BIJLAGEN A-C

Nationaal Onderzoeksprogramma Broeikasgassen Veenweiden

SOMERS: Subsurface Organic Matter Emission Registration System

Beschrijving SOMERS 1.0, onderliggende modellen en veenweidenrekenregels.

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Inhoudsopgave Bijlage

A. SOMERS 1.0 technical description

SOMERS 1.0 is developed to efficiently make parcel-based computations of peatland CO_2 emission for large areas. SOMERS 1.0 is part of a multi model ensemble that was developed to register and comprehend CO_2 emissions from Dutch peatlands. SOMERS 1.0 consists of two modules: PeatParcel2D and the AAP-module. PeatParcel2D simulates the phreatic groundwater levels that are used to determine soil moisture and temperature over time and depth. The AAP-module uses these simulated soil moisture and temperature conditions to determine the potential aerobic microbial decomposition rate of soil organic matter in the unsaturated zone to calculate CO_2 emissions. This appendix provides the technical description of both modules. The specific application for Dutch peatlands is described in the main report.

A.1. PeatParcel2D module

A.1.1 Model setup

Figure A.1 shows the general set-up of PeatParcel2D. The PeatParcel2D module was developed to estimate two of the most important components of aerobic microbial decomposition of soil carbon: soil moisture and soil temperature (Figure A.1). The calculation of soil moisture and temperature is done on a parcel scale, based on input information that is available on nationwide scale. The foundation of PeatParcel2D is a 2D groundwater model, which simulates the phreatic groundwater level on a daily basis. Based on the groundwater dynamics, a soil moisture profile is determined. Soil temperature profiles are assigned separately, based on field measurements.

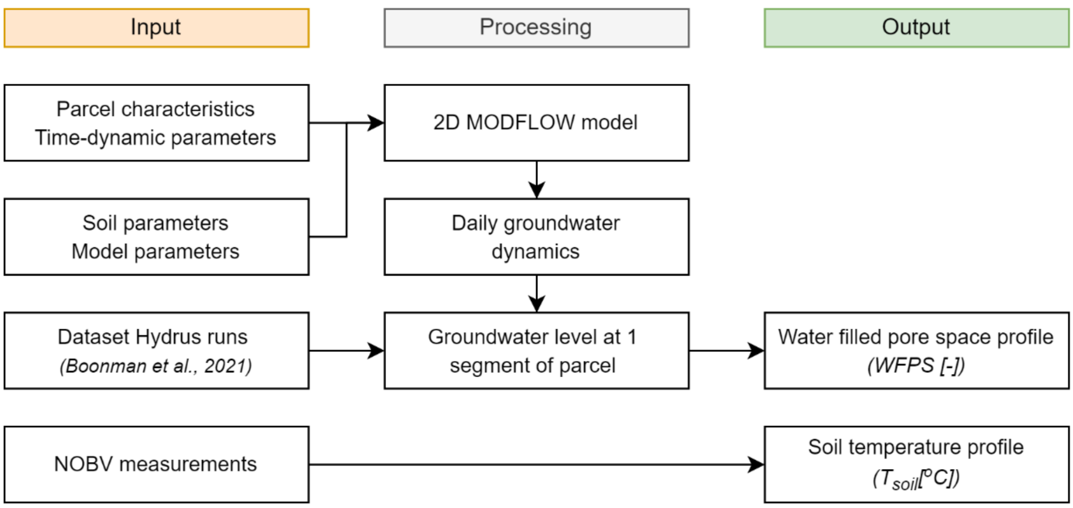

Figure A.1: Schematic design of PeatParcel 2D.

Instead of a dedicated unsaturated zone model, a (saturated zone) groundwater model is used to determine the conditions in the unsaturated zone. This approach was taken because of several reasons:

1. Unsaturated zone models, as opposed to groundwater models, are computationally heavy.
2. Groundwater measurements are, compared to soil moisture measurements, relatively abundant. These groundwater measurements can be used for calibration and validation of the model.
3. Hydrological measures aimed at CO_2 emission reduction, such as pressurized or regular subsoil irrigation and drainage systems, affect soil moisture profile through their impact on groundwater levels.

A.1.2 2D MODFLOW groundwater model

PeatParcel2D is a cross-sectional 2D MODFLOW-based numerical groundwater model to simulate the phreatic groundwater level along the width of the parcel between two ditches for a specified period. MODFLOW is a finite-difference flow model developed by the USGS in the early 1980's (McDonald & Harbaugh, 1988) and is widely used to simulate groundwater flow. The core mathematical model of the MODFLOW combines Darcy's Law (Darcy, 1856) and the principle of conservation of mass to describe movement of groundwater of constant density through a porous media.

PeatParcel2D utilizes the python-based FloPy environment (Bakker, et al., 2016) to automatically generate 2D MODFLOW6 (Langevin et al., 2017) groundwater models for individual peat parcels in the Netherlands. To deploy the model for any given parcel in the Dutch peatlands, all the required parameters should either be available from nationwide mapped datasets or based on logical and transparent assumptions. This means that four types of parameters to standardize the discretization and parameterization of the model can be distinguished:

1. *Parcel characteristics:* The parcel characteristics include the parcel width, surface elevation, ditch water levels and if applicable characteristic of the applied subsurface infiltration system. These parameters define the dimensions of the parcel and ditch water regime. For the national monitoring programme these parameters need to be derived from national datasets:
    - Parcel width: *Agrarisch Areaal Nederland* (PDOK, 2022; abbreviated as AAN) documents the geographical delineation of every individual parcel with agricultural land use in the Netherlands. Based on the assumption that every parcel approximates a rectangular shape, the parcel width can be estimated through Equation 1 using the parcel perimeter (P) and area (A):

$$parcel\ width = \frac{P - \sqrt{P^2 - 16A}}{4} \tag{1}$$

    - Surface elevation: Based on the AAN-shapefile an average surface level can be determined for every parcel using the Actueel Hoogtebestand Nederland (AHN, 2019). This is a digital elevation model of the Netherlands. The used recent version (AHN3) has a horizontal resolution of 0.5m x 0.5m and is based on data acquired between 2014 and 2019.
    - Ditch water levels: the ditch water levels are determined and managed by the water boards and are formally defined in *peilbesluiten.* Target water levels are set for so-called *peilvakken (water management areas),* which comprises numerous parcels. Often, a separate winter and summer target level is distinguished, but in other cases the target levels are variable (within bounds) through the year. In the model ditch water levels can be set either as a winter (October to March) and summer (April to September) level or as a timeseries if required.

    - Ditch depth: The bottom of the ditch is by default set to 50 centimetres below the winter level (Massop et al., 2006), but can also manually be adjusted.
    - Characteristics of a subsurface infiltration system: if applicable, the characteristics of infiltration systems can also be included. Until now these characteristics have not been mapped nationally and must be set manually. The application of infiltration drainage measures in the modelling is described in section A.1.7.
2. Soil and hydrogeological schematization: The soil and hydrogeological schematization determines the depth and interconnectivity of different hydrogeological units. Three sections are distinguished: soil profile, remaining Holocene layer and the aquifer system (Fig. A.2). The hydrogeological schematization is derived from / is explained further in the next section.
3. Time dynamic parameters: The time dynamic parameters are required to incorporate the hydrological boundary conditions of the model. This includes the groundwater recharge by precipitation minus evapotranspiration, which entered on a daily basis in the top cells of the model based on the precipitation map of The Netherlands Hydrological Instrument (NHI) (Hunink et al., 2020). This precipitation map was developed by the KNMI with precipitation and evaporation measurements and has a resolution of 1000 m x 1000 m (Janssen et al., 2020). The hydrologic head of the first aquifer was also obtained from the NHI to account for the interaction between the (Holocene) confining layer and the first aquifer.
4. Hydraulic parameters: The hydraulic parameters reflect the properties of the soil to transmit and store water in response to groundwater fluctuations. These parameters include the vertical and horizontal hydraulic conductivity, specific yield and specific storage. The derivation of hydraulic parameters is explained further in the next section.

The widths of the ditches are currently not taken into account. All height parameters are relative to *Normaal Amsterdams Peil* (NAP), the reference level used in height measurements in the Netherlands. Parameters from existing datasets are always defined for the centre of the parcel.

Figure A.1 shows the standard groundwater model set-up. The model width and top elevation are determined directly by the parcel characteristics. In the next section the model discretization, boundary conditions and parameterization will be discussed:

A.1.3 Discretization

A 2D model grid is created along the short side of a parcel in between two ditches. By default, the horizontal cell size is 0.5 m. The vertical discretization of the model is determined by the soil and hydrogeological schematization and is subdivided in three parts, as shown in Figure A.2.:

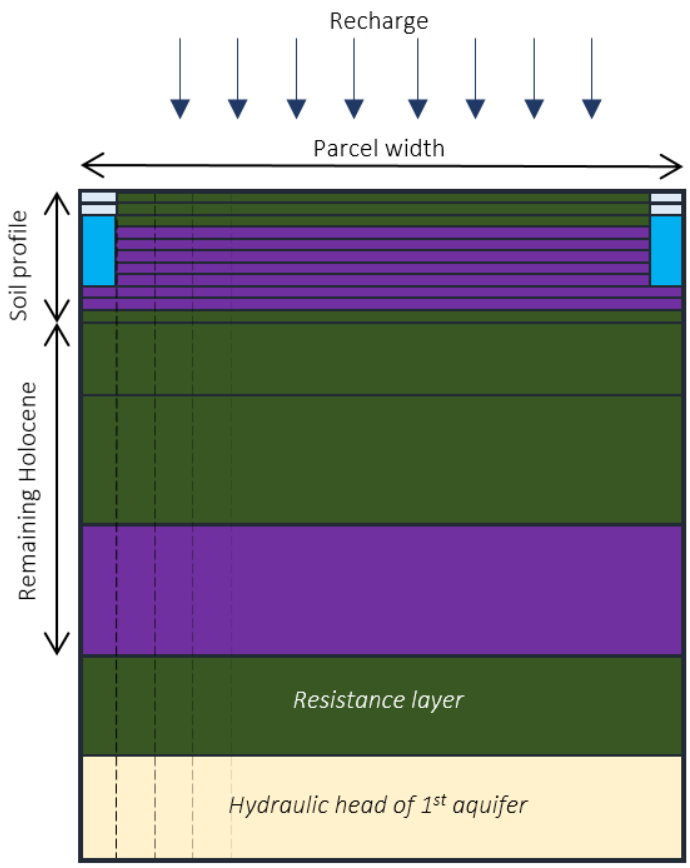

Figure A.2: Example of the setup of a PeatParcel2D model grid. Cells above the ditch level are non-active. The vertical discretization is based on the plot characteristics and the soil structure. The cells are assigned one of 3 categories: peat (purple), clay (green), or sand (yellow). The top cells have a fine discretization (5cm), since most of the groundwater fluctuation and aerobic degradation takes place in these cells. The resistance layer represents the vertical resistance of the Holocene layer on the hydraulic head of the 1st aquifer. The dimensions of both layers are obtained from the NHI (Hunink et al., 2020), as well as the resistance and head.

- Soil profile: The soil profile comprises the upper 1.2 meters of the model. The soil profile is assigned based on the archetype-classification and the BRO soil map (Brouwer et al., 2021), as described in Section 3.1 of the main report. Based on a characterization of Dutch soils by de Vries (1999), the archetype soil type gives information on the depth, lithology and organic matter content of different soil horizons. The soil profile is subdivided in model cells of 5 centimetre each. The vertical resolution is relatively high in this zone, because the groundwater table will predominately fluctuate within this zone and the aerobic decomposition occurs here.

- Remaining Holocene confining layer*:* The remainder of the Holocene layer is based of GeoTOP, which is the most detailed 3D subsurface model of the Netherlands (Stafleu et al., 2012). GeoTOP comprises of 100m x 100m x 0.5m voxels with information on the most likely lithology and geology up to 50 m below the surface. The attribute lithology is used to assign hydraulic parameters at a later stage. The attributed geology is used to determine the depth of the Holocene base. Below the Holocene base the aquifer system is present. As the upper 1.2m is already described by soil profile, the upper two voxels are excluded and the height of third voxel is adjusted to 0.3 m.

- Aquifer system: To account for the effects of seepage or infiltration the upper aquifer is incorporated in the model as constant head boundary. The dimensions of this layer are therefore not relevant. The aquifer is separated from the rest of the model by a resistance layer with a standard thickness of 0.5 m. This resistance layer represents the combined vertical resistance of the full Holocene layer and affects accordingly the vertical seepage or infiltration fluxes. The resistance is obtained from the schematization of The Netherlands Hydrological Instrument (NHI; Hunink et al., 2020).

For each cell, a distinction is made between 3 lithologies: peat, clay or sand, which determine the hydraulic parameters.

A.1.4 Boundary conditions

The boundary conditions represent locations in the model where water flows into or out of the model region due to external factors, such as ditches, precipitation, drainage etc. The standard model set-up includes 4 boundary conditions: the ditches, surface drainage, recharge by excess precipitation and the hydraulic head in the upper aquifer. The first two boundary conditions are defined by the parcel characteristics, the second two are defined by the time-dynamic parameters. Pressurized or non-pressurized subsurface infiltration systems are also represented in the model as boundary condition, but this is separately discussed in Section A.1.7.

- Ditches are incorporated in the model through a River package that is part of MODFLOW. A river stage, bottom and conductance must be specified. In a river package water leaves the model through the river boundary when the hydraulic head in the cell is higher than the river stage. Water enters the model through the river boundary when the head in de cell is below the river stage, but higher than the river bottom. The rate of flow is proportional to conductance and the difference between the river stage and the head in the cell.
  The river stage is directly determined by the ditch water levels, either as fixed winter and summer levels or as a timeseries. The river boundary is only active in the cells between the specified river stage and ditch bottom and may vary per timestep. The river bottom is equal to the cell bottom of every cell where the river boundary is active. Lastly, the conductance depends on the cell size, but corresponds by default to a resistance of the river bed material of 1 day. This is plausible given the fine discretisation, which means that the ditch covers several cells and no additional resistance is required.

- Surface drainage is incorporated in the model through a Drain package. Whenever the phreatic groundwater table rises above the surface level, the water is drained. A drain elevation and conductance must be specified. The drain elevation equals the surface level of a parcel and the conductance is by default 100 m^2/d.

- Recharge: recharge is incorporated in the model through a Recharge package. Only a recharge rate must be specified. Recharge represents groundwater recharge by surplus precipitation, from which runoff is not deducted. The daily recharge rate is obtained from the difference between precipitation and reference grass evapotranspiration calculated from interpolated maps produced by the Royal Netherlands Meteorological Institute (KNMI) for the Netherlands Hydrological Instrument (Janssen et al., 2020). The horizontal resolution of these maps is 1000m x 1000m.

- Hydraulic head of the first aquifer: the hydraulic head is the first aquifer is enforced through a constant head boundary. To account for the interaction between the (Holocene) confining layer and the first aquifer, the upper aquifer or entire aquifer system is included as boundary condition based on the Netherlands Hydrological Instrument (Hunink et al., 2020). The simulated hydraulic head at the location of the parcel is assigned to the first aquifer in the model.

A.1.5 Parameterization

The hydraulic parameters reflect the properties of the soil to transmit and store water in response to the groundwater fluctuations. These parameters include the vertical and horizontal hydraulic conductivity, specific yield and specific storage. Unfortunately, these parameters have not been mapped on a national scale and due their strong spatial variability, depending on the lithology, origin and human interaction (Holden et al., 2006), it will be difficult to do so.

To find representative values for these parameters nevertheless, the parameters are treated in two ways: 1) the horizontal hydraulic conductivity and specific yield are estimated through means of a calibration-analysis; 2) vertical hydraulic conductivity and specific storage are included under fixed assumptions. As parameters also relate to each other, not all hydraulic parameters can be determined by calibrating simultaneously. This could result in a large set of parameter combinations that do not necessarily reflect the physical properties of the subsurface and/or equifinality.

The hydraulic parameters are estimated by a calibration analysis using phreatic groundwater measurements. This is further explained in Section 4.1 in the main report, where a distinction is made between the 30 best parameter combinations for each region with different hydrological conditions. This regional approach for the calibration-analysis is discussed in depth in Chapter 4 of the main report. Here the focus is on the other assumption that underpins the approach for each of the parameters:

- Horizontal hydraulic conductivity (k_h): The hydraulic conductivity is often recognized as most dominant hydraulic property (Hooghoudt 1940, Ernst 1983). The phreatic aquifer is assumed to have a constant horizontal hydraulic conductivity over depth. This is an oversimplification but given only a single measurement of the groundwater level is available (rather than a series of head measurements over depth), variations in horizontal conductivity with depth cannot be identified reliably. The total transmissivity, or the rate at which groundwater flows horizontally through an aquifer, is most important when it comes to saturated groundwater flow, considering a large vertical flow resistance is absent in the phreatic aquifer, since this is represented by the resistance layer (section A.1.3). Therefore, the vertical hydraulic conductivity has a limited influence on the phreatic water table. A sensitivity analysis demonstrated that the model results are not very sensitive to this assumption indeed. A fixed vertical conductivity of 20% of the horizontal conductivity was assumed. The conductivity of the soil layers was calibrated within the model setup.

- Specific yield (S_y): The specific yield or drainable porosity is the volume fraction of a layer that will yield when the water can drain out under gravity. A distinction was made between a specific yield for clay and oxidised peat ($S_{y,clay}$) and a specific yield for reduced peat ($S_{y,peat}$) in the calibration analysis. Oxidised peat and clay share the parameter for specific yield because the degree of oxidation affects the hydraulic properties of peat. Oxidised peat often contains more mineralized components compared to reduced peat. Therefore, it was assumed that oxidised peat has properties more similar to clay as compared to reduced peat (Vos, 1975; Boonman et al., 2022).
  Also, a relation was implemented between the calibrated specific yield and depth consistent with De Louw (2013). In winter – when the groundwater table is relatively high, and the soil is moist – the specific yield is relatively small, whereas in the summer – with high groundwater levels and low soil moisture – the specific yield is relatively high. Therefore, the calibrated specific yield is multiplied by a correction factor, which linearly increases over the soil profile from 0.5 at surface level to 1.0 at a depth of 1.2 m.

- The elastic storage is by default set to 1.0e-5 (-).

- The drainage resistance is the resistance encountered by the groundwater flow towards or away from the drains. No distinction is made between different drainage and infiltration resistance. The use of drainage systems is elaborated in section A.1.7.

The 30 best parameter sets for each region can be seen in the tables below, Table A.1 to Table A.3.

Table A.1: 30 best parameter combinations for West Nederland.

Parameter set	Horizontal hydraulic conductivity (m/day)	Specific yield peat (-)	Specific yield clay (-)	Drain resistance (day)
1	0.3	0.6	0.25	20, 22
2	0.3	0.6	0.3	30, 40
3	0.4	0.3	0.5	28, 30
4	0.4	0.4	0.3	20, 22
5	0.4	0.4	0.4	28, 30
6	0.4	0.5	0.2	26, 28
7	0.4	0.5	0.25	26, 28
8	0.4	0.5	0.3	26, 28
9	0.4	0.6	0.1	22, 24
10	0.4	0.6	0.15	26,2 8
11	0.4	0.6	0.2	22, 24
12	0.4	0.6	0.25	24, 26
13	0.4	0.7	0.1	26, 28
14	0.4	0.7	0.15	28, 30
15	0.5	0.2	0.5	28, 30
16	0.5	0.3	0.4	26, 28
17	0.5	0.4	0.2	24, 26
18	0.5	0.4	0.25	30, 40
19	0.5	0.4	0.3	28, 30
20	0.5	0.4	0.4	30, 40
21	0.5	0.5	0.1	26, 28
22	0.5	0.5	0.15	28, 30
23	0.5	0.5	0.2	28, 30
24	0.5	0.5	0.25	28, 30
25	0.5	0.5	0.3	26, 28
26	0.5	0.6	0.1	26, 28
27	0.5	0.6	0.15	24, 26
28	0.7	0.2	0.3	30, 40
29	0.7	0.3	0.2	24, 26
30	0.7	0.3	0.25	38, 30

Table A.2: 30 best parameter combinations for Overijssel.

