Modelling climate change impacts on crop production and management in different regions of Germany using different algorithms to consider the CO_2 effect

K. C. Kersebaum
C. Nendel

Introduction

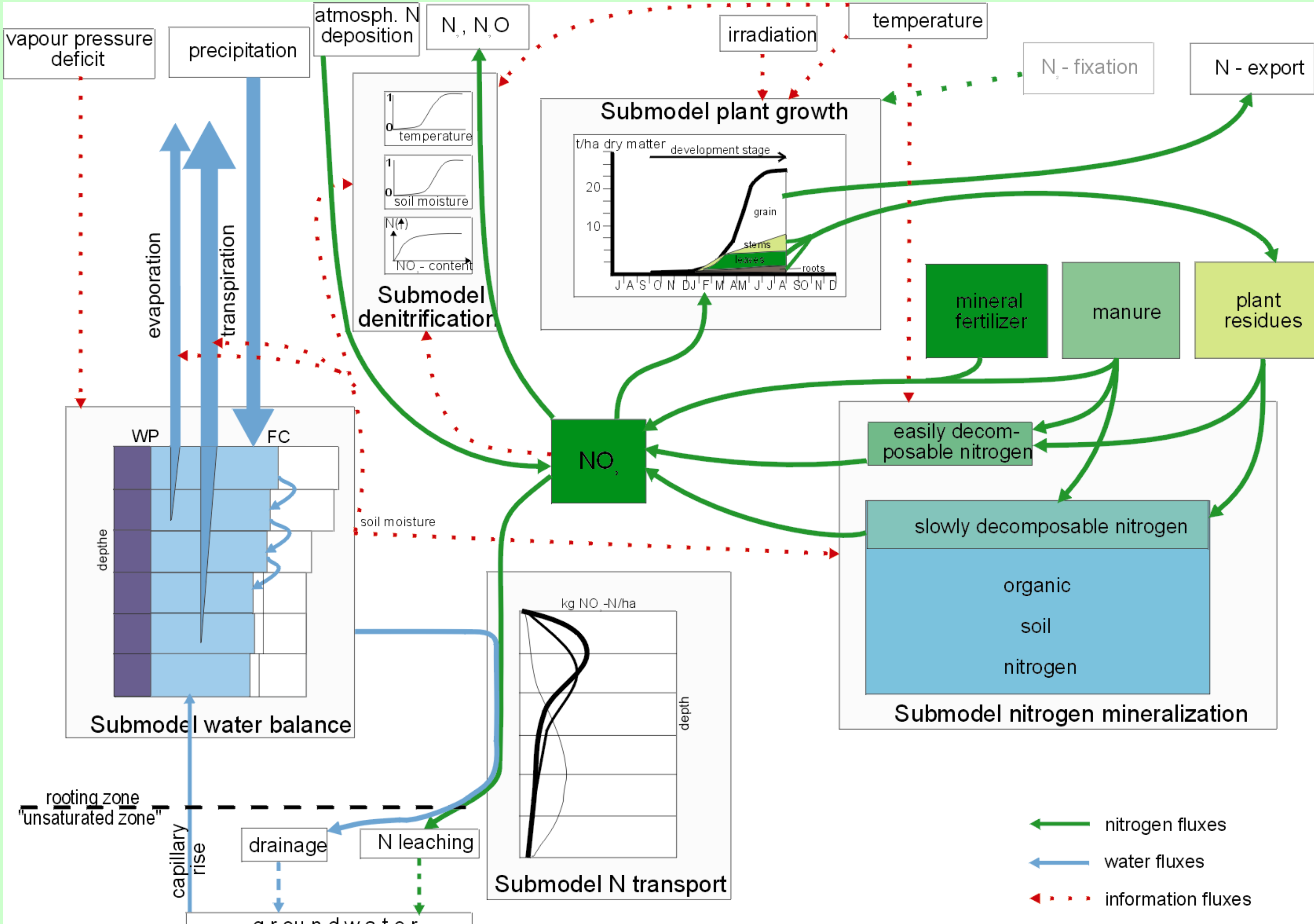
- downscaled GCM outputs are available to show the different regional expressions of Climate Change and to provide dynamic agro-ecosystem models with daily input data for impact assessment on agricultural crops and their future management.

- beside the pure climatic effect, rising CO_2 has physiological effects on photosynthesis and water consumption.

- based on findings of the German FACE experiment we tested different approaches to consider these effects in our model HERMES.

- we use the calibrated model to estimate the possible impact of climate change and rising CO_2 on crop yield and management of winter wheat on a regional scale accross different regions in Germany.

The model platform: HERMES



Source: K. C. Kersebaum, ZALF Müncheberg

The algorithms

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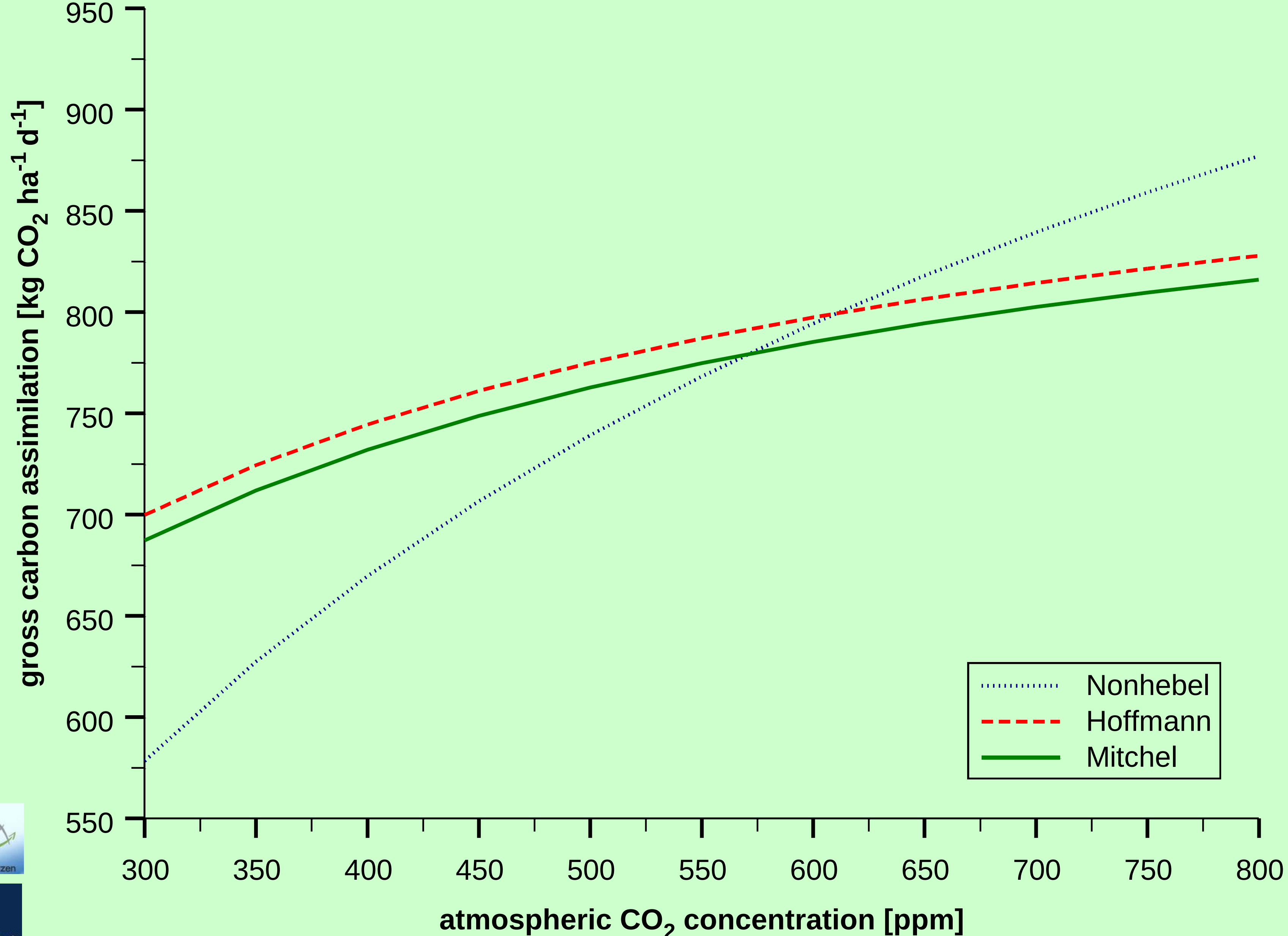
CO_2 – Crop growth :

