

# Food Production and Climate Change in Egypt - ProCliC

Report

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Gode Gravenhorst  
Ronald Kuehne  
Heinrich Kreilein  
Diethard Mai  
Myrtle Seepersad

Centre of Biodiversity and Sustainable Land Use  
Section Tropical and Subtropical Agriculture and  
Forestry  
Georg-August-Universitaet Goettingen

in cooperation with a STDF project of the

Cairo University (CU)  
and the  
Agricultural Research Centre (ARC) of the Egyptian  
Ministry of Agriculture and Land Reclamation

Prof. Dr. Hala Aref. Aref, CU  
Prof. Dr. Semiha Ouda, ARC

Centre of Biodiversity and Sustainable Land Use, Section Tropical and  
Subtropical Agriculture and Forestry,  
Georg-August-Universität Göttingen  
Büsgenweg 1, 37077 Göttingen, Tel. 0551 - 393908, mail:  
[cetsaf@gwdg.de](mailto:cetsaf@gwdg.de), [www.tropenzentrum.de](http://www.tropenzentrum.de)

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## I Goal

**The German-Egyptian project ProCliC aims to improve the food supply and food security of Egyptian people within the next century by estimating the effect of Climate Change on wheat growth and grain yield in the Nile Delta and the valley of the Nile.**

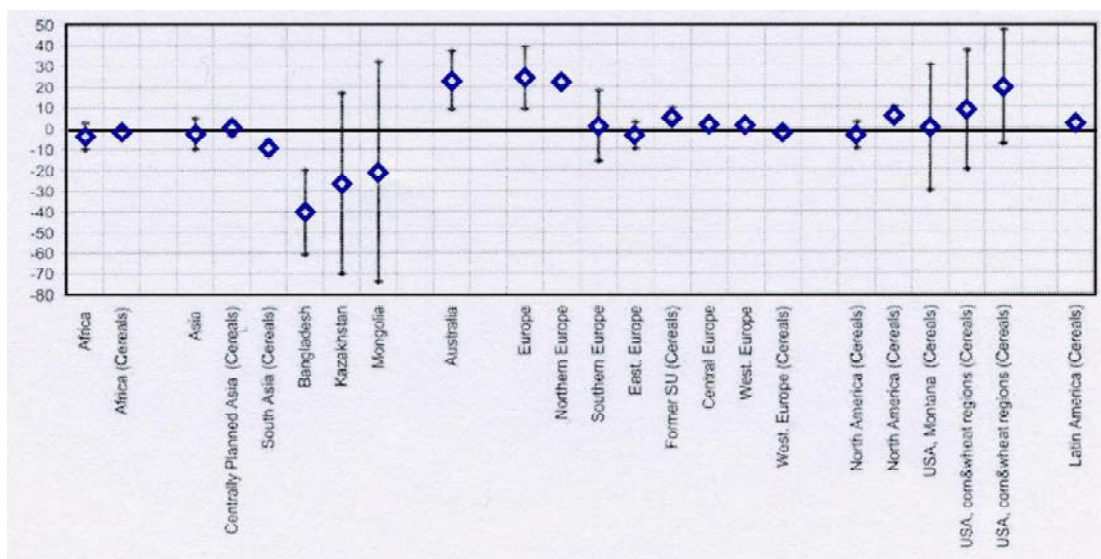
The wheat growth and grain yield estimation will be done by modeling wheat processes with the DSSAT CERES crop model, which is fed with climate change data of the ocean-atmosphere integrating ECHAM 5 OM model and with data of Egyptian wheat field experiments within the last years.

For this task an interdisciplinary group of Egyptian and German scientists was formed. The final goal could be best reached only, if information, knowledge and experience of the various scientists could be merged. It turned out, however, that the Egyptian partners hesitated to get involved, because they were not supported financially, for what reasons so ever. Maybe specific cultural attitudes contributed to this restriction.

In general the effect of climate change on crop production has been addressed in research work for many areas in the world (Fig. 1). To be able to elaborate these effects for food crops mechanistic understanding of the reaction kinetics involved in plant growth and grain yield formation is necessary. Several works have been published, which shed light on the special problems and on the entire issue (Betts 2005, Weigel 2005, Doleschel 2005, Erda et al. 2005, Sivakumar and Hansen 2007, Weber 2011, Kumar et al. 2012, Genet 2012, Ibrahim et al. 2012).

The individual situation in a special region deserves the consideration of the regional conditions of the weather, the soil, the cultivars and the crop management, so that specified research for the very region is necessary.

For the Nile Delta in Egypt, even opposite directions of yield changes for future atmospheric conditions were derived. El Maboud et al. (1998) suggested an increase in wheat yield of about 20 % to 40% for various cultivars at climate change conditions for doubled CO<sub>2</sub> concentration at the northwestern coast of the Nile Delta, whereas Ibrahim et al. (2012) reported a 24% to 28% yield reduction according to their modeling approach for South Tahrir Research Station in the west of the Nile Delta. Hassanein et al. (2012) calculated a decrease of up to 31% at three sites north of 31° N. For two sites in Tunisia the time calculated in a crop model for wheat growth shortened and the sowing date could be earlier, because rainfall started earlier (Lhomme et al. 2009). Since Egypt is a state of high risk concerning food security, ProCliC was specially designed for Egypt. A high risk means both the probability of its occurrence is high and the economic, social and political damage could be high.



**Fig. 1: Estimation of the change of plant production (in % of the present amount) for future atmospheric climate change conditions in various regions of the world (from Weigel 2005).**

**Incidents, which hindered ProCliC to reach the goal in an optimal way:**

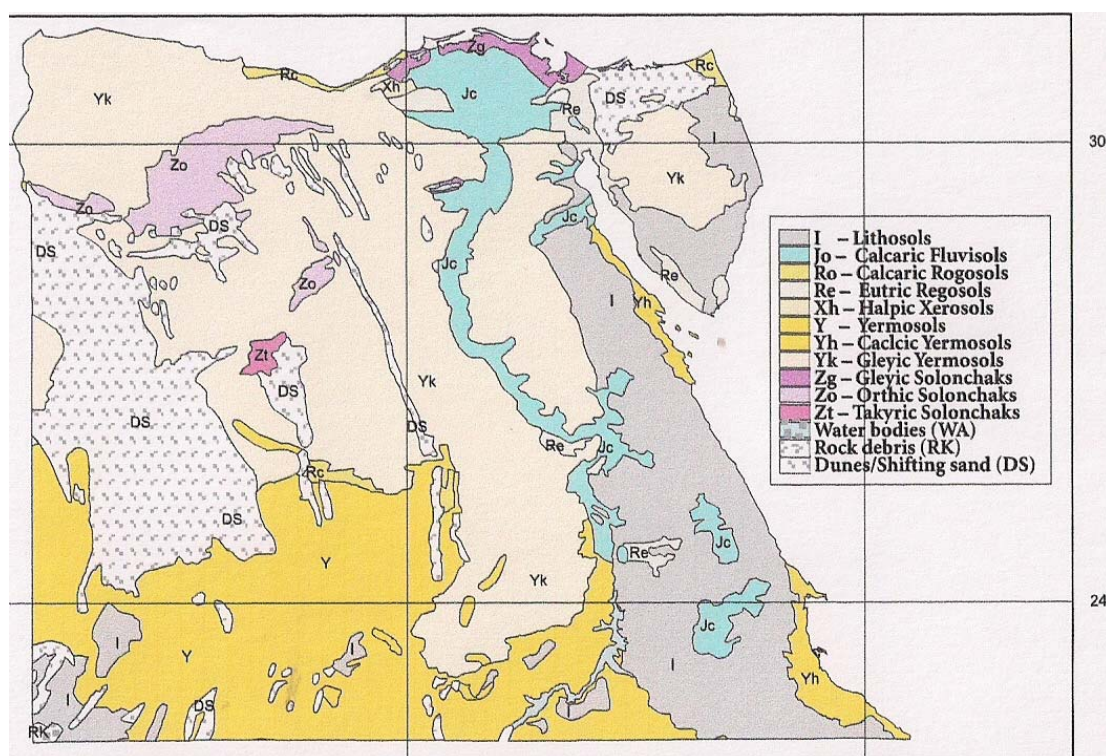
- A. Egyptian spring revolution, during the course of which our partner, Prof. Dr. Ayman Abou Hadid, the former Head of the Laboratory for Agricultural Climate (CLAC), the former Director of the Egypt Environmental Affairs Agency and the former President of the Agricultural Research Centre (ARC), was first promoted to Minister for Agriculture and Land Resources and then moved on as Professor at Faculty of Agriculture at Ain Shams University, Cairo. The direct scientific contact was interrupted.
- B. The Egyptian research money did not reach our partners. The partners could, therefore, not contribute as planned to the research agenda and foster ProCliC.
- C. The Egyptian counterpart for Climate Change, Dr. Gamal El.Afandi, Al Azar University, moved to the United States and got two positions at research institutions, there. The direct communication and cooperation was not possible any more in the way anticipated.
- D. The climate data manager on the German side, PhD student B. Barnabee passed away very suddenly in spring 2012, so that all the climate data and their production ways and storage sites were lost. We had to start from scratch.

## **II Framing wheat, the main food commodity in Egypt**

Wheat is being grown in Egypt since thousands of years. The annual flooding of the Nile valley and the Nile Delta by Nile water from the Ethiopian Highlands deposited new fertile soil, about a millimeter per year before 1964 (Shahin 1985) and even more in older times (Goodfriend and Stanley

1996), so that water, sun radiation and nutrients could support plant growth, especially of cereal grasses. In Fig. 2 the fertile strip along the Nile is seen as the Fluvisol soil type. Because of the increasing food and feed demand in the last decades in Egypt, new desert land was reclaimed for agricultural use and by the help of fertilization and irrigation about a third of the agricultural land in Egypt is today new land. Its productivity is, however, lower compared to the old land. The new land contributes to food supply in so far, as it compensates somehow the loss of fertile land for urbanization, construction work, and industrialization (Weber et al. 2011). It is suggested that during the years after the closure of the High Aswan Dam the groundwater rises, because of year-round irrigation activities and erosion of the coastal plain and not due to climate change sea level rise. This rise of the ground water level makes the salinization problem even more severe.

The chemical and physical properties of main agricultural regions in Egypt are summarized in Tab. 1. In the modeling experiment of ProCliC the same soil was assumed at three different regions of the Nile in order to see the effect of climate change alone. During the weather patterns of the wheat growing season many atmospheric factors change within one season and from season to season, so that it is already difficult to pinpoint cause – affect relationships. The consideration of more soil types would make it even more difficult.

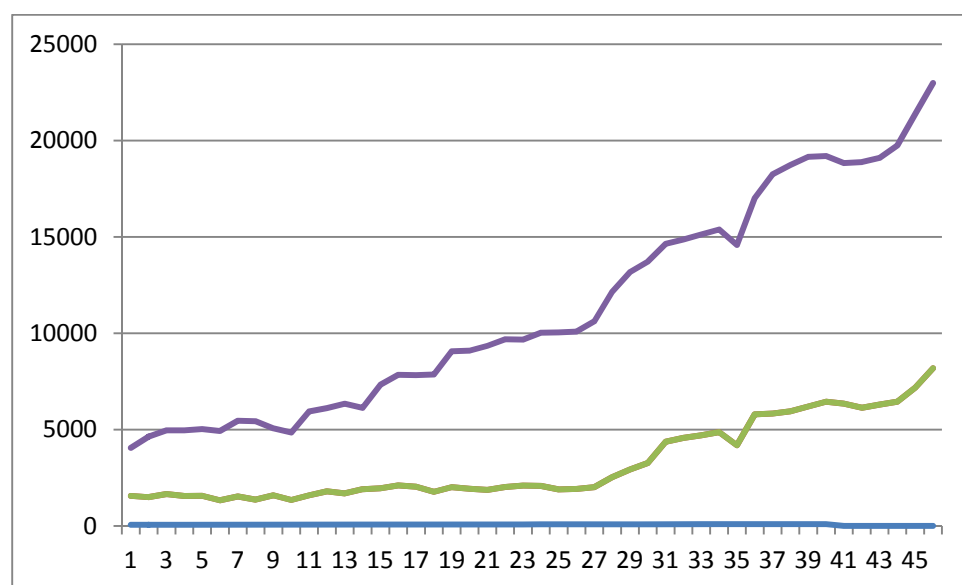


**Fig. 2: Soil map of Egypt. The fertile agricultural land along the Nile is shown as Fluvisol (in blue). (FAO 2005)**

**Tab. 1: Physical and chemical soil properties in agronomic important parts of Egypt (FAO 2005)**

Item	North Delta	South Delta	Middle & Upper Egypt	East Delta	West Delta
<b>Soil texture</b>	<b>Clayey</b>	<b>Clayey</b>	<b>Loamy clay</b>	<b>Sandy</b>	<b>Calcareous</b>
pH (1:2.5)	7.9-8.5	7.8-8.2	7.7-8.0	7.6-7.9	7.7-8.1
Percent total soluble salts	0.2-0.5	0.2-0.4	0.1-0.5	0.1-0.6	0.2-0.6
Percent calcium carbonate	2.6-4.4	2.0-3.1	2.6-5.3	1.0-5.1	11.0-30.0
Percent organic matter	1.9-2.6	1.8-2.8	1.5-2.7	0.35-0.8	0.7-1.5
Total soluble N (ppm)	25-50	30-60	15-40	10-20	10-30
ppm available P (Olsen)	5.4 -10	3.5-15.0	2.5-16	2-5.0	1.5-10.5
ppm available K (amm. acetate)	250-500	300-550	280-700	105-350	100-300
Available Zn (DTPA) (ppm)	0.5-4.0	0.6-6.0	0.5-3.9	0.6-1.2	0.5-1.2
Available Fe (DTPA) (ppm)	20.8-63.4	19.0-27.4	12.4-40.8	6.7-16.4	12-18
Available Mn (DTPA) (ppm)	13.1-45	11.2-37.2	8.2-51.6	3-16.7	10-20

Wheat has become the main food constituent in Egypt. Wheat is used – 180 to 200 kg/person/year – in large amounts and together with losses during all stages of production and distribution the gap between production and consumption in Egypt is high. The huge Egyptian demand for wheat cannot be supplied by wheat production in Egypt. This is evident in Fig. 3, in which the courses of the wheat production and consumption amounts per year in Egypt are compared over the last 45 years.



**Fig 3: Wheat production (green) and wheat consumption (blue) in Egypt (Mill t/ year) during the last 45 years. The absolute gap between consumption rate and production rate is widening with time (after IndexMundi Home Egypt Wheat Production, Consumption, Imports, Exports, 18. 12.12).**

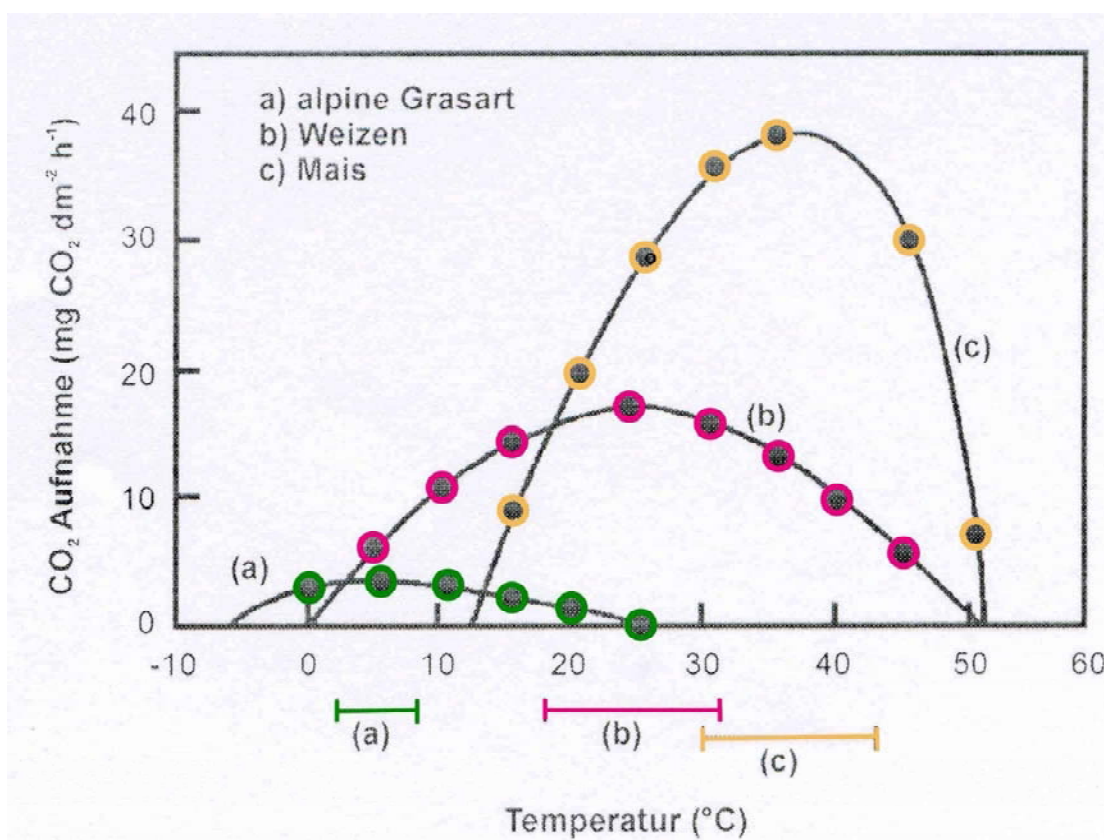
Egypt is, therefore, one of the countries with the largest wheat import amounts. Egypt is depending on foreign wheat production, on the global wheat and transportation prizes and on the willingness of the foreign countries to sold wheat to Egypt. Thus Egypt is economically and politically depending on foreign conditions and decisions.

Internally Egypt is subsidizing some important public goods as water, gasoline and wheat for the general population. Some ten billions EUR are spent by the government to keep the consumer prizes low. This is a huge amount of money if compared to similar amounts of money of the State reserves and to the several billions of financial aid from international donors like the USA, IWF and World Bank. In addition the state income via tourism is decreasing. The revenue from Suez Canal toll has, however, increased since 2003 by a factor of two. To stabilize Egypt socially, economically and politically it is, therefore, necessary to improve the use of internal resources. To increase the growth and production of food crops, especially wheat, within Egypt could be one possible way among others. The wheat production in Egypt has increased enormously by a factor of four within the last 30 years (Fig. 3, Tab. 2) in a way similar to maize. This increase could, however, not pace with the increase in the growing demand of the individual Egyptian and the growing population. How wheat yield is affected by future climate conditions, which may be quite different from today, is one open question for planning future agricultural production in Egypt.