Parameter set	Horizontal hydraulic conductivity (m/day)	Specific yield peat (-)	Specific yield clay (-)	Drain resistance (day)
1	2.5	0.6	0.3	18, 20
2	2.5	0.6	0.4	22, 24
3	2.5	0.7	0.1	14, 16
4	2.5	0.7	0.3	20, 22
5	2.5	0.8	0.1	16, 18
6	2.5	0.8	0.15	18, 20
7	2.5	0.8	0.3	22, 24
8	5	0.4	0.4	20, 24
9	5	0.4	0.5	26, 28
10	5	0.5	0.1	12, 14
11	5	0.5	0.15	14, 16
12	5	0.5	0.2	16, 20
13	5	0.5	0.3	18, 22
14	5	0.5	0.4	26, 28
15	5	0.5	0.5	28, 30
16	5	0.6	0.2	18, 20
17	5	0.6	0.25	20, 22
18	5	0.6	0.3	24, 26
19	5	0.6	0.4	28, 30
20	5	0.7	0.1	18, 20
21	5	0.7	0.15	20, 22
22	5	0.7	0.2	22, 24
23	5	0.7	0.25	24, 26
24	5	0.7	0.3	26, 28
25	5	0.7	0.4	30, 40
26	5	0.8	0.1	20, 22
27	5	0.8	0.15	22, 24
28	5	0.8	0.2	24, 26
29	5	0.8	0.25	26, 28
30	5	0.8	0.3	28, 30

Table A.3: 30 best parameter combinations for Groningen / Friesland.

Parameter set	Horizontal hydraulic conductivity (m/day)	Specific yield peat (-)	Specific yield clay (-)	Drain resistance (day)
1	1.5	0.4	0.6	18, 20
2	1.5	0.5	0.1	18, 20
3	1.5	0.5	0.15	18, 20
4	1.5	0.5	0.2	18, 20
5	1.5	0.5	0.25	18, 20
6	1.5	0.5	0.3	18, 20
7	2.5	0.4	0.4	20, 22
8	2.5	0.4	0.5	20, 22
9	2.5	0.4	0.6	20, 22
10	2.5	0.5	0.1	22, 24
11	2.5	0.5	0.15	22, 24
12	2.5	0.5	0.2	22, 24
13	2.5	0.5	0.25	22, 24
14	2.5	0.5	0.3	22, 24
15	2.5	0.5	0.4	22, 24
16	5	0.3	0.3	22, 24
17	5	0.3	0.4	22, 24
18	5	0.4	0.1	26, 28
19	5	0.4	0.15	26, 28
20	5	0.4	0.2	26, 28
21	5	0.4	0.25	26, 28
22	5	0.4	0.3	26, 28
23	5	0.4	0.4	28. 30
24	5	0.4	0.5	28, 30
25	5	0.4	0.6	28, 30
26	5	0.5	0.1	28, 30
27	5	0.5	0.15	28, 30
28	5	0.5	0.2	28, 30
29	5	0.5	0.25	28, 30
30	5	0.5	0.3	28, 30

A.1.6 Regional groundwater model approach

Ditch water levels and/or implemented measures can differ between neighbouring parcels. But in case of a lower groundwater flow resistance due to thin peat or clay layers and/or a highly conductive layer underneath, the influence of measures in neighbouring parcels may stretch over larger distances. In these same conditions, the hydraulic head in the aquifer below the peat layers has a larger influence on the phreatic groundwater level. To simulate the groundwater dynamics in a parcel with more interaction with neighbouring parcels and the aquifer, the regional groundwater model approach was developed. This approach consists of two model modifications.

First, for the horizontal discretization, roughly 25 cells with exponentially increasing widths are added on either side of the ditches. Aside from the cell widths, all other parameters are kept constant. Next to these neighbouring parcels, roughly 2 kilometres of land is added, also with increasing cell widths. All these cells are assigned a ditch in their upper cells, which operates similar to the ditches in the main parcel but can also maintain a steady level.

Secondly, 7 aquitards and 7 aquifers are added below the parcel as given in the NHI discretization, instead of the single layers used in the single parcel method. Moreover, the heads in these aquifers are not assigned to each cell, but only to the outermost cells on the left and right borders of the model. This approach should dampen the extremes in the aquifer heads, more equally distribute pressures between the layers and therefore, reduce potential errors induced by the NHI.

This approach was implemented for the calibration of the Overijssel and Friesland/Groningen region (see chapter 4 in main report), since the simulations with the original model showed a big influence of the aquifer head on the groundwater level. This is a result of the relatively thin peat layer and therefore lower resistances. The calibration is further elaborated in the main report.

A.1.7 Water management measures

The effects of three different water management measures can be calculated in PeatParcel2D: increase of ditch water levels, pressurized or regular subsoil irrigation and drainage, or a combination of these measures. A ditch water level increase is implemented in the model through an adjustment of the river stage in the ditch boundary conditions.

Subsoil irrigation and drainage systems are represented in the model as a RIVER package and have a fixed depth and horizontal spacing. For a regular subsoil irrigation and drainage system the stage is equal to the ditch water level. For pressurized subsoil irrigation and drainage systems an explicit infiltration and drainage scenario is defined. Whenever the hydraulic head is lower than the stage in the drains, the water enters the model through this boundary (infiltrating), and whenever the head is higher than the head in model water leaves the model through this boundary (drainage).

The actual effect of the system is proportional to the difference between the stage and the hydraulic head in the cell and the predefined conductance. The conductance depends on the dimensions of the model cell and the drain resistance. The drainage resistance in this case is the resistance encountered by the groundwater flow towards or away from the drains. This means that it depends on the drain system itself, but also on the properties of the subsurface. In reality, the drain resistance can be different for water leaving and entering the drains, but this it at present not distinguished in the parametrisation.

Similar to the hydraulic parameters the drain resistance was determined through a stochastic approach. A large set of drain resistances was tested against measured phreatic groundwater level from parcels with subsoil irrigation and drainage systems. This is more extensively described in Chapter 4 of the main report.

A.1.8 Soil moisture

Soil moisture is based on the relation between simulated groundwater level and soil moisture (water filled pore space, or WFPS) profiles by Boonman et al. (2022). Although dedicated soil moisture simulations on parcel scale would provide more accurate results, the use o models on a national scale at present not applicable due to the long calculation times and required input parameters. In addition, measures such as (pressurized) subsoil irrigation and drainage, affect the soil moisture profile via the groundwater level.

The profiles compile average soil moisture profiles for a given groundwater level in 75 HYDRUS simulations from the study of Boonman et al. (2022) (Figure A.3). The 75 runs comprise different weather and surface water conditions. The simulations were made for a parcel width a width of 35 m and a typical peat meadow soil profile. A clay layer was absent in this profile, but it contained decomposed peat up to 60 cm below surface level. The moisture profiles were modelled for a profile at 2/5 of the ditch distance, which was assumed to be representative for 1/3 of the parcel, which was used in this study. Accordingly, the soil moisture profiles are assigned based on the with PeatParcel2D simulated groundwater level at 1/3 of the parcel width.

The profiles of Boonman et al. (2022) are based on the average from a simulation of one year per groundwater level on 2 locations. Different soil archetypes or the presence of measures are not yet considered. All of this may have a significant effect on the soil moisture profile. For future versions it will be examined whether these factors can be explicitly added to the system.

In addition to the groundwater level, in reality the soil moisture profile is affected by soil properties such as unsaturated permeability and porosity, by precipitation and (crop) evapotranspiration. These are currently not included in the model. However, the relationship between precipitation/evapotranspiration is implicitly included in these archetype profiles, because a low average groundwater level occurs more often in situations with relatively high evaporation.

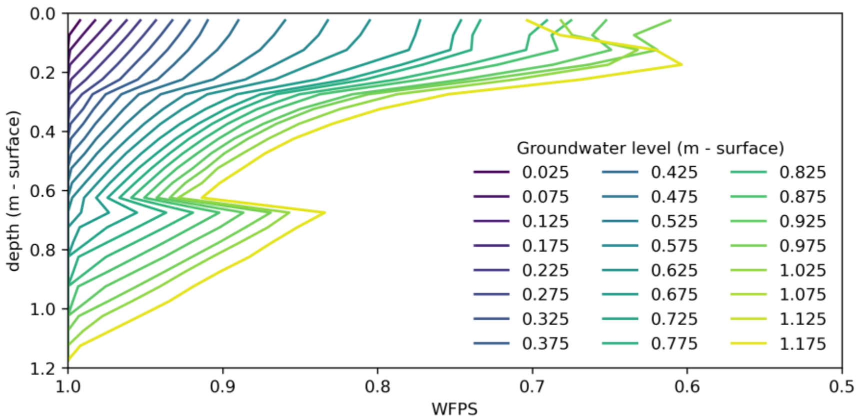

Figure A.3: Soil moisture profile from Boonman et al. (2022). A specific soil moisture profile (water filled pore space, or WFPS) is determined for each groundwater level, representative of the situation at 1/3 of the ditch distance, with a typical peat meadow soil without a clay layer with decomposed peat up to 60 cm below ground level. In subsequent versions of PeatParcel2D this will be expanded to represent different soils. Soils moisture profiles of 1.075, 1.125, and 1.175 m -surface are identical to the profile of 1.175 m and are not separately shown in the figure.

A.1.9 Soil temperature

Soil temperature is measured at all NOBV measurement sites. This version of PeatParcel2D is based on the temperature measurements at 4 locations on the reference and measure plots between 01-05-2020 & 01-02-2022. These measurements show relatively little variation between the different locations. Hence, PeatParcel2D uses averages of these measurements on all locations distinguishing between a summer and winter temperature profile (Figure A.4).

Distinguishing between a summer and winter temperature profile means that there is an abrupt transition from summer to winter temperature, which is in reality a slow transition depending on the air temperature. Furthermore, the soil structure and groundwater level are not explicitly included in the temperature calculations. Also, it is not taken into account yet that drainage measures can increase soil temperatures (Boonman et al., 2022). Therefore, the approach of other models in the multi model ensemble will be examined, and it will be investigated whether the soil temperature can be modelled in a simple way on the basis of the air temperature and soil properties for SOMERS 2.0.

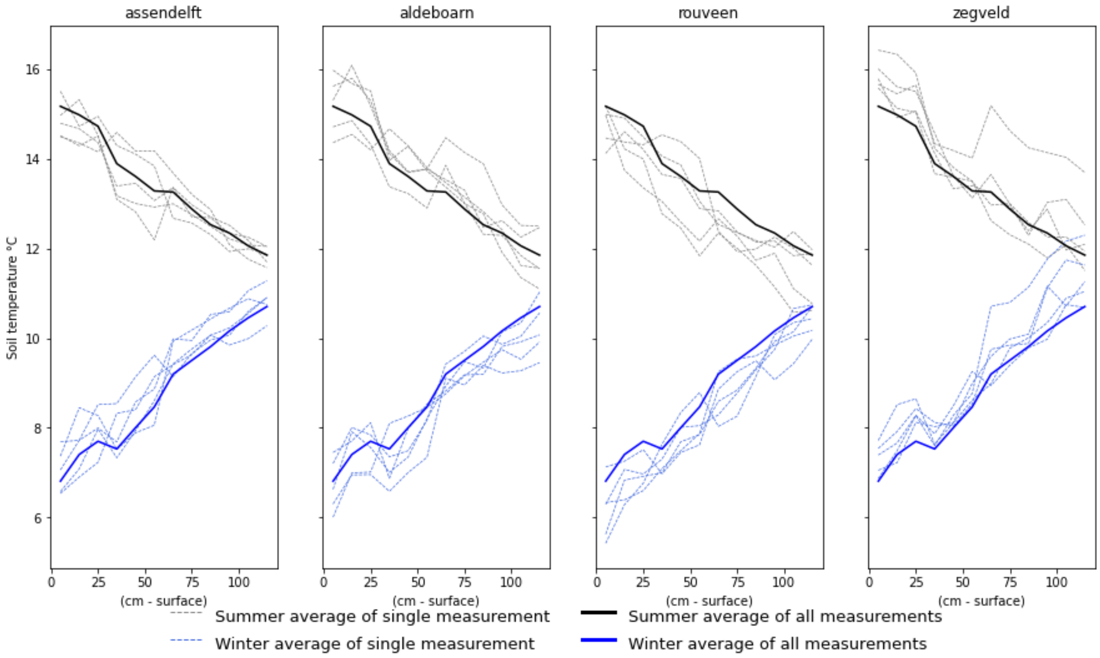

Figure A.4: Soil temperature profiles of measurements at NOBV locations between 01-05-2020 & 01-02-2022. during summer (black lines) and winter (blue lines). Dotted lines represent the average of summer or winter measurements at each location in either the reference plot or the plot with a measure. Due to the small variations are seen between the locations, summer and winter averages of all locations were used, shown as the solid lines.

A.2. Peat decomposition model (AAP-module)

A.2.1 Model set-up

The AAP-module is a peat decomposition model that was set up to make large scale estimations of CO_2 emission by aerobic microbial decomposition of soil organic matter in the unsaturated zone in a time-efficient manner. The approach to simulate potential aerobic microbial respiration rate is similar to the methodology presented by Boonman et al. (2022). The authors introduced a method to independently quantify the effect of soil temperature and soil moisture on the potential aerobic microbial respiration rate. In our peat decomposition model (Fig. A.5) the decomposition model of Boonman et al. (2022) was further expanded to estimate annual CO_2 emissions of drained Dutch peatlands at parcel resolution. The model does not account for the effect of secondary factors, such as soil pH or nutrient concentrations, as more complex models do.

Figure A.5 shows the general set-up of the AAP-module. The AAP-module estimates CO_2 emissions from soil moisture, soil temperature and soil organic matter content. The input grid conditions can either be based on modelled or measured data. However, the model was designed to seamlessly work with modelled output of PeatParcel2D. Therefore, the model is described based in the context of PeatParcel2D. The stepwise approach and underlying principles are explained in Sections A.2.2 to A.2.6.

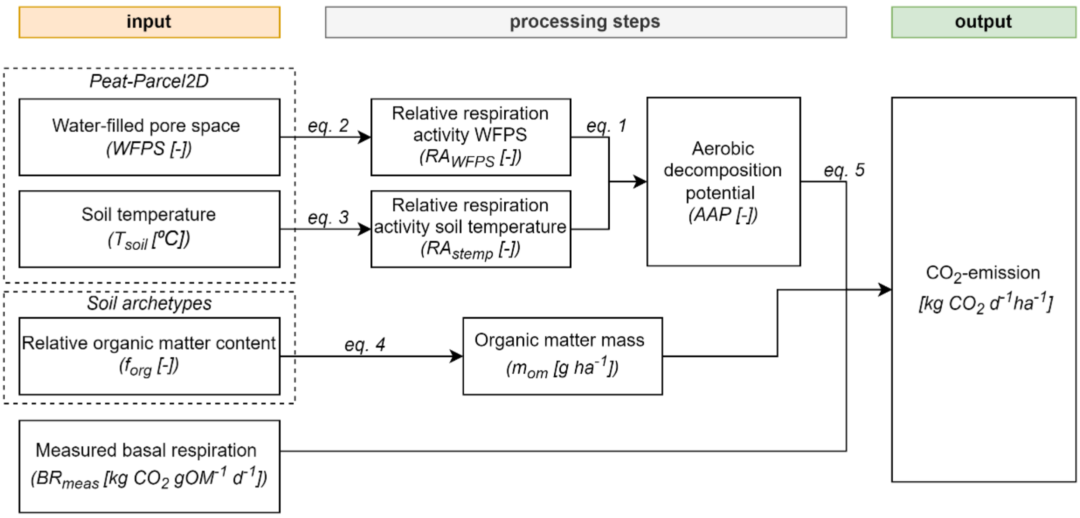

Figure A.5: General set-up of the AAP-module.

The AAP-module calculates the CO_2 emissions for each stochastic run (n) at every grid cell (z) and timestep (t). By default, PeatParcel2D returns water-filled pore space as a stochastic set to account for the uncertainty in the hydrological modelling. The stochastic uncertainty is then transferred in the aerobic decomposition potential, as n. The grid cell (z) has a vertical resolution of 5 cm and the timestep (t) has a temporal resolution of one day.

A.2.2 Aerobic decomposition potential

The aerobic decomposition potential (AAP) describes the potential aerobic microbial activity as compared to a reference situation. In the same manner as the work of Boonman et al. (2022), it was assumed that AAP is solely and independently affected by soil moisture and soil temperature. Accordingly, AAP is given by Equation 2, which is the product of two terms that separately describe the effect of soil moisture ($WFPS$) and soil temperature (T_{soil}) on the aerobic respiration activity (RA) compared to a reference situation. It is thus assumed that there is no interaction between these factors.

$$AAP(n,z,t) = RA_{WFPS}(n,z,t) * RA_{T_{soil}}(z,t)$$

(2)

The aerobic decomposition potential is 1 for a soil temperature of 20 $°C$ and water-filled pore space of 0.65. Soil temperatures or soil moisture contents that differ from these values will negatively affect the effectivity of the microbial community and thus lower the respiration rates. Alternatively, a higher soil temperature will stimulate the microbial activity and increase the CO_2 production. Using Equation 1, the aerobic decomposition potential is calculated for each stochastic run (n) at every grid cell (z) and timestep (t).

A.2.3 Relative aerobic respiration activity – soil moisture

For effect of soil moisture on the aerobic microbial decomposition activity the study of Boonman et al. (2022) is used. Boonman et al. (2022) used the shape of the parabolic response curves of CO_2 fluxes to water-filled pore space (WFPS), derived by Säurich et al. (2019) based on long-term incubation experiments, to create and test an ensemble of WFPS-activity curves against measured nocturnal ecosystem respiration rates at two Dutch (NOBV) measurement sites. The best fit was found as a beta distribution shown in Equation 3.

$$RA_{wfps}(n,z,t) = \frac{\beta(WFPS(n,z,t),2.59,1.84)}{\beta(0.65,2.59,1.84)}$$

(3)

The effect of WFPS on aerobe microbial activity (Figure A.6.a) is optimal for a WFPS of 0.65. This is roughly equal to 70% of the field capacity of peat soils, depending on the structure of the peat. Figure A.6.b shows an example of the relative aerobic respiration activity related to soil moisture in time and depth. The largest respiration activity occurs in the shallow, unsaturated soil during the summer period with relatively low phreatic ground water tables.

