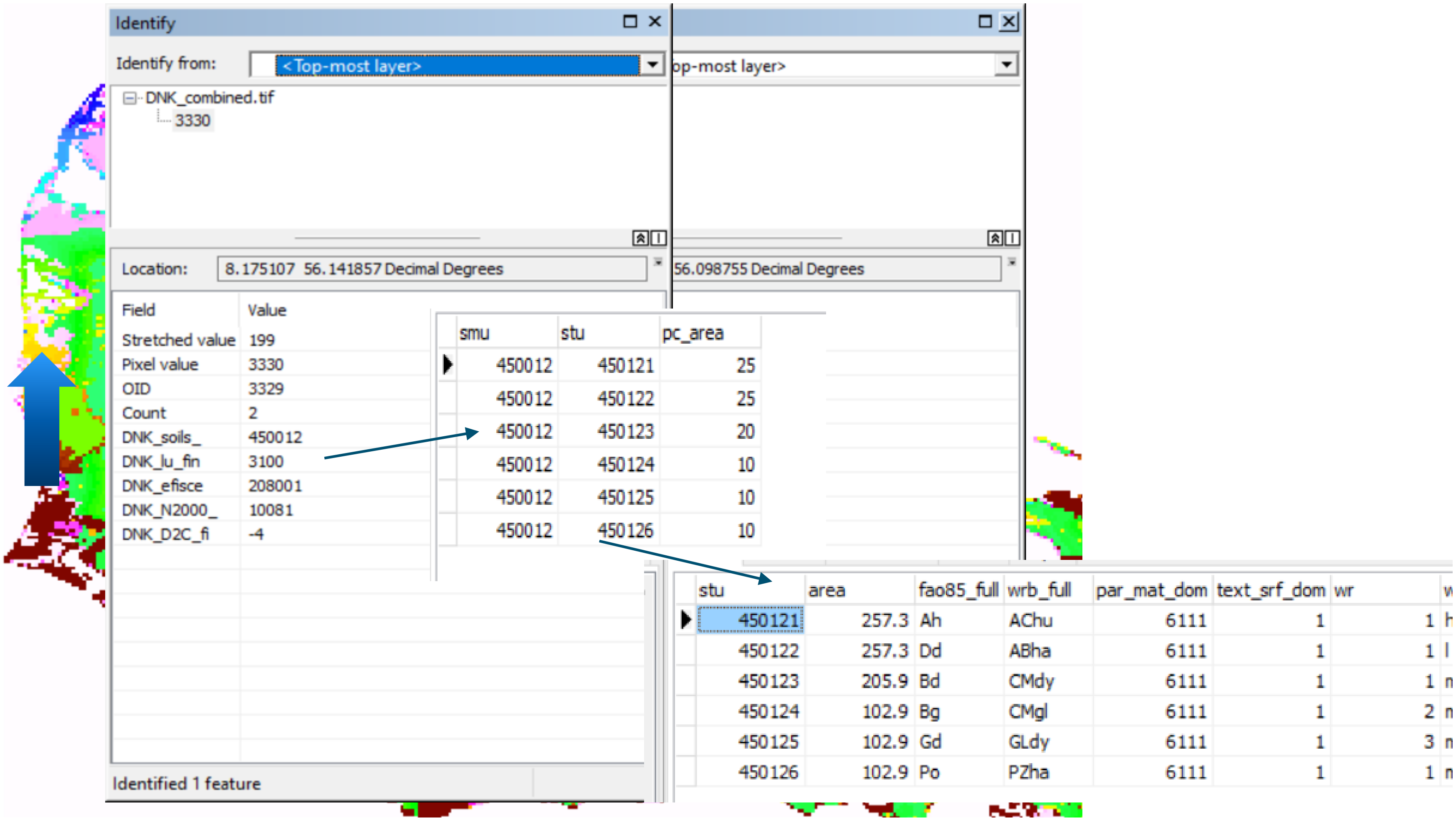
WP1: Compilation of data; geographical data

An ArcGIS-pro script in Python was made to combine maps of:

- *Land cover*: The harmonised LRTAP land cover map
- *Soils:* The latest version of the European Soil Database v2 map at a scale 1:1 M.
- *Forest growth regions*: Forest growth regions for Europe associated to the EFI database. For the parts of Russia mapped, 74 administrative regions.
- *Distance to coast:* The distance to coast from a NASA dataset
- *Nature 2000 areas:* The European Union's the latest delineation of Natura 2000 (N2k)
- Delineation of countries

Data are stored in georeferenced tiff files per country at 0.01*0.01 grid cells yielding 8.6 million unique receptors