**Tab. 2: Production amounts, production area, and yields for wheat in Egypt during the years 1981 to 1992 (AW Hassan et al. 1995).**

	Production, Area and Yields				Growth Rates (%) 80-93
	81-83	84-86	87-89	90-92	
	<b>Egypt</b>				
Production (1000 t)	1943	2175	3374	4402	8.2
Area (1000 ha)	542	527	662	823	3.5
Yield (t/ha)	3.6	4.1	5.1	5.4	4.7
	<b>Delta</b>				
Production (1000 t)	1178	1263	1942	2542	7.7
Area (1000 ha)	309	300	379	448	3.2
Yield (t/ha)	3.8	4.2	5.1	5.7	4.5
	<b>Middle</b>				
Production (1000 t)	339	421	662	860	9.4
Area (1000 ha)	95	94	121	155	4.2
Yield (t/ha)	3.6	4.4	5.5	5.6	5.2
	<b>Upper</b>				
Production (1000 t)	426	490	772	879	7.6
Area (1000 ha)	138	133	163	175	2.0
Yield (t/ha)	3.1	3.7	4.7	5.1	5.6

The net production rate of a plant depends on the temperature of the plant. In Fig. 4 it is shown that different plant species have adapted their physiological processes to the environmental conditions they have been exposed to during their long lasting evolution. Wheat could be favored or hindered in its growth processes, when climate is changing now. In Fig. 4 a general dependence of wheat growth on temperature is shown. Different wheat species - hard wheat, soft wheat, summer wheat, winter wheat - , and different varieties, see e.g. Tab. 3, can react differently on changing atmospheric conditions (Kumar et al. 2012). However, a general maximum of CO<sub>2</sub> uptake as a function of temperature is all in common, so that future heat stress can reduce yields or future heat support can increase yields.



**Fig. 4: Uptake of CO<sub>2</sub> by plant species having been evolved under long term different thermal conditions: a. alpine grass b. temperate wheat c. subtropical maize**

Besides climate, several other factors influence wheat growth and yield.

In Tab. 3 e.g., wheat cultivars are listed, which are judged to fit best present climate conditions in Upper or Middle Egypt. ProClic hypothesises that the present climate conditions in Middle and Upper Egypt might resemble future conditions in the Nile Delta and in Lower Egypt.

For these cultivars listed in Tab. 3 phenological observations are to our knowledge not available, so that crop modeling for these cultivars is not seriously possible, because respective crop models cannot be calibrated and verified.

**Tab. 3: List of wheat cultivars for Egypt according to the region, for which they are best adapted, to seeding time and to estimation of their yield potential (low 2 - 3t/ ha, very high > 6t/ha). (Basnet et al. 2011)**

Cultivar	Region in Egypt	Sowing time	Yield
Germanize 7	middle	early	very high
Gemaiza 9	middle	late	very high
Sids 4	middle	very late	low
Giza 156	middle	middle	average
Giza 158	mid/up	early	middle
Giza 164	mid/up	early	high
Giza 147	upper	late	low
Giza 148	upper	late	low
Giza 156	upper	middle	average
Giza 160	upper	early	high
Chenab 70	upper	middle	average

The type of cultivars being available, the type of seed preparation and seed distribution, the pest and disease situation and its control, the mineral and organic fertilizer application, the irrigation method, the social and economic situation of the farmers – all these factors influence the growth and yield of wheat in Egypt.

Under future climate conditions thermal incoming irradiance at the ground and as a consequence air temperature close to the ground should in general increase. Also the seasonal course of the values of atmospheric variables will change. Therefore, ProCliC uses day to day projections of the atmospheric state for past and future years to run the DSSAT crop model for wheat. ProCliC does not want to predict the weather pattern within the next season and derive crop yields for the running year, as is discussed by Hammer et al. (2000). ProCliC does, furthermore, not forecast the exact weather situation at a certain future date, e.g. the 31st January 2077. Instead ProCliC wants to use individual weather patterns for many years to get a statistical reasonable picture of the seasonal courses of atmospheric properties. ProCliC does not want to predict or forecast but to project a set of weather patterns representative for past and future decades in Egypt. It wants to project growth rates and grain yields of wheat for reasonable dynamics of air temperature, sun radiation and CO<sub>2</sub> concentrations, which are prevailing within this next century.

ProCliC concentrates its research activities on the Climate Change effect on wheat yield in Egypt by modeling future grain yields and compare those results with the modeled results for past and

today's climate. In addition ProCliC is searching for regions in Egypt, which have already today atmospheric conditions, which are projected for other parts of Egypt for the future. Thus an "incorrect" time course of atmospheric conditions and their effect on wheat growth could be set up and interpreted, if in some regions the climate situation of today resembles the future situation in another region.

### **III Climate Change**

The values of atmospheric properties close to the earth surface depend to a large degree on the properties of the overlying entire atmosphere, e.g. the scattering and absorption of sun radiation

(short wave < 2000 nm) and of thermal radiation (long wave > 2000 nm) by gaseous molecules, particles and cloud droplets. The heat balance within each air volume is driving the entire atmospheric system. Good introductions to understand the climate system and to model it numerically are given by v. Storch et al. (1999) and Cubasch (2002). To understand ProCliC problems better a short remark is made here: concentrations of carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), dinitrogen oxide (N<sub>2</sub>O) and other greenhouse gases in the atmosphere have increased during the last century and will probably continue to increase in the future. They absorb the outgoing long wave thermal radiation and emit it afterwards in all directions, thus also down to the earth's surface. The heat flux to the earth surface is, therefore, increasing due to stronger long wave irradiance from the atmosphere than before. More clouds can, however, form under future higher water vapor concentrations and vertical air exchange features, so that more sun radiation is reflected back from the cloud tops to space and therefore less sun radiation can reach the earth surface and heat it up. Keeping all other factors constant, e.g. the reflectivity of the earth surface, this cloud effect could reduce the warming effect of the clouds due to absorption of long waves coming from below the cloud base. The air temperature at one site does, however, not only depend on the vertical exchange of energy at the site, but also on the horizontal advection from neighboring terrestrial and marine sites. Fluctuation of the solar activity, of volcanic gaseous emissions, of aeolian particle load, of vegetation cover, of forest fires and their carbon black particle emission besides others can alter the energy transport within the atmosphere on short and long term time scales. To the best of present scientific knowledge these complex terrestrial and marine interactions have been interconnected in global numerical models to quantify atmospheric properties in the past, at present and in the future.

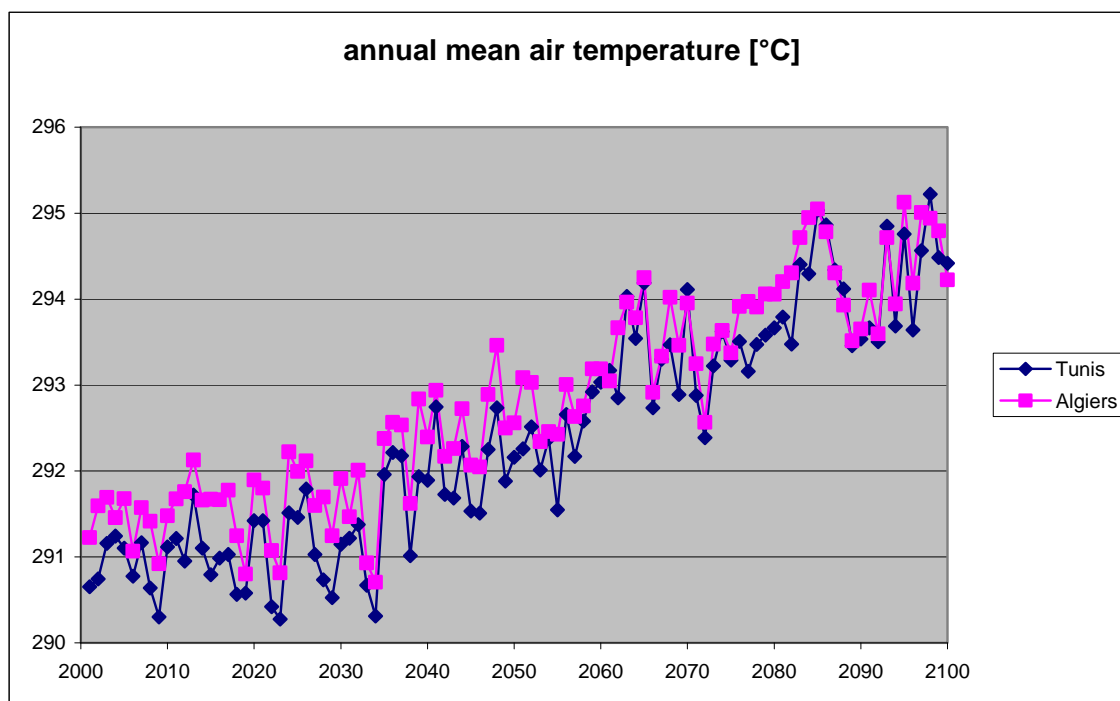
The overall change of the atmospheric composition will certainly be an increase in the surface-near air temperature. But how much, when and where this increase will occur is difficult to quantify. Different ocean-atmosphere coupling models differ in their structure and their parameter values. It is not surprising, that different numerical models result in different values for atmospheric traits under future conditions. They all project, however, an increase in surface-near air temperature, higher in

polar regions than in equatorial ones, higher in inner continental areas than in marine areas. The modeled future precipitation patterns are less consistent between different models. In our case of Egypt the projection of precipitation is not so important, since the crops will not be rain fed, but irrigated with Nile or ground water. Already today nearly 100% of the agricultural land in Egypt is irrigated.

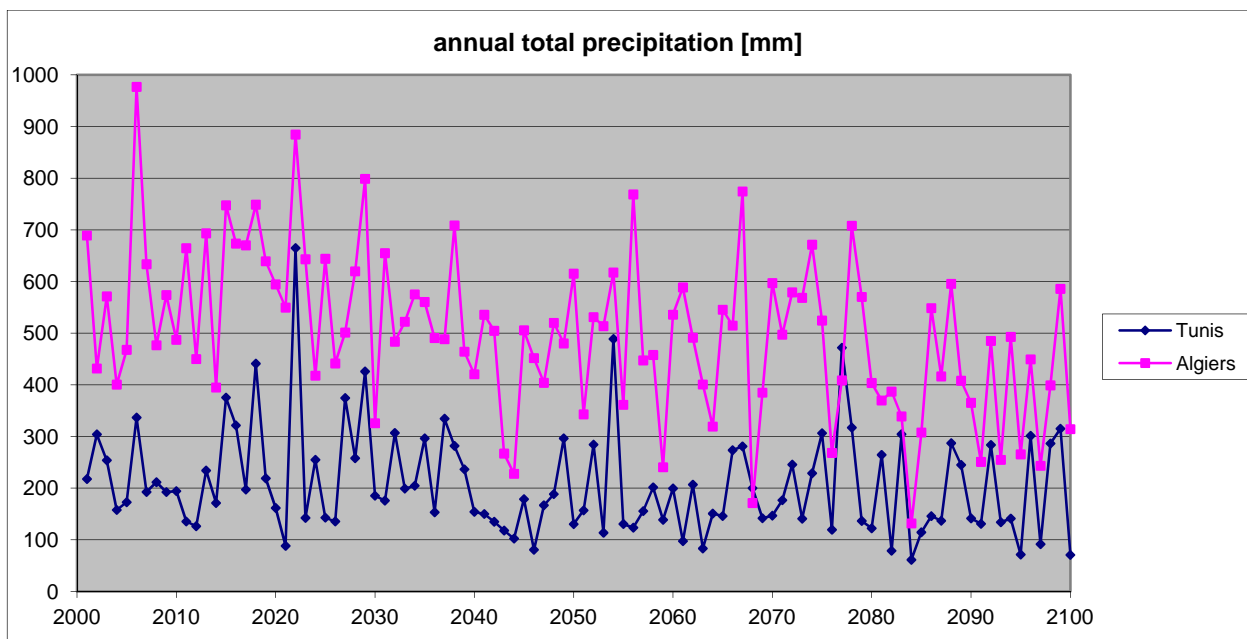
ProCliC has planned to use regional model results to characterize atmospheric conditions along the Nile with respect to sun radiation and near-surface air temperature. Because of the sudden death of ProCliC's climate modeler, Banabee Baryel, we could not use the results of a regional model but the results of the global model ECHAM 5 OM of Max- Planck- Institut für Meteorologie, Hamburg (Roeckner et al. 2003). The data were downloaded from CERA data bank (ISSN [www.dkrz.de/CERA](http://www.dkrz.de/CERA)).

The Nile topography is not that heterogeneous, so that neglecting the small scale regional differentiation will not drastically alter the values of air temperature, sun radiation, relative humidity and wind speed. We therefore took the results of ECHAM 5 OM for our comparison between wheat yields at present and in future.

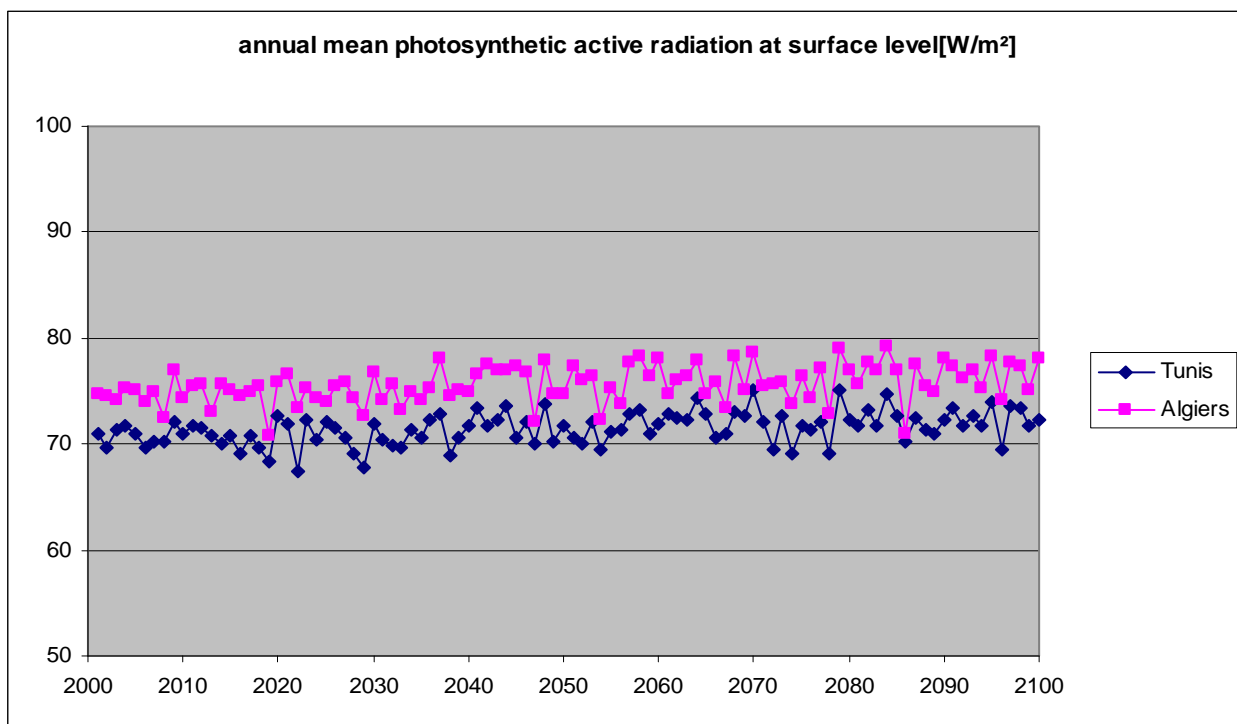
For Algiers and for Tunis at the Mediterranean coast of North Africa, a similar position as Alexandria, we recovered from the preparatory work for ProCliC the calculated courses of air temperature and precipitation of the regional model REMO, which was nested by D. Jacob, Climate Service Centre, Geesthacht, into ECHAM 5 –OM (Fig 5a,b,c,).



**Fig 5a: The modeled atmospheric temperature (K) near the ground for Tunis and Algiers according to D. Jacob, CSC, Geesthacht for the years 2000 to 2100.**



**Fig. 5 b:** Similar to Fig. 5 a but for precipitation (mm/a)



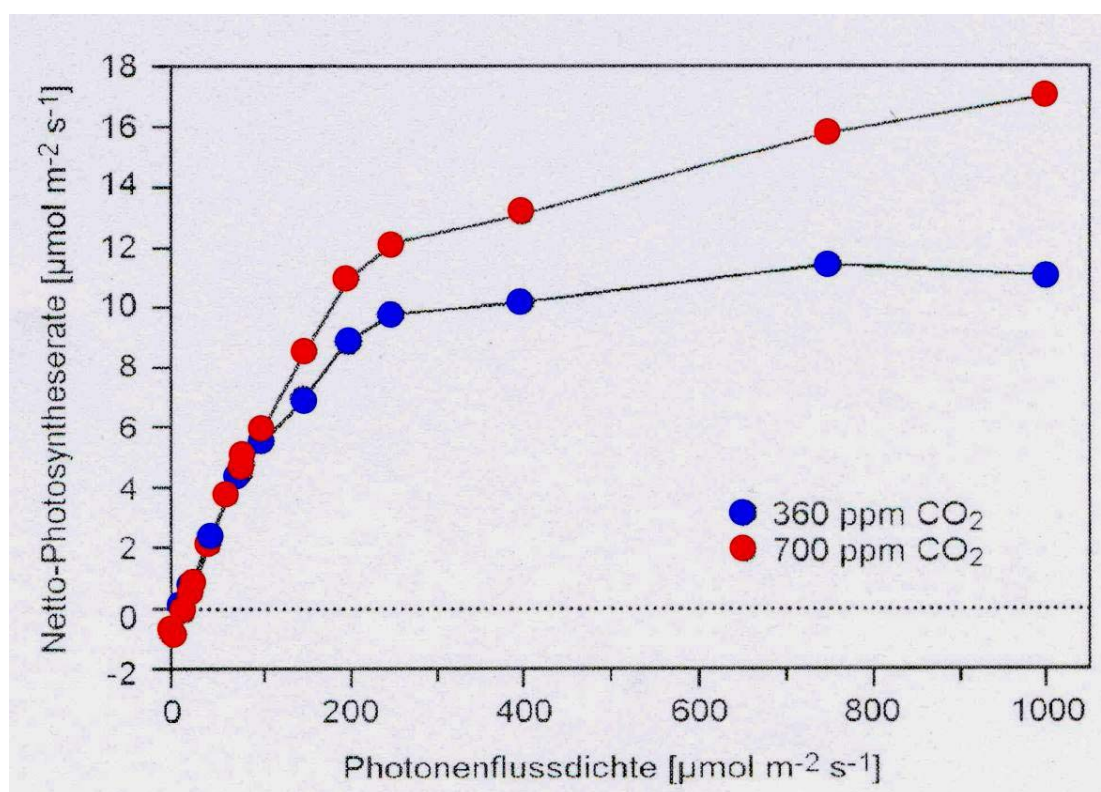
**Fig. 5 c:** The modeled photosynthetic active sun radiation (PAR,  $W/m^2$ ), incoming at the ground at Tunis and Algiers, as a function of time (years)

The annual weather course is different from year to year, so that the effect of climate change on wheat growth and yield is evaluated by ProCliC with weather data for many years for past, present and future time span conditions.