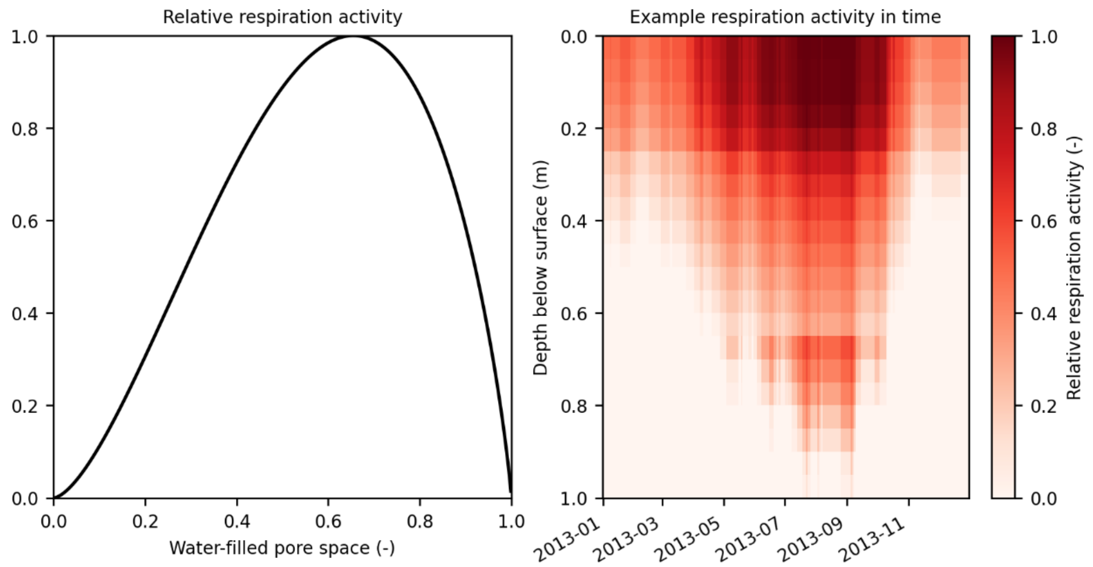

Figure A.6a (left): The effect of water-filled pore space on aerobe microbial activity. A.6b (right): The relative aerobic respiration activity related to soil moisture in time and depth.

A.2.4 Relative aerobic respiration activity – soil temperature

Although the effect of soil temperature on the aerobic microbial decomposition has been more thoroughly studied than that of soil moisture, the effect of soil temperature on aerobic microbial decomposition has also not been unambiguously established. Similar to the soil moisture activity curve, the temperature activity curve for the potential respiration rate as adapted for peatlands by

Boonman et al. (2022) is applied. The relation is based on the work of Ratkowsky et al. (1983), Lloyd & Taylor (1994) and Bååth (2018), see Boonman et al. (2022) for further details. The soil temperature is assumed to influence potential respiration rates according to Equation 4, with fitted $T_{soil,min}$ of -10°C and a of 0.05 (Boonman et al., 2022). The equation relates aerobic microbial activity and soil temperature relative to a reference condition of 20 °C.

$$RA_{stemp}(z,t) = \frac{\left(a\left(T_{soil}(z,t) - T_{soil,min}\right)\right)^2}{\left(a\left(20\,°C - T_{soil,min}\right)\right)^2} \quad (4)$$

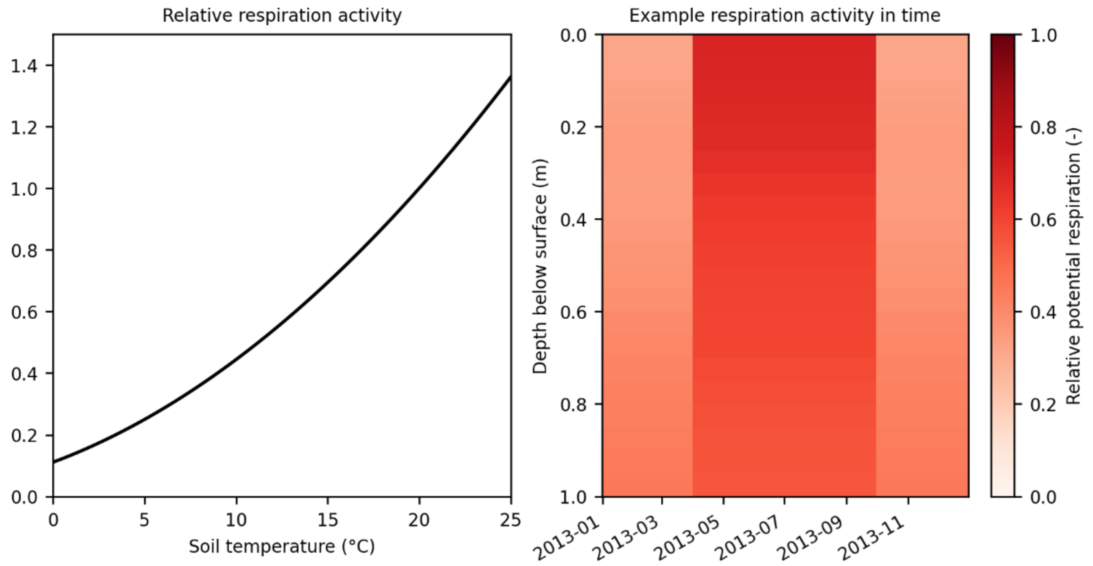

Figure A.7a (left): The effect of soil temperature on aerobe microbial activity. A.7b (right): The relative aerobic respiration activity related to soil moisture in time and depth.

The relation in Figure A.7.a shows that the microbial activity will exponentially increase with temperature. Figure A.7.b shows an example of the relative aerobic respiration activity related to soil temperature in time and depth based on the soil temperature output of PeatParcel2D.

A.2.5 Uncertainty in relative aerobic respiration activity-curves

The relative aerobic respiration activity curves as established by Boonman et al. (2022) are not conclusive. Similar relations have been derived and are used in more complex respiration models, such as PEATLAND-VU (Van Huissteden et al., 2006) and SWAP-ANIMO (Renaud et al., 2005; Kroes et al., 2017). Intercomparing these relations show slightly deviating trends between temperature, water-filled pore space and aerobic decomposition potential for the different models (Figure A.8). At present, none of the relations are substantially better than others.

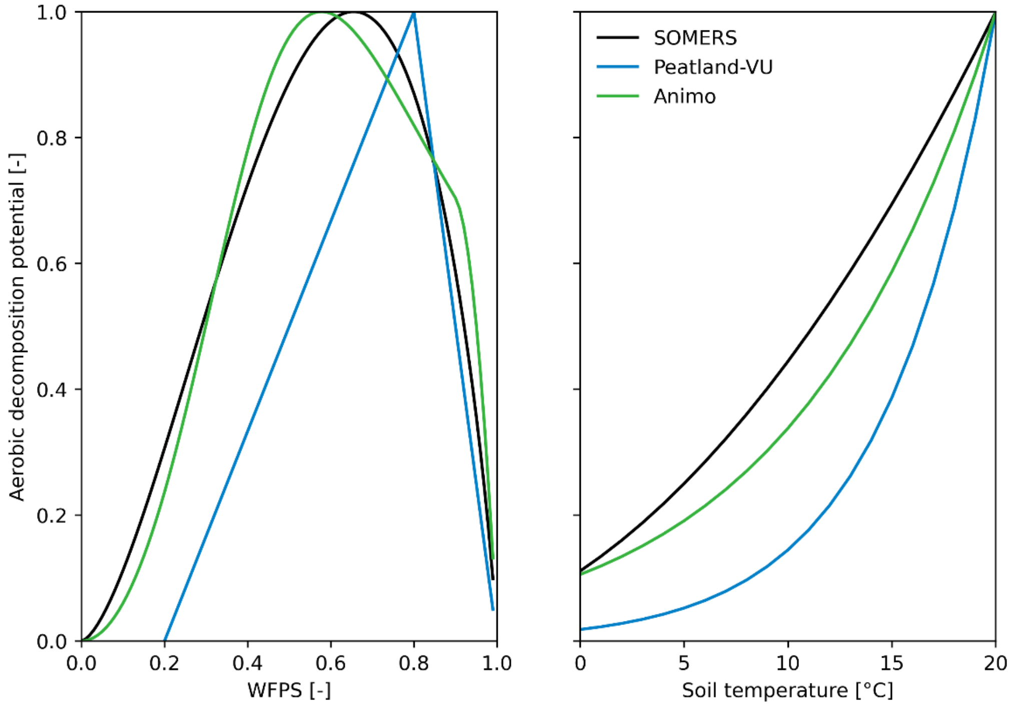

Figure A.8: aerobic respiration activity curves for soil temperature and water-filled pore space for the different models within SOMERS.

A.2.6 CO_2-emission

Incubation measurements have demonstrated that peat samples collected from different NOBV-locations in the Netherlands show largely similar respiration rates when corrected for the organic matter content and when exposed to similar standardised conditions (Erkens et al., 2020). In view of these findings, the *aerobic decomposition potential* can be used to establish the CO_2 respiration in circumstance that the soil moisture and soil temperature conditions deviated from the reference conditions (AAP = 1).
All samples for basal respiration measurements were collected from the oxidation-reduction transition zone and were remoulded exposed to a constant temperature of 20 $°C$ and a soil moisture content of 70% field capacity. These conditions are close to the optimal WFPS conditions and reference temperature conditions for which Boonman et al. (2022) established the activity/respiration-curves (AAP=1).

The results of the incubation experiments done by Erkens et al. (2020) (Figure A.9) show that basal respiration rate (BR_{meas}) roughly varies between 200 and 500 µg CO_2 per day per gram organic matter, with an overall mean of 313.83 (µg CO_2 gOM-1 d-1).

It should be noted that incubation measurements on the peat samples collected from the NOBV-measurement site in Assendelft showed significantly higher respiration rates than the samples collected from the other sites. Potentially the relatively high sulphate concentrations in the soil at Assendelft, which can also act as an oxidizer, increases the basal respiration rate in these samples. However, as neither the guiding mechanisms nor the extent of these conditions are at present not fully understood, these results were not included in the calculation of the mean basal respiration rate (BR_{meas}).

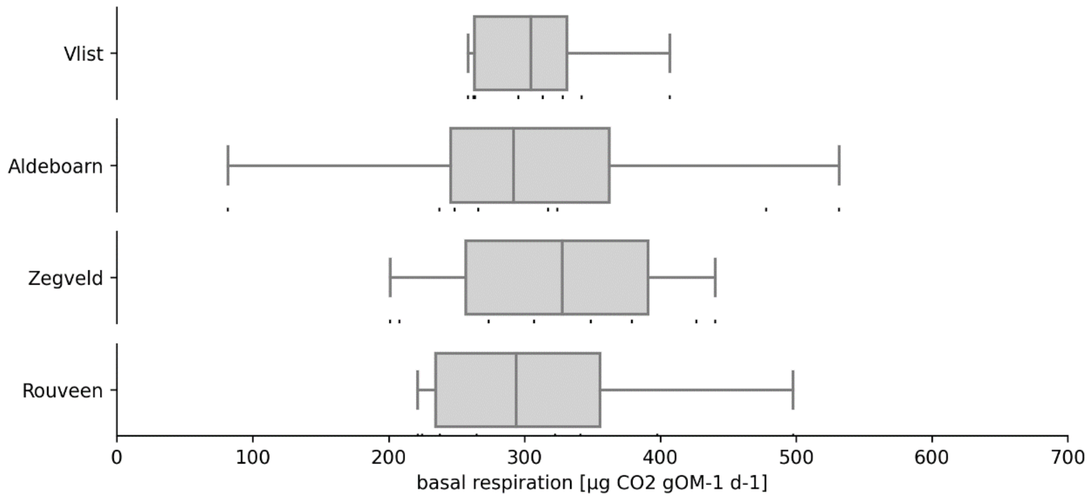

Figure A.9: Measured basal respiration rates of peat samples collected from different NOBV-measurement locations. Measurements were carried out under optimal conditions in a laboratory (Erkens et al, 2020).

Incubation measurements corrected for the soil organic matter content give similar respiration rates, implying that the respiration rates themselves are also affected by the soil organic matter content. Unsurprisingly the CO_2 emission rate increases with the total mass of organic matter in a soil. Although organic matter mass has not been mapped widely for the Netherlands, de Vries (1999) published standardized soil profile characterizations including relative organic matter content (f_{org}) per soil horizon. Based on the empirical relation between relative organic matter content and organic matter density, fitted on almost 1000 analysed soil samples from the Netherlands (Erkens et al. 2016), the mass of organic matter (m_{om}) could be estimated at every grid cell (z) using Equation 5.

$$m_{om}(z) = \frac{100}{f_{org}(z)} * \left(1 - e^{-\frac{f_{org}(z)}{0.12}}\right) * f_{org}(z) * V_{gridcell}(z) \tag{5}$$

By default, $V_{gridcell}$ is 500 m^3 corresponding to cells with a vertical resolution of 5 cm and a horizontal resolution of 100x100 m^2. The latter enables reporting the CO_2 emissions per hectare, which is a unit commonly used in the Netherlands. Multiplied with the area of a parcel (in ha) gives the CO_2 emission for that parcel per year.

Following all the equations as described above, CO_2 emission for every grid cell, day and stochastic run can be estimated using Equation 6.

$$CO_2(n, z, t) = AAP(n, t, z) * m_{om}(z) * BR_{meas} \tag{6}$$

By integrating over time and depth an annual CO_2 budget per ha per year can be established with an uncertainty range reflecting the uncertainty in the hydrological modelling.

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B. Tabel kalibratielocaties

Locatie	*Archetype*	*X (RD)*	*Y (RD)*
West Nederland			
Vinkeveen	hV	125263	467706
Zegveld	hV	117382	461007
Zegveld	hV	117417	461011
Zegveld	hV	117474	461022
Zegveld	hV	117541	461017
Vlist	pV	116282	443895
Assendelft	hV	111039	498872
Spengen	pV	122895	462559
Spengen	pV	122827	463208
Langeweide	hV	114041	452202
Langeweide	hV	114112	452206
Langeweide	hV	113704	452509
Spengen	pV	122858	463149
Overijssel			
Rouveen	kV	202541	516569
Staphorst	hV	206582	518603
Staphorst	hV	204300	518738
Rouveen	aVz	206766	516847
Rouveen	hV	205796	513457
Rouveen	pV	203552	513362
Zwartsluis	pV	203028	514262
Friesland			
Hegewarren	pVc	189089	568681
Lytse Deelen	hVs	191970	562340
Koufurderigge	kV	174107	550797
Koufurderigge	kV	173319	551463
Gaastmeer	kV	165893	552858
Idzega	kV	166382	554946
Gaastmeer	kV	166089	552989
Aldeboarn	kV	189684	563069
Totaal	28		

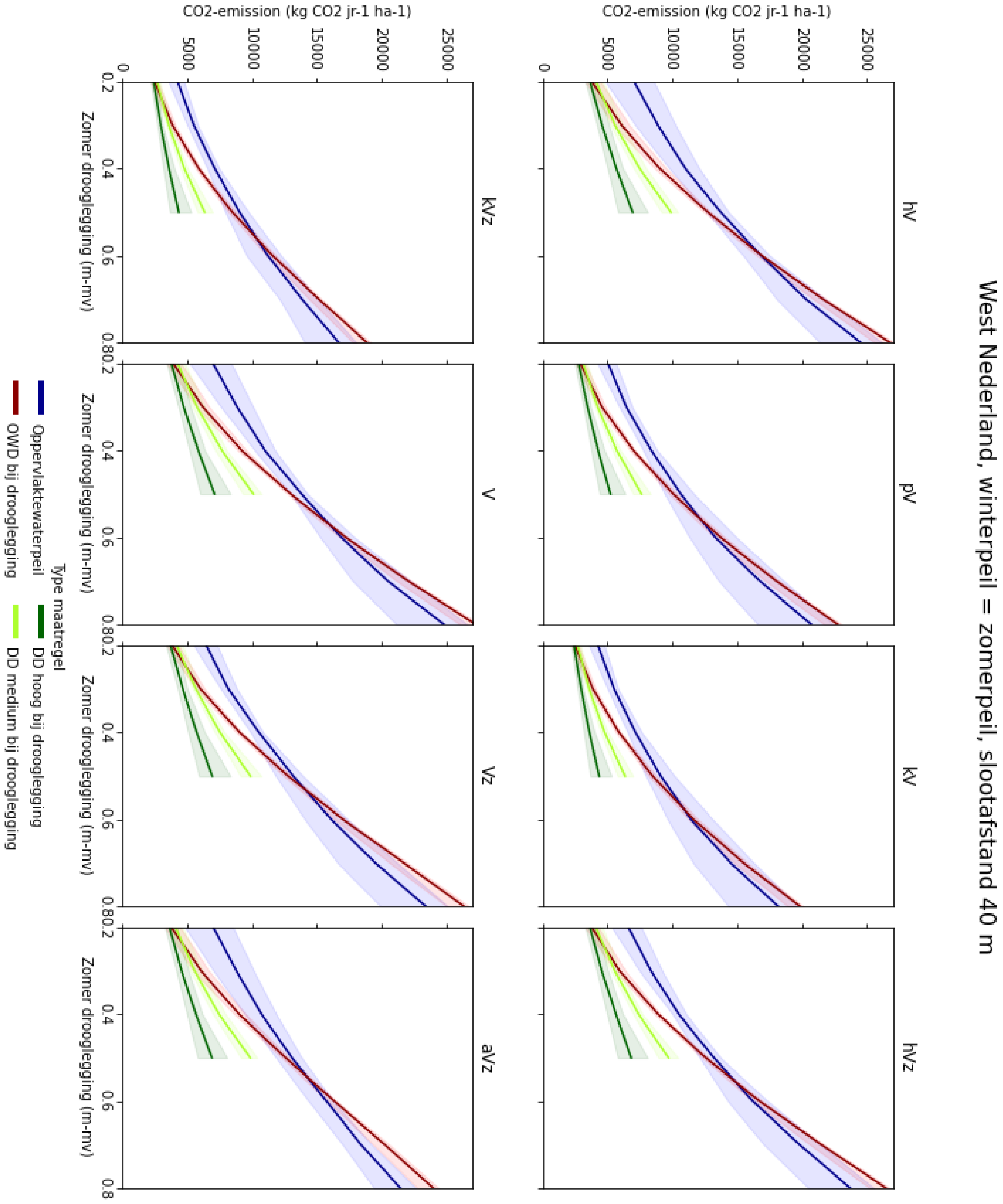
Locatie	*Archetype*	*X (RD)*	*Y (RD)*
West Nederland			
Vlist	pV	116356	443907
Zegveld	hV	117425	460931
Zegveld	hV	117476	460940
Zegveld	hV	117542	460947
Spengen	pV	122858	463149
Langeweide	hV	114276	450553
Langeweide	hV	114360	449790
Langeweide	hV	113964	451379
Langeweide	hV	114492	449500
Langeweide	hV	114630	450084
Overijssel			
Rouveen	kV	202520	516420
Staphorst	pVz	205729	520680
Staphorst	hV	206570	518571
Staphorst	hV	204300	518690
Rouveen	aVz	206942	516805
Rouveen	aVz	207777	512546
Rouveen	hV	205804	513407
Rouveen	pV	203574	513332
Zwartsluis	pV	202788	514412
Friesland			
Koufurderigge	kV	173064	551436
Spanga	hV	188266	537357
Koufurderigge	kV	174101	550736
Gersloot	Vz	192065	560163
Aldeboarn	kV	189543	563101
Totaal	24		

C. Figuren Rekenregels SOMERS 1.0

Op de website van het NOBV (www.nobveenweiden.nl) zijn de rekenregels ook als excelfiles gepubliceerd.