1. SUCROS approach: direct impact of CO_2 to Radiation use efficiency and photosynthesis (Nonhebel, 1996)
2. Michaelis-Menten approach: combined effect of CO_2 and radiation on photosynthesis (Hoffmann, 1995)
3. Simplified Farquhar & von Caemmerer model (Mitchell, 1995)

CO_2 – Transpiration:

1. Combined approach of a transpiration model (Penman-Monteith; Allen et al. 1998) and a model for stomata resistance depending on CO_2, saturation deficit and temperature (Yu, 2004)

Comparing gross assimilation rates for a clear day without stress



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Summary of CO_2 algorithm test

Results given as Wilmott's Index of Agreement (1.0 = Best Fit)

Hoffmann	ambient N+	ambient N-	550 N+	550 N-
Dry matter	0.99	0.98	0.99	0.99
Yield	0.98	0.96	0.97	0.94
LAI	0.61	0.55	0.57	0.54
Soil moisture 0-60	0.82		0.80	
				0.84

Hoffmann + Allen/Yu	ambient N+	ambient N-	550 N+	550 N-
Dry matter	0.99	0.99	0.99	0.99
Yield	0.98	0.98	0.97	0.97
LAI	0.57	0.55	0.61	0.56
Soil moisture 0-60	0.86		0.85	
				0.85

Nonhebel	ambient N+	ambient N-	550 N+	550 N-
Dry matter	0.95	0.94	0.98	0.96
Yield	0.93	0.94	0.95	0.93
LAI	0.66	0.58	0.55	0.52
Soil moisture 0-60	0.82		0.80	
				0.82

Nonhebel + Allen/Yu	ambient N+	ambient N-	550 N+	550 N-
Dry matter	0.95	0.99	0.98	0.98
Yield	0.93	0.94	0.95	0.92
LAI	0.66	0.59	0.55	0.54
Soil moisture 0-60	0.85		0.85	
				0.83

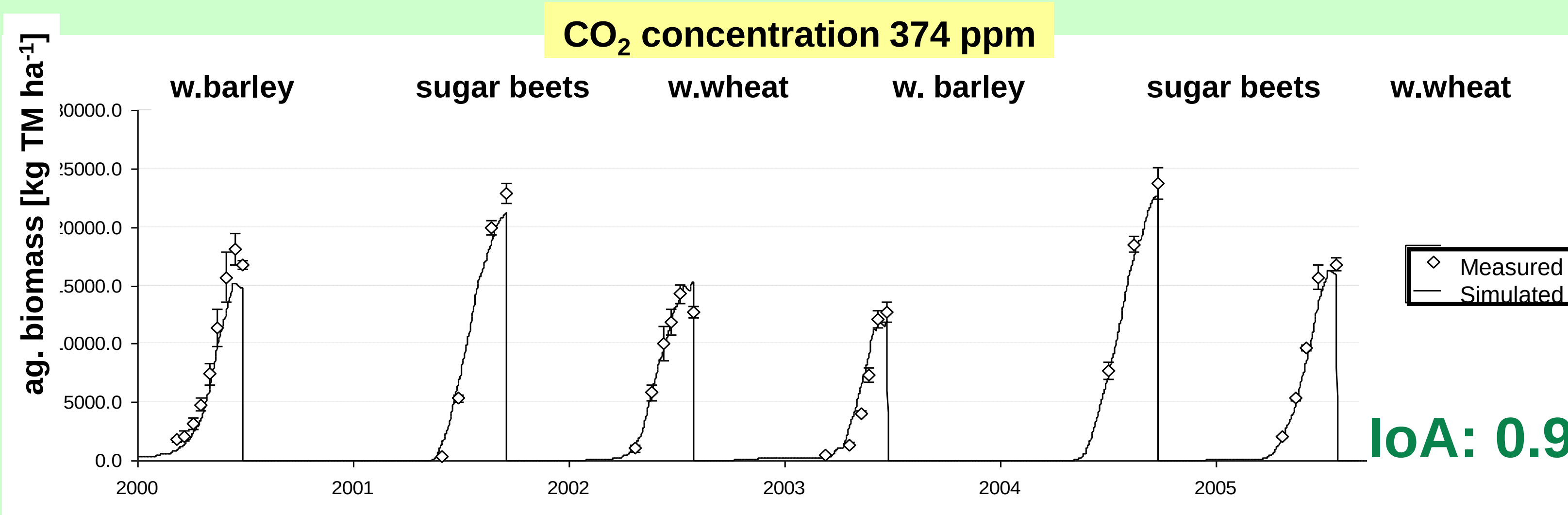
Mitchell	ambient N+	ambient N-	550 N+	550 N-
Dry matter	0.99	0.95	0.99	0.99
Yield	0.98	0.98	0.97	0.96
LAI	0.52	0.49	0.51	0.49
Soil moisture 0-60	0.82		0.79	
				0.82

Mitchell + Allen/Yu	ambient N+	ambient N-	550 N+	550 N-
Dry matter	0.99	0.95	0.99	0.99
Yield	0.97	0.97	0.97	0.96
LAI	0.52	0.50	0.52	0.50
Soil moisture 0-60	0.86		0.84	
				0.82

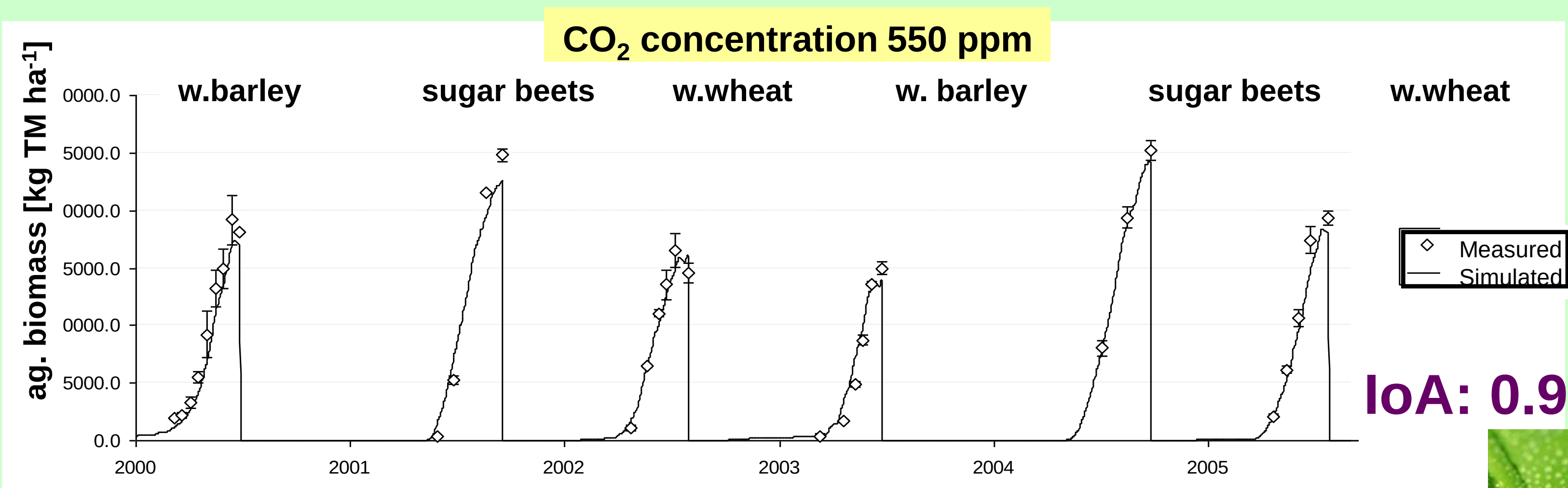
Model results for FACE experiment Braunschweig/Germany