Results of the map overlays



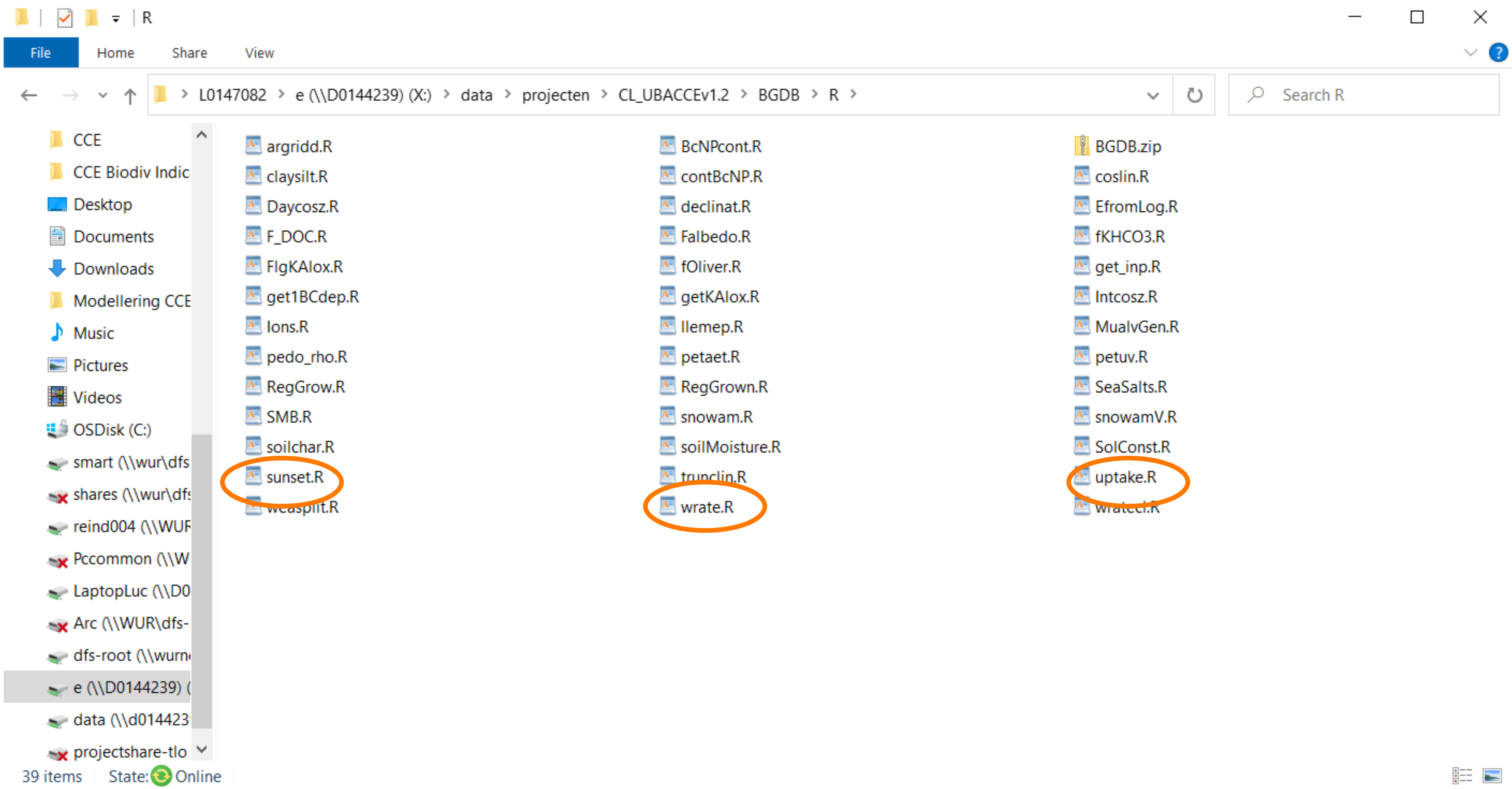
smu	stu	pc_area
450012	450121	25
450012	450122	25
450012	450123	20
450012	450124	10
450012	450125	10
450012	450126	10

stu	area	fao85_full	wrb_full	par_mat_dom	text_srf_dom	wr	w
450121	257.3	Ah	AChu	6111	1	1	h
450122	257.3	Dd	ABha	6111	1	1	l
450123	205.9	Bd	CMdy	6111	1	1	n
450124	102.9	Bg	CMgl	6111	1	2	n
450125	102.9	Gd	GLdy	6111	1	3	n
450126	102.9	Po	PZha	6111	1	1	n