Inhoudsopgave Bijlage C

West-Nederland, winterpeil = zomerpeil, slootafstand 40 m



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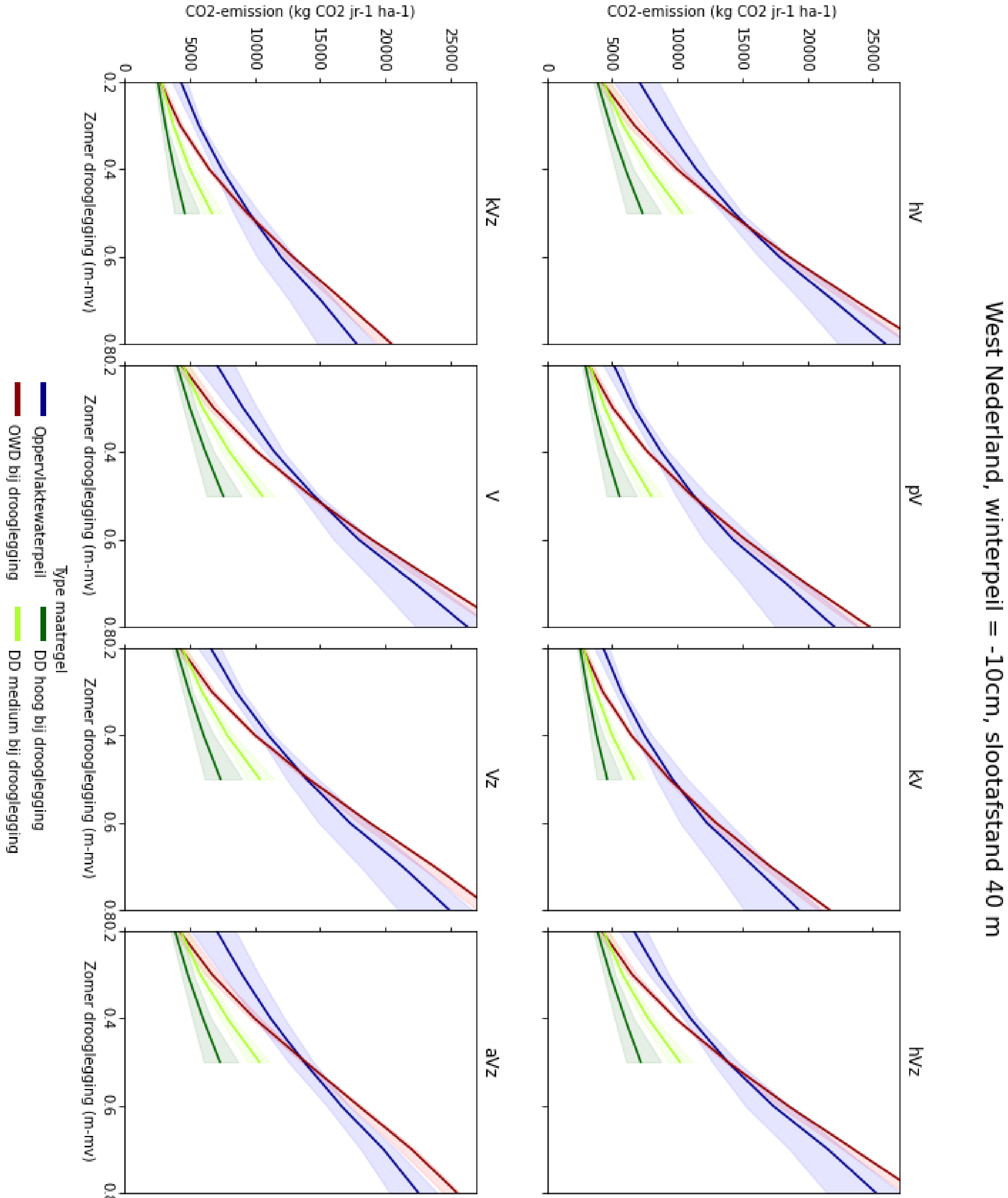

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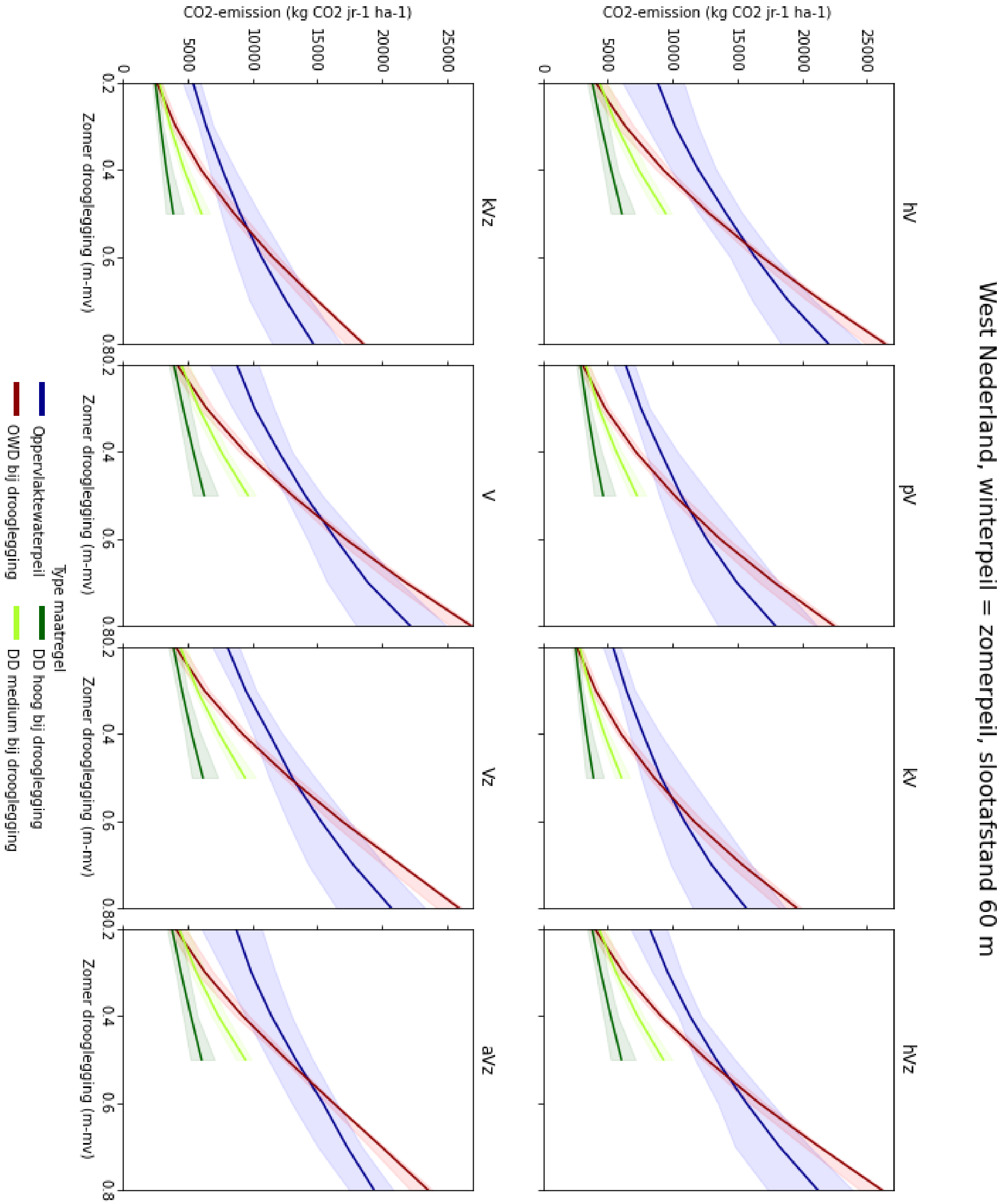

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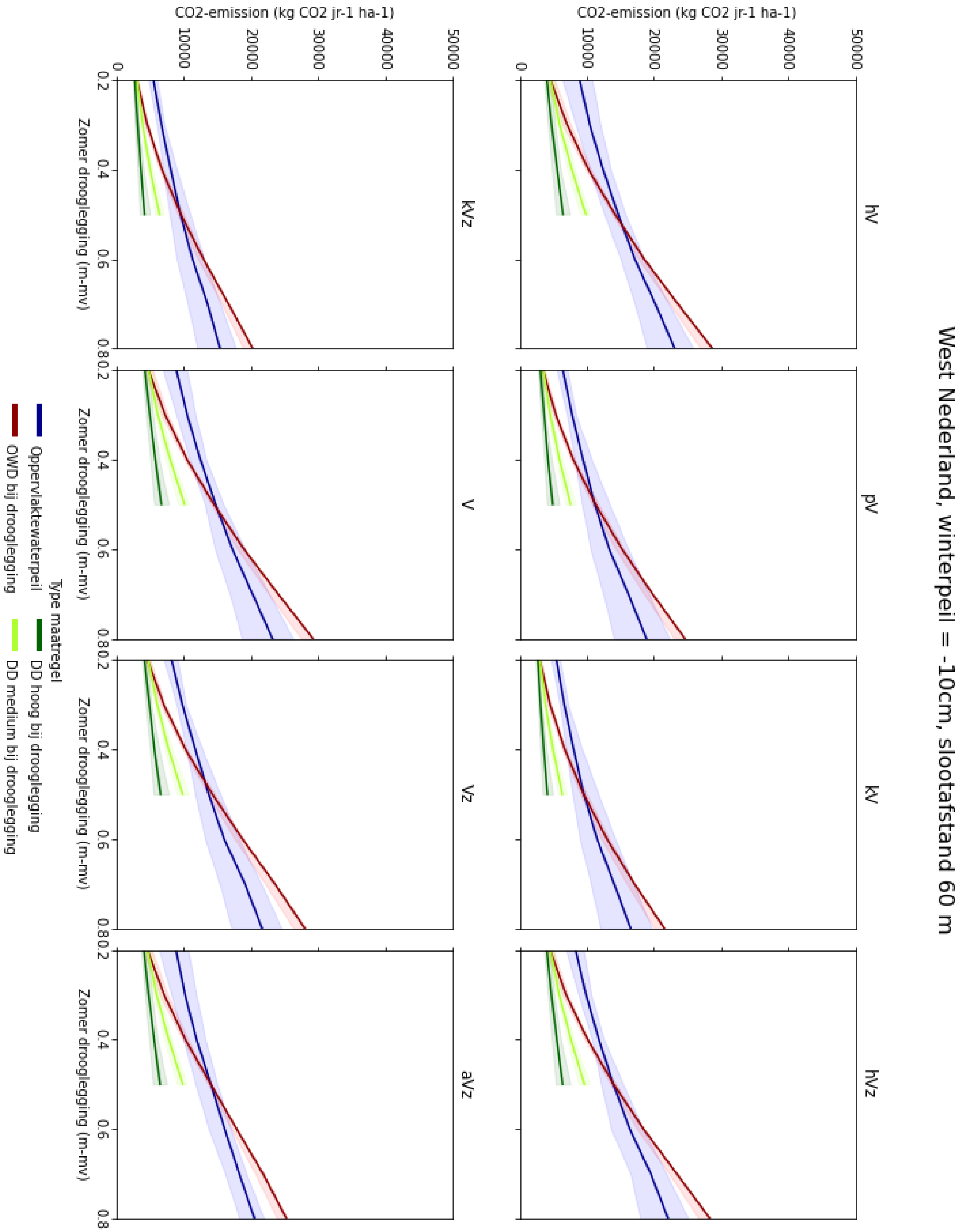

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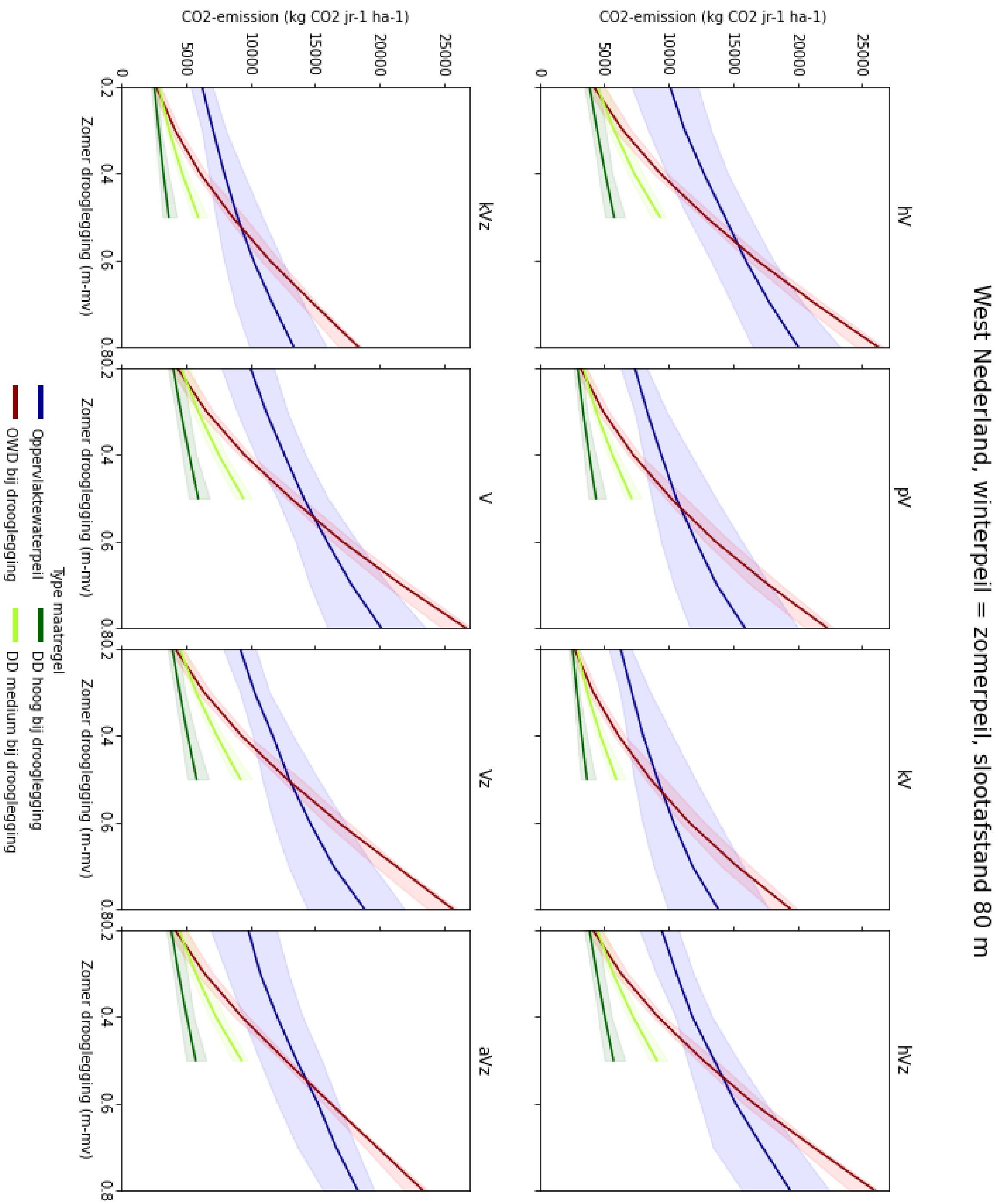

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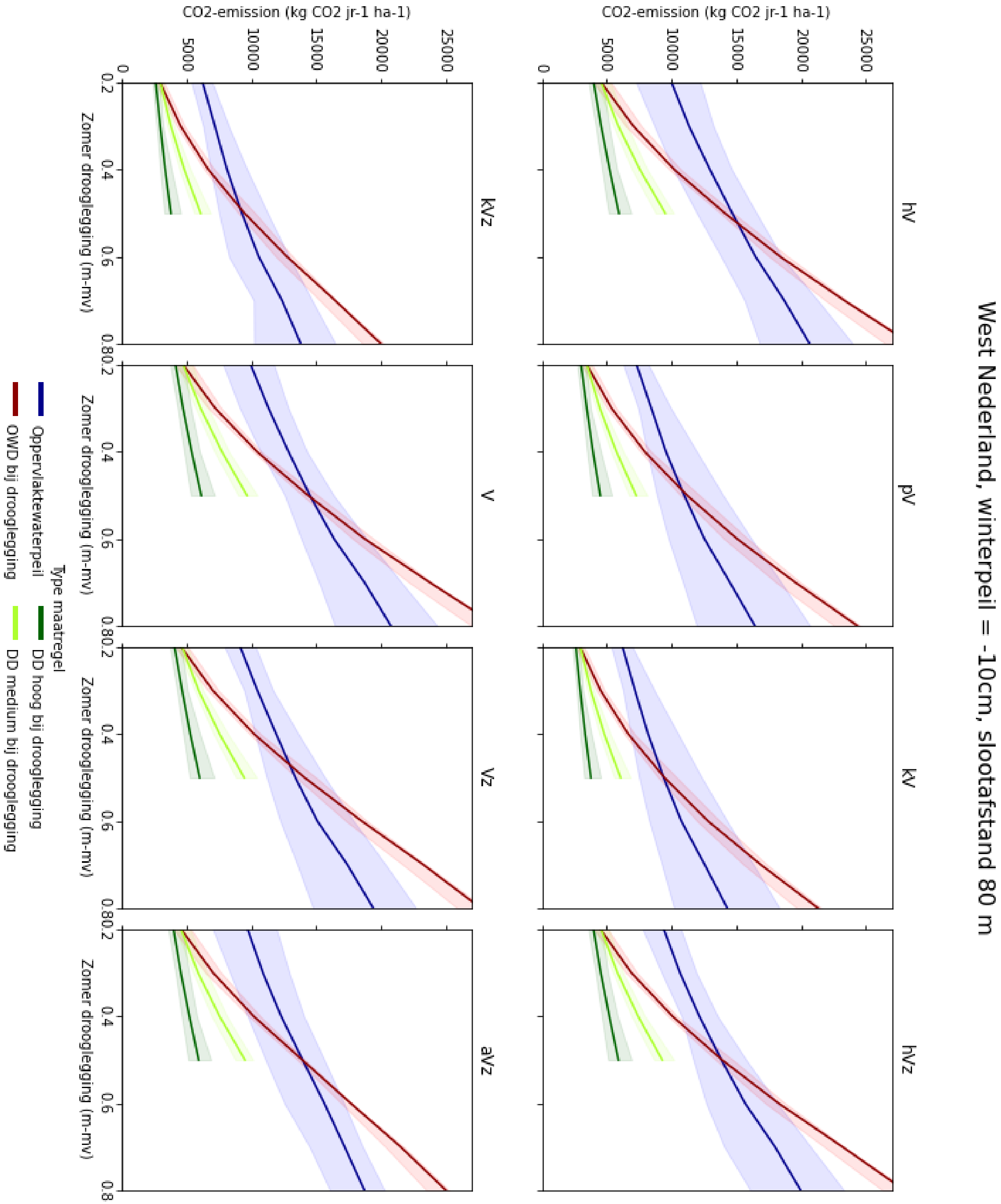

