Supplementary information to the paper:

Horvath et al. Improving the representation of high-latitude vegetation in Dynamic Global Vegetation Models

Supplement S1 – Locations of 20 study plots

Table S1 – Centre coordinates (latitude and longitude) and climatic data for the 20 plots used in this study. Estimates of mean annual precipitation and mean annual temperature are obtained from two sources; data from SeNorge (C. Lussana et al., 2018; Lussana, Tveito, & Uboldi, 2018) interpolated to each centrepoint and from CORDEX (the forcing climate dataset in DGVM).

					SeNorge v2 data (used in DM)		CORDEX climate data (used in DGVM)	
ID	Plot # from (AR18x18)	LAT	LONG	Elevation (m a.s.l) at centre	Mean Annual Precipitation (mm)	Mean Annual Temperature (°C)	Mean Annual Precipitation (mm)	Mean Annual Temperature (°C)
3	405	6.061	58.635	200	2662	6.3	2916	4.7
2	513	6.035	59.934	710	2628	1.0	3530	2.9
1	622	5.956	61.392	596	2520	2.0	2606	2.0
6	801	7.429	58.074	184	1542	6.7	2055	5.9
4	922	6.957	61.456	1437	1799	-3.6	2958	-2.9
5	1131	7.264	62.935	454	1976	4.0	1716	4.8
8	1304	8.862	58.638	88	1395	7.1	1640	4.9
7	1322	8.298	61.529	1670	827	-3.1	2418	-6.1
9	1623	9.278	61.735	852	555	-0.1	808	-3.9
10	2015	10.812	60.496	606	804	1.9	1517	0.5
12	2108	11.268	59.377	130	1072	5.5	1223	4.4
11	2238	11.000	64.223	222	1349	4.3	1542	2.1
13	2332	11.492	63.266	721	1029	0.3	2001	-0.2
14	2425	11.968	62.145	744	715	-1.2	1013	-2.0
16	2948	13.508	65.886	529	1513	1.1	1819	-0.3
15	2962	13.363	68.146	393	1339	5.8	1075	4.4
17	4268	19.167	69.072	354	715	0.7	1122	-1.8
18	5369	24.147	69.040	395	466	-4.0	695	-3.1
19	6473	29.382	69.334	69	503	-1.1	640	-2.5
20	6380	29.703	70.465	387	552	0.2	1132	-2.5

Supplement S2 – Sampling design – RS, DM and AR

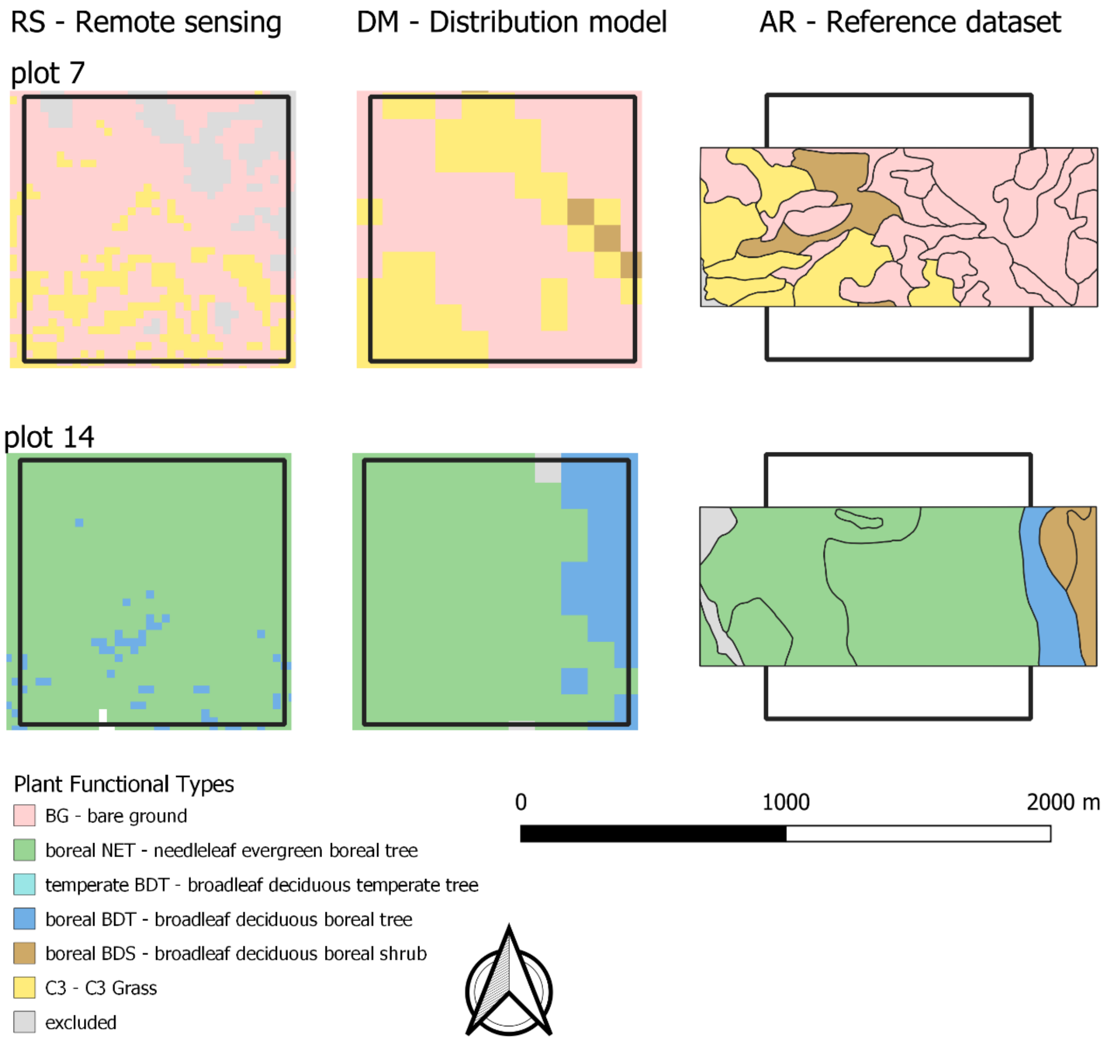


Figure S2 – Sampling design used by the remote sensing (RS) and distribution modelling (DM) methods and to obtain the AR reference dataset. Like DGVM plots (see Fig. S7), the RS and DM plots are 1×1 km, while the AR plots are 1.5×0.6 km. Plots 7 and plot 14 (AR18x18 plot #1322 and plot #2425) are used as examples.