Simulated and measured aboveground biomass

Hoffmann + Allen/Yu



IoA: 0.99



IoA: 0.99

data: Manderscheid und Weigel

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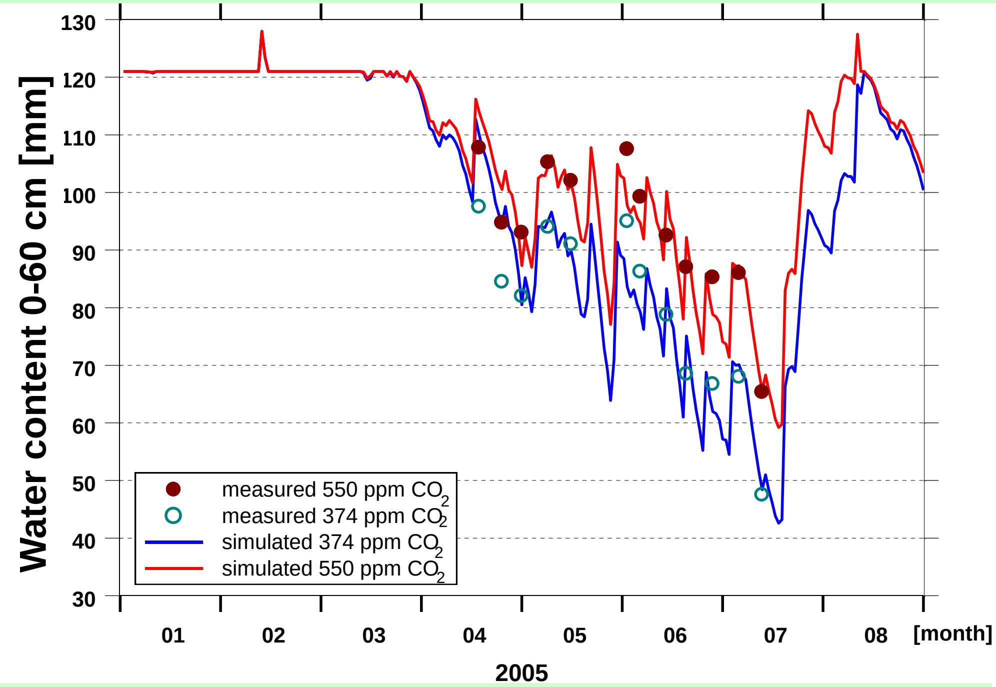
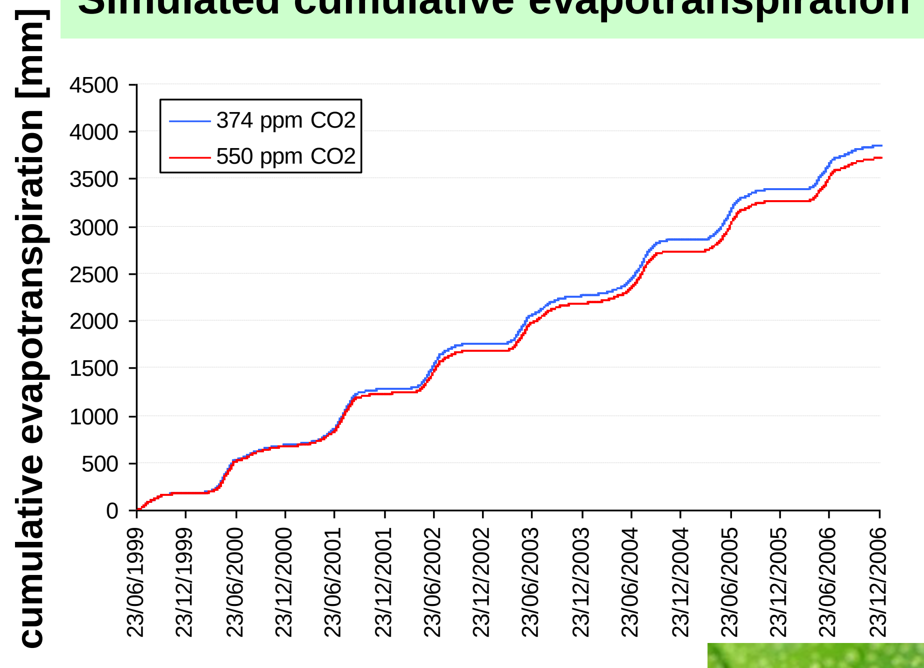
Kersebaum et al. 2009

Comparison of water consumption under ambient and elevated CO_2 concentration

Measured and simulated water content



Simulated cumulative evapotranspiration



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Climate change scenarios for different regions in Germany

Background of the study

- GCM model **ECHAM5/MPI-OMT63L31**
- Scenario A1B
- Daily time series from statistical downscaling model **WETTREG** for weather stations in Germany (period 1961-2050) (SPEKAT et al. 2007)
- 3 representative realisations (wet, dry, **normal**) out of 8 statistical generated time series of weather situations classified for wetness
- Reference period **1970-1989 (350ppm)**, projected period **2031-2050 (550ppm)**
- simulated crop: winter wheat, model runs without and with CO_2 effect using the 3 different algorithms in combination with the one for evapotranspiration

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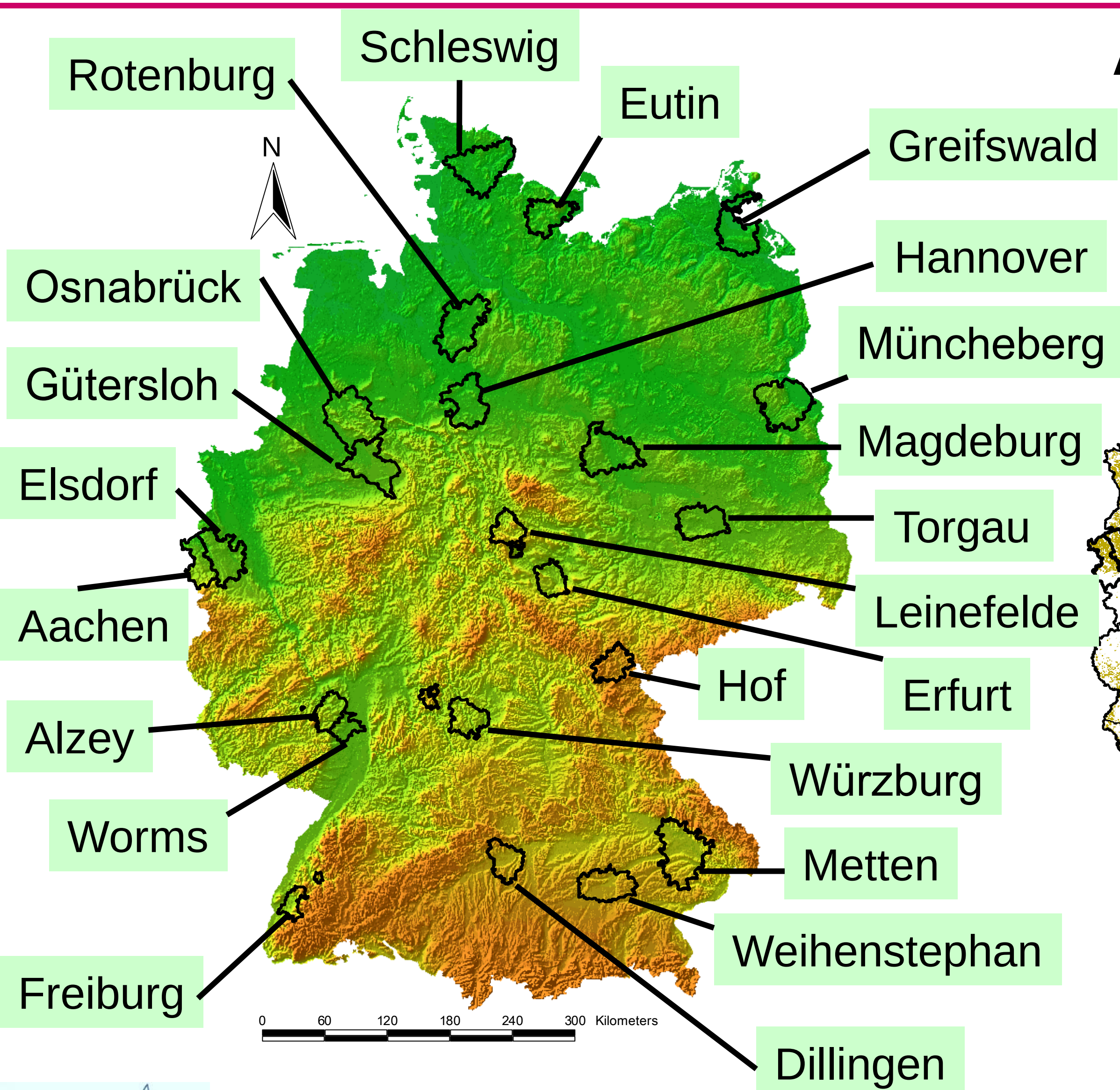
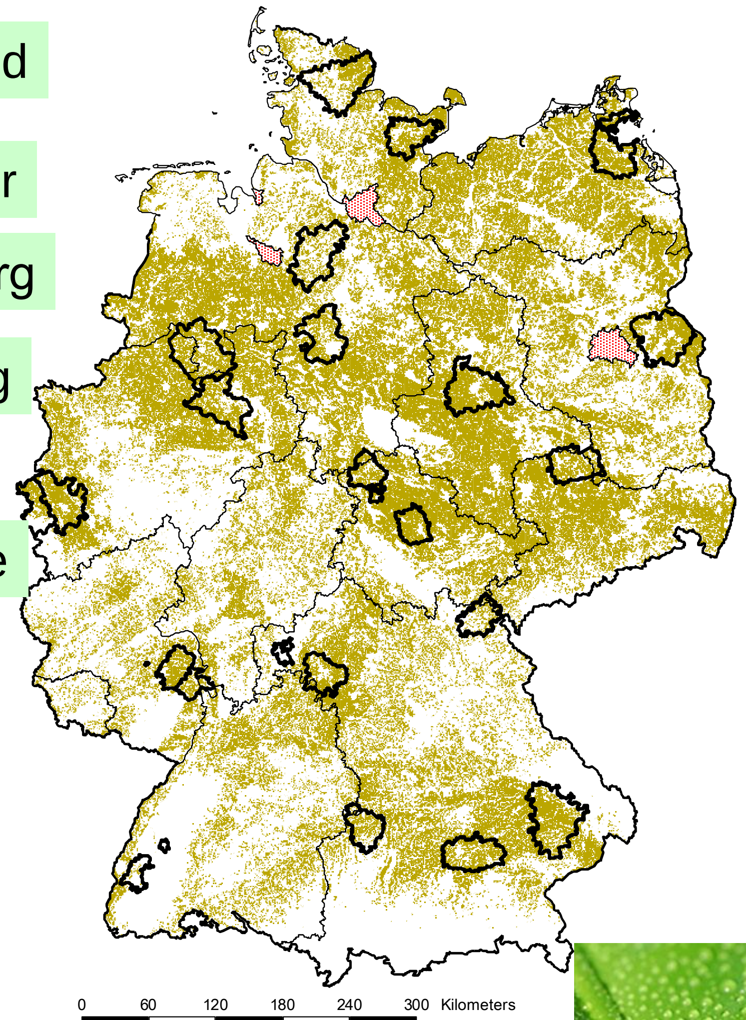
Selected regions with related met stations, elevation map, arable land (CORINE)