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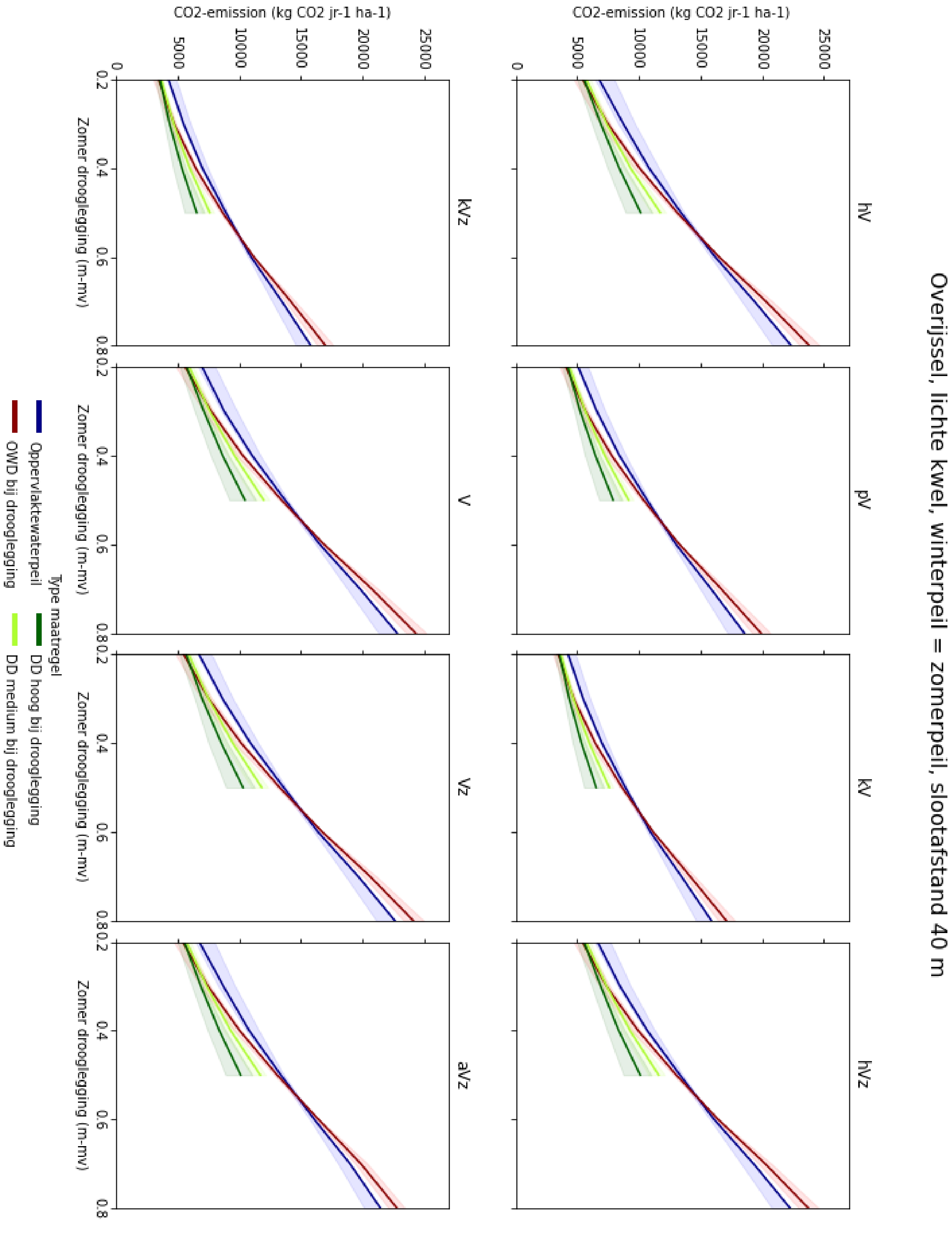

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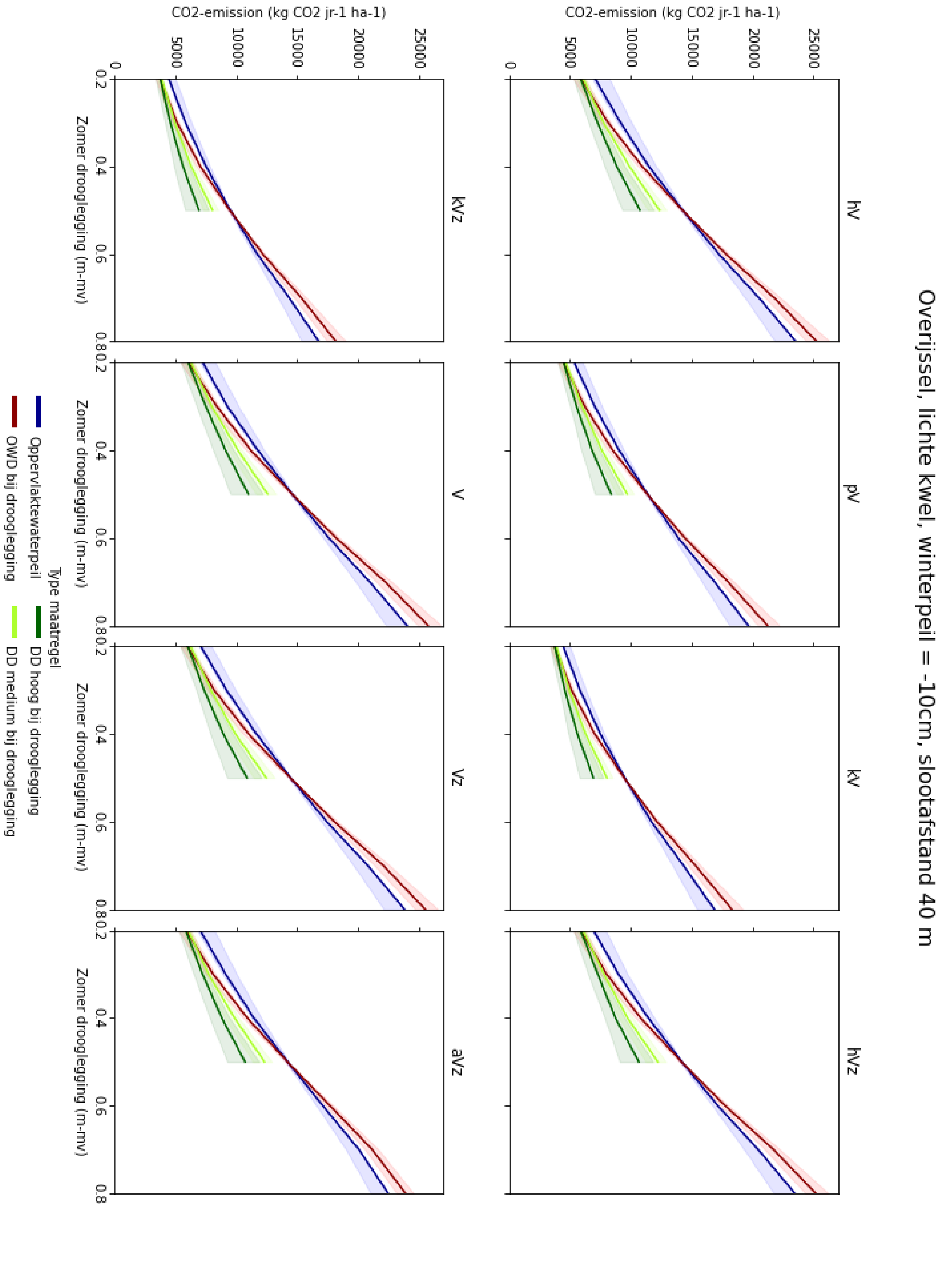

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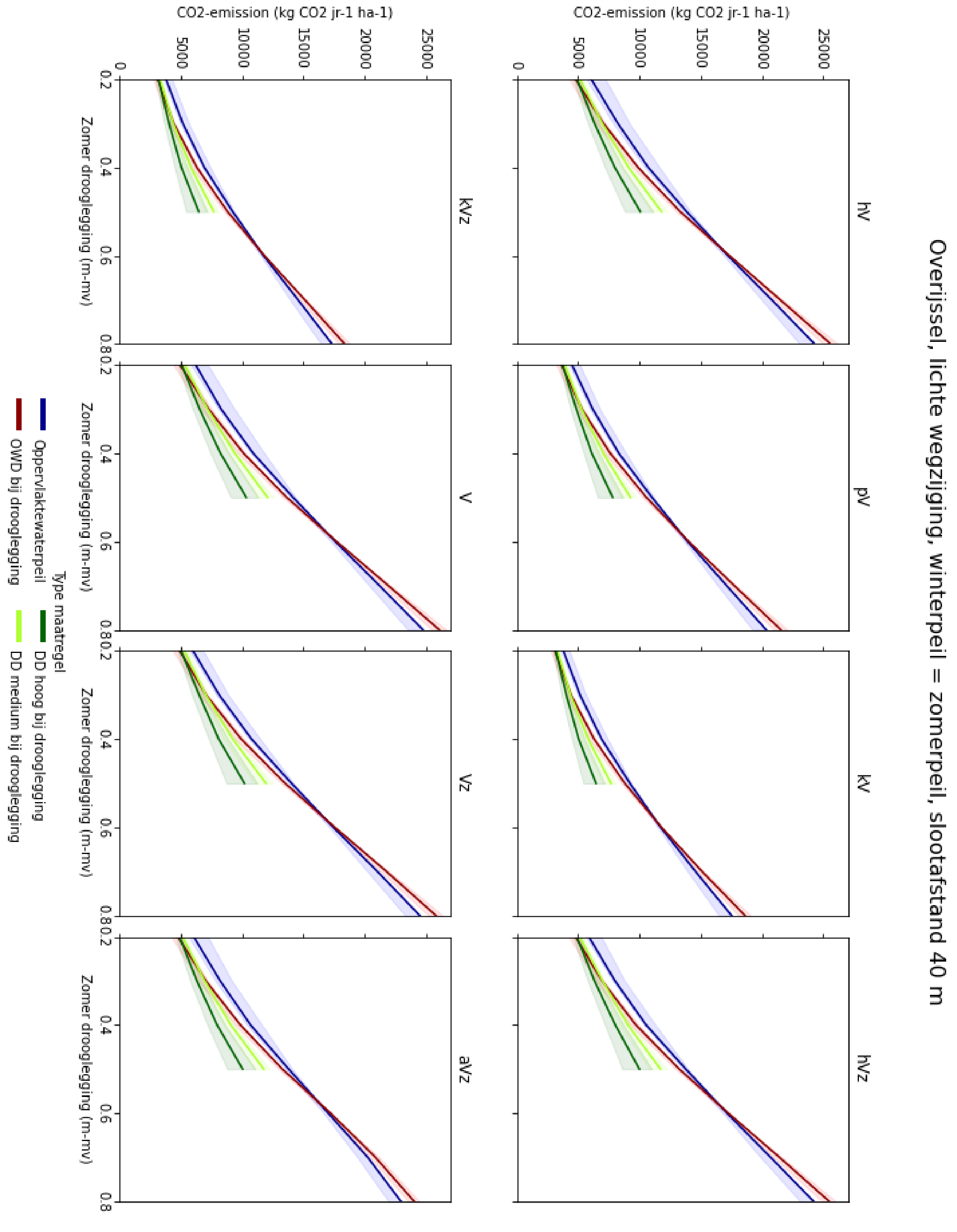

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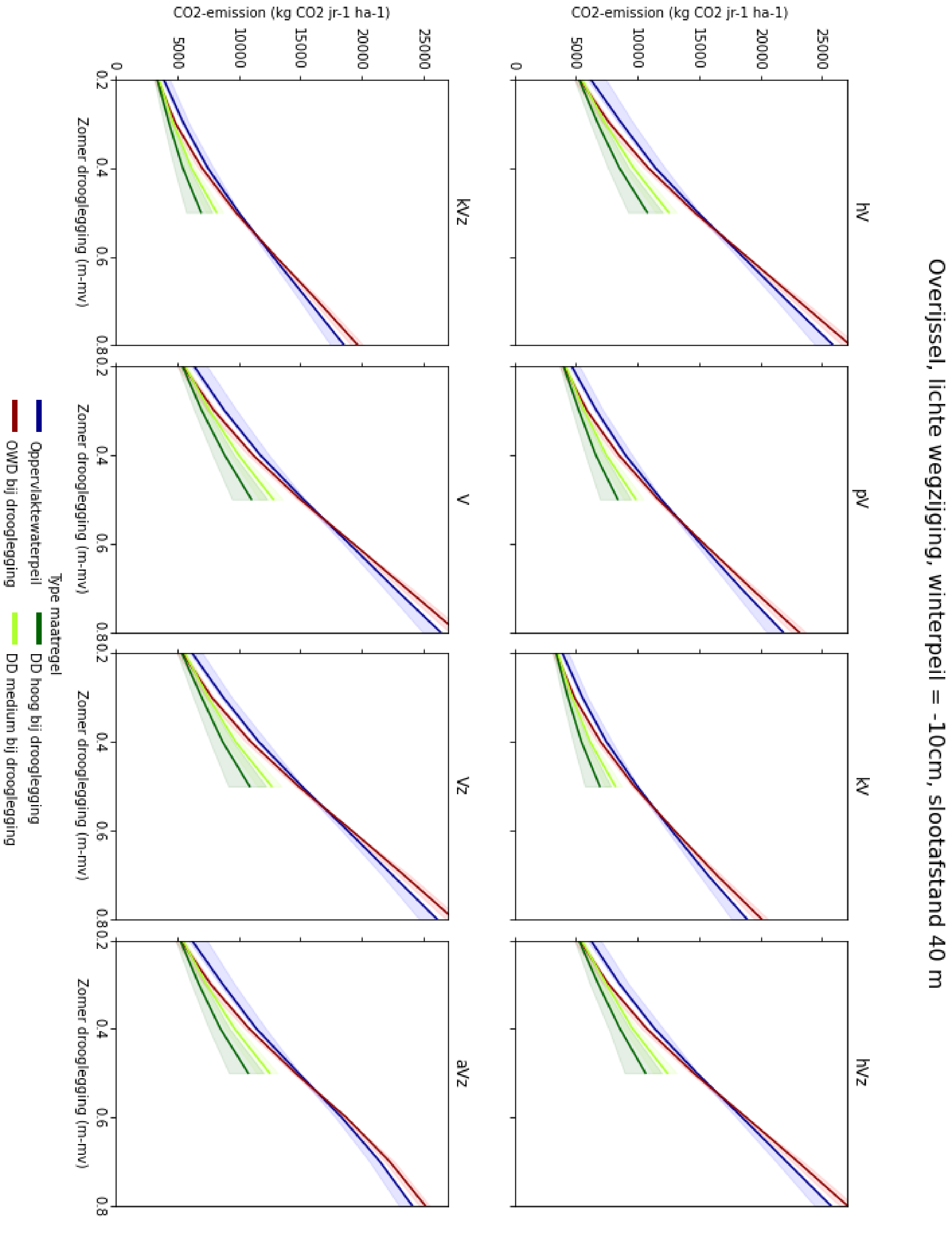

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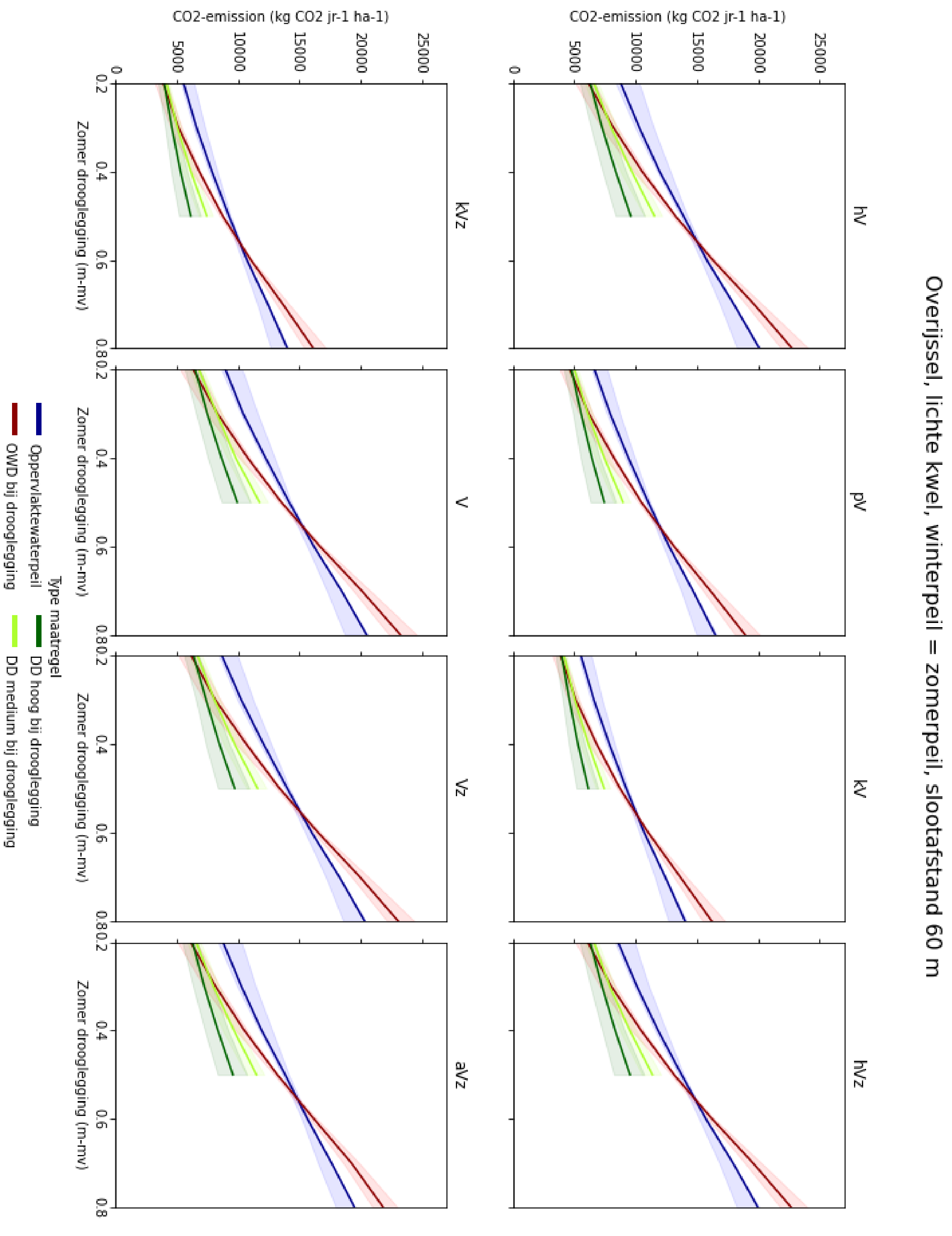

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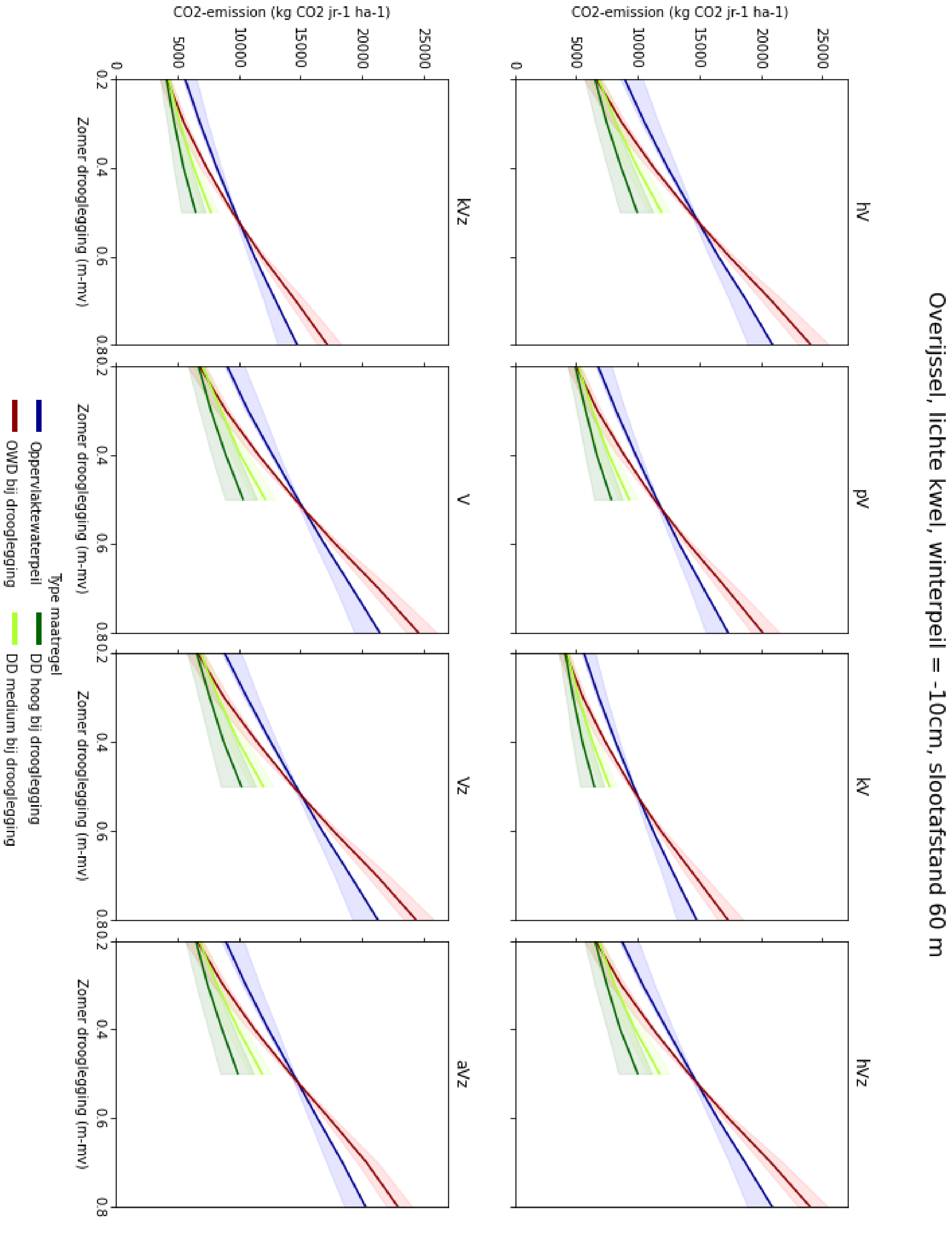