The growth of plants does, however, not only depend on the plants' temperature, on sun radiation and water supply, but also on fertilization via the soil, via the irrigation water (fertigation) and via the atmosphere (CO<sub>2</sub>). Weed and pest pressure reduce the growth.

Atmospheric carbon dioxide (CO<sub>2</sub>) is a prime fertilizer for photosynthesis of plants combining inorganic substances to form new organic biomolecules.

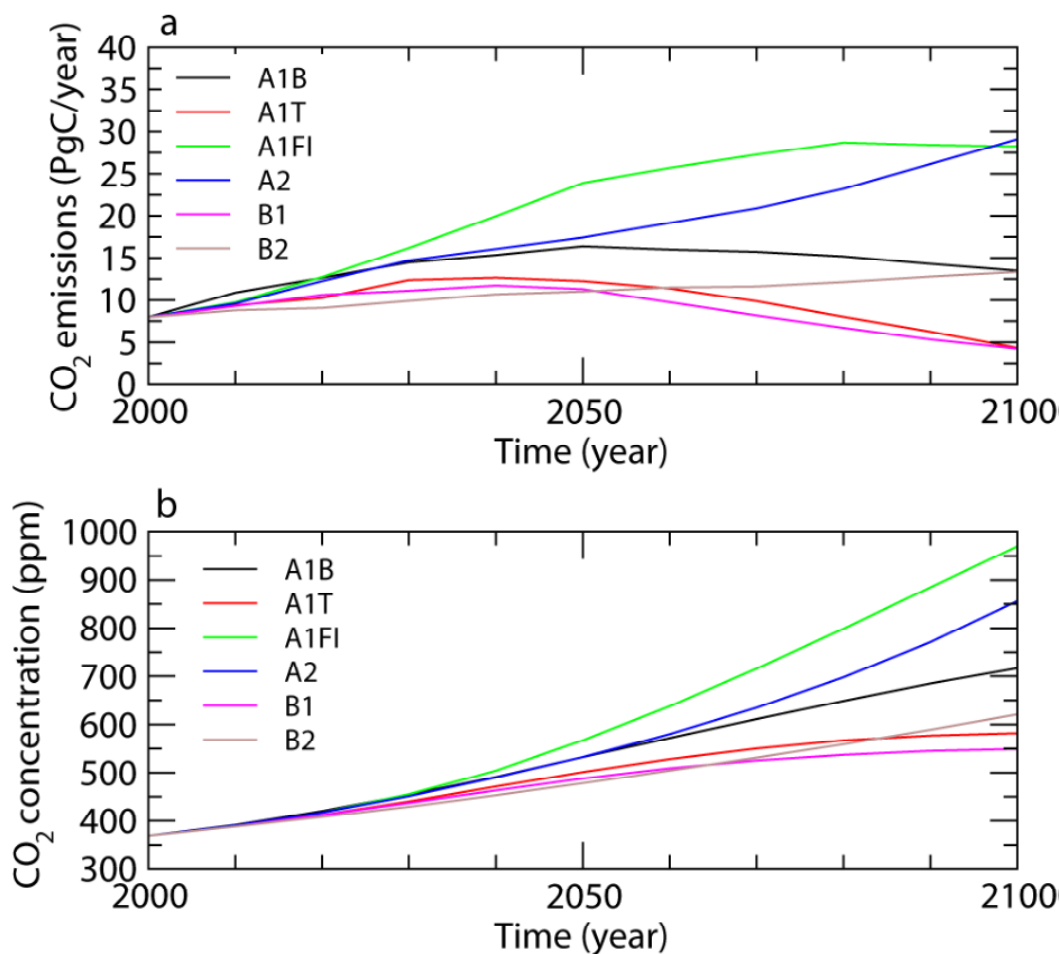
Increasing atmospheric carbon dioxide is, therefore, a first candidate to increase plant growth. This increase does, however, depend on other growth factors, which could limit the growth. In numerous field and laboratory research work on the influence of atmospheric CO<sub>2</sub> concentration on C3 plants like wheat, doubled CO<sub>2</sub> concentrations increased, in general, the yields by 10% to 20%. In Fig. 6 it is shown as one example, that the photosynthetic rate at the same solar irradiance in the range of the plateau values increases by about 40 % while increasing atmospheric CO<sub>2</sub> concentrations from 360 ppm to 700 ppm.



**Fig. 6:** At higher atmospheric CO<sub>2</sub> concentrations than today the net photosynthesis rate of C3 plants like wheat can increase at the same photon flux density (Weigel 2005).

CO<sub>2</sub> is a greenhouse gas. Greenhouse gases in the atmosphere influence the heat balance and therefore, the air temperature close to the ground. The future atmospheric greenhouse gas concentrations depend on many scientific, technical, economical, and political decisions and developments. Different scenarios were developed in the scientific community to summarize the

integral effect of these circumstances. In Fig 7a and Fig 7b, these situations are quantified for CO<sub>2</sub> concentrations equivalent in their energy – flux effect to the entire sum of greenhouse gases.



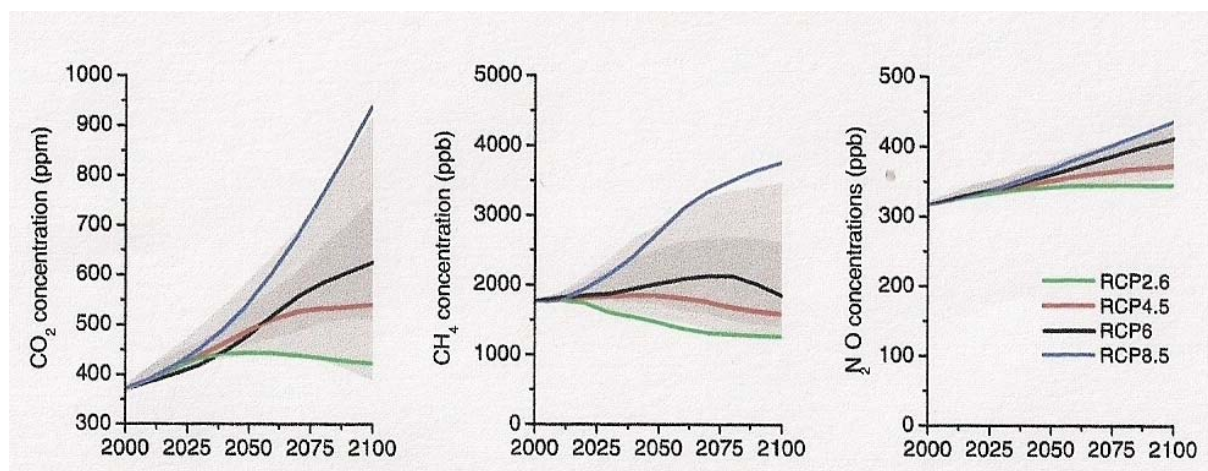
**Fig. 7 a and 7 b:** CO<sub>2</sub>-equivalent emission scenarios and the corresponding CO<sub>2</sub>- equivalent atmospheric concentrations for climate change modeling, but not for crop modeling (Moss et al. 2008, van Vuuren et al. 2011)

For climate change modeling, not only CO<sub>2</sub> is a greenhouse gas, but also atmospheric constituents like CH<sub>4</sub>, N<sub>2</sub>O, O<sub>3</sub>, SF<sub>6</sub> and others are absorbing IR radiation, too. Their combined effect is often summarized as a CO<sub>2</sub>- equivalent concentration. A doubled CO<sub>2</sub>- equivalent concentration does, therefore, not indicate, that the specific CO<sub>2</sub> concentration has doubled. The plants do, however, react in their photosynthesis processes on the specific atmospheric CO<sub>2</sub> concentration only. Therefore, in crop modeling CO<sub>2</sub> concentrations and not CO<sub>2</sub>- equivalent concentrations should be taken.

The emission and concentration scenarios are discussed by v. Vuuren et al. (2011) and by Moss et al. (2008). The SRES family (Special Report on Emission Scenarios) of the IPCC and the suggestions of the newer RCP (Representative Concentration Pathways) family are explained and discussed. Detailed information can be looked up there.

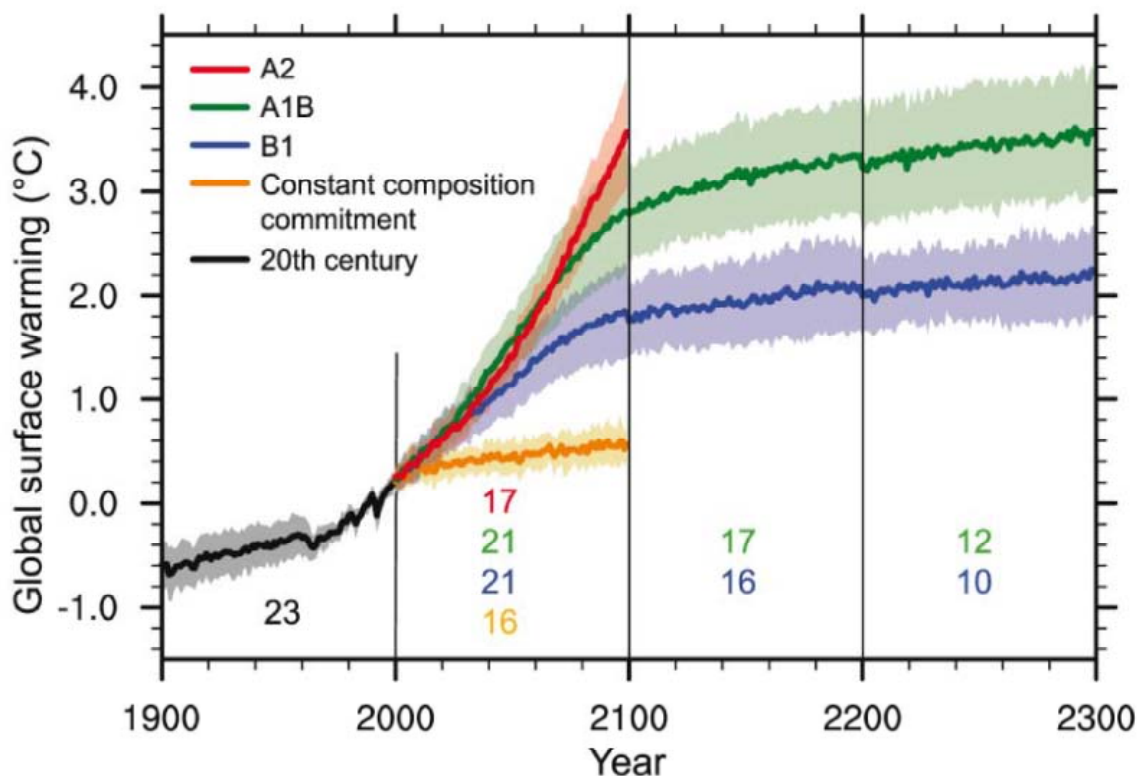
In Fig 8a concentration scenarios for the individual gases CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O are given. A CO<sub>2</sub> concentration (or mixing ratio between CO<sub>2</sub> molecules and total air molecules, e.g. 380 CO<sub>2</sub>

molecules per one million air molecules = 380 ppm, parts per million) of about 600 ppm seems to be a reasonable range for CO<sub>2</sub> concentrations at the end and of 500 ppm at the middle of this century.



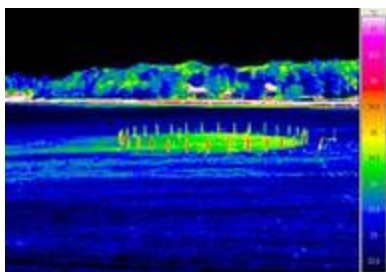
**Fig. 8 a: Scenarios for individual greenhouse gas concentrations in the atmosphere. CO<sub>2</sub>- values for today of about 390 ppm, for the year 2050 of about 500 ppm and for the year 2100 of about 600 ppm seem reasonable (see Moss et al. 2008, van Vuuren et al. 2011).**

For assumed emission and absorption rates of greenhouse gases a family of CO<sub>2</sub> equivalent gas concentrations in the atmosphere over time are generated. With these concentrations the trends of air temperature close the ground increases. Some temperature trends are given in Fig. 8b. The temperature trend for general and special geographical regions might develop quite differently. This holds also true for the Nile Valley and for Egypt.



**Fig 8b: The modeled increase of the global atmospheric air temperature close to the ground for different emission scenarios (Goose et al. 2010)**

In a Free-Air-CO<sub>2</sub>-Exchange experiment (FACE) in the field an artificially manipulated higher CO<sub>2</sub> concentration (ca 500 ppm during daytime) caused a higher stomata resistance and, therefore, a smaller cooling effect, visible on an IR photo of the canopy (Fig 9). The field experiments in Braunschweig, northern Germany, from which this photo was taken, revealed, that higher yields between +7 % to +15 % for all C<sub>3</sub>- species investigated (wheat, sugar beet and barley) were found, but for the C<sub>4</sub> plant maize the yield did not increase. But maize could withstand dry periods better and showed less yield reduction. The quality of the grain crop yield (protein content) decreased however.



**Fig. 9 Higher CO<sub>2</sub> concentration within a ring of a wheat field causes a higher canopy temperature compared to the surrounding wheat field because of less evaporative cooling of the wheat plants within the ring. FACE (Free Atmosphere Carbon Exchange) experiment in Braunschweig, Germany, see "Bisherige Ergebnisse zur Auswirkung erhöhter CO<sub>2</sub> Konzentrationen", Thuenen Institut, Weitere Infos zu FACE )**

Scenarios for projected atmospheric CO<sub>2</sub> concentrations are given in Fig. 8b.

These CO<sub>2</sub> concentrations could be used in crop modeling, because they do not represent the entire greenhouse gas concentrations but the individual CO<sub>2</sub> concentration alone. The uncertainties in future emission and removal rates of CO<sub>2</sub> are so large, that the “right” future CO<sub>2</sub> concentration can hardly be proclaimed.

A higher atmospheric CO<sub>2</sub> concentration can change many processes within plants. In a laboratory research work in Germany on the effect of higher CO<sub>2</sub> concentrations (by about + 320 ppm). Ommen (2003) found the following changes for summer wheat (*Triticum aestivum* L. cv Minaret):

- a. the grain yield increased by about 23 %,
- b. above ground biomass increased by about 21%,
- c. the effect of drought stress was reduced,.
- d. below ground biomass increased,
- e. straw fraction augmented most,
- f. the end of grain filling was reached faster,
- g. during tillering more and more fertile tillers were formed,
- h. leaf area increased,
- i. culm length increased,
- j. fastening of leave senescence, of chlorophyll destruction, of kernel filling
- k. water-soluble carbohydrates increased slightly

In the DSSAT crop model the variable CO<sub>2</sub> concentrations can alter plant growth processes.

The overall effect of a future increase in CO<sub>2</sub> concentration on the crop yield can, therefore, be evaluated via this empirical model.

#### **IV Crop growth model (DSSAT CERES)**

The growth of crops and formation of the wheat kernels which represent the harvested yields mainly depend on following influences:

- a. genetic constitution of seeds
- b. atmospheric properties
- c. physical, chemical and biological soil structures
- d. management of the crop production
- e. pest and deceases.

Possible future growth and yield conditions can be experienced by manipulated experiments in present time and by numerical models for past, present and future times. As climate change

modeling crop modeling is a complex task with many options. Nevertheless crop modeling is an effective research and application tool to project future conditions, which influence growth and yield of crops, and to analyze the crop growth and the formation of yield. Crop modeling is, therefore, quite a helpful assistance to evaluate and to answer questions like “What processes will happen, if these boundary and starting conditions are given?”

For elucidating the issue of food production and climate change in Egypt ProCliC uses the DSSAT 4.5 CERES Wheat model in order to project future growth and yield values for wheat in Egypt. The DSSAT model system has been documented by Jones et al. (2010).

DSSAT is a process-oriented dynamical model, which calculates under prescribed framing conditions the consecutive steps of crop development and growth. The growth rates in the DSSAT model depend on environmental conditions and on empirical development rate coefficients. These measured coefficients depend mainly on the temperature of the shoot and root systems, of incoming sun radiation, on water and nutrient supply. Selected cultivars and the interaction with the plot conditions will let the crop grow via individual and separated stages of development.

For wheat these main steps and degree-days can be distinguished:

- a. germination and seedling growth (ca 400 °C x days)
- b. tillering (development ca 300 °C x days)
- c. stem elongation (ca 750 °C x days)
- d. anthesis and grain filling (ca 1000 °C x days)

The length of these stages depends mainly on the heat sum (° C x days) the crop receives in the course of time. A biological process is usually the result of two opposing reaction path ways producing or destroying individual process constituents. Increasing the temperature can increase the rate of the production or destruction pathway thus favoring or hindering the development of certain phenological stages of the crop. Thus the overall result of an increase in air temperature is uncertain from the beginning, because the individual process rates depend in a different manner on temperature.

ProCliC concentrates in dealing with climate change and crop production in Egypt on a wheat crop system, the properties of which held constant at the beginning besides the atmospheric parameters. The wheat cultivar is kept the same, the soil is taken to be the same, irrigation or fertigation are applied the same, the plot management procedure is kept constant, only the weather patterns are changed and, therefore, are not the same in our modeling runs.

The effect of climate change is usually related to the air temperature change close to the ground. The cause of climate changes is, however, a change in long wave thermal radiation balances due to changing concentrations of greenhouse gases and particles in the atmosphere. This change in long wave energy balances can induce vertical and horizontal temperature changes in the climate system,

thus change water fluxes, cloud and rain formation in the atmosphere, and other atmospheric processes, which in their turn change temperature distributions. The climate system is a recoupled (feedback) system, which makes it difficult to envisage the overall effect of individual changes of parts of the system on the entire atmosphere - ocean – continent - biosphere system and selected fractions in space and time.

Such a numerical crop system can help to understand the process interactions and the sensitivity of the system to individual variations. The model results will lead our attention to possible developments and reactions within the crop production system.

The effect of climate change on wheat production was judged in quite a different way by different groups. Two of them projected a decrease, another group an increase in wheat yield under future climate change conditions. (Abd El Maaboud et al. 1998, Gamal El Afandi et al. 2010, Hassanein et al. 2012). A change in the annual course of weather along the Nile could well increase or decrease the yield depending on planting date of the seeds and on the individual weather pattern in each year.

ProCliC will, therefore, keep every parameter constant in model runs except atmospheric properties like air temperature and sun radiation. Thus the effect of climate change on yield production in the future can be best evaluated and separated from other influencing factors like crop management. However, at different crop management practices the effect of climate change could be different. Therefore, a whole set of crop production changes should be modeled in order to find out the best practice under climate change conditions. However, due to the encountered extraordinary circumstances during the course of ProCliC this will be postponed to a follow up research work.