Supplement S3 – Assessment of climatic representativeness of selected plots

We assessed the representativeness of the 20 plots, selected from the original AR18×18 dataset which consists of 1081 plots, by comparing frequency distributions with respect to the two main bioclimatic gradients in Norway, expressed as annual mean temperature and annual precipitation. For each of temperature and precipitation, we obtained interpolated values for the centrepoint of each AR18×18 plot (cf. Fig. S1) and compared the frequency distributions of the selected plots with those of all plots (Fig. S3). The 20 selected plots span elevations from 88 to 1670 m a.s.l., covers an annual temperature range from -4°C to 7.1°C, and an annual precipitation range from 466 to 2661 mm (Fig. S1), which accords well with the variation in the AR18×18 dataset (Fig. S3).

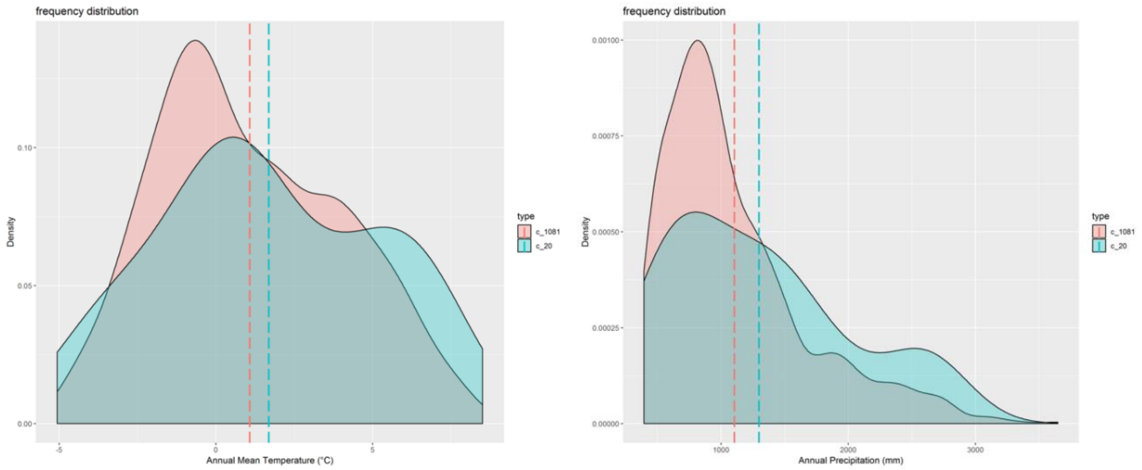


Figure S3– Frequency distributions of plots in the original AR18×18 dataset (n=1081; in red) and in the set of 20 plots selected for this study (in blue), with respect to annual mean temperature (left) and annual precipitation (right). Dashed lines indicate means for the respective datasets.

Supplement S4 – Assessment of the representativeness of PFT profiles

We also assessed the representativeness of the 20 study plots, selected from the original AR18×18 dataset which consists of 1081 plots, by comparing the aggregated PFT profiles for the two datasets given in Table S4. PFT profiles were first obtained for each plot by the conversion scheme in Table 2, thereafter aggregated to dataset level by calculation of mean frequencies for each of the six PFTs (and 'EXCL'; land not assigned to any PFT type).

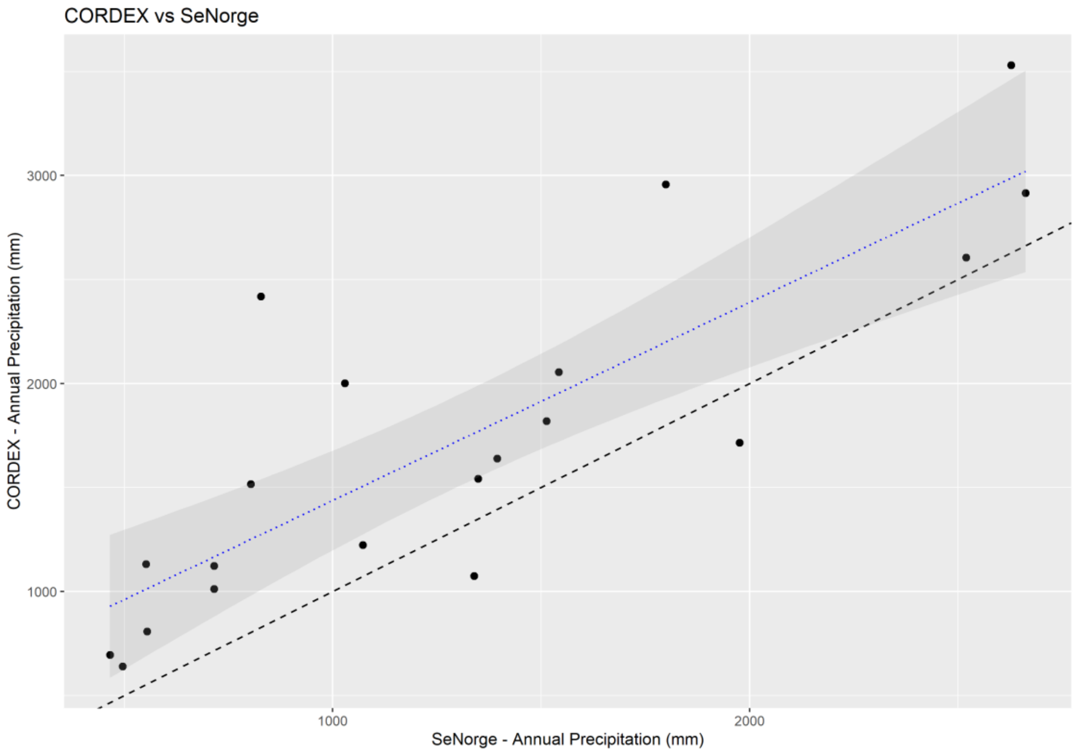
The comparison between the aggregated PFT profiles in Table S4 by use of the chi-square test (see section 2.6 for method) shows that the two datasets are much more similar than expected by chance (χ^2=1.991, df = 6, p = 0.079). Despite slight overrepresentation of the boreal NET PFT and underrepresentation of boreal BDT and C3 grasses, we conclude that the selected plots are sufficiently representative for the conclusions drawn from the sample of 20 plots to be acceptably representative for Norway. Note that percentage for EXCL category has been proportionally re-distributed through relevant PFTs in the study as shown on the **Error! Reference source not found.** (so that the six PFTs cover 100%).