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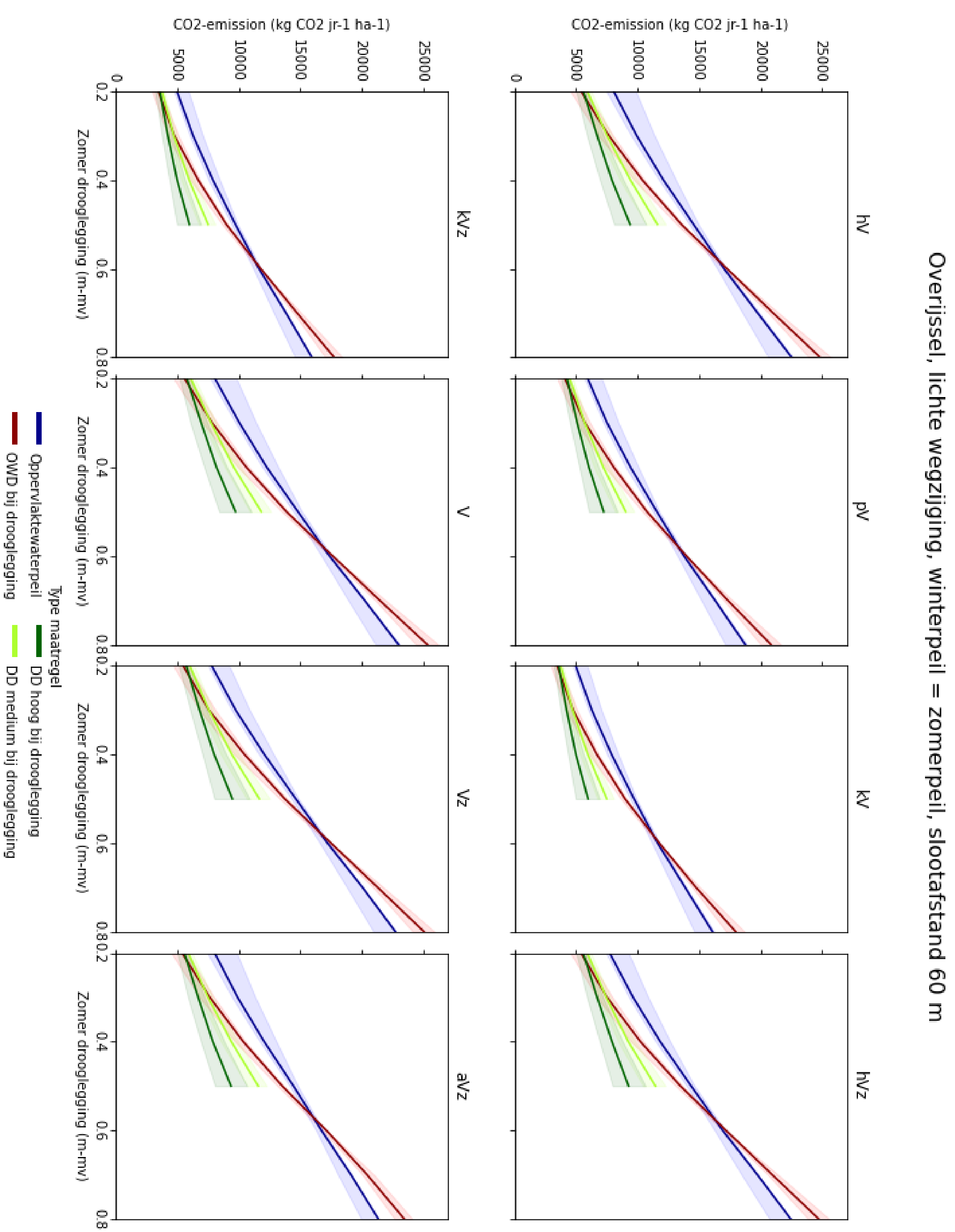

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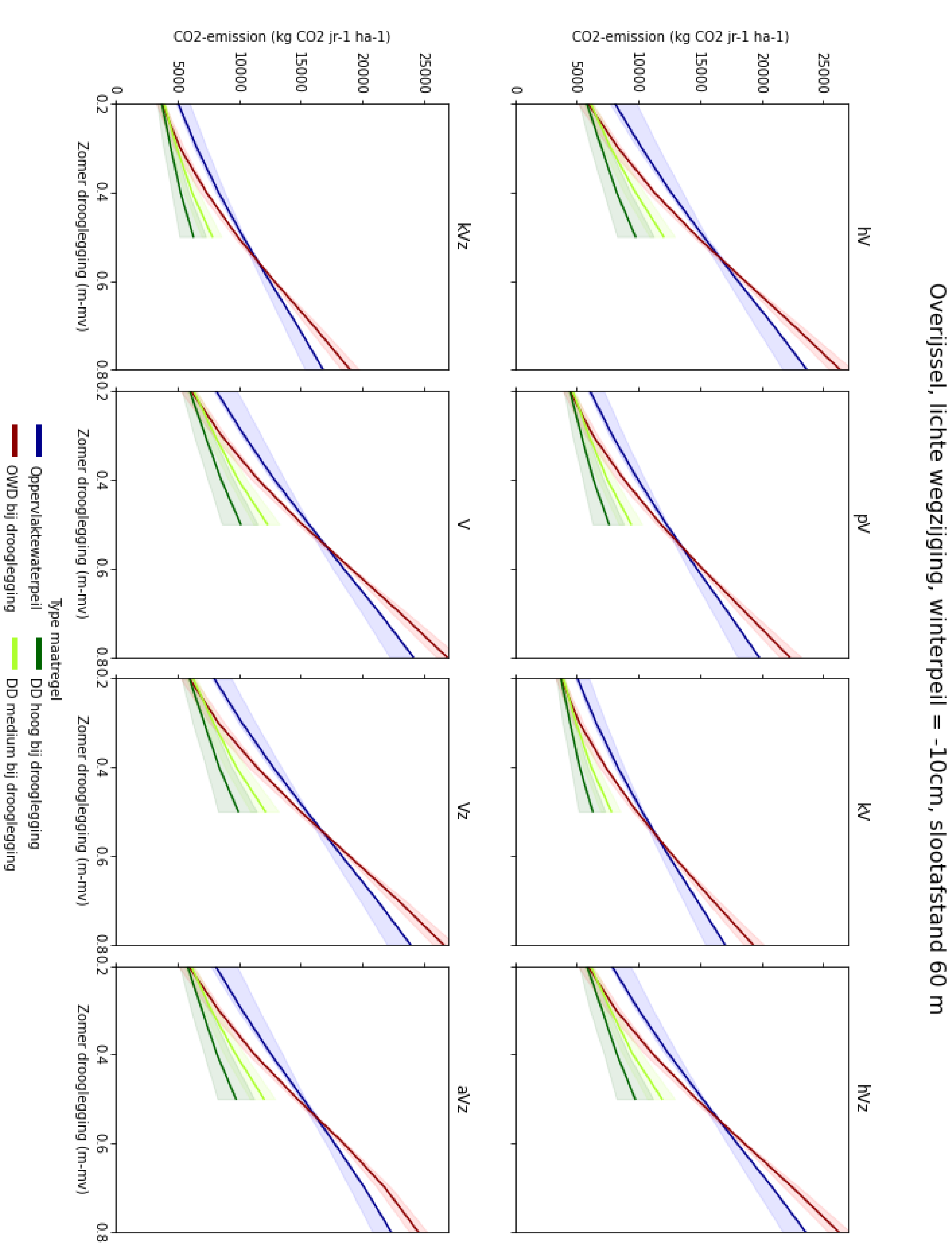

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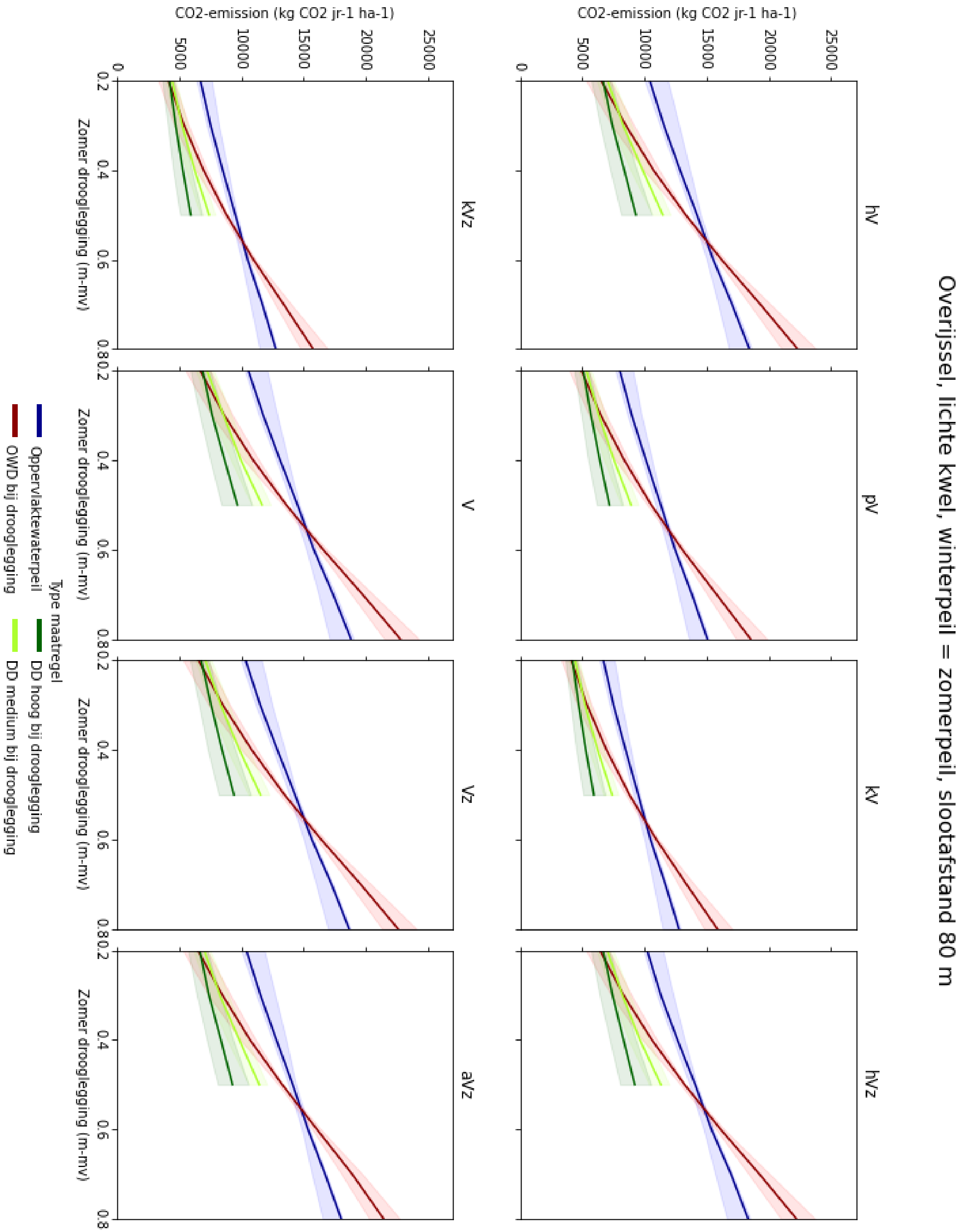

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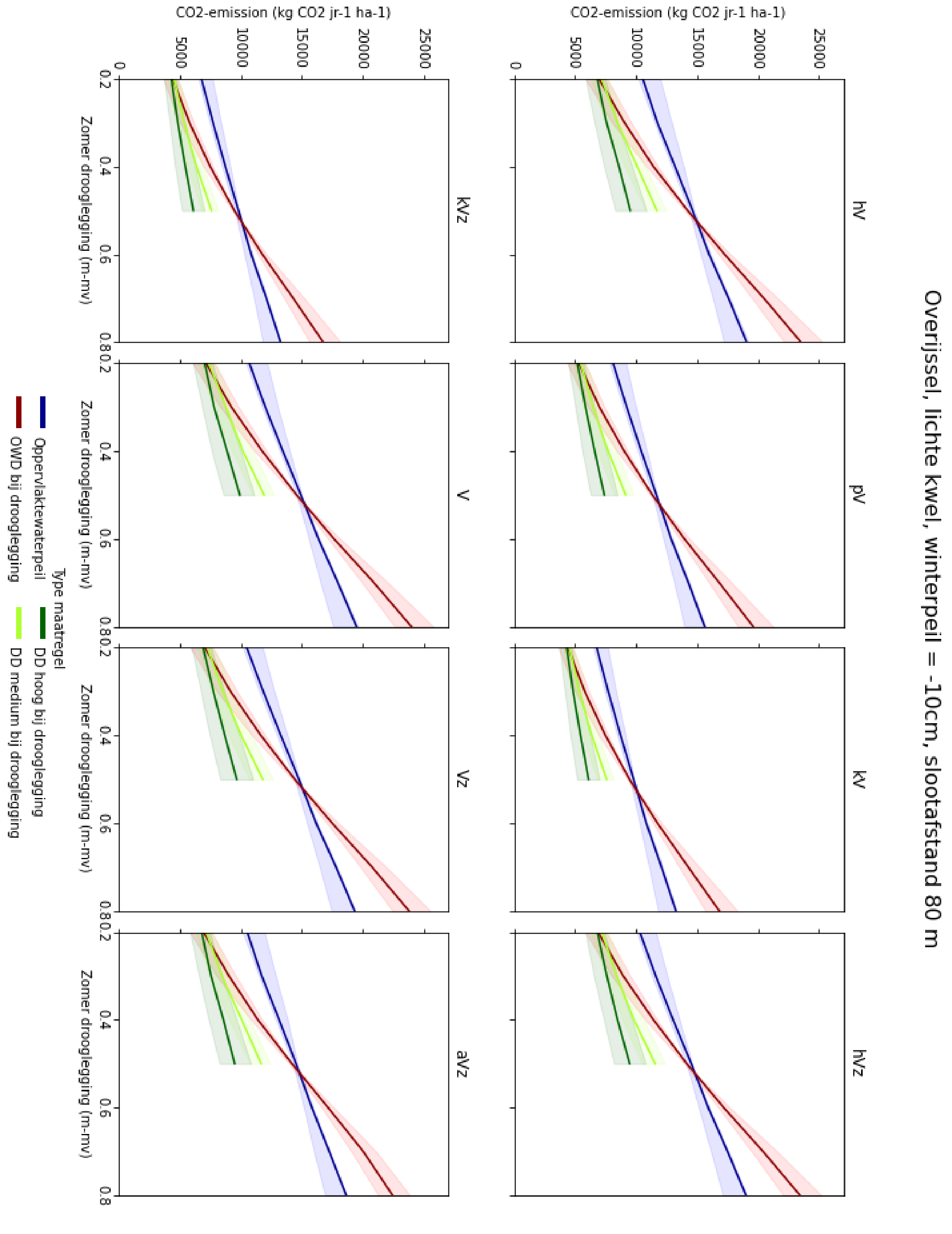