Computing critical loads; setup

- A package (BGDB) was developed in R containing basic routines for e.g. computing weathering rates, nutrient uptake, sunset as a function of day in the year and latitude,etc.
- A number of scripts (BGRUN) was made for more elaborate computations, such as preparing meteorological data for use in MetHyd, reading the map overlay data, MetHyd computations of leaching etc.
- A main script was made (MainLoop.R) that carries out all tasks from initialisation, reading in data, running MetHyd, running SMB to writing out results

Basic routines are stored in a R package



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Example: compute the bicarbonate equilibrium constant as a function of temperature

3.2.2 Bicarbonate

The concentration of bicarbonate is computed according to:

$$[HCO_3] = \frac{K_1 \cdot K_H \cdot p_{CO2}}{[H]} \quad (3.6)$$

where K_1 is the first dissociation constant, K_H is Henry's constant and p_{CO2} is the partial pressure of CO_2 in the soil solution. Both the values of K_1 and K_H are temperature dependent and computed according to (Harned and Davis 1943):

$$lgK_H = \frac{2386}{T_{abs}} + 0.0153 \cdot T_{abs} - 14.018 \quad (3.7a)$$

$$lgK_1 = \frac{-3404}{T_{abs}} - 0.0328 \cdot T_{abs} + 14.844 \quad (3.7b)$$

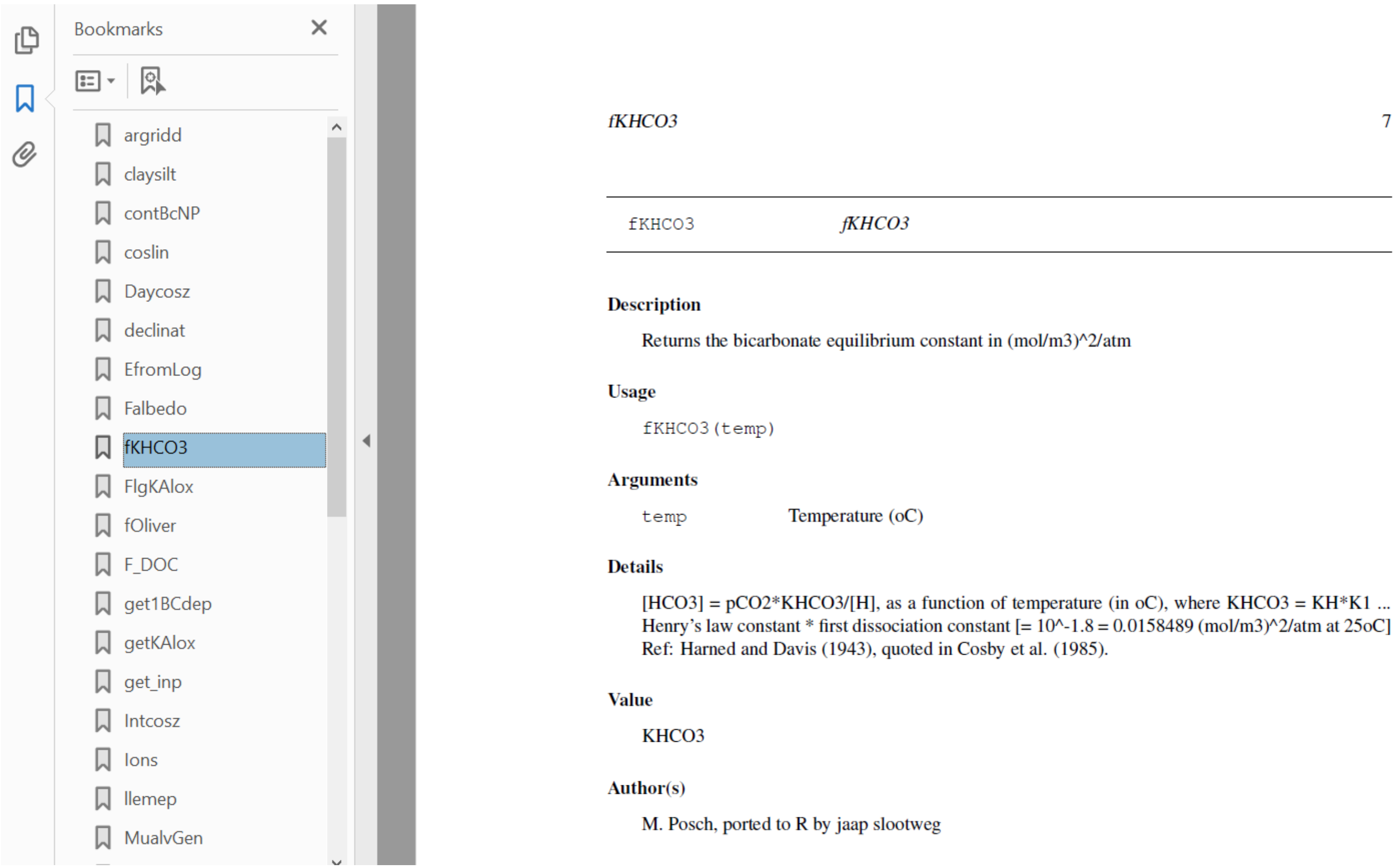
With T_{abs} is the temperature in K. Also the partial pressure of CO_2 in soil solution is computed as a function of temperature (after (Gunn and Trudgill 1982); see also Mapping Manual):