Table S4 – PFT profiles of the full AR18x18 dataset (n = 1081) and the 20 plots selected for this study.

PFT code	PFT name	Fraction of PFT in 1081 plots (%)	Fraction of PFT in 20 plots (%)
BG	Bare Ground	10.37	10.95
Boreal NET	needleleaf evergreen tree - boreal	21.50	31.18
Temp BDT	broadleaf deciduous tree - temperate	0.46	0.40
Boreal BDT	broadleaf deciduous tree - boreal	16.02	12.55
Boreal BDS	broadleaf deciduous shrub - boreal	25.11	24.35
C3	C3 grass	7.27	3.00
EXCL	excluded	19.27	17.57

Supplement S5 – Assessment of the representativeness of climate forcing data

The comparison of SeNorge and CORDEX estimates of temperature and precipitation in Fig. S5.1 shows that precipitation estimates by CORDEX for the 20 plots were generally higher than SeNorge estimates while the converse (but less strongly) was true for temperature.



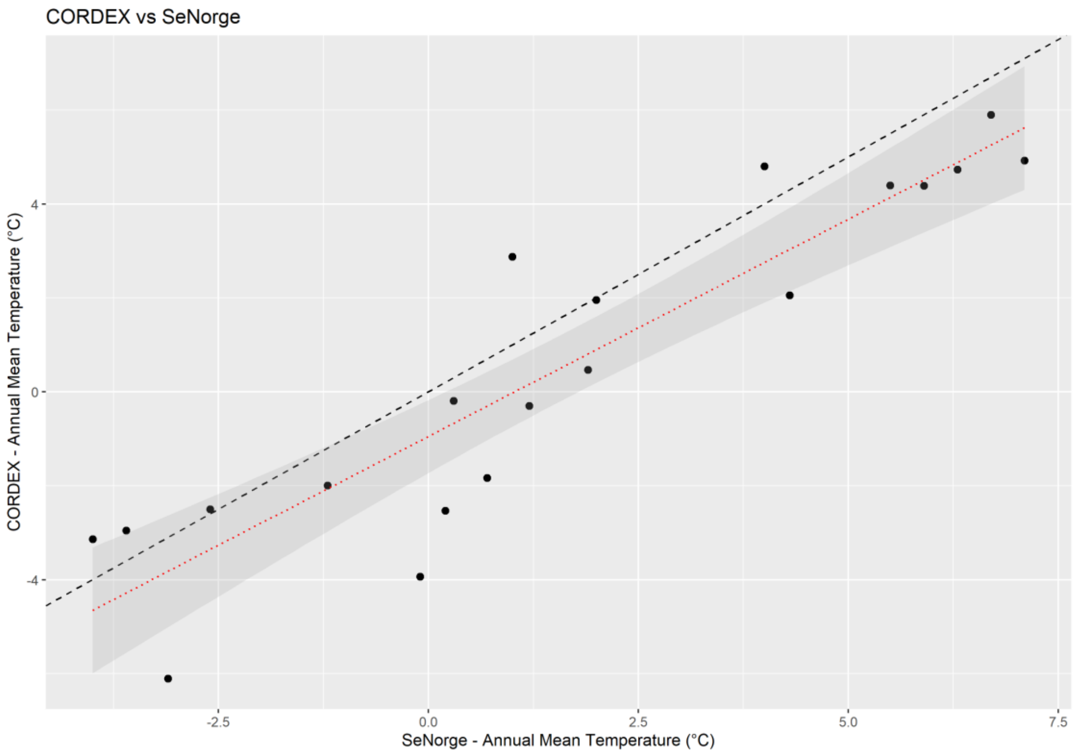


Figure S5 – Scatterplots showing the relationship between temperature and precipitation estimates obtained by the two data sources used in this study; SeNorge for DM (see Sect. Error! Reference source not found.**) on the horizontal axes and CORDEX for climate forcing data used in DGVM (see Sect.** Error! Reference source not found.**) on the vertical axis. The dashed black line represents the 1:1 relationship, while the dotted red line represents a linear model of y~x.**

Supplement S6 – DGVM parameters for PFTs (CLM4.5-BGCDV)

Table S6 – Some important PFT parameter settings for DGVM (CLM4.5-DV). PFTs relevant for the study area (Norway) in bold font. The last three columns contain the adjusted parameters used in the sensitivity experiment. Bioclim_15 – Precipitation Seasonality (Coefficient of Variation); SWE_10 – Snow water equivalent in October (mm); TMIN_5 – Minimum Temperature in May (°C)

		Prescribed heights		Survival	Establishment		Sensitivity tests		
Plant functional type (PFT)	Acronym	ztop (m)	zbot (m)	$T_{c,min}$ (°C)	$T_{c,max}$ (°C)	GDDmin	Bioclim_15	SWE_10 (mm)	TMIN_5 (°C)
Needleleaf evergreen tree – temperate	Temp NET	17	8.5	–2	22	900			
Needleleaf evergreen tree – boreal	Boreal NET	17	8.5	–32.5	–2	600	50	150	–5
Needleleaf deciduous tree – boreal	Boreal NDT	14	7						
Broadleaf evergreen tree – tropical	Trop BET	35	1	15.5	No limit	0			
Broadleaf evergreen tree – temperate	Temp BET	35	1	3	18.8	1200			
Broadleaf deciduous tree – tropical	Trop BDT	18	10	15.5	No limit	0			
Broadleaf deciduous tree – temperate	Temp BDT	20	11.5	–17	15.5	1200			
Broadleaf deciduous tree – boreal	Boreal BDT	20	11.5	No limit	–2	350		180	–7.5
Broadleaf evergreen shrub – temperate	Temp BES	0.5	0.1						
Broadleaf deciduous shrub – temperate	Temp BDS	0.5	0.1	–17	No limit	1200			
Broadleaf deciduous shrub – boreal	Boreal BDS	0.5	0.1	No limit	–2	350		380	–10
C3 arctic grass	C3 A	0.5	0.01	No limit	–17	0			
C3 grass	C3	0.5	0.01	–17	15.5	0			
C4 grass	C4	0.5	0.01	15.5	No limit	0			
Non vegetated/bare ground	BG								