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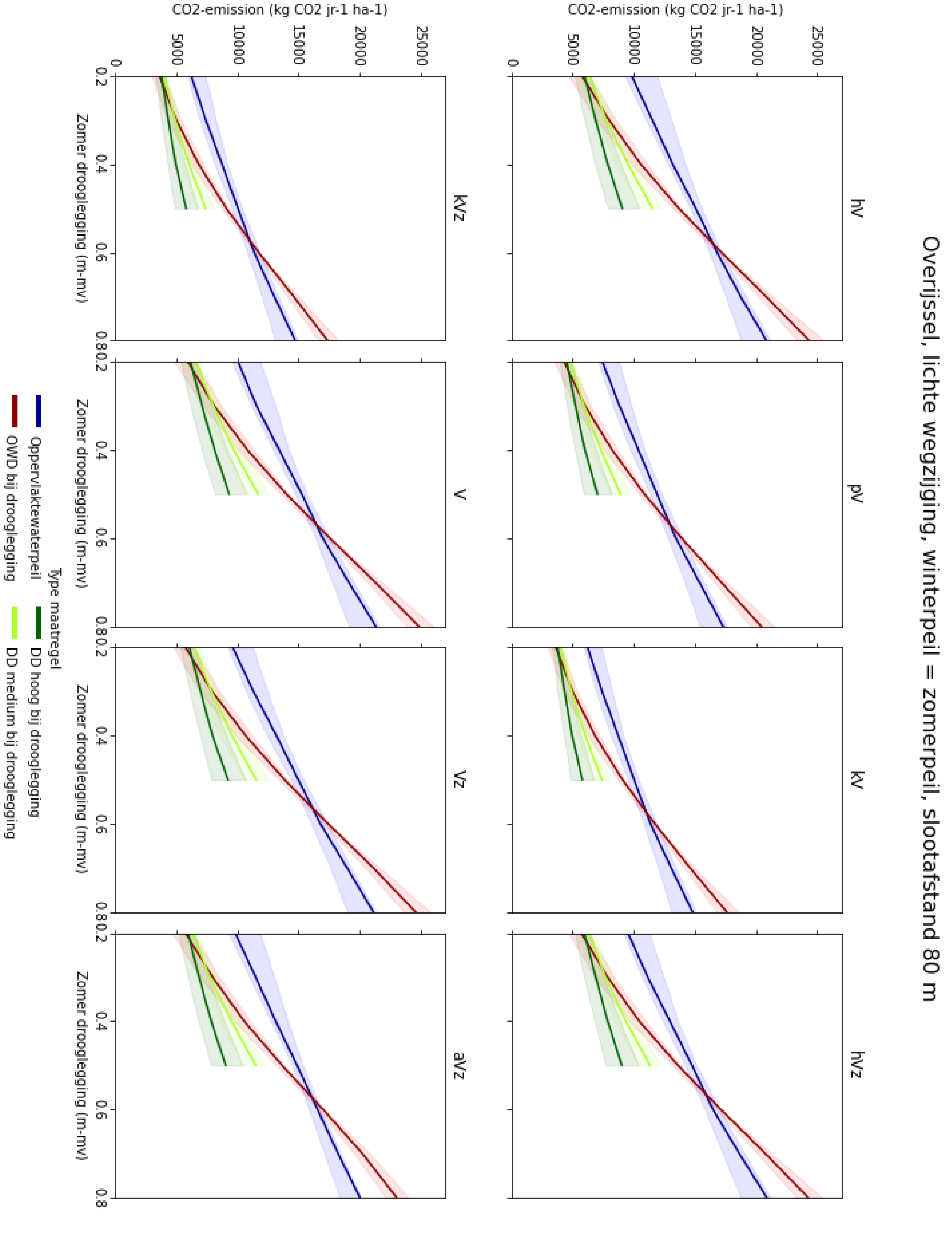
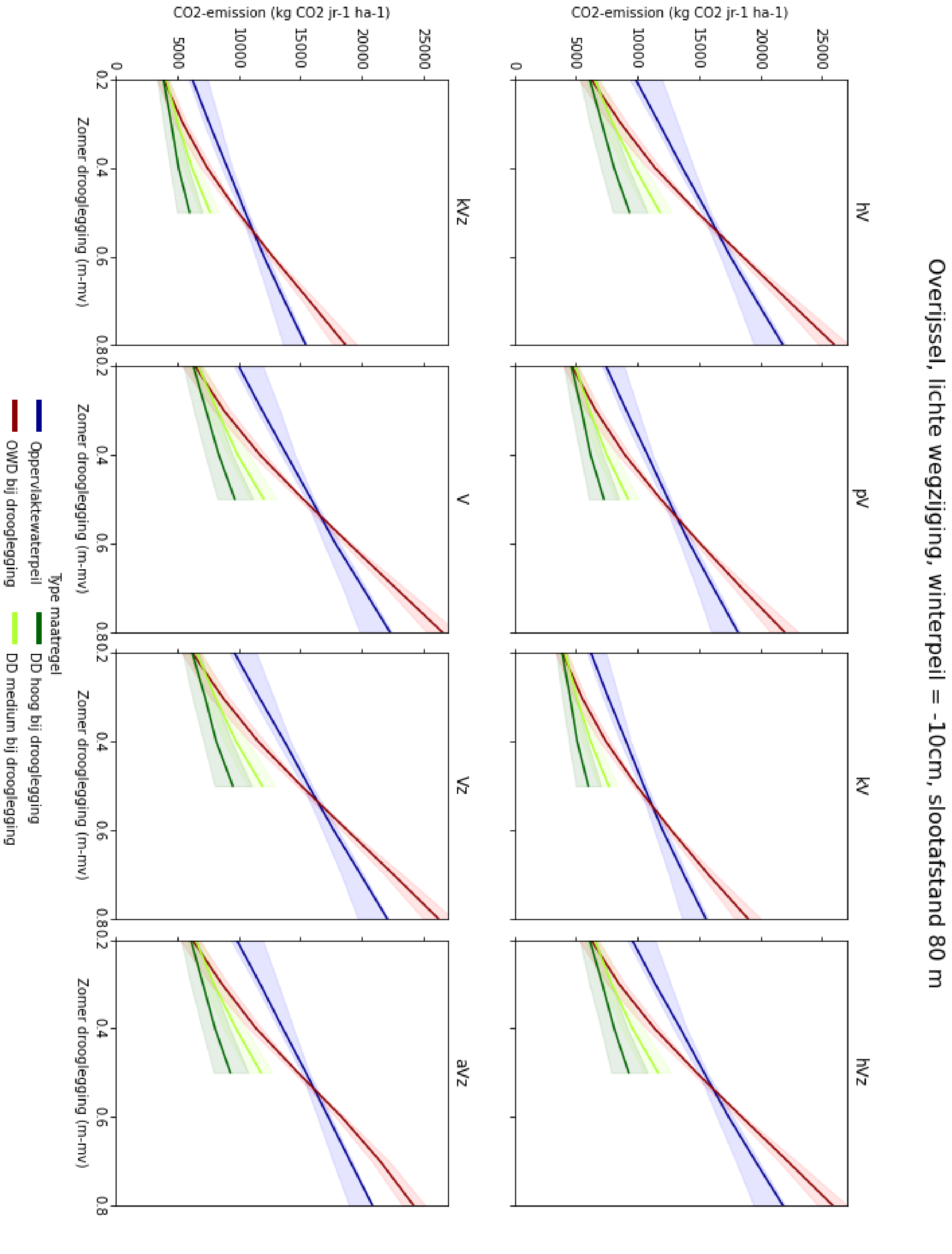
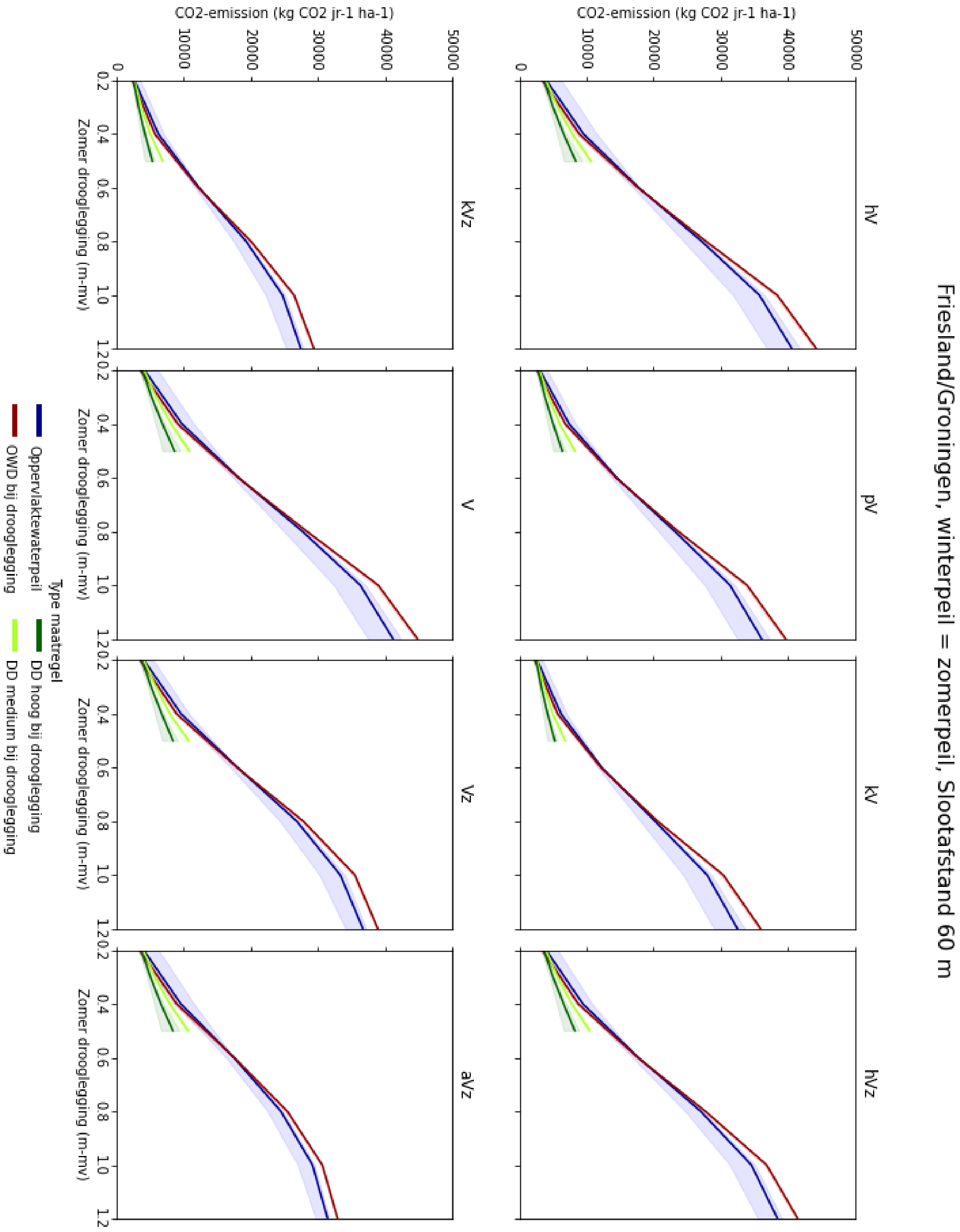


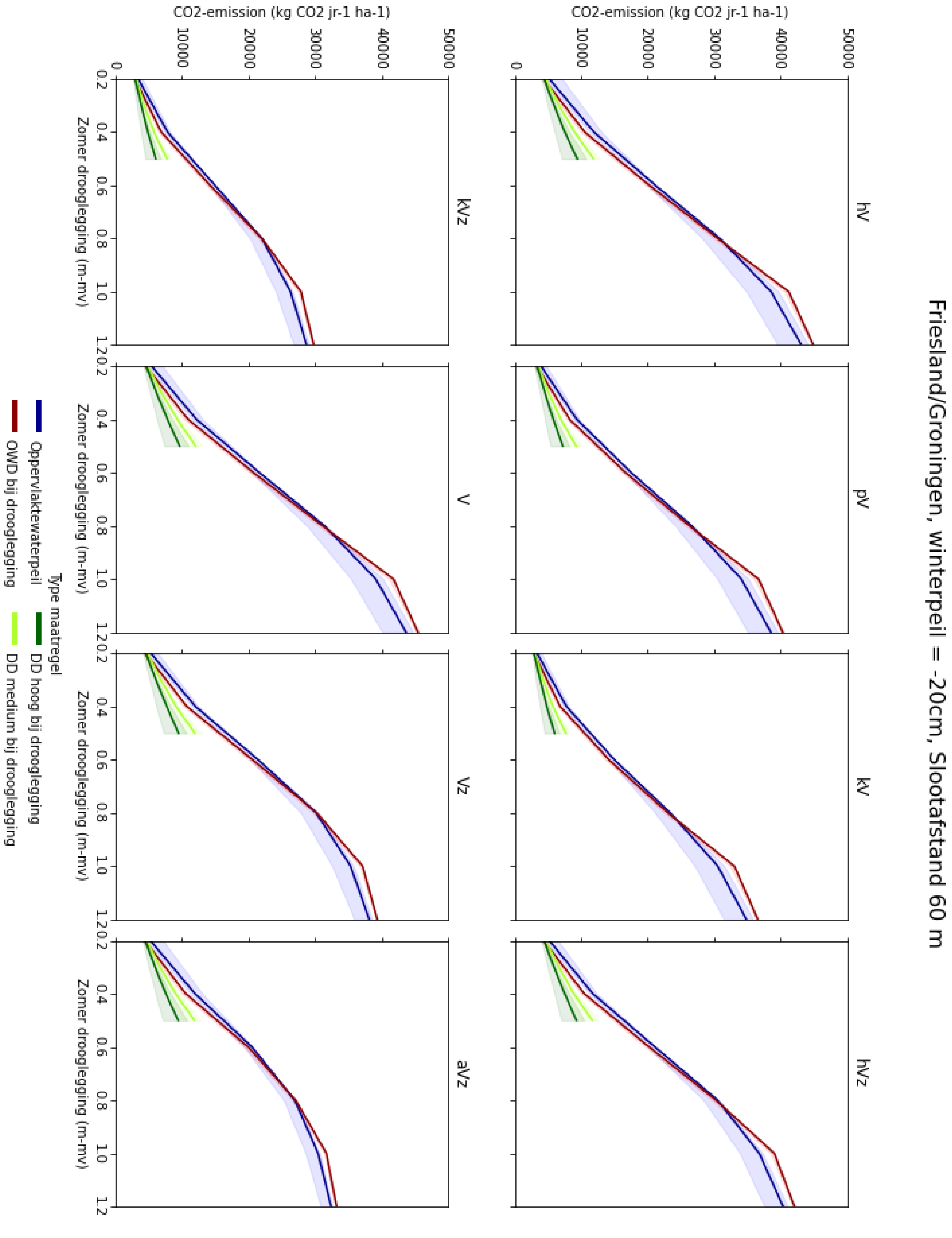
Overijssel, lichte wegzijging, winterpeil = -10 cm zomerpeil, slootafstand 80



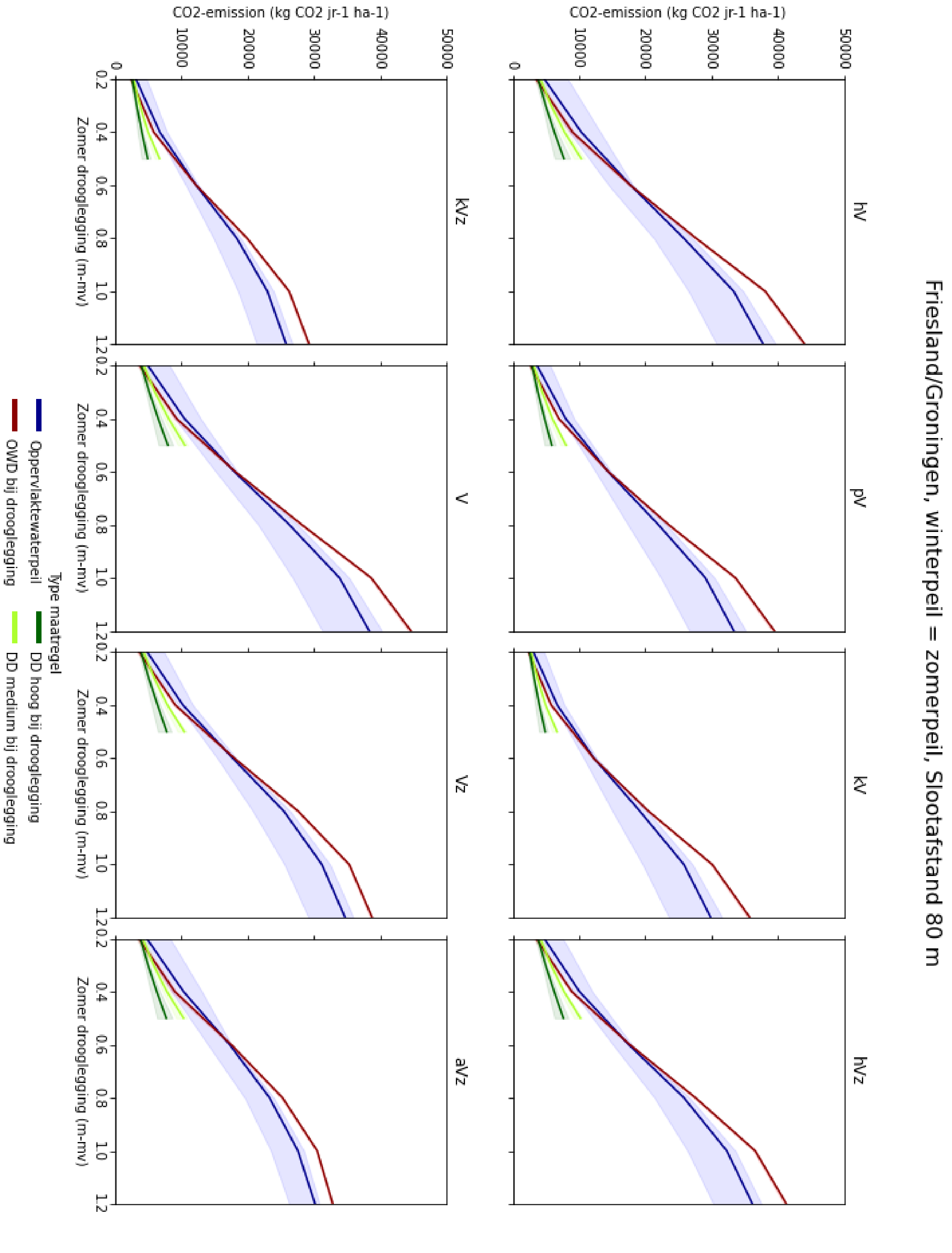
Friesland/Groningen, winterpeil = zomerpeil, slootafstand 60 m



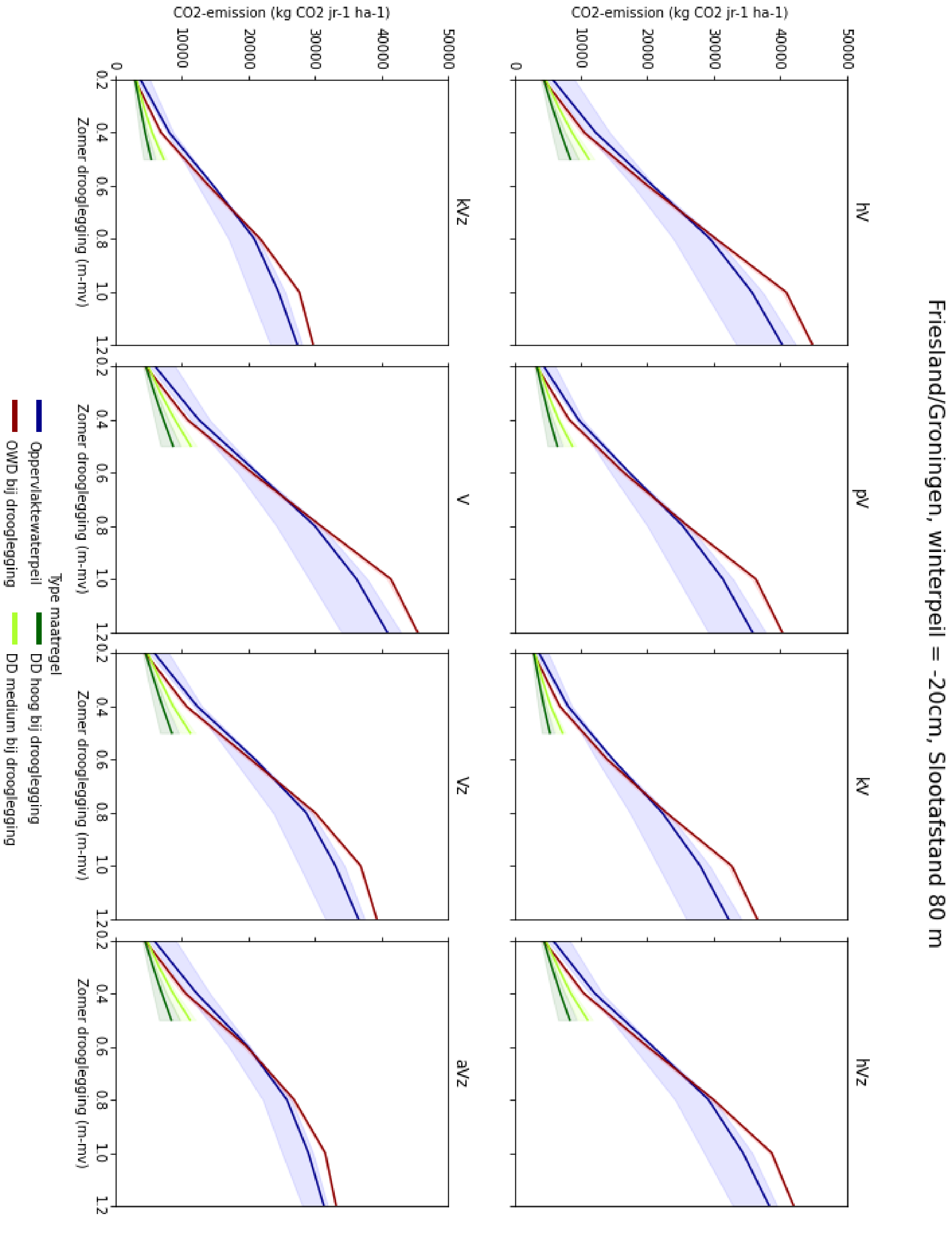
Friesland/Groningen, winterpeil = -20 cm zomerpeil, slootafstand 60 m