Arable land acc. to Corine 2000



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Data base: soil map 1:1.000.000 for Germany with 71 soil classes and profiles

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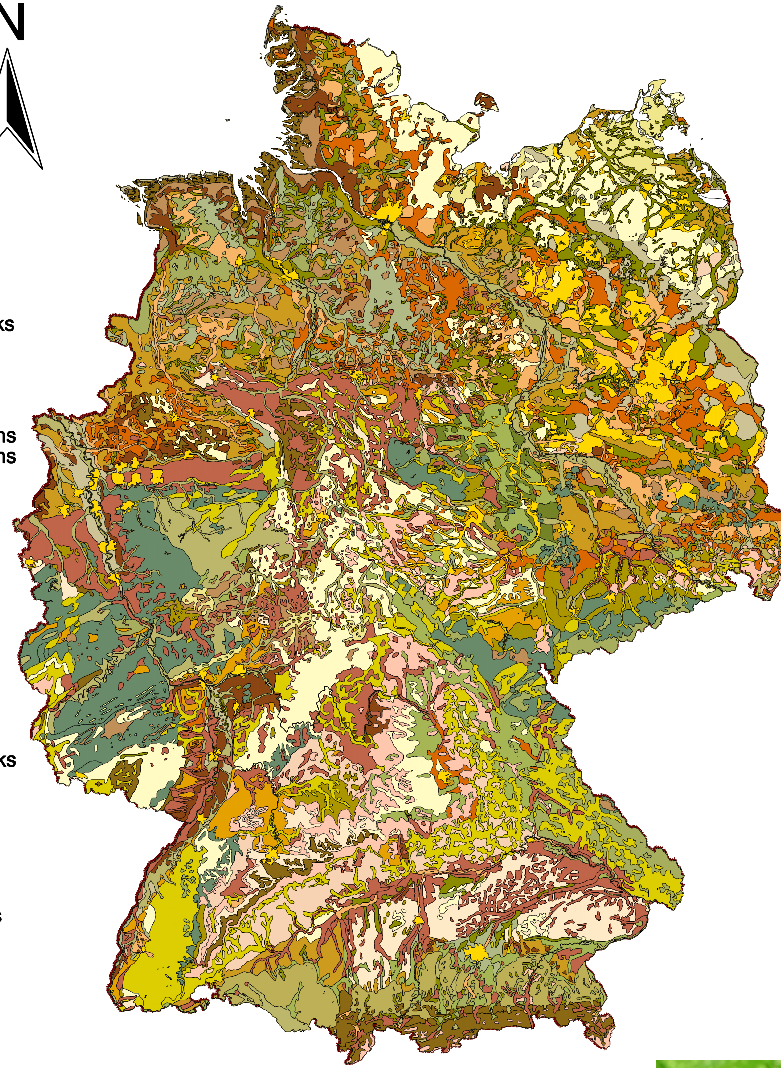

0 100 200 300 Kilometers

Soil classification (acc. to FAO)

- Fluvisols / Gleysols from rapidly alternating sandy to clayey fluviatile sediments
- Gleyic Chernozems from calcareous clayey and silty sediments in the river valleys of the chernozem area
- Fluvisols / Gleysols from loamy to clayey fluviatile sediments
- Fluvisols / Gleysols from sandy to loamy fluviatile sediments
- Calcaric and Umbric Regosols / Luvic Arenosols from sandy to loamy end moraine deposits (alternating patches)
- Haplic Luvisols / Eutric Podzoluvisols / Eutric Cambisols from sandy loess overlying sand or loam
- Eutric Cambisols from basic and intermediate igneous rocks
- Dystric Cambisols from sandy river-terrace deposits
- Dystric Cambisols/Stagnic Gleysols from metamorphic rocks; sandstone; quartzite; acid to intermediate igneous rocks
- Spodic Cambisols from hard argillaceous and silty slates with greywacke; sandstone; quartzite; and phyllite
- Eutric Cambisols / Luvic Arenosols from eutrophic sand deposits
- Dystric Cambisols from quartzitic sandstones and conglomerates with low base status
- Dystric Cambisols from acid igneous and metamorphic rocks
- Alternating Rendzic & Umbric Leptosols / Spodic & Vertic Cambisols / Haplic Luvisol / Stagnic Gleysols various origins
- Alternating Rendzic & Umbric Leptosols / Spodic & Vertic Cambisols / Haplic Luvisol / Stagnic Gleysols various origins
- Cambic and Haplic Podzols from sandstone and quartzite with low base status
- Cambic Podzols / Spodic Arenosols from dry dystrophic sand deposits
- Haplic Chernozems / Eutric Cambisols from loess alternating with Rendzic Leptosols from marlstone and limestone
- Haplic Podzols / Dystric Regosols from dry dystrophic sand deposits
- Haplic Luvisols / Eutric Podzoluvisols / Stagnic Gleysols from loess or loessic loam overlying various rocks
- Dystric Podzoluvisols / Luvic Arenosols / Dystric Cambisols from sandy sediments overlying boulder clay
- Surface water
- Gleysols from sandy sediments of the ice-marginal valleys and lowlands
- Haplic Luvisols from loess-covered loamy to sandy river-terrace deposits
- Haplic Podzols / Cambic Podzols / Gleyic Podzols from sandy fluviatile sediments
- Dystric Histosols
- Eutric Histosols
- Haplic Luvisols / Eutric Podzoluvisols / Stagnic Luvisols from boulder clay
- Altern. Dystric and Spodic Cambisols/Rendzic Leptosols/Haplic Luvisols from slate; greywacke etc. over various rocks
- Eutric Cambisols / Haplic Luvisols / Calcaric Regosols from Tertiary loess-bearing sediments
- Haplic Luvisols from silty to loamy periglacial sediments overlying glacial gravels
- Phaeozemic and Haplic Luvisols from sandy loess overlying sandy glacial sediments or boulder clay
- Calcaric Regosols / Calcaric Fluvisols from calcareous sandy to loamy sediments of river terraces
- Calcaric Regosols from loess alternating with Rendzic Leptosols from marlstone and limestone
- Sealed areas in larger cities (Urbic Anthrosols)
- Eutric Cambisols / Stagnic Gleysols from calcareous loamy and sandy to gravelly morainic deposits mixed with loess
- Spodic Cambisols from acid igneous and metamorphic rocks
- Spodo-Stagnic Cambisols / Stagnic Podzoluvisols from loamy to sandy deposits overlying boulder clay
- Stagnic Gleysols from boulder clay with a loamy to sandy cover
- Stagnic Gleysols / Eutric Cambisols / Haplic Luvisols from loess or loessic loam
- Stagnic Chernozems from boulder clay with a loamy to sandy cover
- Rendzic Leptosols from slope deposits over limestone; marlstone etc. alternating with Chromic Cambi- and Luvisols
- Haplic Chernozems from loess of the central German low-rainfall area
- Phaeozemic Luvisols / Luvic Phaeozems from loess or loessic loam