Supplement S7 – Representation of grid-cells in the CLM 4.5 model

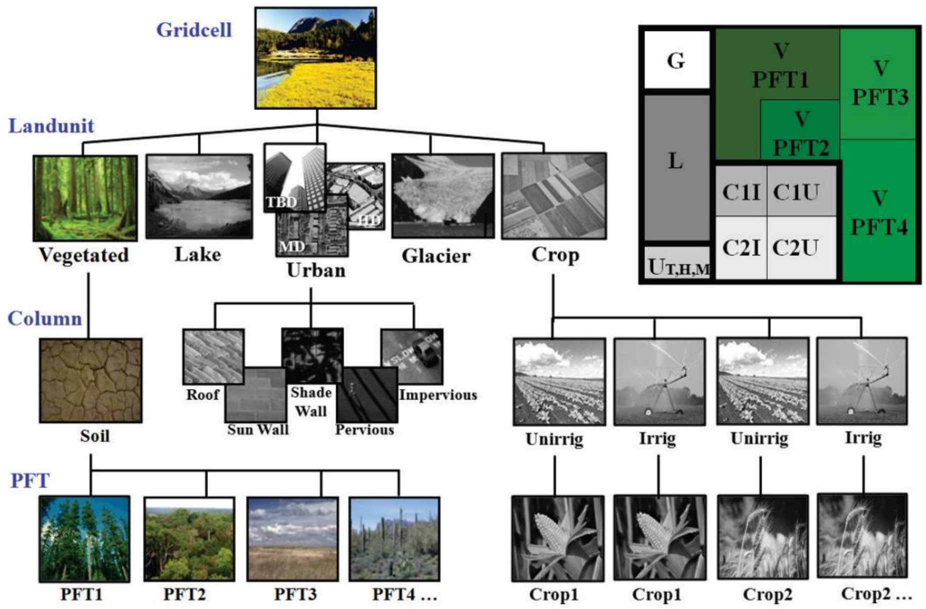


Figure S7 – Representation of a grid-cell in the DGVM model (obtained by CLM4.5-BGCDV method); figure adapted from Oleson et al. (2013). Land units in grey (lake, urban, glacier and crop) were excluded from this study.

Supplement S8 – DM- and RS-units reclassified to PFT units

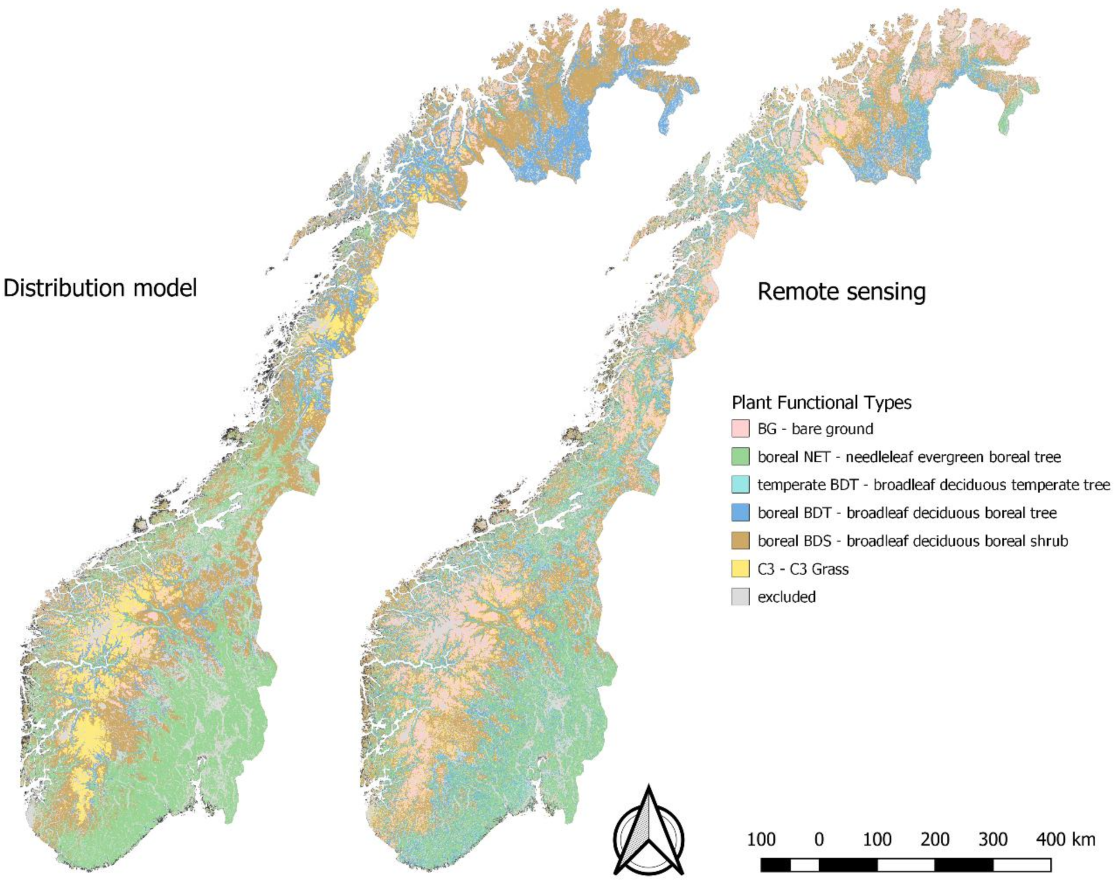


Figure S8– The distribution in Norway of vegetation types (used in distribution modelling – DM) and units obtained by remote sensing (RS), after reclassification to PFT units (see Table 2 for conversion scheme and explanation of PFT codes). The dominating PFT in each grid cell (of 100×100 m for DM and 30×30 m for RS) is shown.