$$log_{10}P_{CO2} = 0.031 \cdot \vartheta - 2.38 \quad (3.8)$$

where ϑ is the temperature in degrees Celsius.

```
#' @title fKHCO3
#' @name fKHCO3
#' @author M. Posch, ported to R by jaap slootweg
#' @description Returns the bicarbonate equilibrium constant in
(mol/m3)^2/atm
#' @param temp Temperature (oC)
#' @details
#' [HCO3] = pCO2*KHCO3/[H], as a function of temperature (in oC), where
#' KHCO3 = KH*K1 ... Henry's law constant * first dissociation constant
#'        [= 10^-1.8 = 0.0158489 (mol/m3)^2/atm at 25oC]
#' Ref: Harned and Davis (1943), quoted in Cosby et al. (1985).
#' @return KHCO3
#' @export
fKHCO3 <- function(temp) {
  Tabs = 273+temp
  lgKH = 2386/Tabs+0.0153*Tabs-14.018
  lgK1 = -3404/Tabs-0.0328*Tabs+14.844
  10^(6+lgKH+lgK1)
}
```

Documentation of the package generated as a (bookmarked) PDF



fKHCO3 7

fKHCO3 *fKHCO3*

Description

Returns the bicarbonate equilibrium constant in (mol/m3)^2/atm

Usage

```
fKHCO3(temp)
```

Arguments

`temp`	Temperature (oC)

Details

[HCO3] = pCO2*KHCO3/[H], as a function of temperature (in oC), where KHCO3 = KH*K1 ...
Henry's law constant * first dissociation constant [= 10^-1.8 = 0.0158489 (mol/m3)^2/atm at 25oC]
Ref: Harned and Davis (1943), quoted in Cosby et al. (1985).

Value

KHCO3

Author(s)

M. Posch, ported to R by jaap slootweg

R procedures for more elaborate tasks: BGRUN

Some examples of R scripts of BGRUN

- Prepare the meteorological data by reading in Eobs data set and CRU data sets and replace missing values by (advanced) interpolation of available data (MakeMetSlice8.R)
- Read the results from the map overlays, remove units with e.g. bare rock or water bodies, assign soil characteristics to soil units such as organic mater content and soil water contents at different pressure heads etc. (GetSoilMap.R)

What is done in MainLoop

(1) Set criteria for the critical loads

(2) Specify whether meteorology must be prepared and/or MetHyd must be run

(3) Basic settings are made in EUCLpar.R on, e.g., soil depth and the wood density of trees.

(4) Get_Inp.R defines all other model parameters such as aluminium dissolution constant and the dissociation constant for organic acids.

(5) Growth and base cation (BC) deposition are read from files.

(6) Countries for which the model(s) need to be run are defined by their ISO-3166 2-letter code

(7) Read the soil map information

(8) Read the file _SoilChar.Tab that contains data for pH, organic carbon and nitrogen and CaCO3 content per soil type

(9) Determine the clay, sand and silt content of the soil based on the STU's texture class

(10) Read the meteorological data previously prepared with MkCrudeMet.R

(11) Get the rasters (.tif files) from the overlay procedures that belong to the countries that have been selected

(12) Start the master loop over the stripes of 0.5 degrees. Run MetHyd if needed

(13) Get from the already read-in data the base cation deposition for this latitude stripe

(14) Compute the weathering rates for all soils in the latitude stripe

(15) Compute the uptake of nutrients for each receptor in the latitude

(16) For critical loads based on base saturation (iAci = 3), set the exchange model to Gapon and set the exchange constants to standard values.