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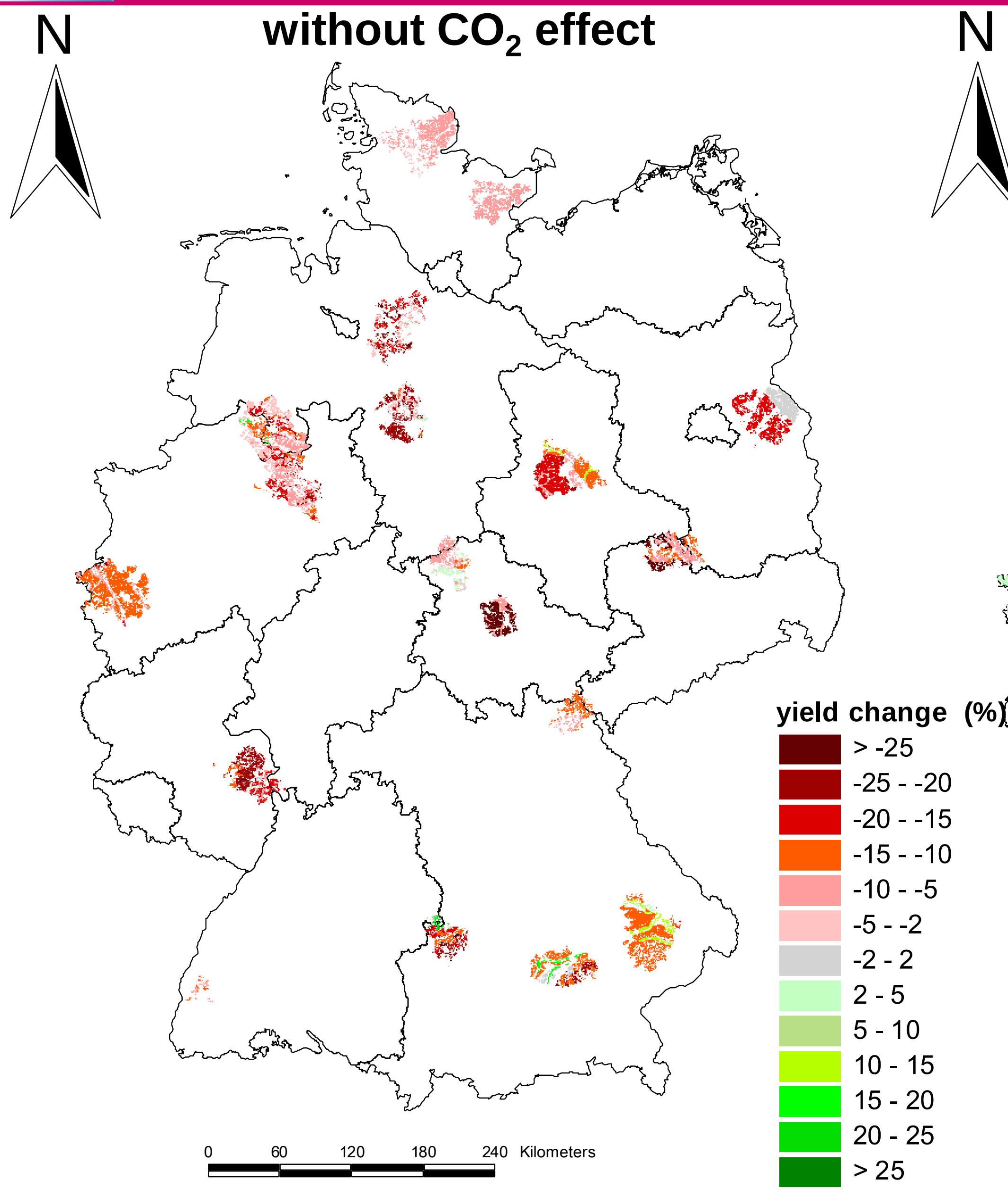
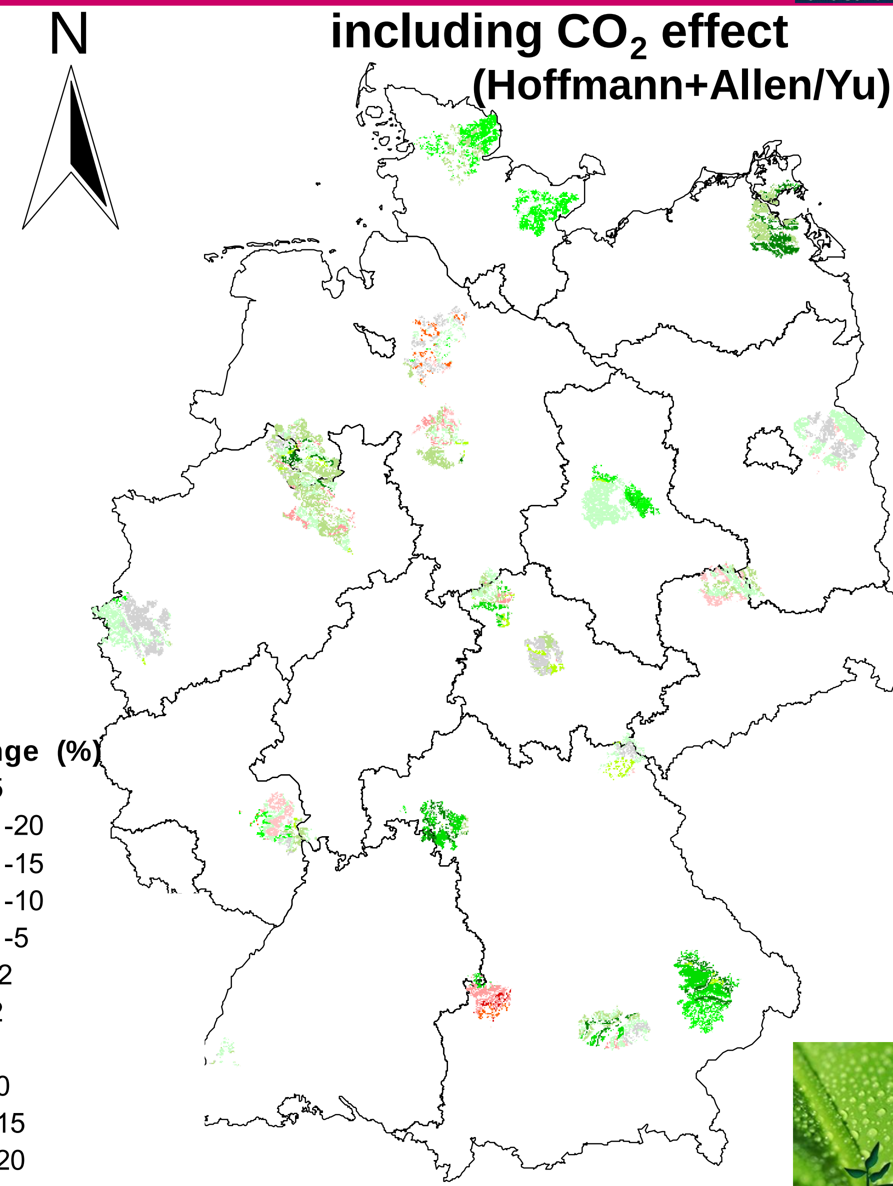
Simulated changes of winter wheat yields with and without CO_2 effect (2031-2050 compared to 1970-1989)