The distributions in Norway of PFTs obtained by conversion of DM- and RS-units using the conversion scheme in Table 2 exhibit considerable similarities (Fig. S8). Both methods show dominance of boreal needleleaf evergreen forest (boreal NET) in southeastern Norway, while most of the western and northern Norway is covered by boreal broadleaf deciduous shrub (boreal BDS) and boreal broadleaf deciduous forest (boreal BDT). Slight differences between the two methods can be seen in the western mountainous part of Norway, where DM predicts dominance by C3 grasses where RS suggests bare ground, and in North Norway where DM predicts boreal BDS where RS predicts bare ground. Accordingly, the fractional area classified to PFTs that are converted to bare ground is three times higher with RS than with DM (Table S8).

Table S8 – Area statistics for Norway for vegetation types (used in distribution modelling – DM) and units obtained by remote sensing (RS), after reclassification to PFT units (see Table 2 for conversion scheme and explanation of PFT codes).

	RS (%)	DM (%)
BG	17.1	5.6
Boreal NET	25.3	31.4
Temperate BDT	5.2	0.1
Boreal BDT	16.9	15.0
Boreal BDS	27.9	39.0
C3	7.5	8.9

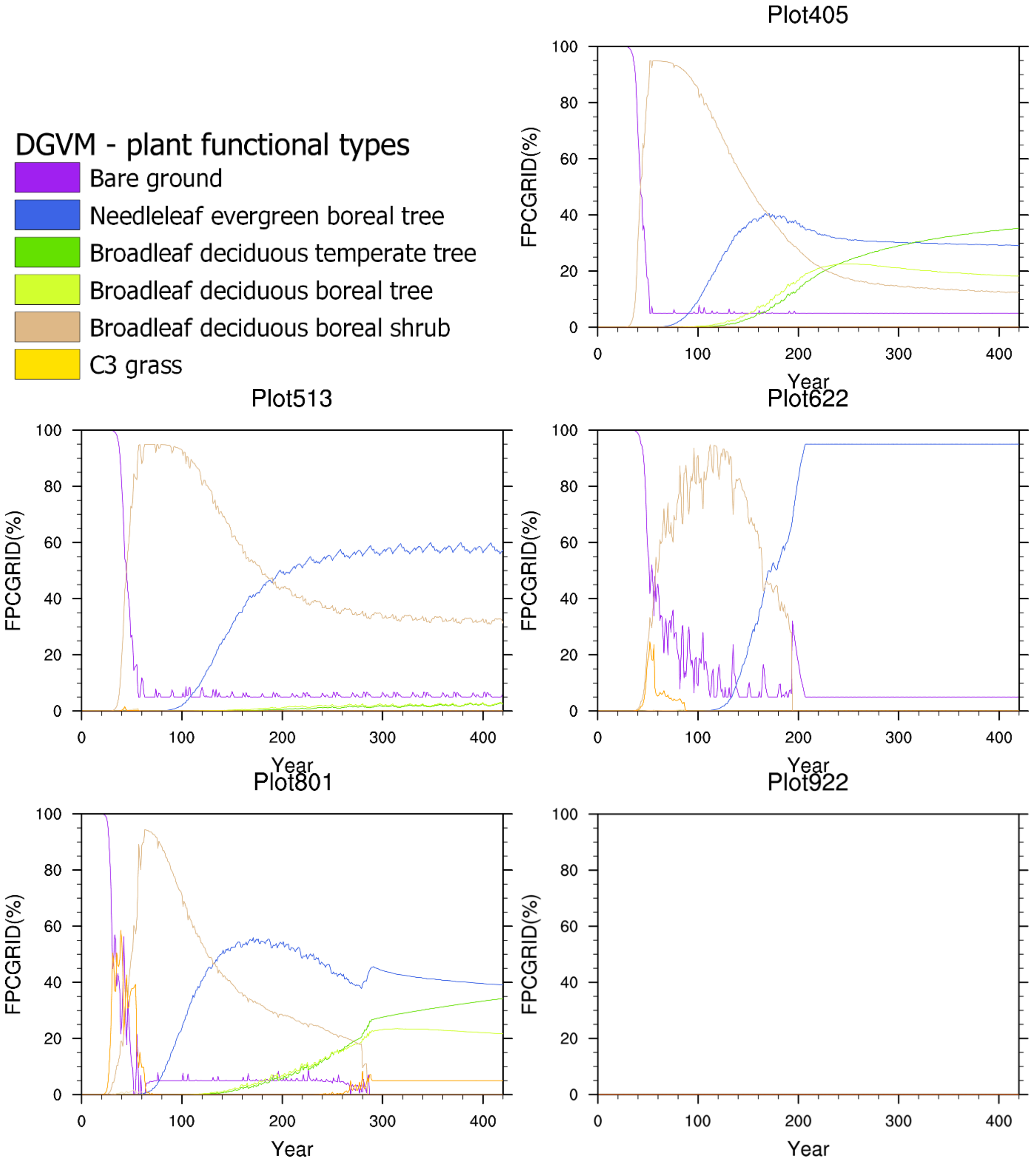
Supplement S9 – PFT profiles for each of the 20 plots