(17) Run the SMB model

(18) Make a dataframe (*AllData*) to store the results from SMB

(19) After all latitude stripes have been processed, write out the list of dataframes to an ASCII-file

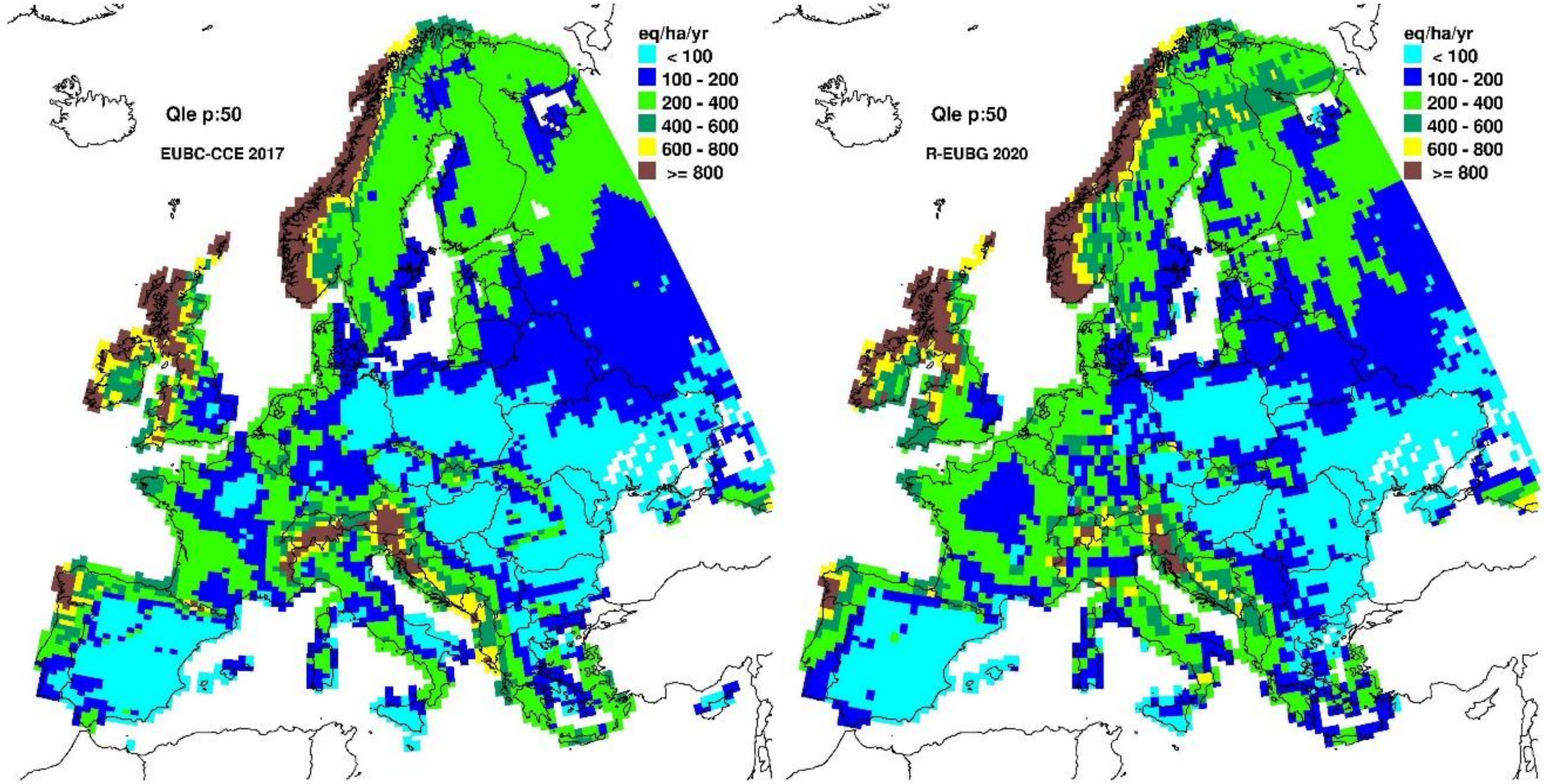
Performance

- A full run for the whole of Europe (8.6 million receptors) with running MetHyd (using 20 years of daily meteo) takes about 5 days
- A full run with an available MetHyd results run takes about 10 minutes!