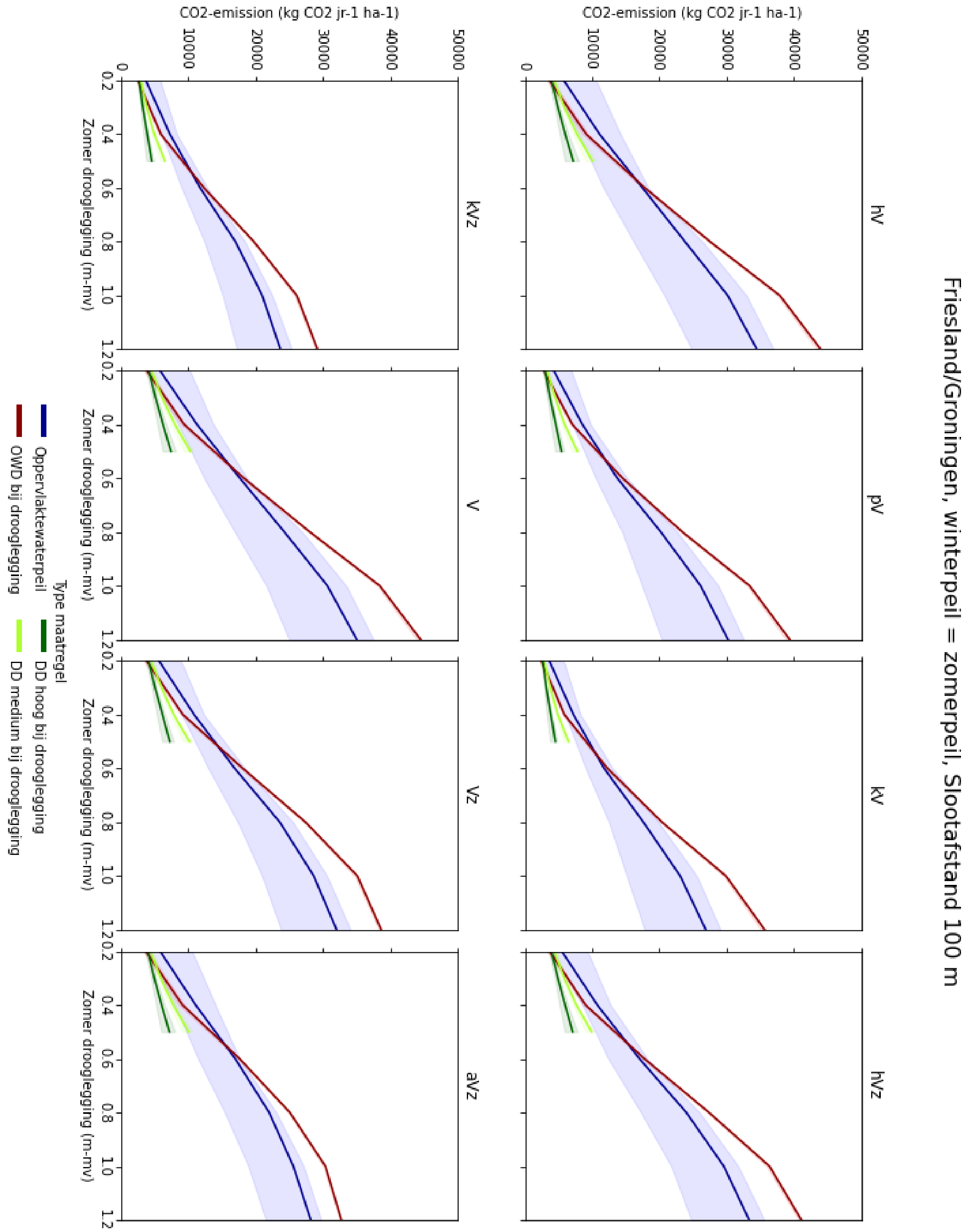
Friesland/Groningen, winterpeil = zomerpeil, slootafstand 80 m



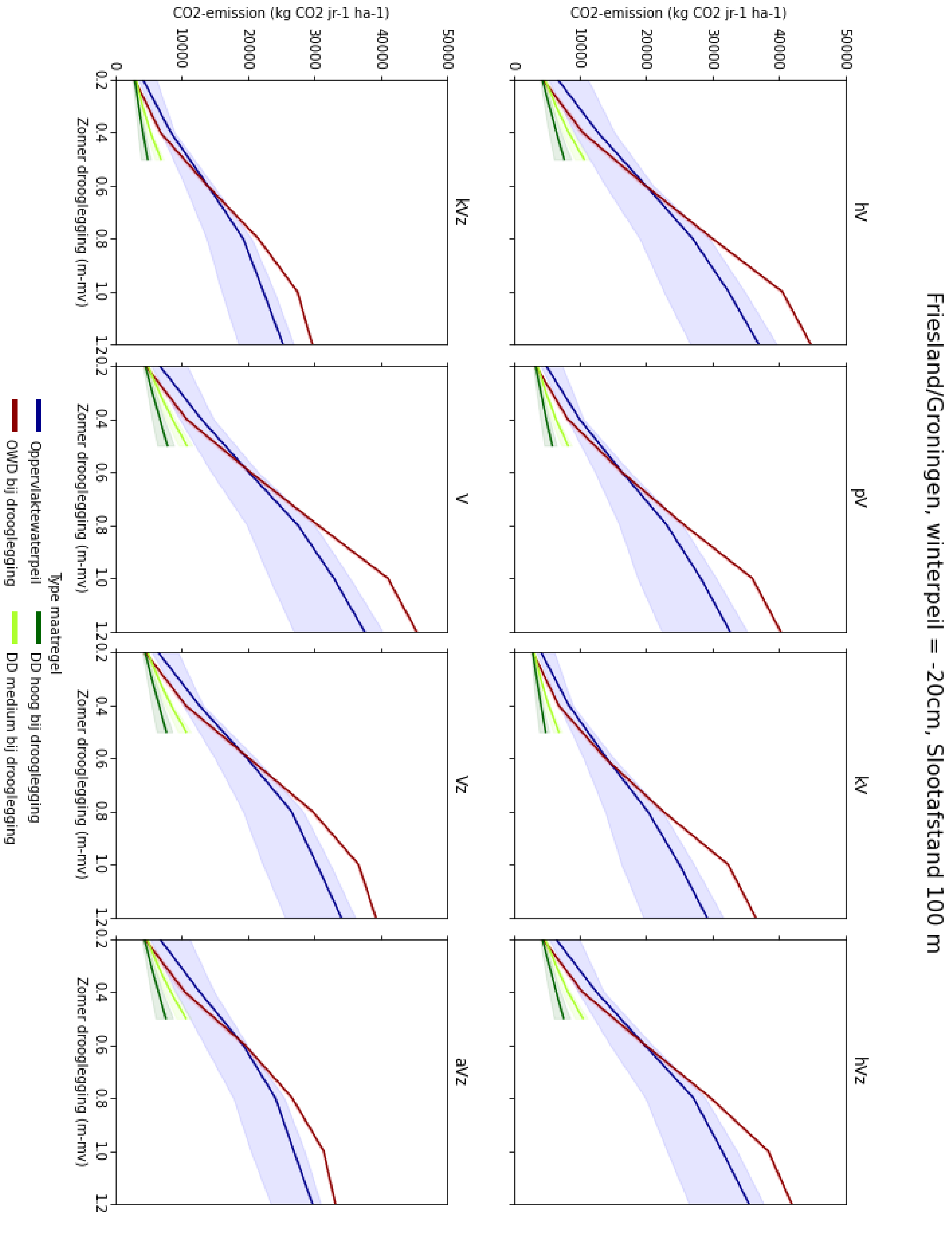
Friesland/Groningen, winterpeil = -20 cm zomerpeil, slootafstand 80 m



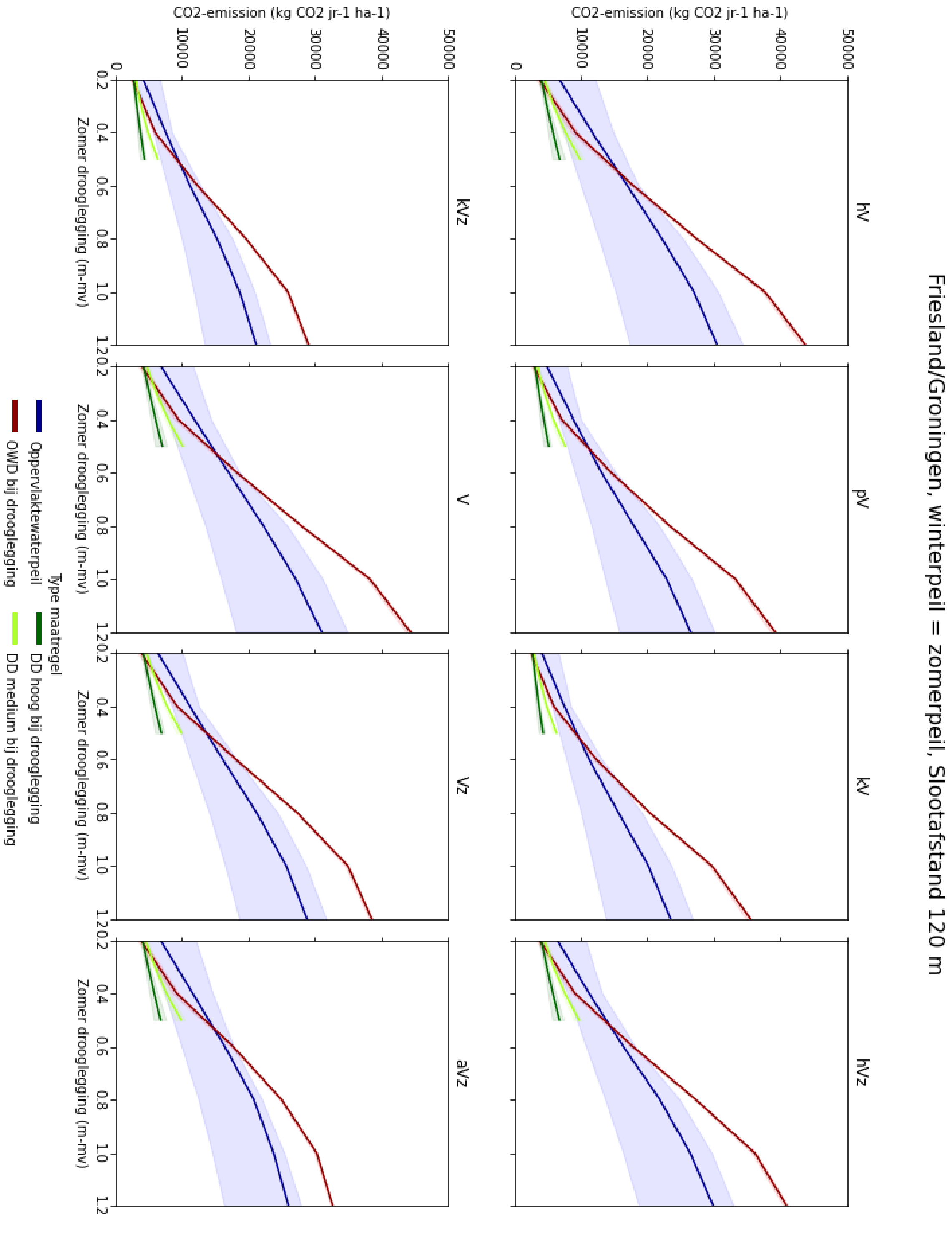
Friesland/Groningen, winterpeil = zomerpeil, slootafstand 100 m



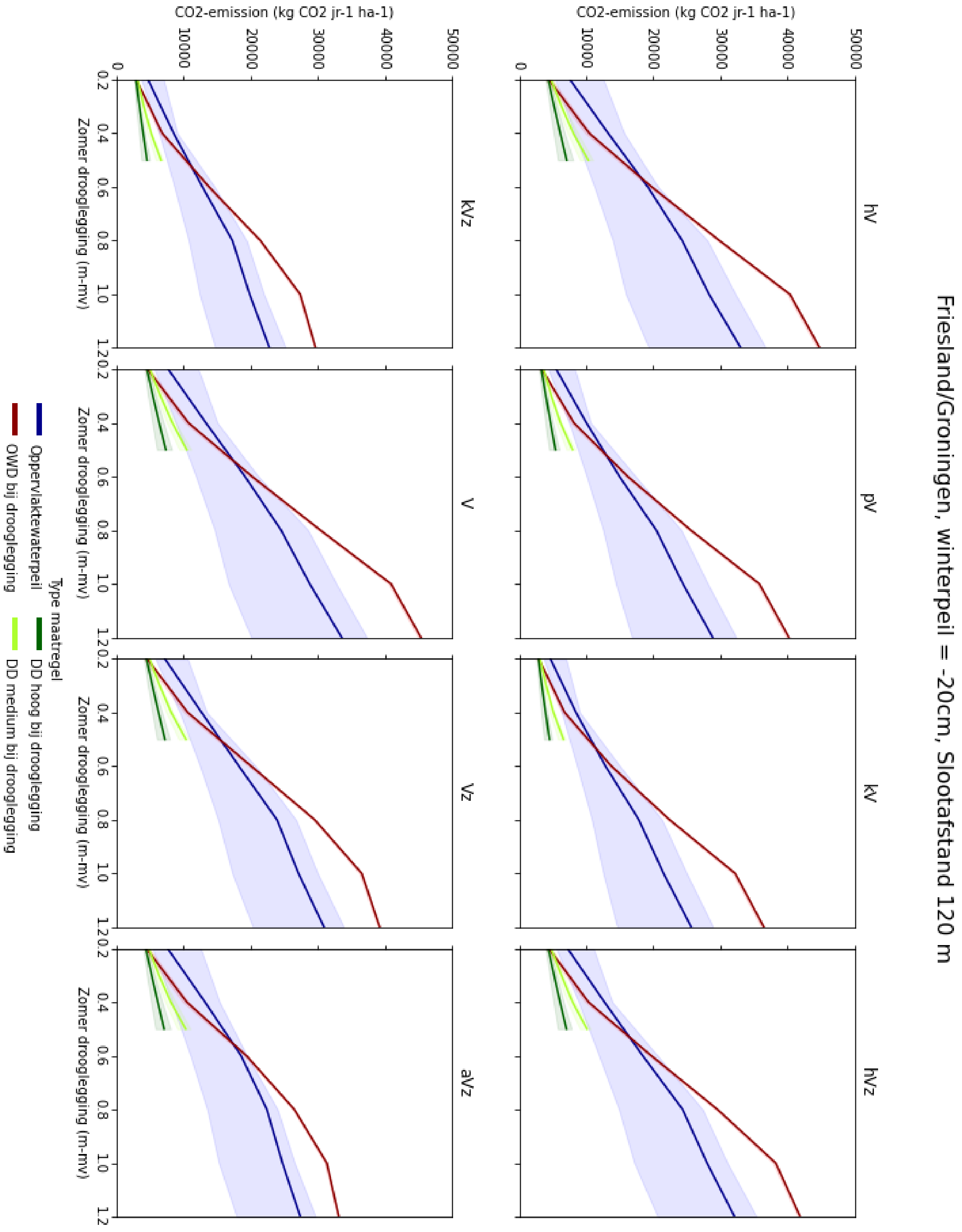
Friesland/Groningen, winterpeil = -20 cm zomerpeil, slootafstand 100 m



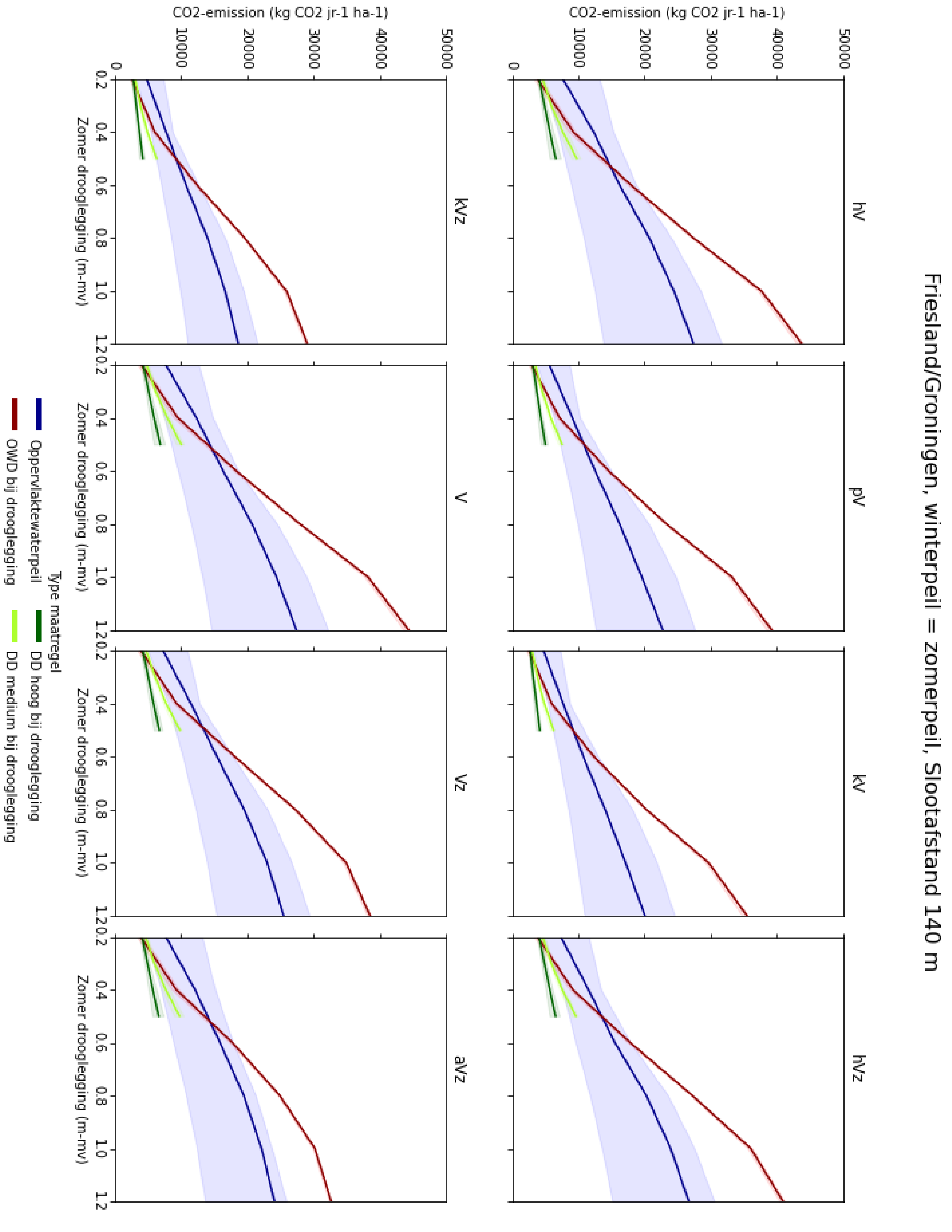
Friesland/Groningen, winterpeil = zomerpeil, slootafstand 120 m



Friesland/Groningen, winterpeil = -20 cm zomerpeil, slootafstand 120 m



Friesland/Groningen, winterpeil = zomerpeil, slootafstand 140 m



Friesland/Groningen, winterpeil = -20 cm zomerpeil, slootafstand 140 m