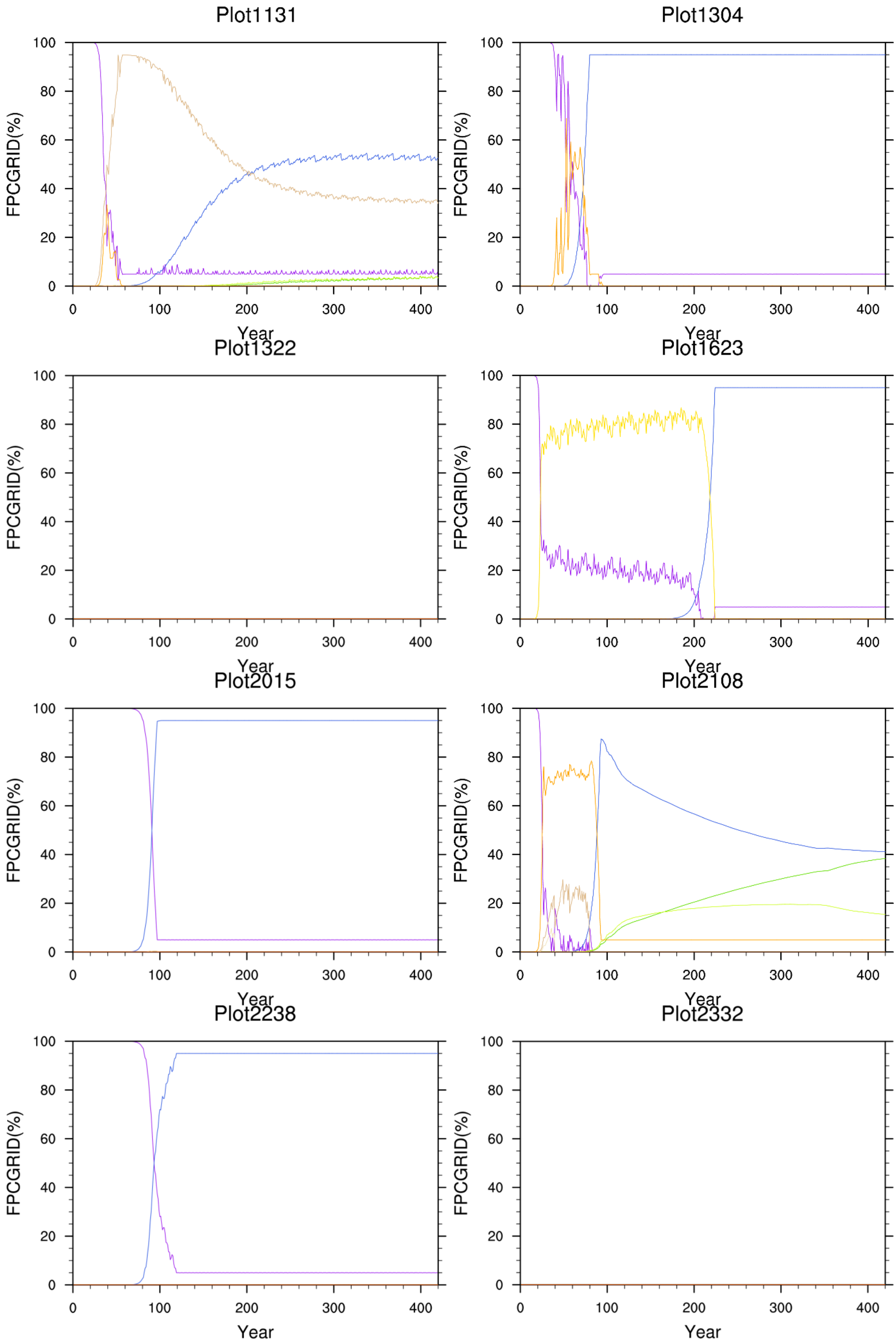
Table S9– PFT profiles (percentage of vegetated land assigned to each of six PFTs) for each of the 20 plots in this study, obtained by remote sensing (RS) and distribution modelling (DM) methods and for the AR reference dataset. Original units (vegetation types, etc.) are converted to PFTs by use of the scheme in Table 2.