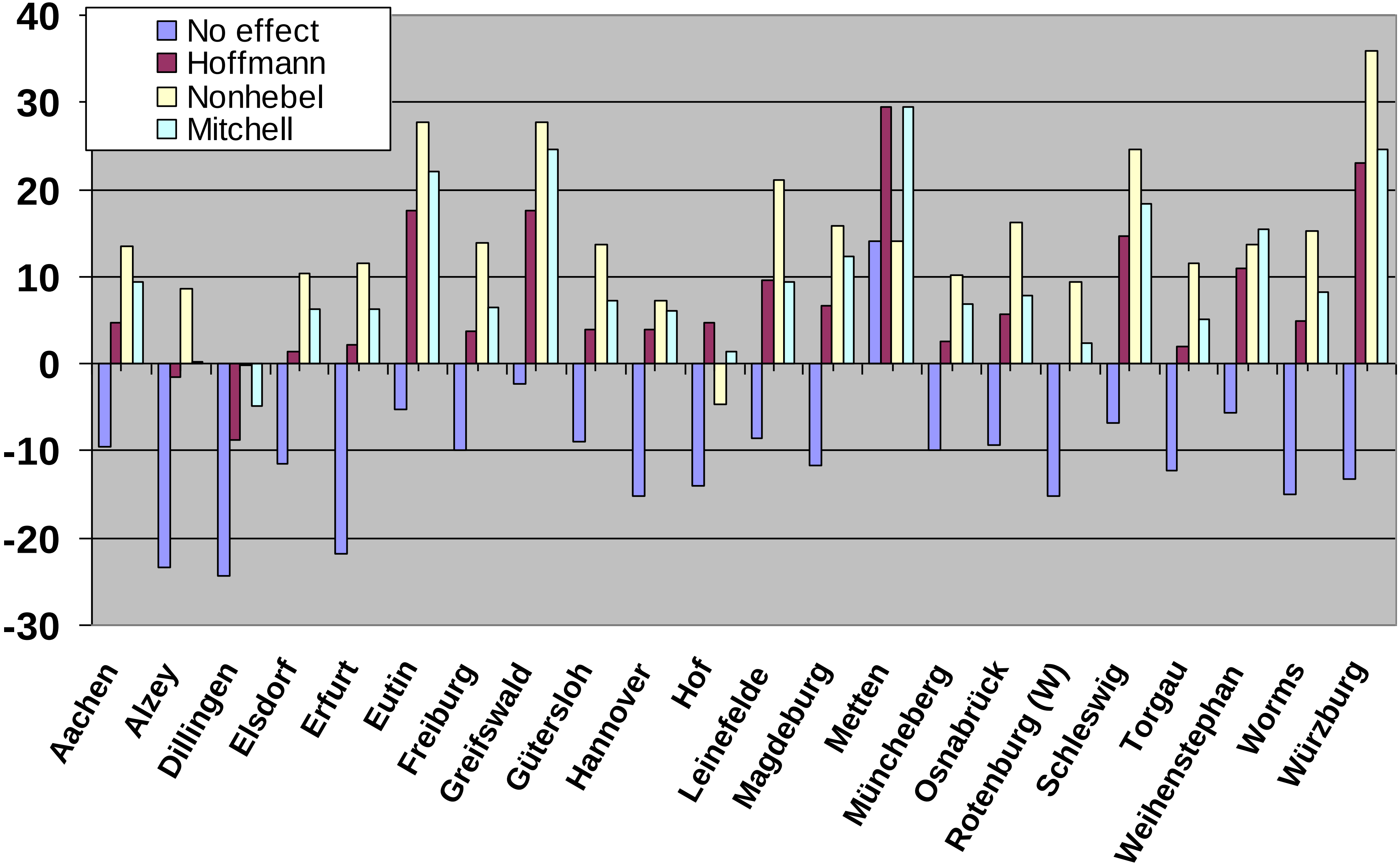
without CO_2 effect



including CO_2 effect (Hoffmann+Allen/Yu)

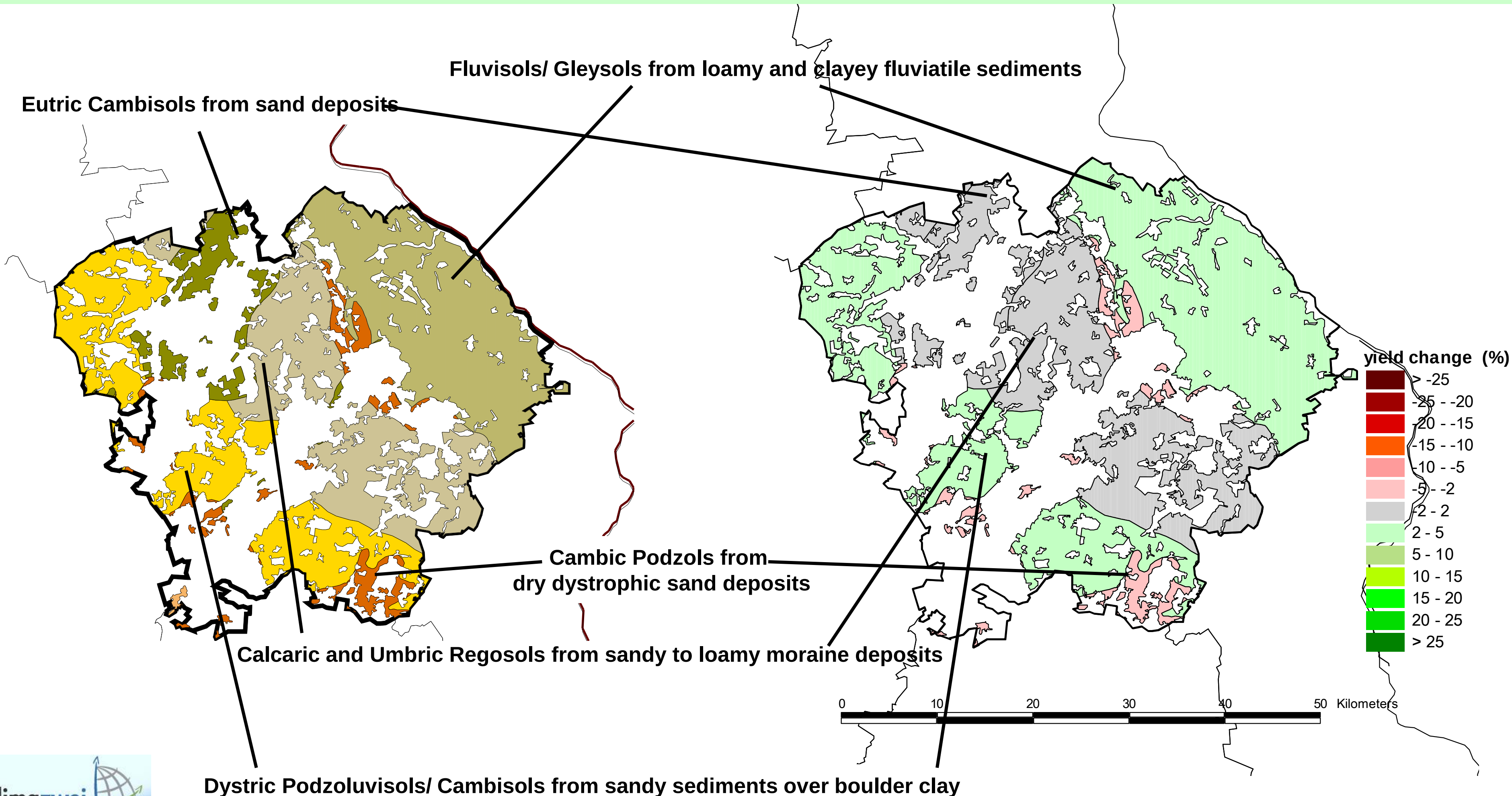


Summarized yield changes in selected regions using different CO_2 algorithms



Soil distribution and climate change impact on grain yield of winter wheat in Müncheberg region

	Annual mean temperature	summer precipitation	winter precipitation
1970 – 1989	8.8	280 mm	253 mm
2031 – 2050	9.4 (+7%)	266 mm (-4.7 %)	239 mm (-5.5 %)