One of the difficulties in future plant growth modeling is, that one does not know exactly the properties of future cultivars. Laboratory breeding and dynamic field selection of different plant traits could adjust the plant traits, so that the plants are better adapted to future weather conditions. These growth properties are introduced into the module structure. Empirical coefficients to quantify growth processes are derived from field experiments with the respective cultivars. These set of coefficients are adjusted to fit the observed entire phenological appearance of the plant or crop best. This calibration is not a single solution situation, but a multiple choice solution, where many sets of input data can all result in the same output data. Such a calibration is usually verified by independent field observations, which were not used for calibration. It is very difficult or frankly speaking it was impossible for ProCliC to get hold of such crop data for Egypt. ProCliC used, therefore, phenological data of Ouda et al. (2005), which were derived for 3 wheat cultivars at the Giza Experimental site. They could not be verified by independent field observations by ProCliC.

The numerical values needed in DSSAT CERES model are given in Tab 4a and 4b.

**Tab. 4 a: Genetic crop (wheat) coefficients for three cultivars in the South Delta of Nile for DSSAT 3 model according to Ouda et al. (2005) and Ouda, private communication (2012).**

Coefficients	Cultivar		
	Sakha 93	Giza 168	Sids 1
PIV	2.5	?	?
PID	3.5	3.3	3.4
PS	5.0	?	?
G1	5.0	5.1	5.0
G2	6.0	6.1	6.0
G3	1.9	1.7	1.9
PHINT	81	80	80

**Tab.4 b: Genetic crop (Wheat, Sakha 93) coefficient for DSSAT 4.5 model converted from Tab. 3a by R. Kuehne, Georg-August-University Goettingen, Crop Production Systems in the Tropics**

PIV	days of optimal vernalisation	25
PID	respond on photoperiod	70
PS	grain filling degree-days	530
G1	corn number per canopy weight	30
G2	kernel weight	73
G3	tiller weight	1.33
PHINT	days until leaf top appearance	81

**DSSAT model is constructed on a modular base. The main modules are:**

- a. WeatherMan module
- b. soil module
- c. soil-plant atmosphere interaction module
- d. individual crop module (e.g. wheat, maize, barley)

#### **IV a Modules in ProCliC**

The numerical values of the modules used in ProCliC are given in the appendix. Two modules are sketched briefly in the following.

##### **1. Weather(Man)**

The daily weather data from 1960 to 2100 were taken from the coupled ECHAM 5-OM Model of Max-Planck-Institute for Meteorology, Hamburg, on a pixel scale of 1° x 1°. The topography in Egypt is not that heterogeneous, so that regional models will give a better view on future crop growth conditions. Only the Nile valley and the neighboring desert lands differ in their surface properties (e.g. albedo, surface water). The Nile Delta is about 200 km wide at the Mediterranean coast and 20 km wide at Cairo and this size width of about 20 km for agricultural land is kept along the Nile upwards. The real encountered air temperature will not alter much within one pixel field, since

horizontal and vertical advection will smooth the distribution.

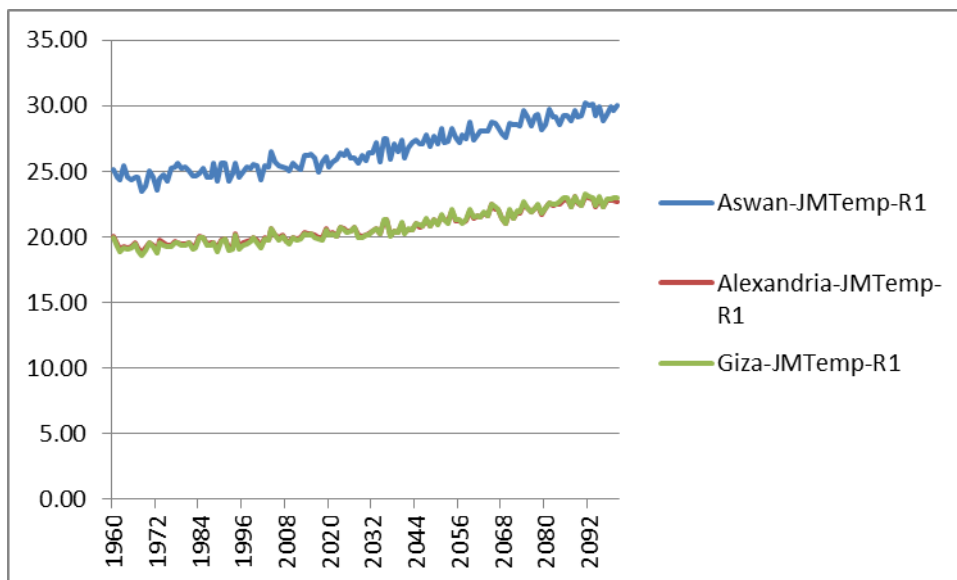
The numerical General Circulation Model ECHAM 5 – OM (coupled ocean – atmosphere) was run for the years from 1960 to 2100. Therefore 140 years of daily weather values are available to feed crop models. 4 time steps per day were integrated to one daily value for Tmax, Tmin, sun irradiance, wind speed, and relative humidity (RH). The consecutive results of this dynamical atmospheric model depend on the starting boundary conditions of the atmosphere. Because these starting conditions are not known exactly three different atmospheric starting conditions for each of the three regions were applied to calculate the three courses of the numerical development of weather patterns for the next 140 years. Three different regions (pixels) were chosen in Egypt, which we feel give a good impression for the weather situation in Lower, Middle and Upper Egypt for past and future agricultural activities.

The average air temperature shows an increase of about 5°C at the Upper Egypt region Aswan, and of about 4°C at the two other regions Giza for Middle Egypt and Alexandria for Lower Egypt from the reference time span 1960-2010 to the decade between the years 2090 to 2100 (Fig. 10). The increase will be a little bit smaller in Lower Egypt along the coast and in Middle Egypt about 220 km south of the coast compared to Upper Egypt at Aswan. The dampening effect of the coast on the air temperature close to the ground is probable the reason for this effect. The air temperature in the Nile Delta ( Alexandria and Giza) are quite similar and about 4°C to 5°C lower than in Aswan. However, at the end of this century the Nile Delta will experience a similar temperature level as Southern Egypt (Aswan) today (Fig. 10). The grain yield of wheat in Southern Egypt is about the same as in the Nile Delta today. This gives already a hint that the yield in the Nile Delta might be of similar weight under climate change temperature as today in Southern Egypt.

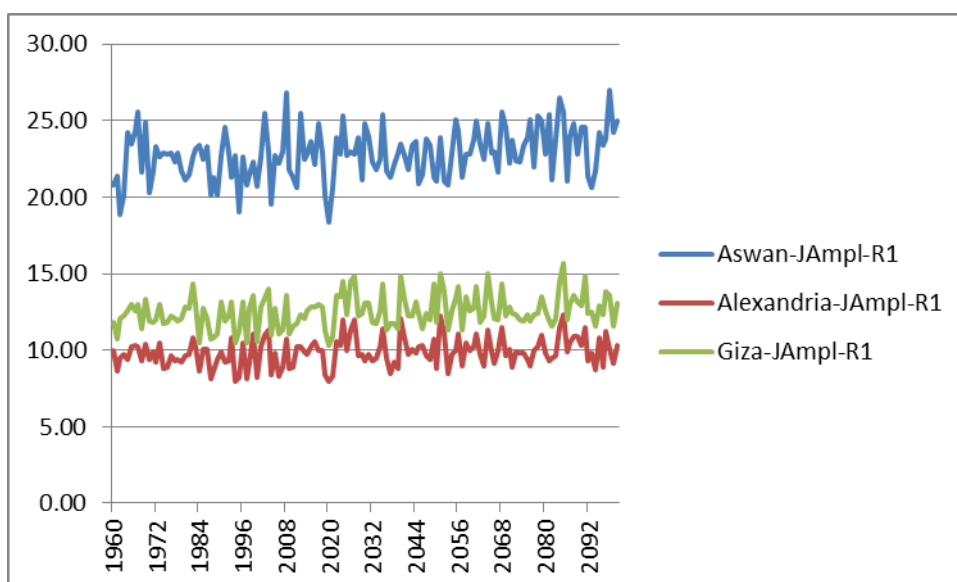
The damping effect of the Mediterranean Sea is also the reason for the different annual amplitude of the monthly air temperature amplitudes going from the coast to the south (Fig. 11). The three starting conditions at each site region (Fig. 12) gave similar increase rates for the modeled air temperature. The statistical behavior of the weather pattern seems to be the same for all three runs in each region. The trend and the absolute values of the annual air temperatures at Alexandria and Giza seem to be nearly the same, whereas the annual air temperature in the region of Aswan in Southern Egypt seems to be 5 degrees higher (Fig. 12). The annual amplitude of the monthly air temperatures shows a slight increase with time (Fig. 11, Fig. 13a). It is smallest at Alexandria, largest at Aswan and in between at Giza.

The average daily amplitude Tmax – Tmin is smaller in Lower Egypt (just below 4 °C, Alexandria) than in Middle Egypt (7 °C – 8 °C, Giza) and in Upper Egypt (13 °C - 14 °C, Aswan) (Fig. 13b). Again the effect of the Mediterranean Sea is influencing the regional climate features. The continuous renewing of the sea surface during day and night and the continuous water vapor supply from the

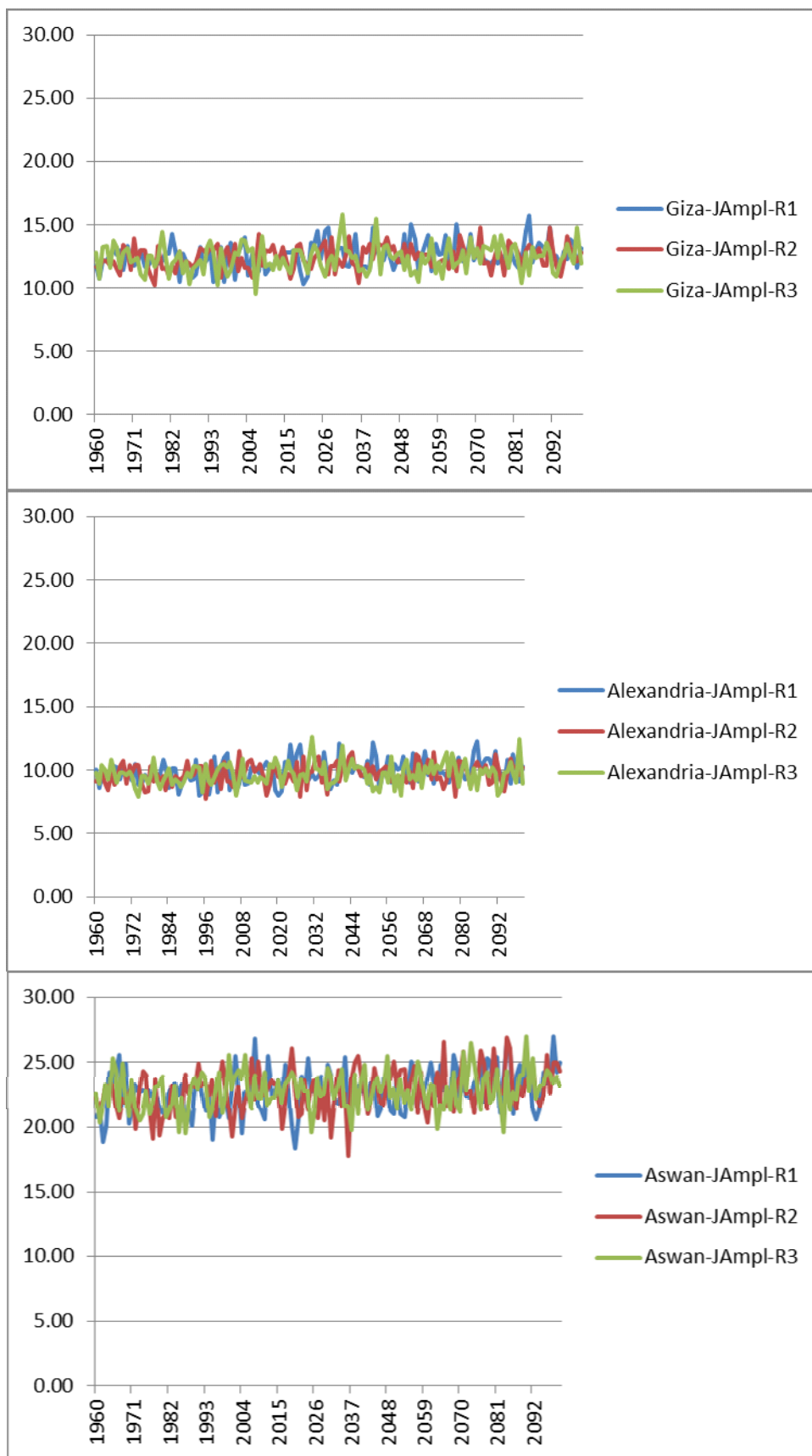
sea surface keep the heat flux between the sea and the atmosphere rather constant over the 24 hours of the day, so that the maritime influence dampens the cooling of the air at night and the heating of the air during daytime. A cool night reduces the CO<sub>2</sub> respiration loss at night and favors, therefore, the build-up of biomass of the plant.



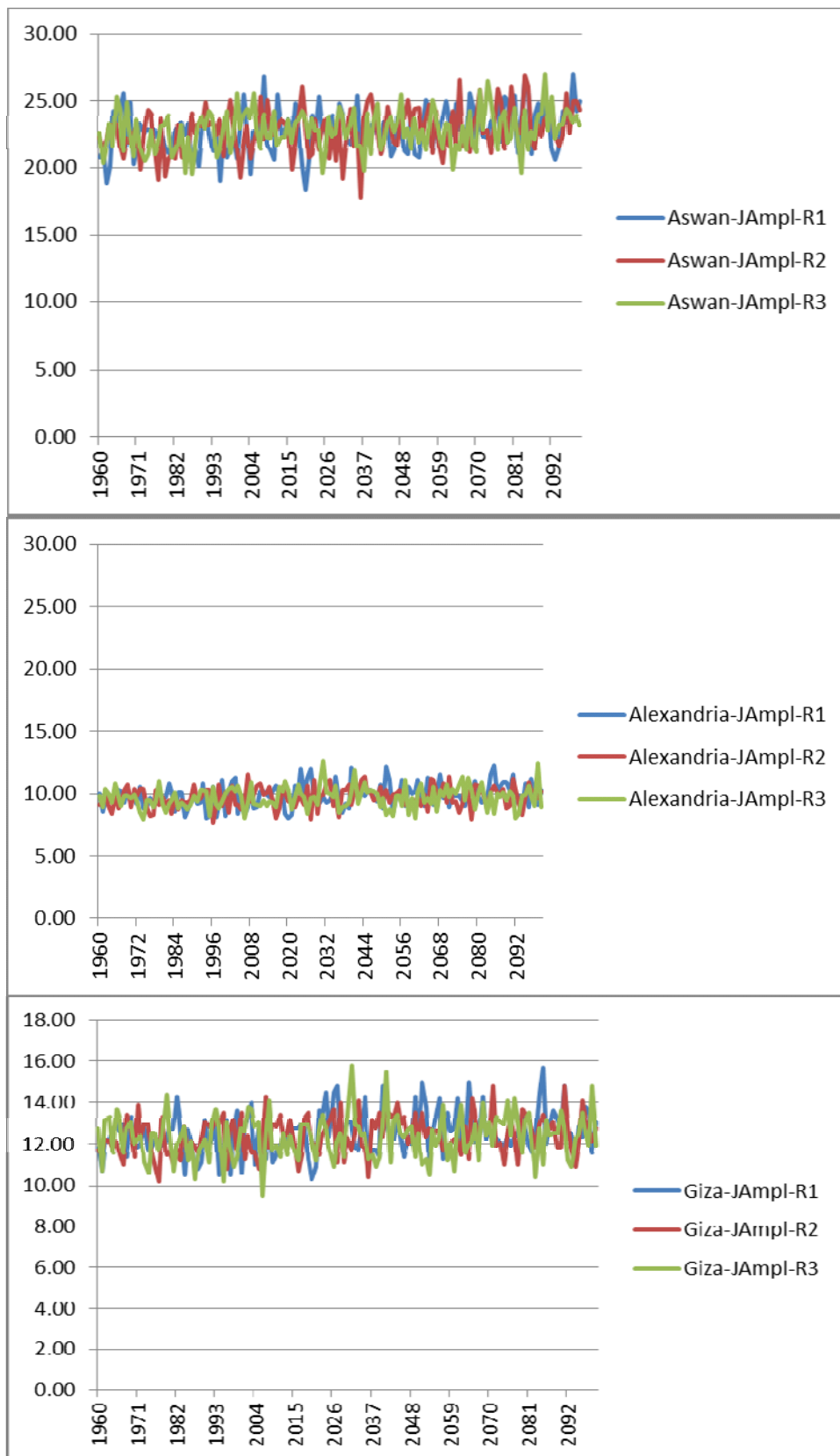
**Fig.10:** The modeled (run 1 R1) trend of annual average air temperature (°C, JMTemp) close to the ground at three regions in Egypt: the areas around Alexandria, around Giza and around Aswan for the years 1960 to 2100. The curves for Alexandria and Giza are nearly identical. All three curves follow each other in their relative variations.



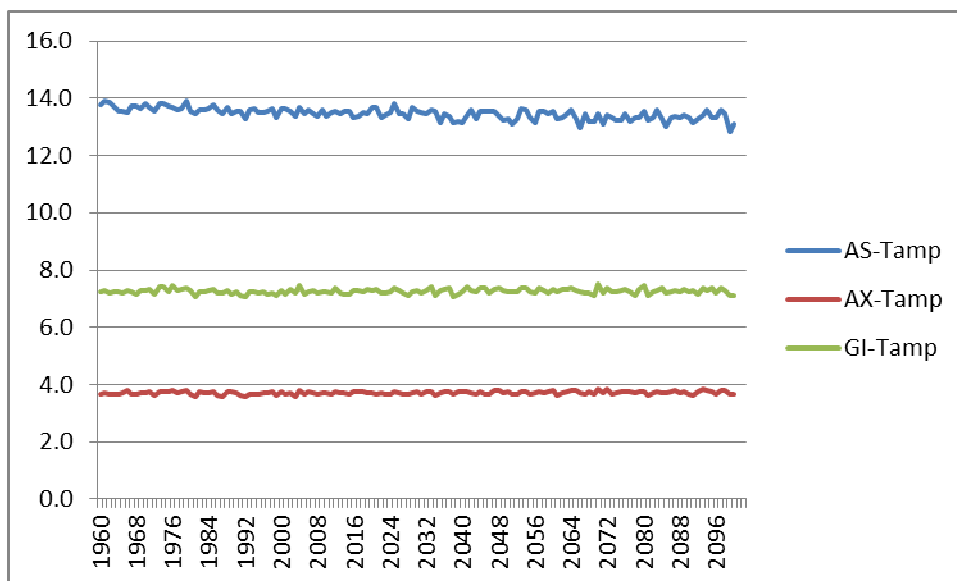
**Fig. 11:** Trend of the annual amplitude of the monthly air temperature (T<sub>month Max</sub> – T<sub>month Min</sub>) (JAmpl) for the regions around Alexandria, Giza and Aswan for model run 1 (R1) for the years 1960 to 2100.