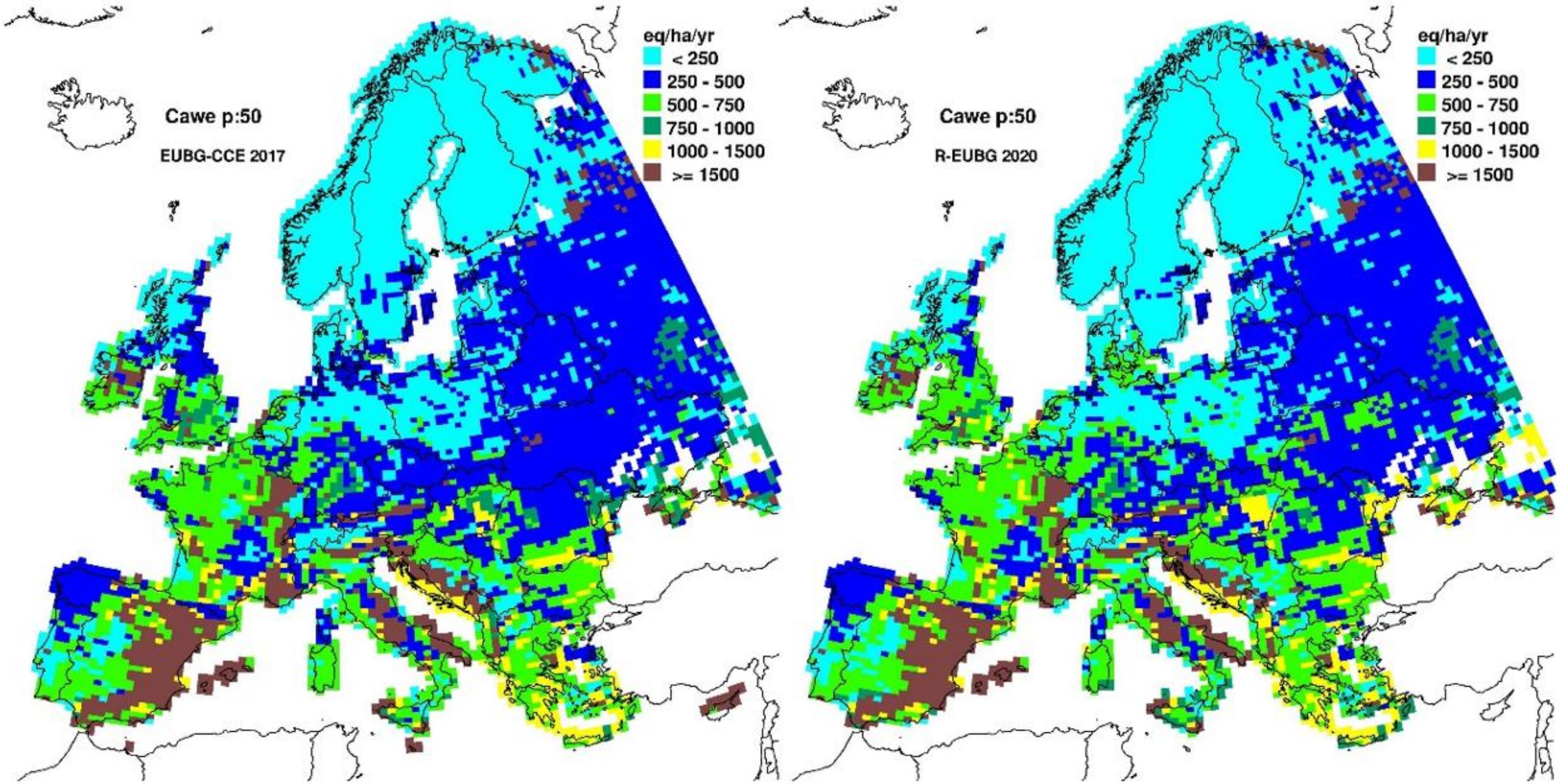
WP 3 Verification

- Results were compared to runs with the background DB of 2017.
- Slight differences may occur because of the update of meteorological data and changes in the setup of MetHyd, and because of updated forest growth data (=changes in nutrient uptake)
- Results were compared to NFC results from Ireland and Germany