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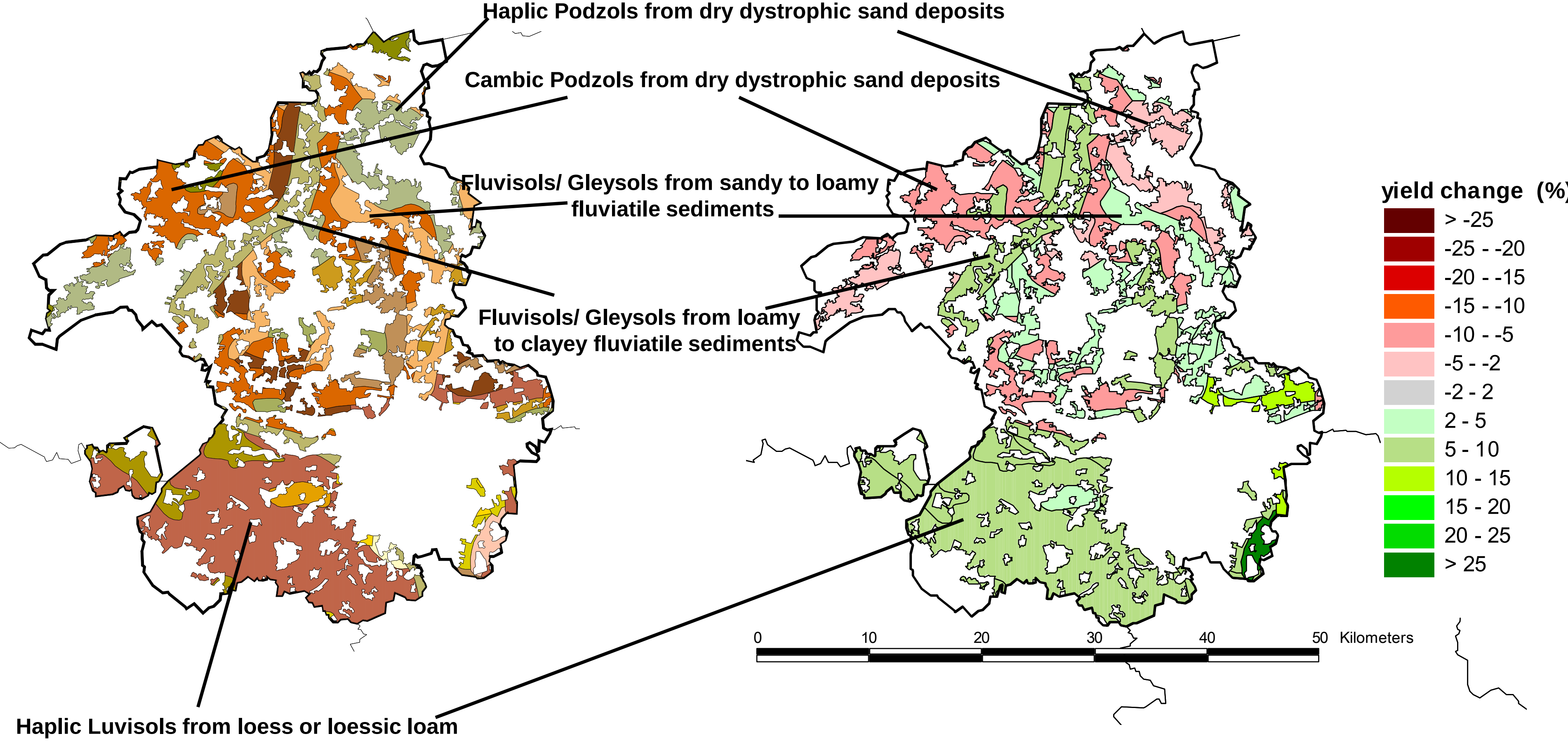
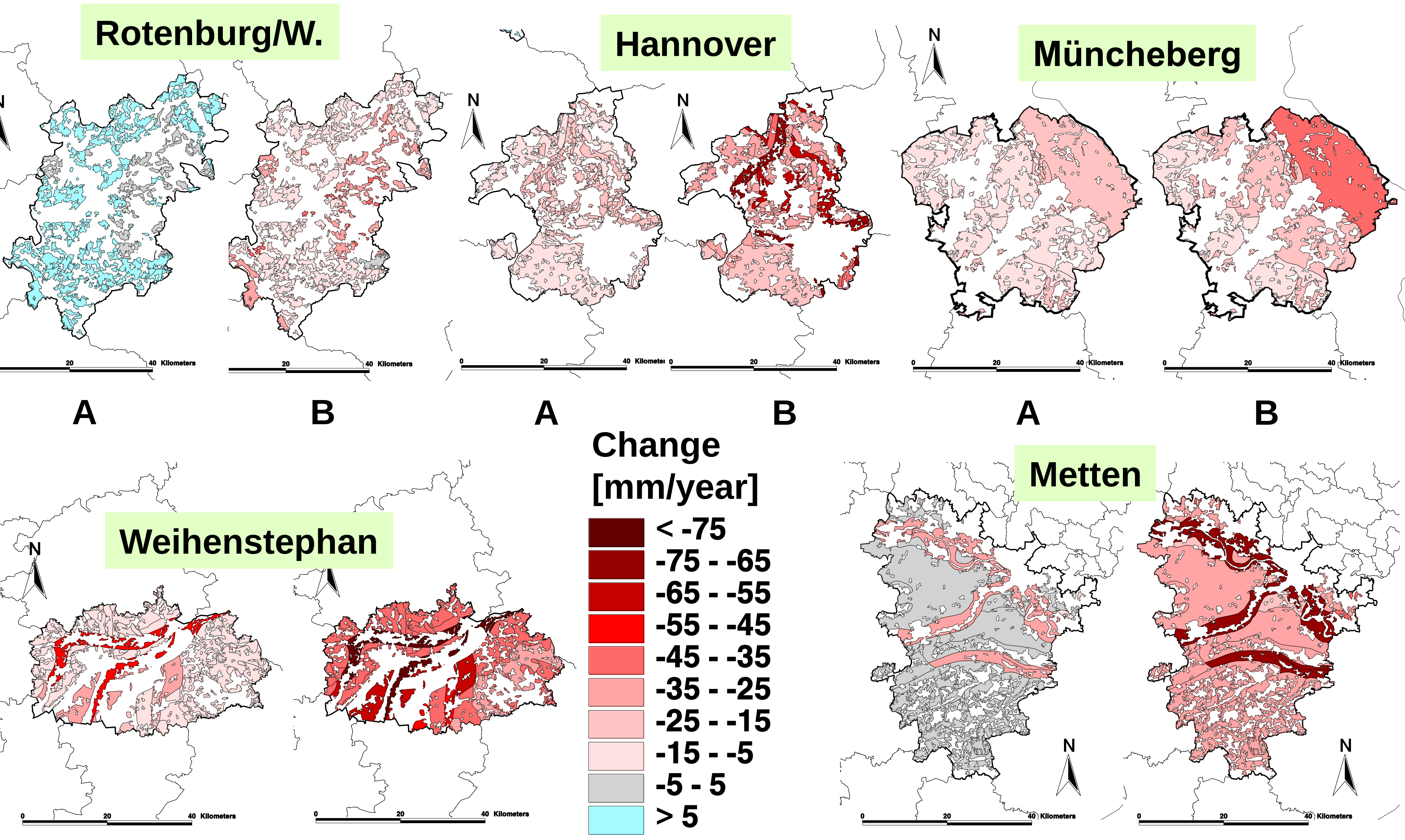
Soil distribution and climate change impact on grain yield of winter wheat in Hannover region