**Fig.12: The calculated trend of the annual air temperature (JMTemp) for the years 1969 to 2100 in the regions of Alexandria, Giza and Aswan for three different starting conditions (R1,R2, R3) of the atmosphere in 1960**



**Fig. 13a:** The calculated trend for the years 1960 to 2100 of the annual amplitude of the monthly air temperature ( $T_{\text{month max}} - T_{\text{month min}}$ ) (JAmpl) for regions around Aswan, Giza and Alexandria for three different atmospheric starting conditions (R1, R2, R3) in 1960.



**Fig. 13 b: The annual mean of the daily amplitude of the air temperature (°C) near the ground in the region of Alexandria (Ax -Tamp), Giza (Gi-Tamp), Aswan (As-Tamp) for the years 1960 to 2100.**

Agricultural crop systems in Upper and Middle Egypt could profit from these cooler nights. The higher daytime temperatures in Middle and Upper Egypt could, however, exert a higher heat stress to agricultural crops, if the optimum temperature is surmounted.

The average annual air temperatures at the coastal site at Alexandria and at the Middle Egypt site at Giza at the southern end of the Nile Delta are rather similar. In evaluating this finding one has to keep in mind that that the model calculates an aerial average temperature for a region of about 120 km x 120 km and not for a special point of an agricultural experimental station.

The air temperature shows an annual cycle because of the changing sun elevation with seasons. Wheat is grown in winter, November to March, in Egypt. The annual amplitude of the monthly mean air temperature shows a large variation for each region and an absolute difference between all three regions (Fig. 13a). In Alexandria this amplitude is presently about 8°C to 11°C, in Giza about 10°C to 14°C and in Aswan about 20° to 25°. This increasing trend towards the south reflects again the Mediterranean influence and the lower water vapor column density in Southern Egypt.

In Aswan in the hottest summer month the air temperature is about 36 °C whereas the lowest winter temperature is about 14°C. In winter the air temperature has probably not reached at present the optimum value for the yield production of the winter crop wheat. This optimum surely depends on the wheat cultivar or land race under field conditions. An increase in air temperature due to climate change could, therefore, increase the average winter wheat yield, because an optimum temperature will be approached. ProCliC does, however, not know yet the optimal temperature for the wheat cultivar of which the growth was modeled.

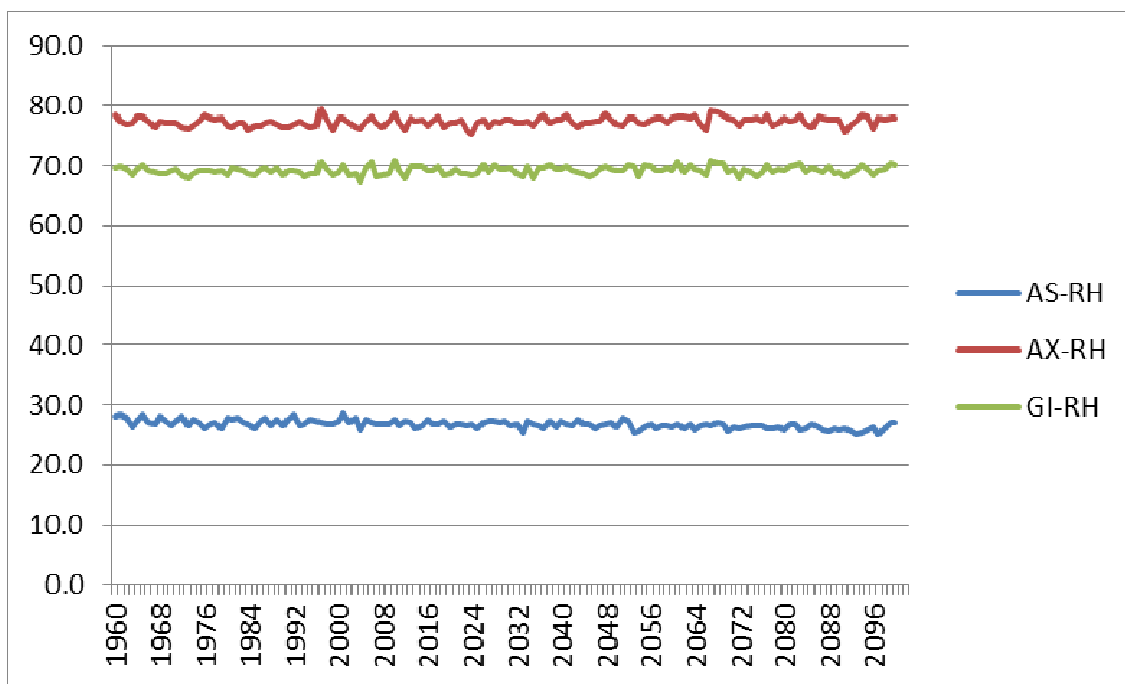
The precipitation amounts along the coast support on a very small land strip rain fed agriculture.

In future this situation will not get better. The rain amounts there will rather decrease by some per cent. Since all agricultural activities are supported by irrigation with Nile and ground water, a new precipitation pattern in Egypt will not greatly influence the agricultural perspectives.

Climate change and precipitation amounts in Ethiopia and Sudan and in the other riparian states contributing to the Nile water is, however, of prime political relevance in the international water issue already today. The states contributing to the Nile water entering Egypt could use the Nile water for their purposes and thus shorten irrigation water for Egypt. At the moment the Nile treaty diverts 85 % of the Nile water flux to Egypt and 15 % to Sudan. This old contract is, however, under critical discussion.

The relative humidity in the vegetation layer influences the transpiration rate through the stomata and the evaporation rate from open irrigation water surfaces. The relative humidity is a measure of the water vapor deficit or difference of water vapor pressure between the atmosphere and the stomata interior of the plants. This difference contributes to the stomata resistance for water and carbon dioxide diffusion between the plant and the surrounding atmosphere. Since ProCliC assumes no water stress in our DSSAT crop model, the transpiration rate of wheat is not reduced by adaptation processes of the plants like closing the stomata openings to save water.

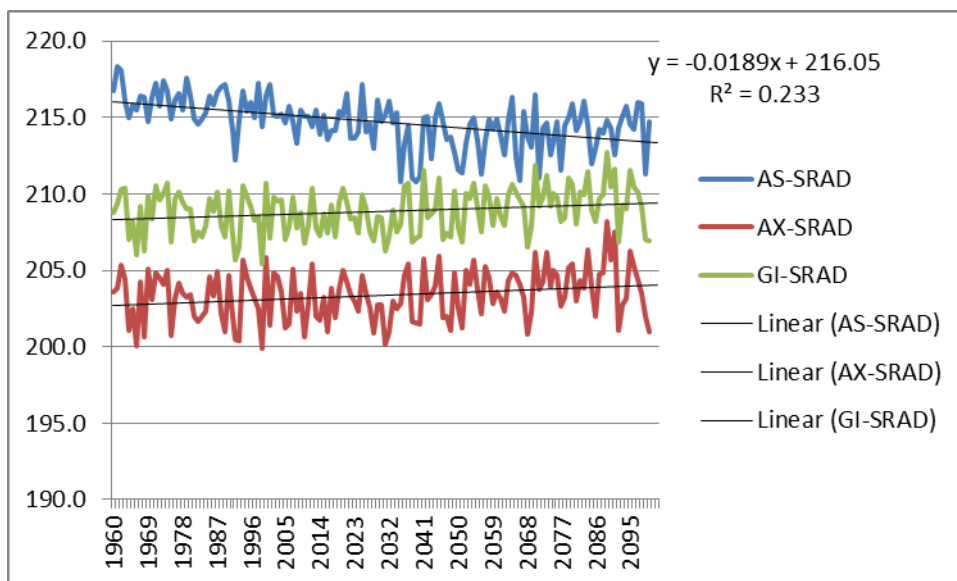
The optimal use of water by the wheat plants could reduce the canopy temperature to evaporative cooling compared to the ambient air temperature. The canopy depression temperature (CDT) is a proxy parameter (see e.g. van Ginkel et al. 2012). The larger the CDT value is, that means, the larger the canopy can cool down itself by transpiration, the better the crop can withstand dry soil conditions. In the Egypt case, however, irrigation supplies sufficient water to the plant. The plant gets probably not a hormonal signal from the roots to close the stomata to save water but instead can open the stomata to absorb the CO<sub>2</sub> offered in the atmosphere. Growth processes and formation of the mature seeds to be harvested could, therefore, be supported to deliver finally a yield larger than at lower CO<sub>2</sub> concentrations and larger than at higher relative humidity values.



**Fig. 13 c: The Relative Humidity annual average) over time (years) in the atmospheric boundary layer in the regions Aswan (AS- RH), Giza (GI-RH), and Alexandria (AX-RH) calculated with ECHAM 5- OM.**

Photosynthesis of plants needs photosynthetic active sun radiation (PAR) to produce new organic biomass. Climate change could change this irradiance. In ECHAM 5 –OM the incoming sun radiation at the earth or vegetation surface is calculated. PAR is a rather constant fraction of the total sun radiation (global radiation). In Fig. 13 d the global radiation at the three regions is plotted as a function of time. Some small trends with time are seen.

At Alexandria and Giza a general small increase of about half a percent is calculated over the 140 years and a decrease of about 1.5 per cent for Aswan. A slow shift of the general circulation pattern with clouds absorbing less sun radiation in Northern Egypt and more in Southern Egypt could be the cause. The effect of these radiation trends on the wheat yield has to be compared in relation to other influences.



**Fig. 13d:** The trends of sun radiation (W/m<sup>2</sup>) with time at the regions Alexandria (AX-SRAD), Giza (GI-SRAD), and Aswan (AS-SRA) calculated with ECHAM 5-OM (Notice: the radiation axes does not start at zero!). The time span covers the years 1960 to 2100.

## 2. Soil Module

The soil in Egypt is quite different with respect to agricultural use (see Fig. 2). The surface of the Nile Delta and the Nile valley consists of fluvial soil, which was formed by fertile silt deposits of about a millimeter per year, when the land was annually flooded before the closure of the Aswan dam in 1964 and the consecutive filling of the reservoir. After the construction of the dam, the agricultural land could be irrigated with Nile water throughout the year. This rich fluvial soil is best suited for agricultural purposes. The highest yields are gained here in conjunction with a nearly optimal weather pattern for usually two crops: a winter and a summer crop. Since the first objective of ProCliC is to investigate the effect of climate change on wheat production, we kept the starting properties of the soil constant for all model runs. In addition we allowed no water stress and no nitrogen stress. Water and nitrogen were supplied in a sufficient way.

One soil type with the same soil characteristics was used in ProCliC modeling for the three regions of Alexandria, Giza and Aswan. Thus, modeled differences in crop yield are only due to different weather patterns in Upper, Middle and Lower Egypt and not to different soil properties at the time of sowing the wheat seeds. Also the production management and the cultivar were the same. The different atmospheric parameters at different places could, however, invoke different reactions in the soil, so the soils at the three different regions may divert from each other during the wheat growth process. The chosen soil type is Vertic Torrifuvents, the most frequent soil type in the Nile Delta. The texture in the upper 70 cm of the soil is fine silty clay (SiC). Further down to 120 cm depth a fine, unconsolidated layer was assumed. The pH (water) was between 8.25 and 8.5, the organic matter made up 0.7% to 2.01 % in different soil depths.

All numerical values for the soil properties used by ProCliC modeling are given in the appendix.

## V Results of the Crop Model Runs

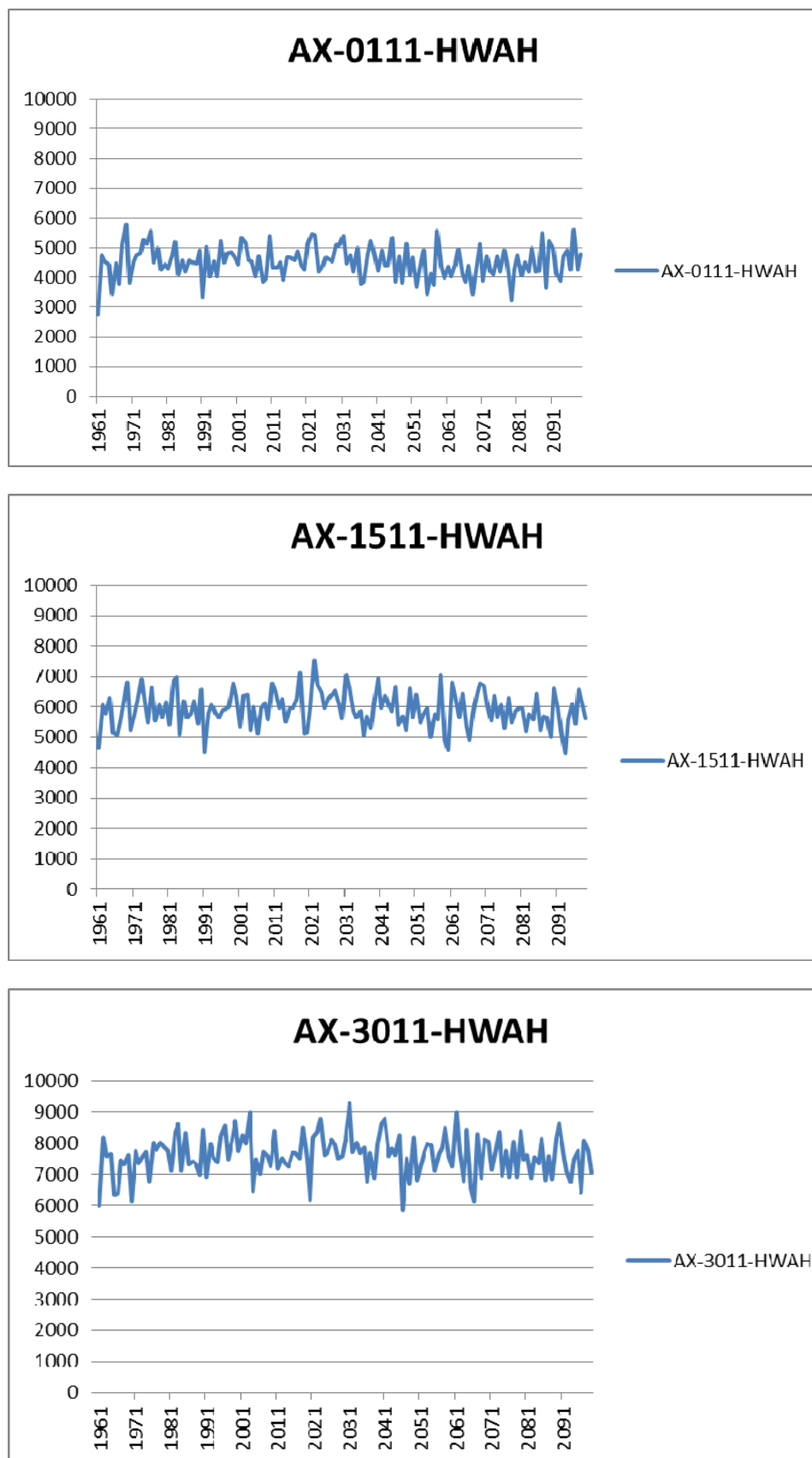
The different DSSAT modules are connected to calculate the growth of the wheat crop and the buildup of the wheat yield. The value of the wheat yield is the prime goal of ProCIC.

The intermediate steps of emergence, of tillering, of flowering, of grain filling and maturity of the plants give hints to the causes of the yield formation. They help to understand the interferences between atmospheric parameters and plant growth processes and they can identify critical processes for yield formation. The entire management of plant production can be followed up with the model and deficits of our understanding to numerically model crop growth and yield formation can be identified. The field truth can be confronted with model results and vice versa.

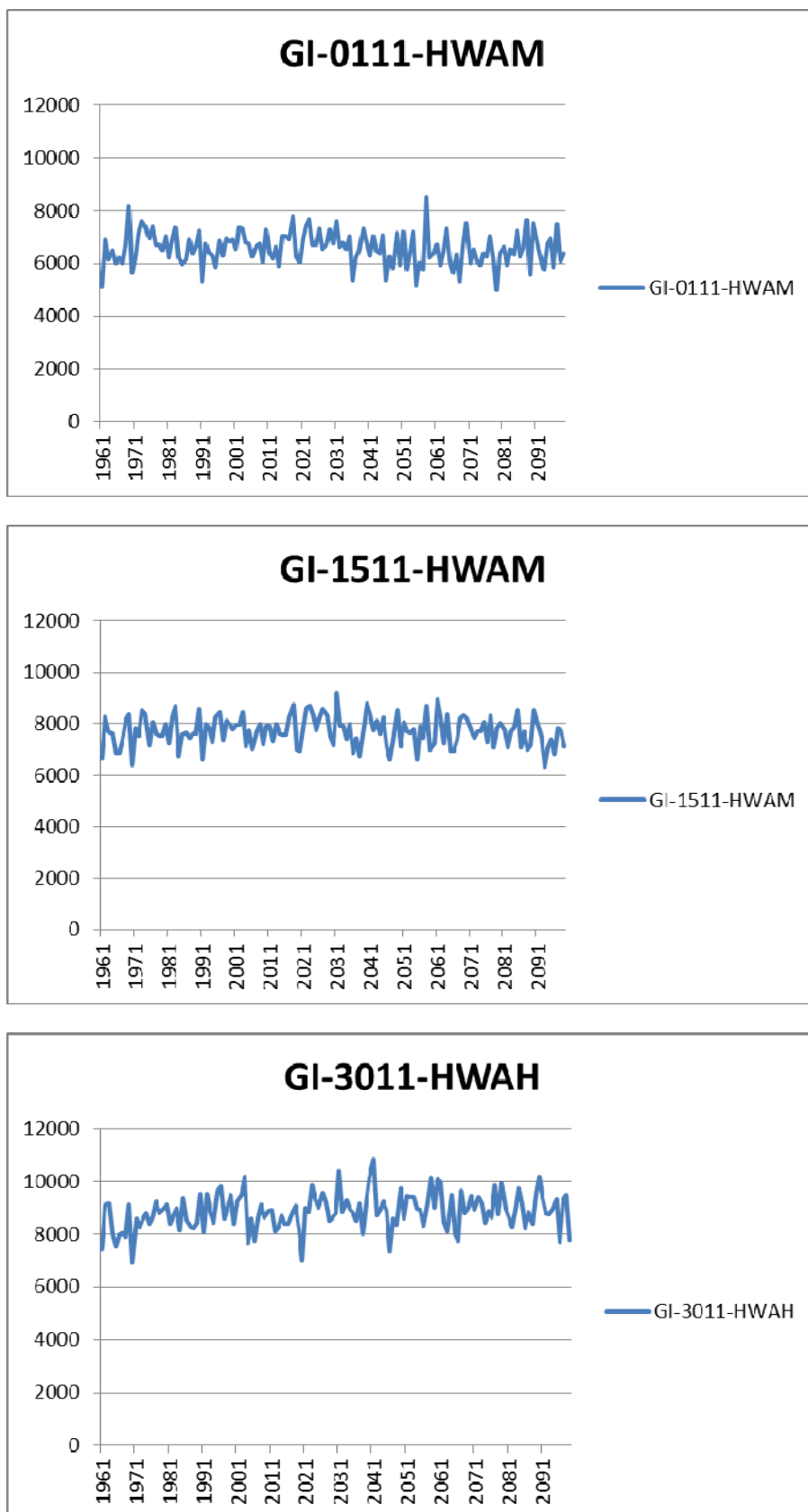
Bilateral difficulties encountered hindered ProCIC to investigate the many steps from seeding to harvest and their interaction with atmospheric parameters in detail. Thus ProCIC presents and demonstrates the wheat yields of the cultivar Shake 93 at three sites with the same soil, under no nitrogen and water stress in Northern (Alexandria), Middle (Giza), and Southern (Aswan) Egypt under future climate change conditions.