Comparing results with 2017: Leaching



Comparing results with 2017: Ca weathering



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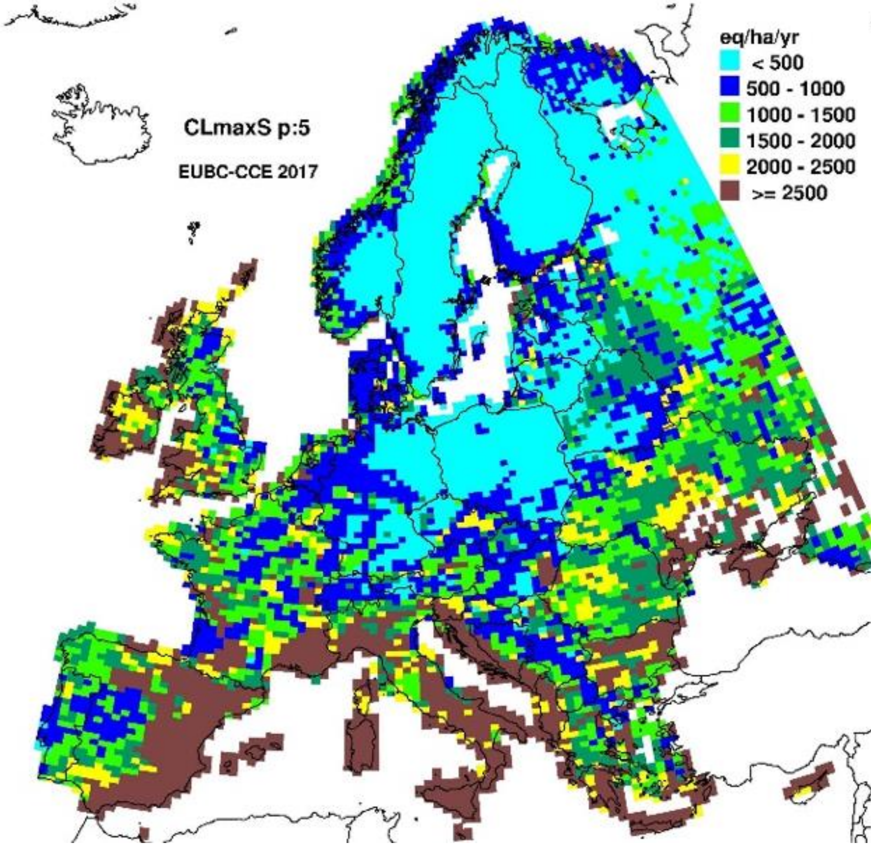
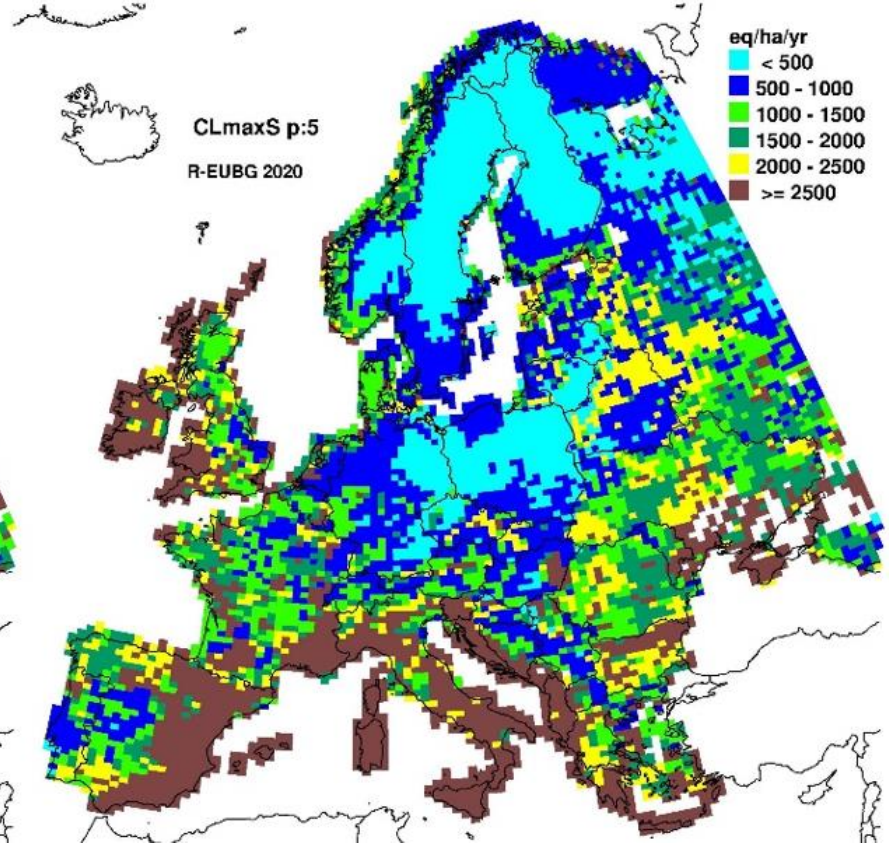
Comparing results with 2017: CLmaxS