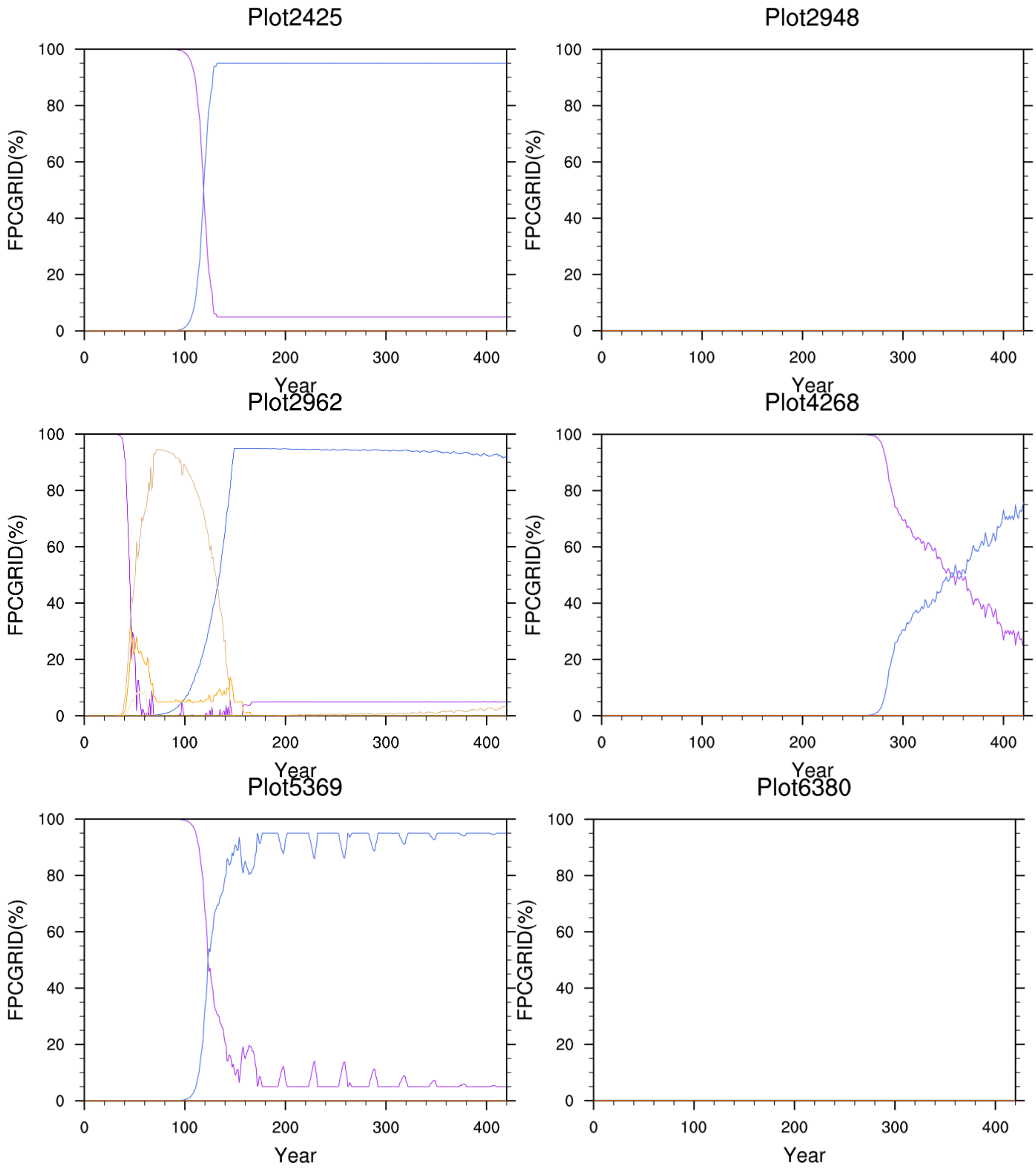
Method	PFT_shortcut	plot 3	plot 2	plot 1	plot 6	plot 4	plot 5	plot 8	plot 7	plot 9	plot 10	plot 12	plot 11	plot 13	plot 14	plot 16	plot 15	plot 17	plot 18	plot 19	plot 20
DGVM	BG	5	6	5	0	100	6	5	100	5	5	0	5	100	5	100	5	28	5	100	5
DGVM	boreal NET	29	58	95	39	0	52	95	0	95	95	41	95	0	95	0	92	72	95	0	95
DGVM	temp. BDT	35	2	0	34	0	4	0	0	0	0	38	0	0	0	0	0	0	0	0	0
DGVM	boreal BDT	18	2	0	22	0	4	0	0	0	0	16	0	0	0	0	0	0	0	0	0
DGVM	boreal BDS	13	32	0	0	0	35	0	0	0	0	0	0	0	0	0	3	0	0	0	0
DGVM	C3	0	0	0	5	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
RS	BG	9	7	4	0	92	8	0	78	0	0	0	0	7	3	24	52	0	1	54	1
RS	boreal NET	30	2	0	75	0	0	68	0	93	75	69	91	0	86	0	0	20	0	0	70
RS	temp. BDT	6	0	0	6	0	0	15	0	0	2	7	1	0	0	0	0	0	0	0	1
RS	boreal BDT	2	1	1	19	0	0	17	0	7	22	20	8	0	8	0	0	48	68	0	28
RS	boreal BDS	18	68	80	0	1	85	0	0	0	1	3	0	78	3	35	37	28	30	9	1
RS	C3	35	23	14	0	7	7	0	22	0	0	1	0	16	0	41	11	3	0	37	0
DM	BG	0	8	0	0	2	0	0	70	0	0	0	0	0	0	0	33	0	0	46	0
DM	boreal NET	60	1	0	100	0	0	96	0	47	100	100	100	0	72	0	0	0	0	0	0
DM	temp. BDT	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
DM	boreal BDT	0	0	0	0	0	0	0	0	53	0	0	0	0	23	0	0	77	91	0	100
DM	boreal BDS	40	91	100	0	0	100	0	3	0	0	0	0	100	4	100	63	23	9	54	0
DM	C3	0	0	0	0	98	0	0	26	0	0	0	0	0	0	0	4	0	0	0	0
AR	BG	0	4	0	0	87	0	0	66	0	0	0	0	0	0	11	13	0	0	78	0
AR	boreal NET	63	0	0	79	0	0	79	0	82	84	83	86	0	82	1	0	0	0	0	97
AR	temp. BDT	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0
AR	boreal BDT	9	12	35	21	0	0	11	0	18	16	17	14	5	9	3	0	66	70	0	3
AR	boreal BDS	28	75	63	0	0	99	0	10	0	0	0	0	87	9	79	83	34	30	18	0
AR	C3	0	9	1	0	13	1	0	25	0	0	0	0	8	0	6	5	0	0	3	0

Supplement S10 – DGVM spin-up and simulation of PFT profiles for each plot

DGVM spin-up for 400 years and 20 years of simulation of PFT profiles for each of the 20 plots used in this study.




Plot1131
Plot1304
Plot1322
Plot1623
Plot2015
Plot2108
Plot2238
Plot2332
FPCGRID(%)
Year
0
20
40
60
80
100
0
100
200
300
400


Plot2425
Plot2948
Plot2962
Plot4268
Plot5369
Plot6380
FPCGRID(%)
Year
0
20
40
60
80
100
0
100
200
300
400

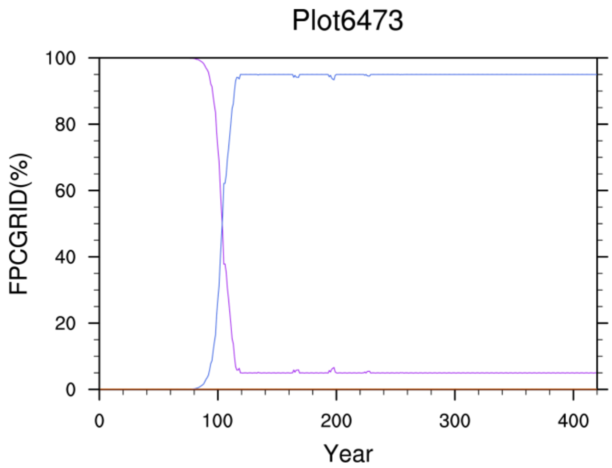


Figure S10 – DGVM spin-up for 400 years and simulation of PFT profiles for each of the 20 plots used in this study. FPCGRID – estimated percentage per PFT per grid cell. Reference number of plots accords with the AR18x18 dataset, and plot numbers can be found in Table S1

Supplement S11 – Sensitivity experiments: frequency-of-presence (FoP) plots

Frequency-of-presence (FOP) plots based upon output from distribution models (DM) for the nine combinations of three environmental variables and three vegetation types modelled, used to indicate threshold values that were explored in the sensitivity experiments, are shown in Fig. S11. Thresholds for new variables in DGVM models were chosen based upon visual inspection of the FoP plots.