The most representative and important area for crop growth in the future for Egypt is the area around Giza. The yield trend for varying climate conditions but for constant all other conditions from 1960 on to 2100 does not show any trend: no increase and no decrease for the region of Alexandria and Giza, but a small increase or decrease for the region of Aswan. (Fig 14, Fig 15, Fig. 16) From year to year the yield amount varies in each region by about  $\pm 20\%$  for all three planting dates, the 1st, the 15th, and the 30th of November. But the absolute level of the yield amounts is different for the three planting dates for all three regions. In the Alexandria region the yield for the planting dates 1st November is about 4 t/ha to 5 t/ha, for the planting date 15th November is about 5 t/ha to 7t/ha and for the planting date 30th November is about 7 t/ha to 8 t/ha. The yield increases, when the planting date is shifted to later time in the year. This holds true for the region around Giza as well. The yields are rather constant over the entire time span and vary by about 20% from year to year. But again the absolute yields for different planting dates differ by a constant value and are higher the later in November the planting took place: for the planting date 1st November the yield amounts to 5 t/ha to 7.5 t/ha, for the 15th November the yield amounts to about 7 t/ha to 8.5 t/ha and for the 30th November to 8 t/ha to 10 t/ha. Development responses to sowing date for wheat are also reported by Miralles et al. 2001.

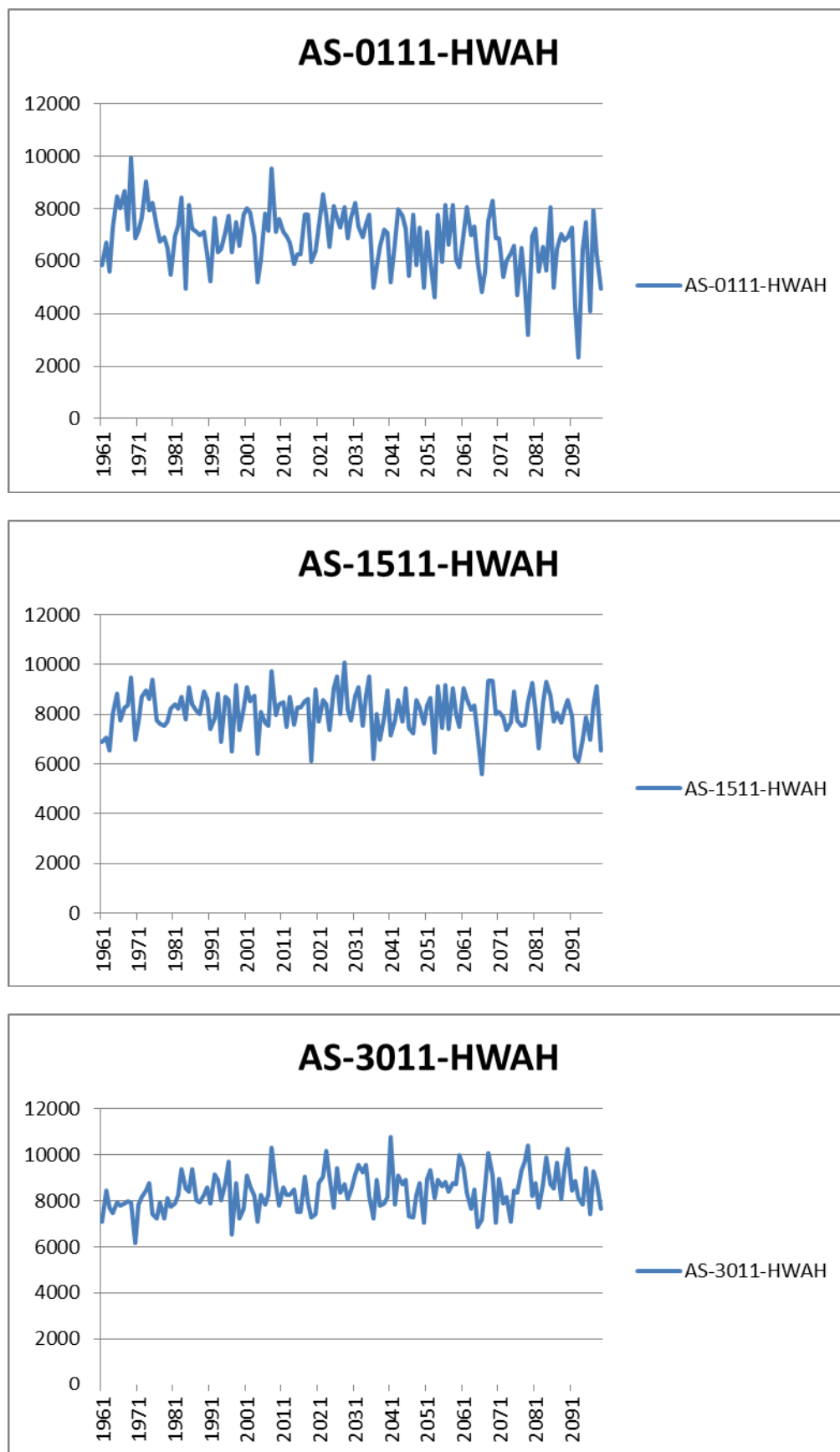
For the most southern region Aswan (Fig. 16) a small trend in yield amount over the entire time span is calculated. For the planting date 1st November the yields decrease from the decade 2020 to 2030 to the end of this century from 6 to 8 t/ha to about 4 t/ha to 8 t/ha.



**Fig. 14:** The modeled trend for wheat yield (t/ha) (HWAH) for the region of Alexandria for three different sowing dates: a. 1.Nov, b. 15.Nov, c. 30.Nov. for the year 1960 to 2100.



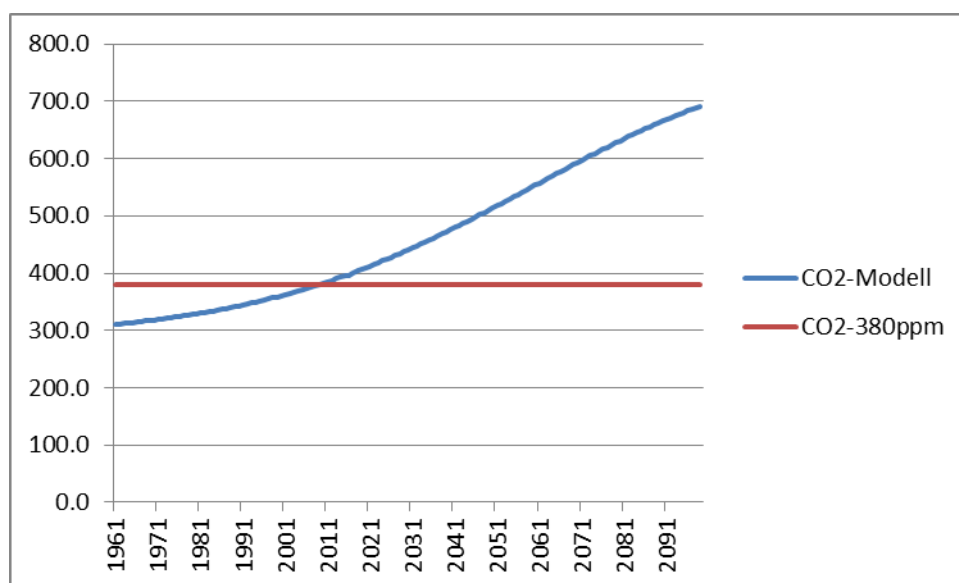
**Fig. 15:** The modeled trends for wheat yield (t/ha) (HWAM or HWAH) for the region of Giza for three different sowing dates: a. 1. Nov, b. 15. Nov, c. 30. Nov. for the years 1960 to 2100.



**Fig. 16:** The modeled trends for wheat yield (t/ha) (HWAH) for the region of Aswan for three different sowing dates: a. 1.Nov, b. 15.Nov, c. 30.Nov. for the years 1960 to 2100.

Sowing at the Nov. 15<sup>th</sup> results in a rather constant yield of 7 - 9 t/ha and for the sowing date 30. November a small increase from about 8 t/ha at present times to about 9 t/ha at the end of the century is derived in the model. Also at Aswan the relation holds: the later in November the sowing dates are, the absolute higher the yield values are.

A change in atmospheric CO<sub>2</sub> concentration is influencing the photosynthesis rate especially for C3 plants. The CO<sub>2</sub> concentration in reality and in the model is increasing. For comparison in another set of runs the CO<sub>2</sub> concentration was kept constant (380 ppm). The two courses of CO<sub>2</sub> concentrations, used in the model, are given in Fig. 17.



**Fig. 17 :** Atmospheric CO<sub>2</sub> concentrations (ppm, y axe) as a function of time (years, x axe).Crop model runs were performed with a constant CO<sub>2</sub> concentration (red) and with an increasing concentration (blue).

A general result was obtained: at constant CO<sub>2</sub> concentration the grain yields decreased with time in parallel with increasing air temperatures. With increasing CO<sub>2</sub> concentration this decrease was compensated and the yield stayed rather constant with time.

The assumed constant CO<sub>2</sub> concentration is higher in the past (380 ppm) than the one assumed as changing with time (ca. 320 ppm). In future the constant concentration is lower than the increasing CO<sub>2</sub> concentration.

At higher CO<sub>2</sub> concentration the uptake of CO<sub>2</sub> usually increases. This augmentation of photosynthesis seems to compensate for loss rates in CO<sub>2</sub> accumulation due to higher temperatures. If in the model the future CO<sub>2</sub> increase is set to zero, that means the concentration is set constant at 380 ppm, the CO<sub>2</sub> fertilization is constant and cannot be any more the reason for any change in the harvested yield. The yields with and without additional CO<sub>2</sub> fertilization do change in a quite noticeable way (Fig. 18 – Fig. 20). The higher the CO<sub>2</sub> concentration is the more the CO<sub>2</sub> fertilizer

effect can compensate loss rates due to other reasons, e.g. heat stress or too short times to grow and ripen. This model result is in line with the general understanding of the CO<sub>2</sub> uptake by plants. In growing situations with no water and nitrogen limitations the stomata can open widely and the formed organic C- compounds can be built into internal process lines of plant growth and grain yield formation.

In reality these optimal conditions are not reached all the time. In open top chambers and in free atmospheric CO<sub>2</sub> exchange experiments (FACE) the CO<sub>2</sub> fertilization effect is estimated to cause a yield increase of about 10 to 20 per cent. ProClic has modeled in this project growth and yield for wheat in Egypt for nearly optimal conditions concerning soil, water and the atmosphere. A noticeable CO<sub>2</sub> effect of the increasing atmospheric CO<sub>2</sub> concentration on wheat growth and grain yield is, therefore, not surprising. Hassanein et al. (2012) reported a modeled decrease for bread wheat of up to 31% under a constantly added temperature increase of 3.5°C. It was not stated, whether an increase of atmospheric CO<sub>2</sub> was considered at the same time, too. The conclusion, “that reduction in wheat grain yield at the three locations has high probability in the future” can, therefore, be questioned.

The wheat yield in absolute values in our crop model is least at Alexandria and increases going south towards Giza and Aswan. This order could be influenced by the effect of CO<sub>2</sub>. Fig. 18 to Fig. 20 show the grain yield at all three regions calculated with a constant CO<sub>2</sub> concentration of 380 ppm since 1960 and with an increasing CO<sub>2</sub> concentration from 320 ppm in the year 1960 to 600 ppm in the year 2100. The two concentration courses with time are given in Fig. 17. The graphs show, that the CO<sub>2</sub> effect is always increasing the grain yield. At the end of this century the grain yield increases with the increasing CO<sub>2</sub> concentration by about 27% to 66%. Around the time period 1960 to 1980 the model results are lower with increasing CO<sub>2</sub> than the results with the constant CO<sub>2</sub> concentration. This result is consistent with the result for the end of this century, since at the beginning the constant CO<sub>2</sub> concentration of 380 ppm is larger than the increasing CO<sub>2</sub> concentration, which starts from about 320 ppm in the years of 1960 to 1970.