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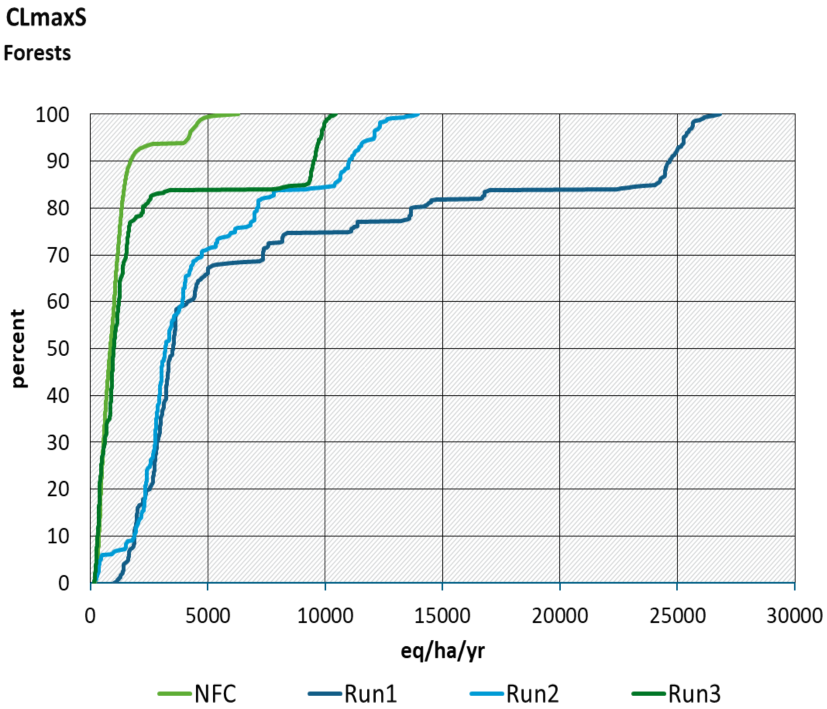
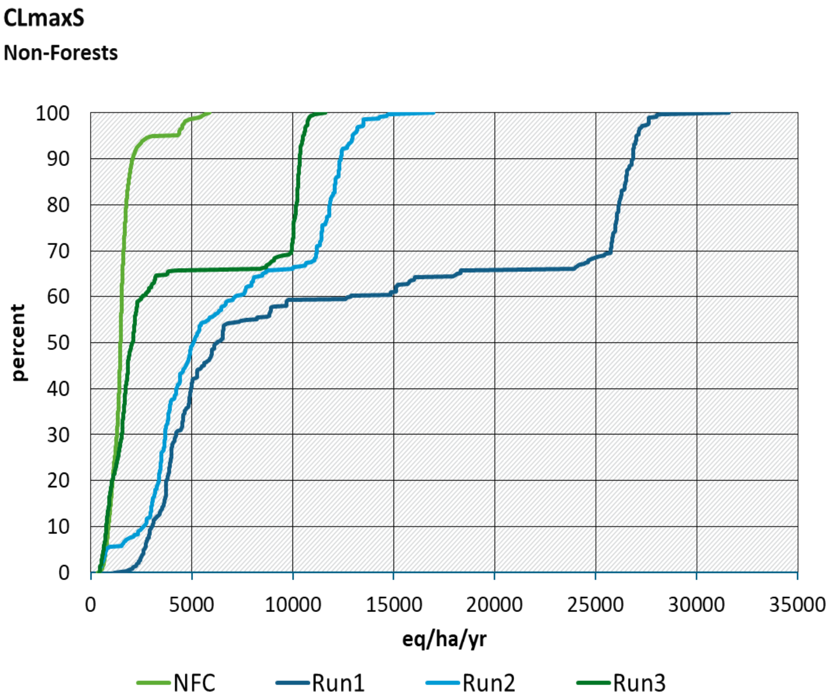
Comparison with CL's from the Irish NFC





Run1: Standard run with Al/Bc = 1, all BC ions separate, fixed lgKAlox (8.7 for mineral soils, 6.7 for peat)
Run2: Run with critical pH = 4.2 and BC merged in Ca, Mg deposition considered as sea-salt, fixed lgKAlox (8.7 for mineral soils, 6.7 for peat)
Run3: Run with critical pH = 4.2 and BC merged in Ca, Mg deposition considered as sea-salt and lgKAlox as a function of soil type

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Conclusions

- A fully operational system to compute critical loads with SMB was delivered to UBA. Map overlays are made using ArcGIS, computations in R
- By also making an R version of MetHyd, there is no more need for UBA to use any of the RIVM CCE FORTRAN based software
- Computational speed is very good given the fact that MetHyd needs to be run only once (unless meteorological data are updated)
- Result compare very well with the RIVM CCE background data base critical loads of 2017

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Conclusions (2)

- Comparison of results to national data is hampered by the fact that NFC's use different criteria, different underlying maps and different methods that cannot be reproduced (e.g. Germany uses > 20 different critical pH values depending on soil types on the German soil map)
- The project was fun to do, but costed more time than envisaged; especially testing and adapting the R procedure to make it reproduce the 2017 results was time consuming
- Cooperation with UBA was constructive and pleasant
- There will be an UBA report available on the work, hopefully this summer. Accessible to all.

Thank you for your attention!

To explore the potential of nature to improve the quality of life

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Python procedure