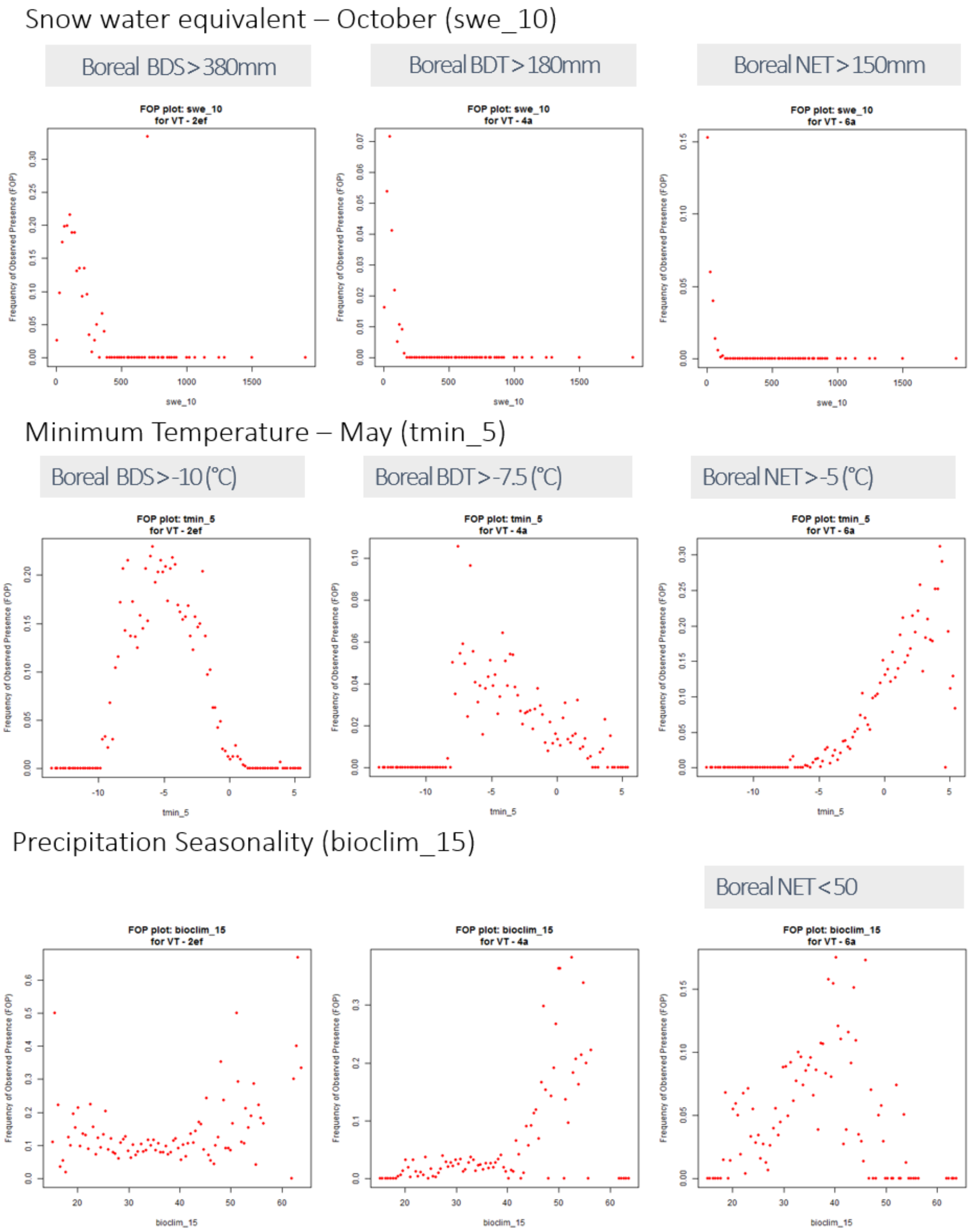


Figure S11 – Frequency-of-presence plots from the distribution modelling (DM) study by Horvath et al. (2019) for the combinations of environmental predictors and vegetation types (VTs) used in the sensitivity experiments with DGVM. FOP is the frequency of 100×100 m pixels in the AR18×18 dataset in which the VT in question is present, expressed as a fraction of all pixels in that interval along the environmental variable. All environmental variables were a priori divided into 100 intervals with the same number of pixels. The environmental gradients were: swe_10 – snow water equivalent in October (mm); tmin_5 –- minimum temperature in May (°C); bioclim_15 – precipitation seasonality (unitless index). Boreal BDS – boreal broadleaf deciduous shrubs, Boreal BDT - boreal broadleaf deciduous trees, Boreal NET - boreal needleleaf evergreen shrubs.

Supplement S12 – Sensitivity experiments: results

Table S12 – PFT profiles for the six out of the 20 plots (plot numbers 1, 2, 5, 15, 17, 18) which were included in the sensitivity experiments, for four 'generations' of DGVM parameter settings and the AR reference dataset. From left to right the column represent: DGVM before adjustment of parameters; DGVM_adj1 after adjustment of swe_10; DGVM_adj2 after adjustment of tmin_5; DGVM_adj3 after adjustment of bioclim_15; and the PFT profile of the reference dataset AR. Full names for the PFTs are given in Table S6 and names of parameters and their values in Error! Reference source not found.**.**

	DGVM	DGVM adj1	DGVM adj2	DGVM adj3	AR	DGVM	DGVM adj1	DGVM adj2	DGVM adj3	AR	DGVM	DGVM adj1	DGVM adj2	DGVM adj3	AR	DGVM	DGVM adj1	DGVM adj2	DGVM adj3	AR	DGVM	DGVM adj1	DGVM adj2	DGVM adj3	AR	DGVM	DGVM adj1	DGVM adj2	DGVM adj3	AR
	plot 1					plot 2					plot 5					plot 15					plot 17					plot 18				
BG	5	5	5	9	0	6	5	5	5	4	6	6	6	7	0	5	5	5	3	13	28	100	100	100	0	5	100	100	100	0
boreal NET	95	95	95	0	0	58	58	58	0	0	52	52	52	0	0	92	92	92	0	0	72	0	0	0	0	95	0	0	0	0
temp. BDT	0	0	0	0	0	2	2	2	33	0	4	4	4	13	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
boreal BDT	0	0	0	0	35	2	2	2	31	12	4	4	4	13	0	0	0	0	2	0	0	0	0	0	66	0	0	0	0	70
boreal BDS	0	0	0	91	63	32	32	32	31	75	35	35	35	67	99	3	3	3	89	83	0	0	0	0	34	0	0	0	0	30
C3	0	0	0	0	1	0	0	0	0	9	0	0	0	0	1	0	0	0	6	5	0	0	0	0	0	0	0	0	0	0