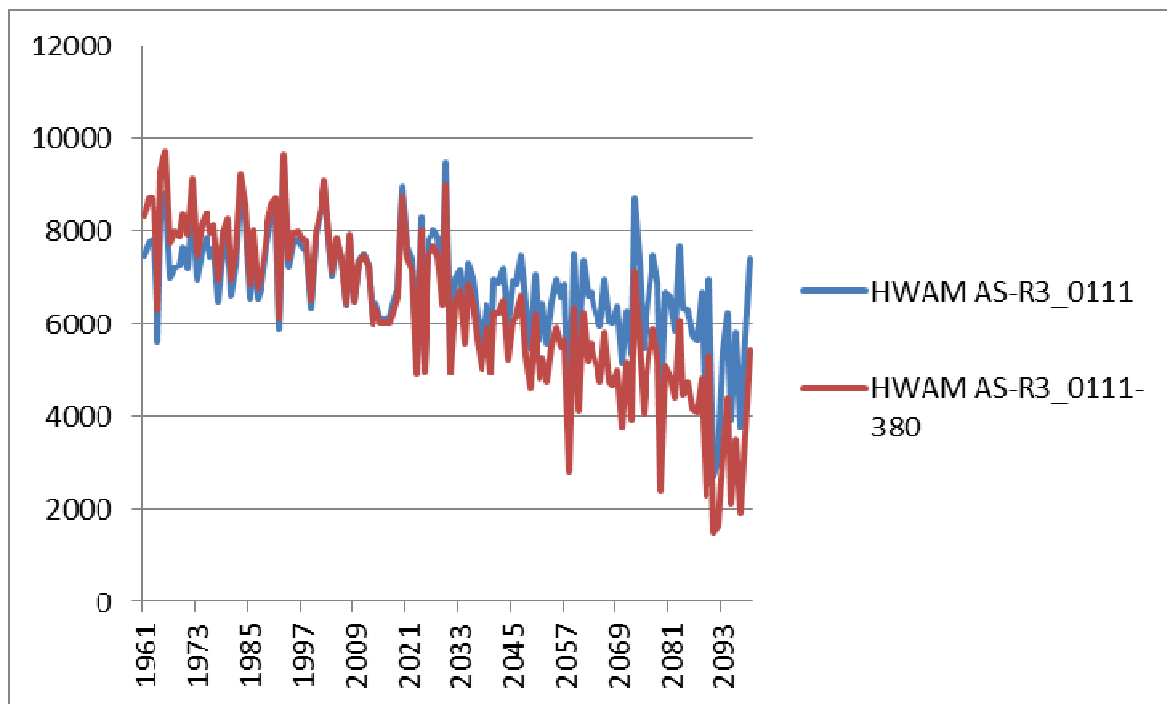


Fig. 18

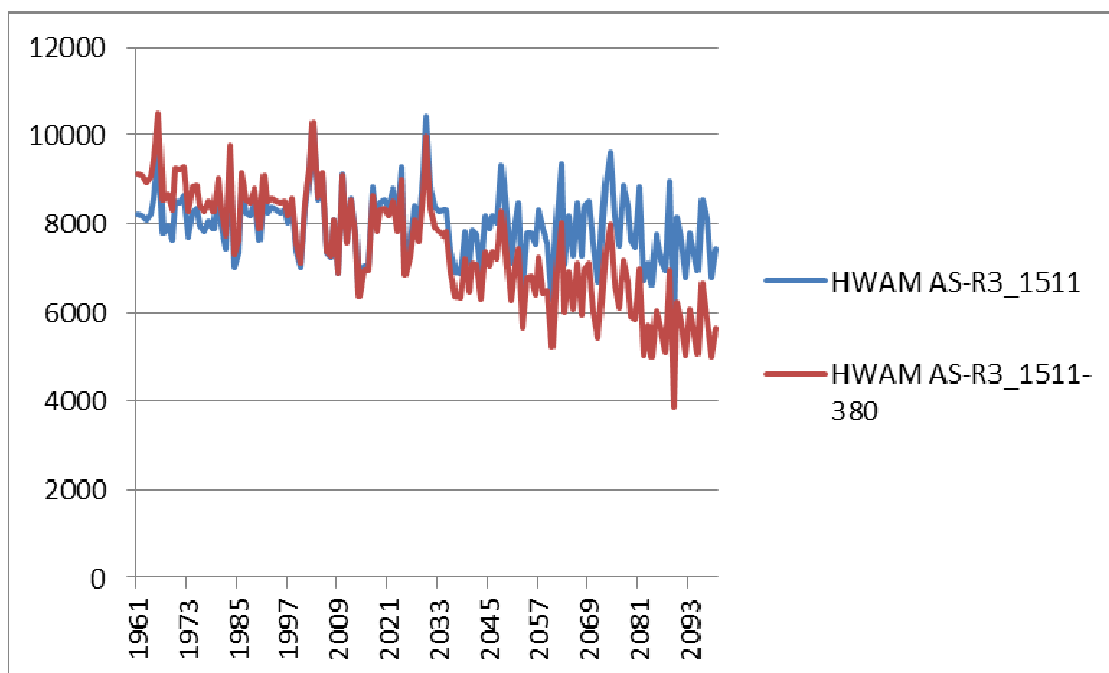
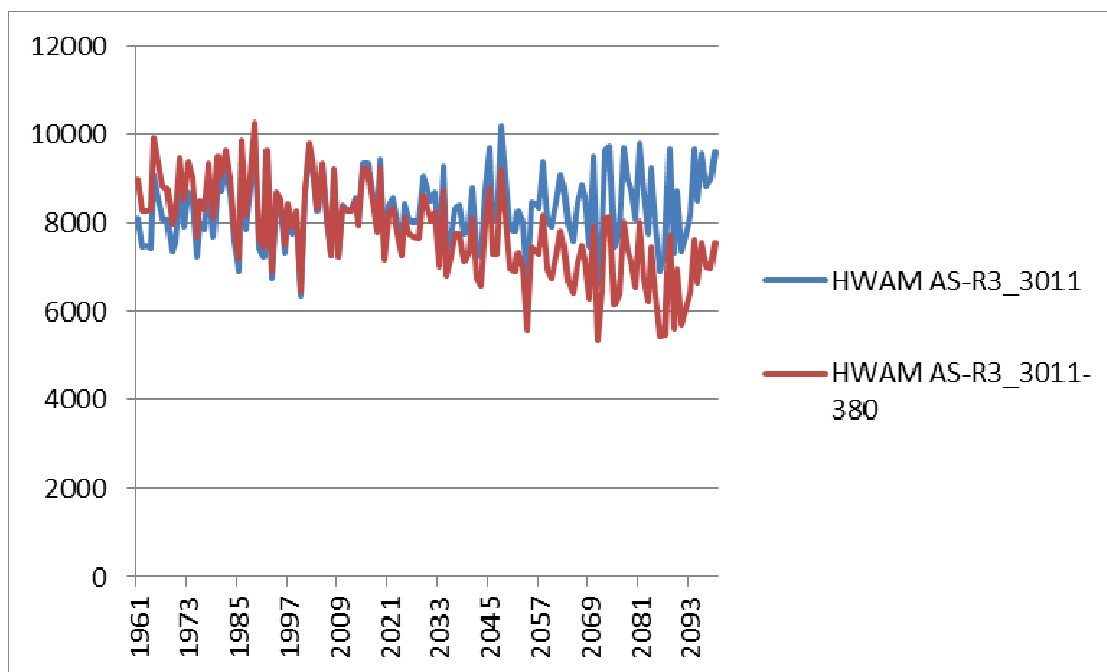
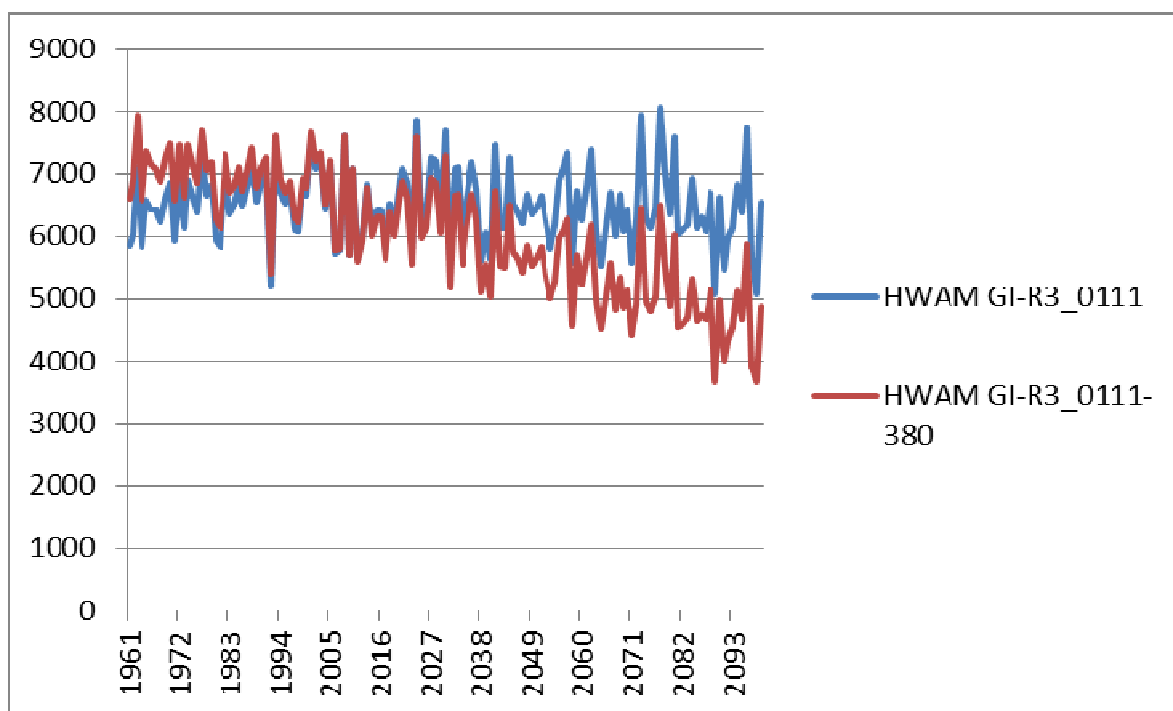


Fig. 18 b



**Fig.18c**

Fig. 18a, 18b and 18c represent the grain yields of wheat kg/ha /a, (HWAM), for three planting dates (01.11. ; 15.11. ; 30.11.) at Aswan (AS) for ECHAM 5 run three (R3). One run (red) with constant CO<sub>2</sub> concentration (380 ppm), the other (blue) with increasing CO<sub>2</sub>.



**Fig. 19 a**

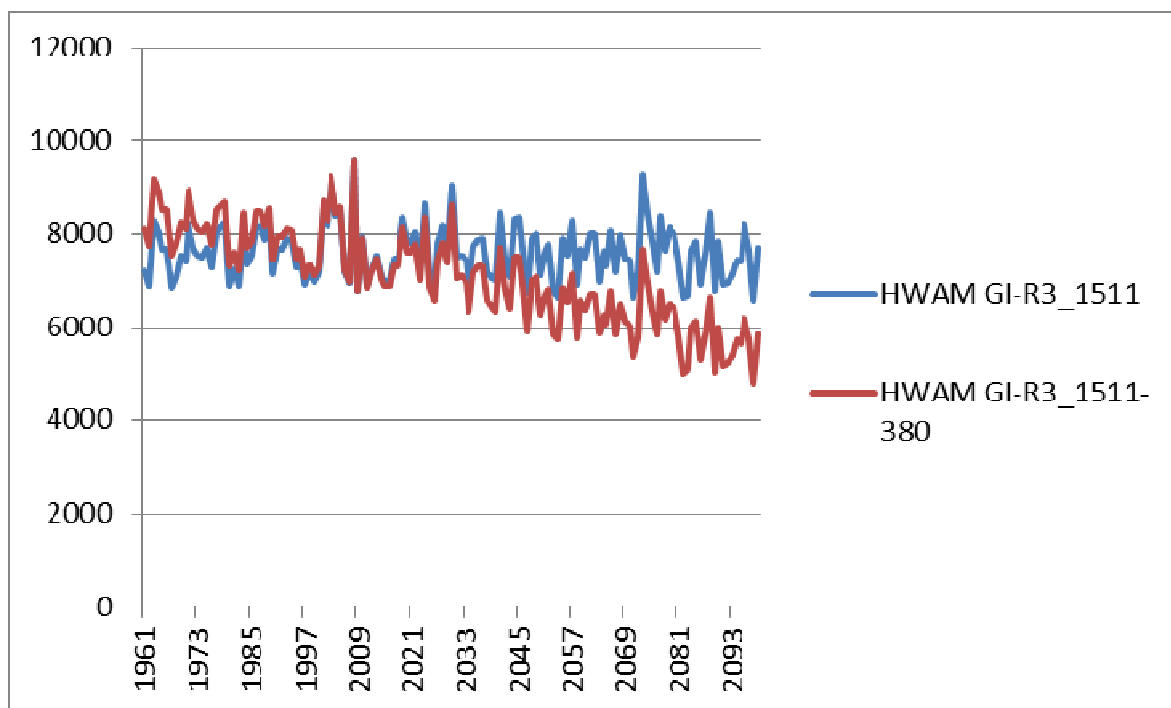


Fig. 19 b

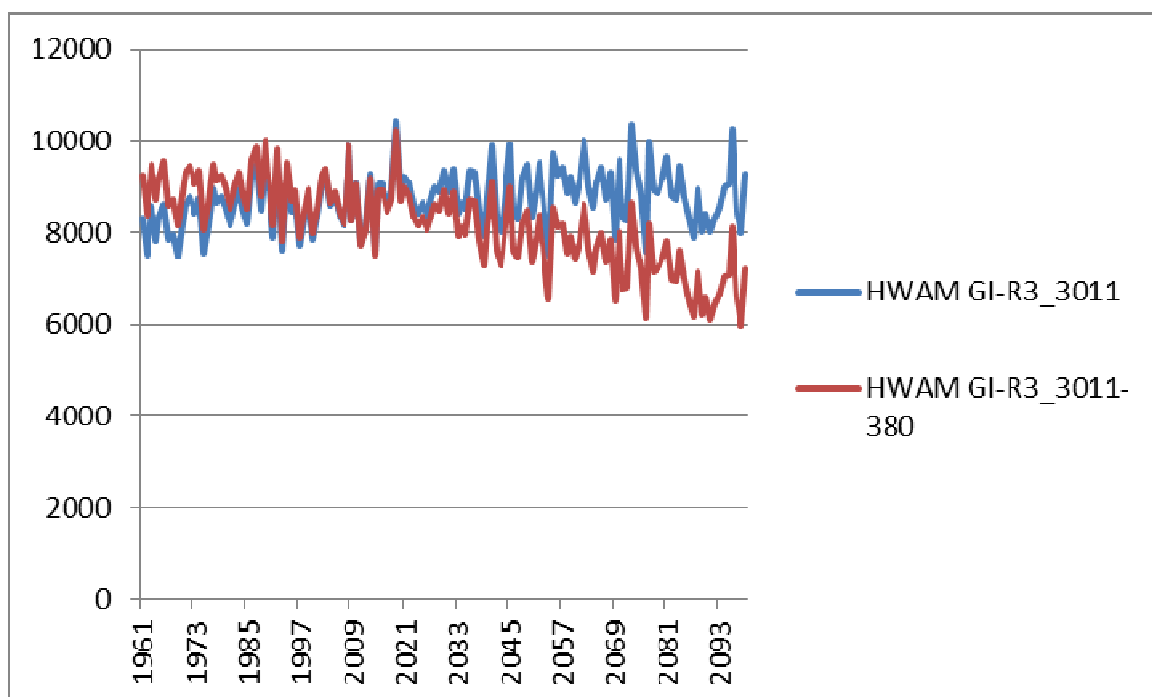


Fig. 19 c

Fig. 19 a, 19 b, and 19 c similar as 18a to 18c, but for Giza

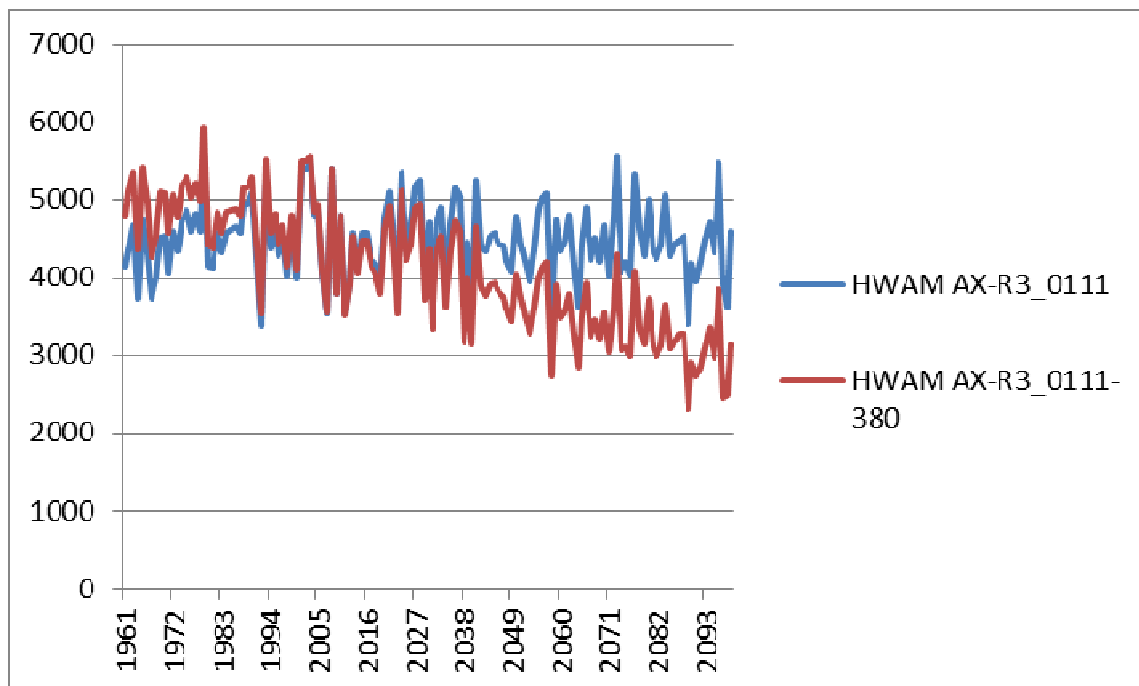


Fig. 20 a

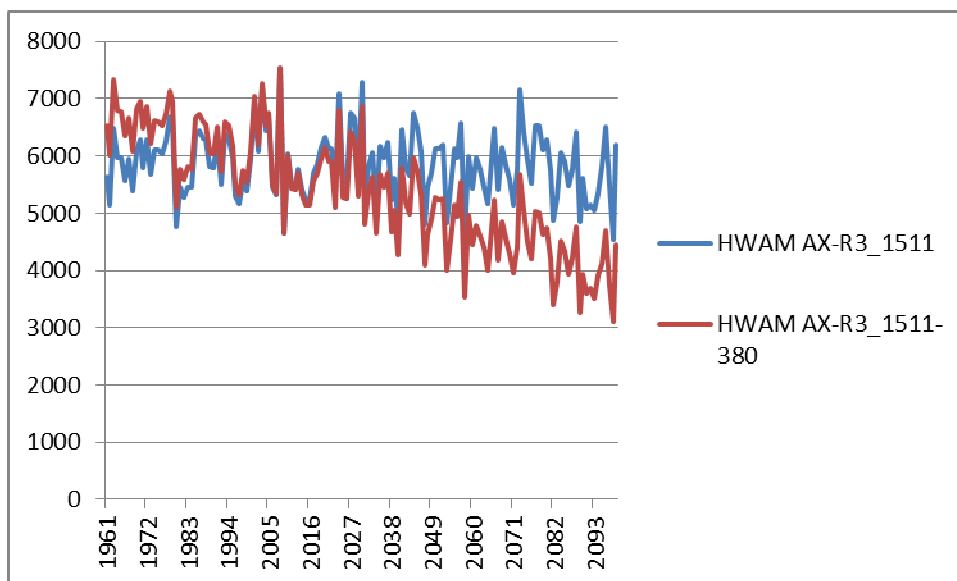
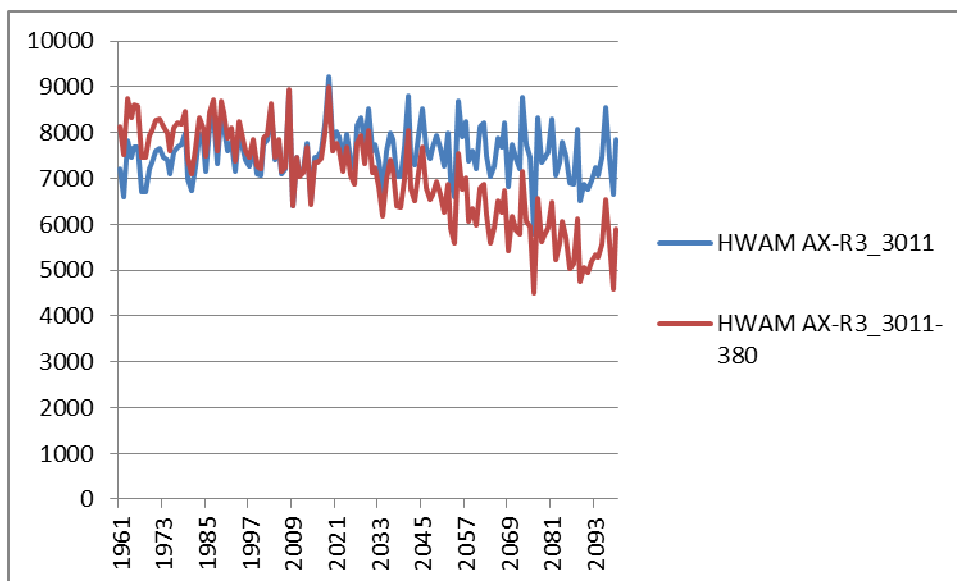


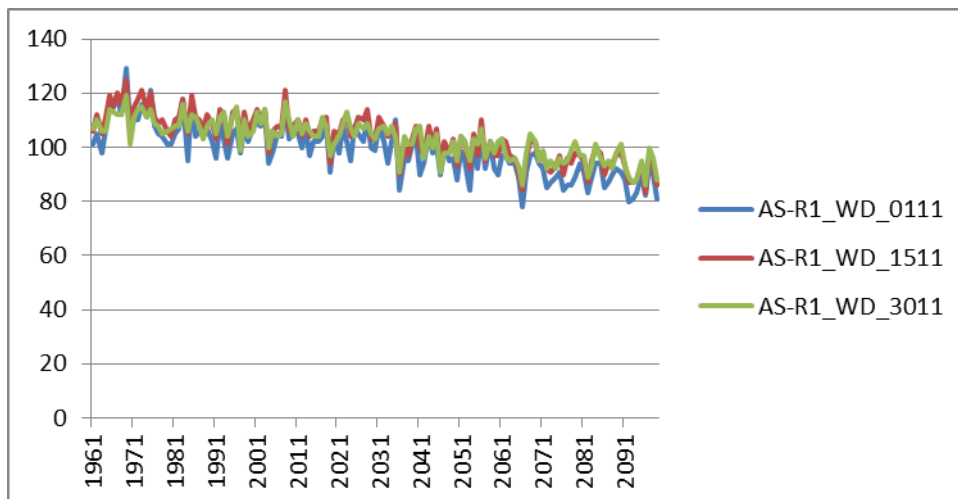
Fig. 20 b



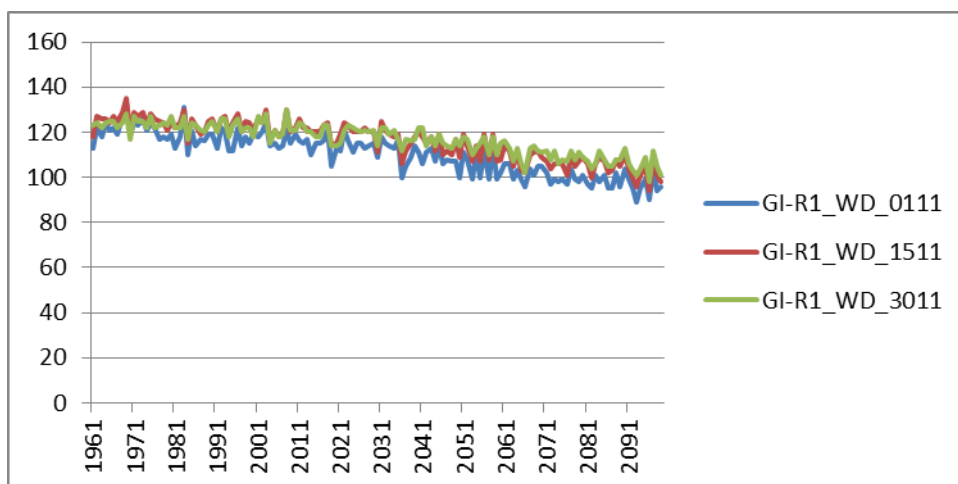
**Fig. 20 c**

Fig. 20a, 20b, and 20c the same as for 18a - 18c and 19a -19 c. The Fig. 20a -20c represent the grain yield of wheat ( kg/ha/a, HWAM) for three sowing dates ( 01.11. , 15.11. , 30.11.) at Alexandria (AX) for EGHAM 5 run three (R3). The red curve stands for constant CO<sub>2</sub> concentration of 380 ppm, and the blue curve for increasing CO<sub>2</sub> concentration with time.