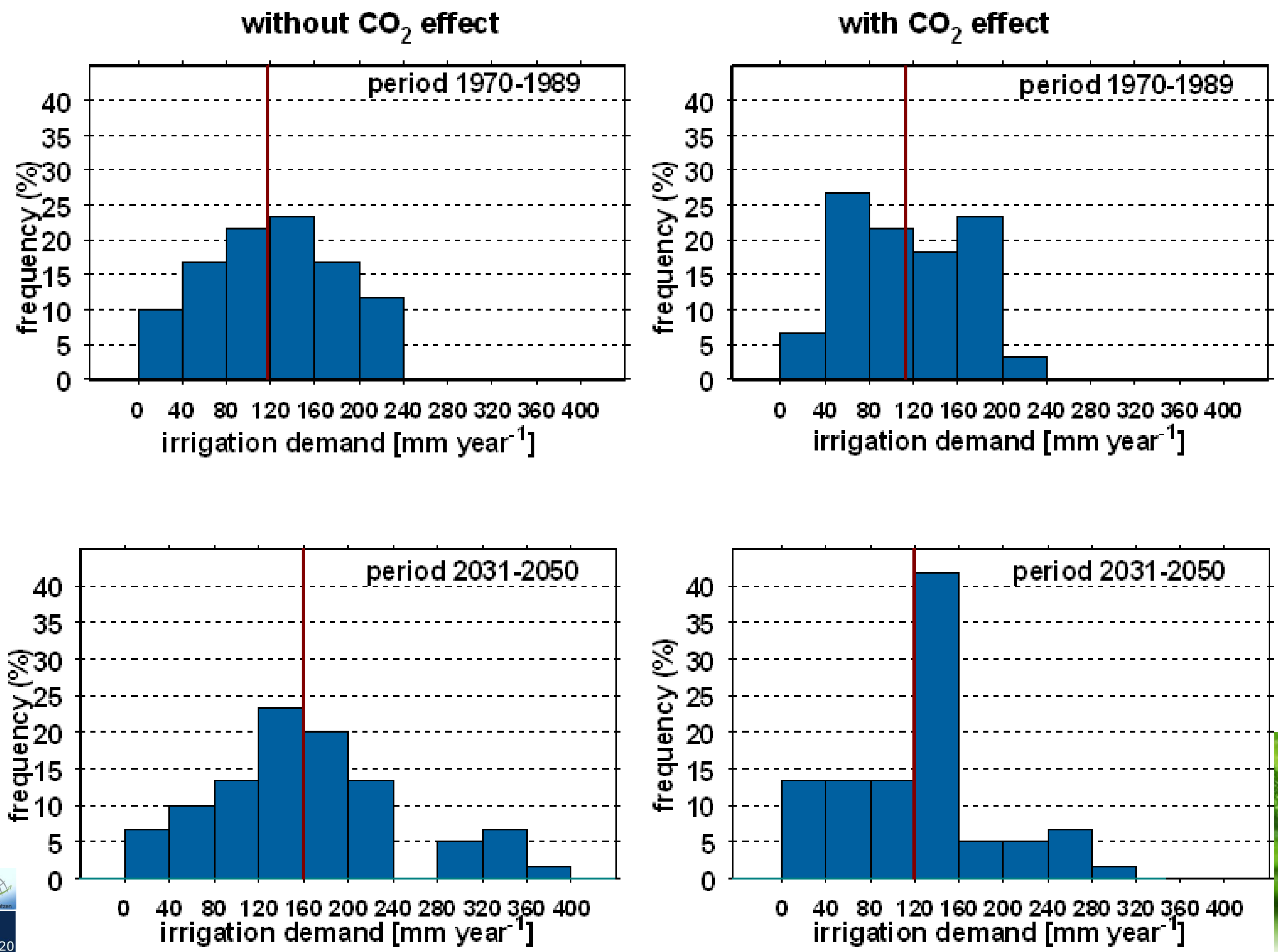
	Annual mean temperature	summer precipitation	winter precipitation
1970 – 1989	9.3	326 mm	303 mm
2031 – 2050	10.1 (+8.8%)	307 mm (-5.9 %)	290 mm (-4.3 %)



Simulated changes of groundwater recharge with (A) and without (B) CO_2 effect (2031-2050 compared to 1970-1989)



Simulated irrigation demand Magdeburg with and without CO_2 effect (typical loess soil)



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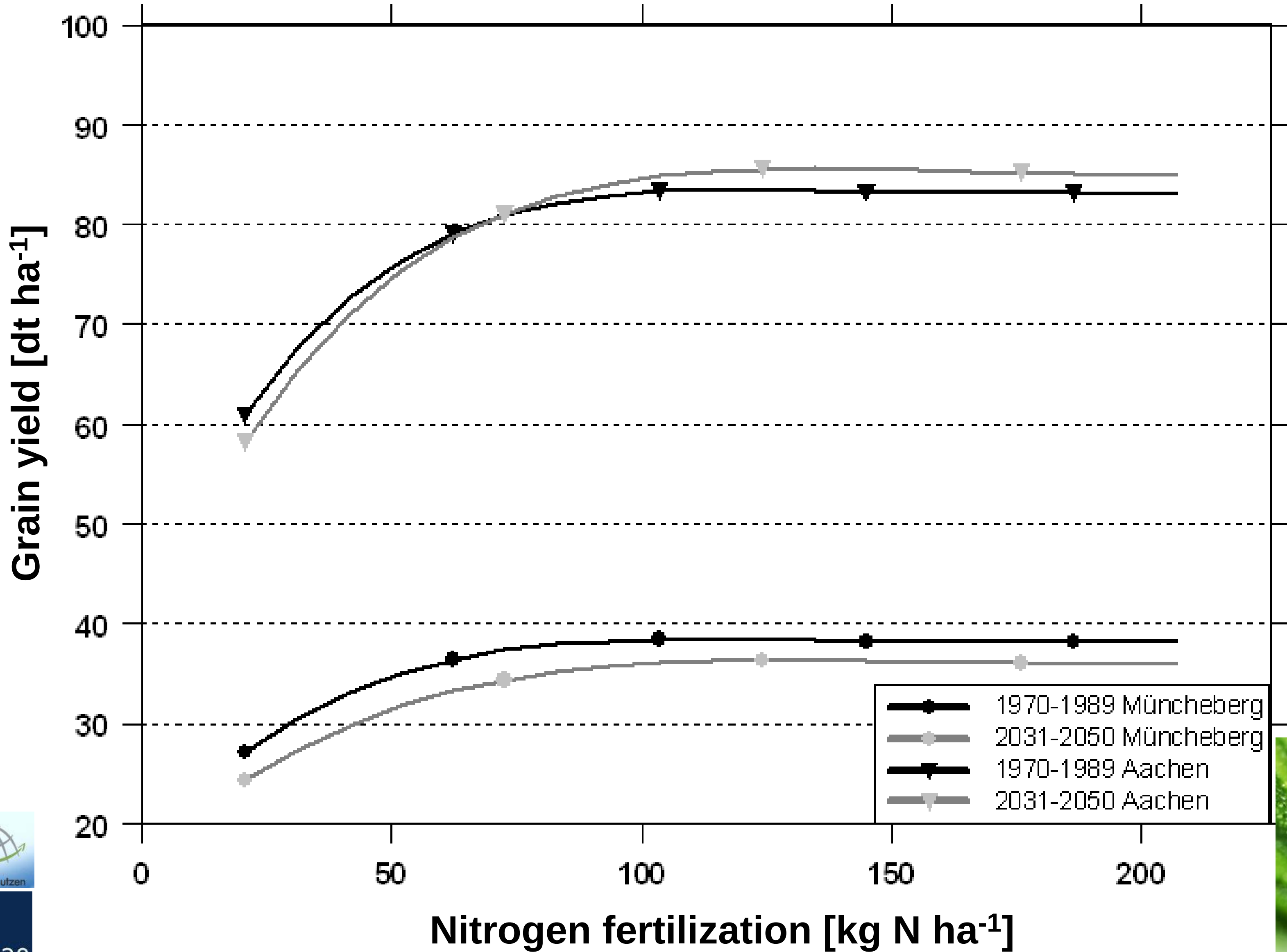
Simulated changes of yield/nitrogen response curves Müncheberg and Aachen for typical soils



Conclusions

- Although different algorithms gave similar results for a FACE experiment, their application on a regional scale under climate change conditions showed higher differences.
- Due to the consideration of the CO_2 effect the impact of climate change on crop yield in Germany turns from negative into mostly positive.
- However, this differs between and even within regions due to different regional patterns of climate change and the combined effect of climate, soil and hydrological boundary conditions.
- Groundwater affected areas, e.g. in river lowlands and soils with higher water holding capacity mainly benefit from climate change while dry sandy sites show yield losses due to drought.
- Higher regions benefit from warming due to longer growing season.
- The CO_2 effect on transpiration will lower the decrease of groundwater recharge and turns is sometimes into an increase. The increase in irrigation demand will be reduced.
- The management of water and nutrient supply has to be adapted site specifically. Drought will reduce nutrient supply and nitrogen fertilizer use efficiency.
- However, the estimated changes are in a range of high uncertainty due to differing regional climate projections, uncertainties of boundary conditions and model uncertainty.
- Therefore, an ensemble of different scenarios and models should be used.

COST Action 734

Thank you for your attention

Perfection is attained not when there is no longer anything to add, but when there is no longer anything to take away

•A. de Saint-Exupéry

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