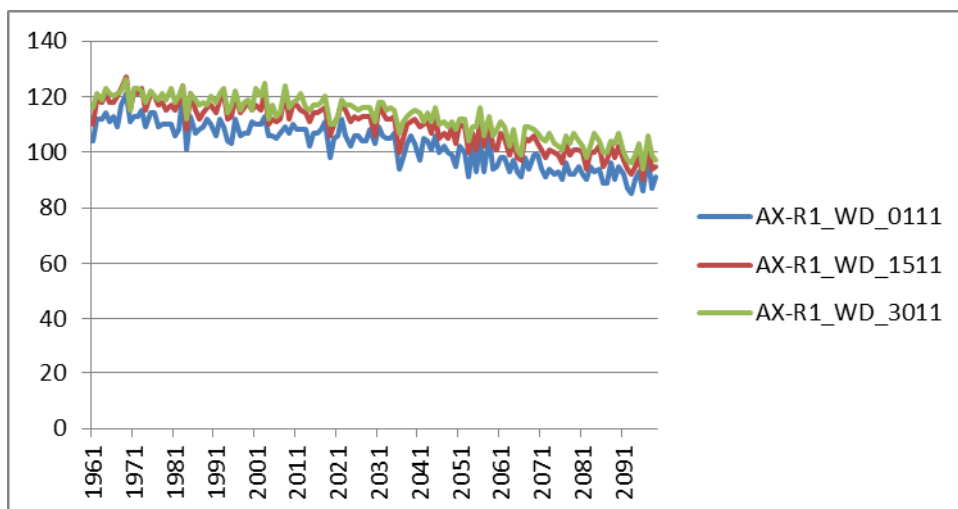
The sowing date influences the grain yield at present and in future as follows. The later in November wheat was sown the larger the wheat harvest was (Fig. 14, 15, 16). This can have multiple reasons in the model. One reason could be the length of time between planting and harvesting; the longer the time between sowing and harvesting is, the longer is the time for growth and ripening. The time between sowing and harvesting is given for all three regions Aswan, Giza and Alexandria for the time period from 1960 until 2100 (Fig. 21a, 21b, 21c; Fig.22c, Fig.22b, Fig. 22c). For all three regions and planting dates in November this growing time period is generally decreasing going from the year 1960 to the year 2100 with large annual variations. Photiades and Hadjichristodoulou (1984) found an optimum date depending on rainfall. The longest time period from sowing to harvest is necessary at Giza, and the shortest at Aswan. The time length falls between 110 to 120 days between the years 1960 and 1990 and between 80 and 110 days at the end of this century. The wheat growth time is shortening by about 15% to 20%. This is probably due to the higher temperatures with time assumed in the crop model. A shorter rotation time has been suggested to be a prime consequence of warmer temperatures (Lhomme et al. 2009, Ommen 2003). This shorter cycle could enable to test other agricultural plants, e.g. maize, to fill the gained growing time. A shorter growing time could, however, reduce the potential grain yield and a higher CO<sub>2</sub> concentration could reduce the nutrition value of the grains (Miglietta et al. 1995, Porter and Semenov 2005). CO<sub>2</sub> enrichment was expected by Fangmeier et al. (1997) to alter leaf demand of spring wheat for micro- and macronutrients.



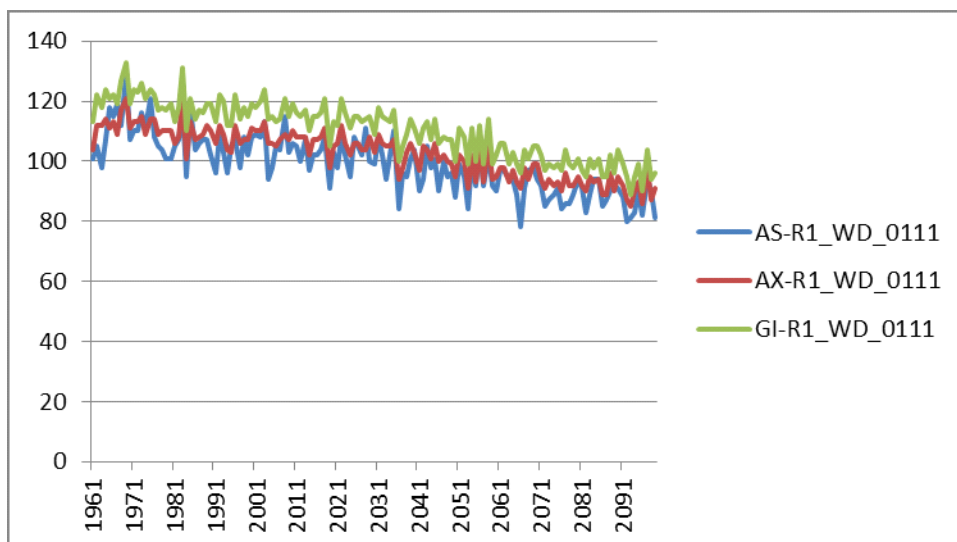
**Fig. 21 a:** Number of days between sowing and harvesting at Aswan for three different planting dates (1. Nov. ; 15. Nov. ; 30. Nov.) as a function of the years 1960 to 2100.



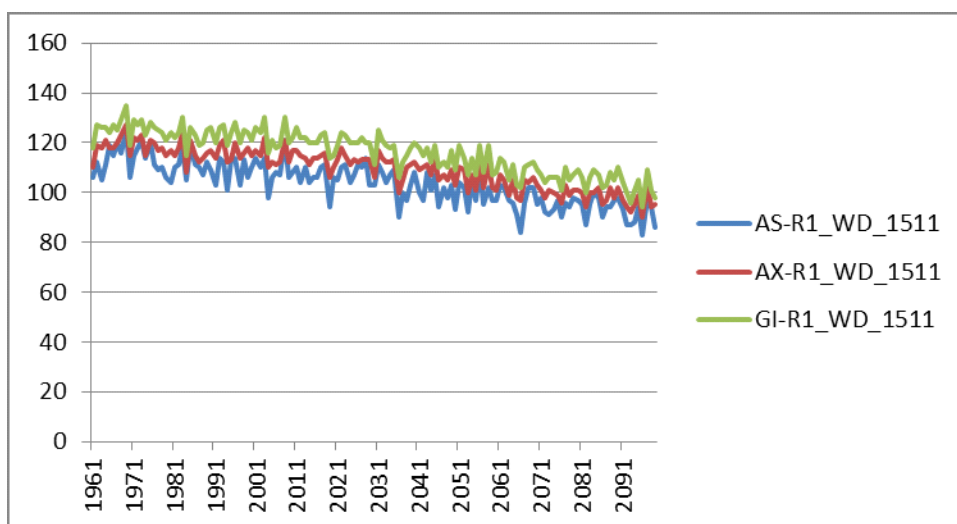
**Fig 21 b:** Same as for Fig 21 a but for Giza



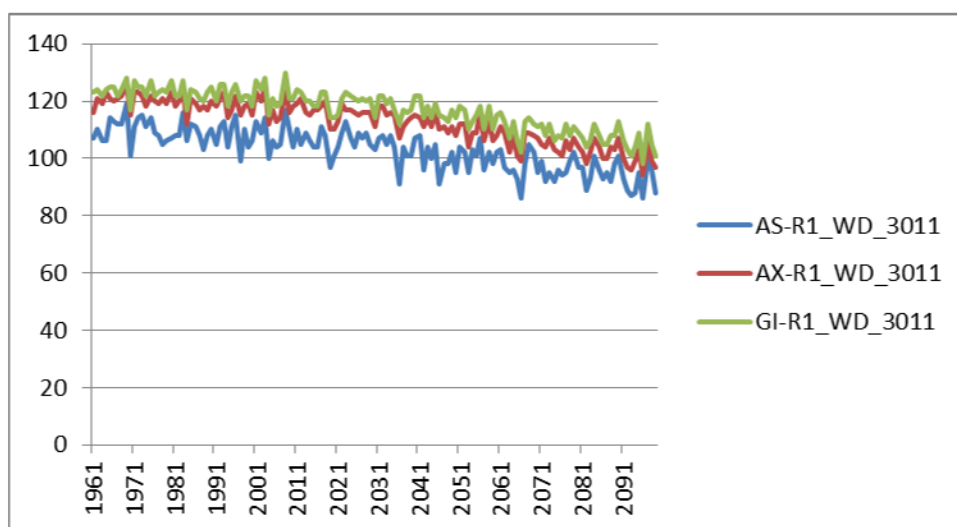
**Fig. 21 c** Same as for 21a and 21b but for Alexandria



**Fig. 22 a:** Number of days between sowing and harvesting for the regions of Aswan, Giza, and Alexandria for the planting date 1. Nov. as a function of the years from 1960 to 2100.



**Fig 22 b:** Same as for 22 a ; but for sowing date 15. Nov.



**Fig. 22 c:** Same as for 22 a and for 22 b but for sowing date 31. Nov.

The date of harvesting falls in general in the middle of February, the growing times from planting in November are varying between 80 days and 130 days depending on actual weather patterns. A detailed investigation on the influence of e.g. length of time, temperature level, heat stress, and thermal length on the consecutive appearance of different growth stages, e.g. grain filling, and expressions of plant traits should be envisaged. The length decreases with time at all three regions, but is shortest at Aswan, and longest at Giza. The shorter time in Aswan is certainly an effect of the increasing air temperature. But the rank order between Giza and Alexandria is not straight forward. More detailed analyses of the entire growing sequence could solve the causes of this difference between Giza and Alexandria.

In general in biochemical processes the reaction speed increase by a factor of two, when you increase the temperature by 10 degrees Celsius. But the morphological structure of plants might not be so fast built, that the ripening proceeds faster than the growing. This slower growing than ripening could well decrease the grain yield and its nutrition value.

The influence of heat length - that means degree - days ( $^{\circ}\text{C} \times \text{days}$ ) - at different phenological stages could result in a dependency of yields and atmospheric influences during certain development stages.

The wealth of data of atmospheric and modeled specific plant stages has not been evaluated in extensor for all interactions. A large potential to mine relations between atmospheric parameters and crop yield in the climate – crop model entity has, however, been prepared by ProCliC. We are sure that the scientists involved in ProCliC will take this unique chance to elaborate the many model results and compare them with field data end field experience.

Other influences fostering wheat yield have been discussed especially for upper Egypt by AW Hassan et al. 1995. They underline the importance of the variety chosen, the management of crop production, and the necessity of an intensive extension service and of the socio-economic effect of the rural development. In Tab. 5 the crop model results of ProCliC for a wheat variety grown in Egypt under optimal water and nitrogen supply and on the same soil and with increasing CO<sub>2</sub> concentrations are summarized:

**Tab. 5: Crop model results of ProCliC for the grain yield per season for wheat variety Sakha 93 grown in three Egyptian areas with no water and nitrogen stress and on the same soil.**

Yield Region	Present Time	End of this Century
Alexandria Lower Egypt Coast	4t/ha – 8t/ha	4t/ha – 8t/ha
Giza Middle Egypt / Southern Delta	6t/ha – 10t/ha	6t/ha - 10t/ha
Aswan Upper Egypt	7t/ha - 9 t/ha	6t/ha – 9t/ha

## **VI The main results of ProCliC**

The main results of ProCliC can be summarized as:

1. The DSSAT model reproduces the values for the wheat grain yield in Egypt in a reasonable way
2. The trend of the wheat yield with time does not show an alarming decrease, but stays rather in the range already experienced today
3. The grain yield depends strongly on the planting date
4. The increase in atmospheric CO<sub>2</sub> concentration compensates for the grain yield loss due to heat stress
5. The modeled grain yield seems to get higher the more southern the modeled wheat variety Sakha 93 is grown in Egypt .

The main issues of wheat crop growing, which can be addressed by the established atmosphere - crop model, are:

1. Crop rotation with time
2. Atmospheric influences on different phenological plant stages and grain yield
3. Different management strategies
4. The interaction of different wheat cultivars with atmospheric variations
5. Plant protection

The main information for improving modeling, which should be gained in Egypt, should be:

1. Field data for soil profiles
2. Field data for phenological stages of different cultivars in different regions in Egypt
3. Field data for wheat yields in Egypt

Attempts to combine atmospheric and crop modeling should be strengthened and supported in order to better address a process oriented understanding of urgent issues of food security in Egypt.

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## Appendix

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FILEA   EGAS1501.SNA C:\DSSAT45\Seasonal\
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ECOTYPE WHCER045.ECO C:\DSSAT45\GENOTYPE\
CULTIVAR WHCER045.CUL C:\DSSAT45\GENOTYPE\
PESTS   WHCER045.PST C:\DSSAT45\PEST\
SOILS   EG.SOL  C:\DSSAT45\SOIL\
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      R R R R M
      Y N Y 10 N N N N N N N N N N
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    30. 50. 25. IB001 IB001
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    0 1960320 100. 0.
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    15. 0.000 0.0 0.0
    30. 0.000 0.0 0.0
    45. 0.000 0.0 0.0
    60. 0.000 0.0 0.0
    90. 0.000 0.0 0.0
    120. 0.000 0.0 0.0
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*FERTILIZERS
*RESIDUES
*CHEMICALS

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\*TILLAGE

\*ENVIRONMENT

\*HARVEST

\*SOIL

EGGI600001 Ouda 2006/9 -99 -99. Clayey

Giza EG 30.020 -31.130 Vertic Torrifluent

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 15. 0.214 0.481 0.535 1.000 .0600 1.15 1.600 53.2 30.5 0.0 0.160-99.00-99.00-99.00-99.00  
 30. 0.217 0.418 0.503 0.638 .0600 1.24 1.600 53.2 30.5 0.0 0.160-99.00-99.00-99.00-99.00  
 45. 0.203 0.340 0.517 0.472 .0600 1.20 1.600 53.2 30.5 0.0 0.160-99.00-99.00-99.00-99.00  
 60. 0.212 0.359 0.488 0.350 .0600 1.28 1.600 53.2 30.5 0.0 0.160-99.00-99.00-99.00-99.00  
 90. 0.212 0.359 0.488 0.223 .0600 1.28 1.600 53.2 30.5 0.0 0.160-99.00-99.00-99.00-99.00  
 120. 0.212 0.359 0.488 0.122 .0600 1.28 1.600 53.2 30.5 0.0 0.160-99.00-99.00-99.00-99.00

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 120.-99.00 -99.0 -99.0 -99.0 -99.0 -99.0 -99.0 -99.0 -99.0 -99.0 -99.0 -99.0 -99.0 -99.0 20.4 -99.

\*CULTIVAR

EG.SOL:

\*SOILS: Egyptian Soils

\*EGGI600001 Ouda 2006/9 C 120 Clayey

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30 -99 0.217 0.418 0.503 0.638 0.06 1.24 1.60 53.2 30.5 0.0 0.160 -99 -99 -99 -99

45 -99 0.203 0.340 0.517 0.472 0.06 1.20 1.60 53.2 30.5 0.0 0.160 -99 -99 -99 -99

60 -99 0.212 0.359 0.488 0.350 0.06 1.28 1.60 53.2 30.5 0.0 0.160 -99 -99 -99 -99

90 -99 0.212 0.359 0.488 0.223 0.06 1.28 1.60 53.2 30.5 0.0 0.160 -99 -99 -99 -99

120 -99 0.212 0.359 0.488 0.122 0.06 1.28 1.60 53.2 30.5 0.0 0.160 -99 -99 -99 -99

@ SLB SLPX SLPT SLPO SLCA SLAL SLFE SLMN SLBS SLPA SLPB SLKE SLMG SLNA SLSU SLEC

15 -99 -99 -99 20.4 -99 -99 -99 -99 -99 -99 -99 -99 -99 -99

30 -99 -99 -99 20.4 -99 -99 -99 -99 -99 -99 -99 -99 -99 -99

45 -99 -99 -99 20.4 -99 -99 -99 -99 -99 -99 -99 -99 -99 -99

60 -99 -99 -99 20.4 -99 -99 -99 -99 -99 -99 -99 -99 -99 -99

90 -99 -99 -99 20.4 -99 -99 -99 -99 -99 -99 -99 -99 -99 -99

120 -99 -99 -99 20.4 -99 -99 -99 -99 -99 -99 -99 -99 -99 -99

EGAS\*.SNX:

\*EXP.DETAILS: EGASX501SN CLIMATE CHANGE EGYPT RUN 1 1960-2015 ASWAN

\*GENERAL

@PEOPLE

Kreilein et al.

## @ADDRESS

-99

## @SITE

-99

## @ PAREA PRNO PLEN PLDR PLSP PLAY HAREA HRNO HLEN HARM.....

-99 -99 -99 -99 -99 -99 -99 -99 -99 -99

## \*TREATMENTS -----FACTOR LEVELS-----

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1 1 1 0 Sim1 1 1 0 0 1 0 0 0 0 0 0 1

## \*CULTIVARS

## @C CR INGENO CNAME

1 WH EG0001 SAKHA 93

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1 ME M M E R S L R 1 G S 2

## @N MANAGEMENT PLANT IRRIG FERTI RESID HARVS

1 MA R R R R M

@N OUTPUTS FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT DIOUT VBOSE  
CHOUT OPOUT

1 OU Y N Y 10 N N N N N N N N N

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@N NITROGEN NMDEP NMTHR NAMNT NCODE NAOFF

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@N RESIDUES RIPCN RTIME RIDEP

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@N HARVEST HFRST HLAST HPCNP HPCNR

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the model, abstract <http://ncbi.nlm.nih.gov/pubmed/117676>