ExpeER

Distributed Infrastructure for EXPErimentation in Ecosystem Research

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SEVENTH FRAMEWORK PROGRAMME
Capacities
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Theme: Environment and Earth Sciences

DELIVERABLE D8.2

Deliverable title: Report on algorithms for improved emulation of field climate environments and on design of new types of experiments

Abstract: Major artefacts in climate warming systems have been identified, and pilots for climate control algorithms for ecotrons, soil monoliths and infrared heating have been devised and are running in a modelled environment and/or in situ. CO_2 enrichment systems are being upgraded by developing new control algorithms that are being tested on a dedicated control unit. The concepts behind the use of model ecosystems and the repeatability/reproducibility of experiments have been developed and experiments have been designed and will be run in 2014. One paper that review challenges, pitfalls and opportunities in studies that manipulate climate and/or plant communities has been submitted and a second paper on biotic interactions and feed-back effects in manipulative experiments in ecology is being prepared. A protocol for testing the relevance of model ecosystems in ecology and determining an optimum level of standardisation as well as two protocols for novel approaches in biodiversity research have been tested in pilot experiments. Further testing is planned for 2014.

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RE Restricted to a group specified by the consortium (including the Commission Services) (precise to whom it should be addressed)	
CO Confidential, only for members of the consortium(including the Commission Services)	

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1. Executive summary

According the the description of work (DoW) of ExpeER project, this deliverable D8.2 reports on algorithms to more realistically simulate future conditions in free air and controlled environment facilities. It also describes the possible features of new types of model ecosystems in ecology, and the features of small-scale proxies of whole ecosystems (up to the earth). Last, it provides design details of future biodiversity/climate experiments.

The major artefacts in climate warming systems have been identified by the partners on their respective facilities and pilots for climate control algorithms for ecotrons, soil monoliths and infrared heating have been devised and are running in a modelled environment and/or in situ. CO_2 enrichment systems are being upgraded by developing new control algorithms using in particular PID algorithms and this is being tested on a dedicated control unit. The concepts behind the use of model ecosystems and the repeatability/reproducibility of experiments have been developed and experiments involving several laboratories across Europe have been designed and will be run in 2014. The design of future climate change and biodiversity experiments was achieved through workshops across ExpeER participants. Papers are being published as outcome of these workshops, and protocols have been design for new biodiversity experiments to be conducted across several European laboratories in 2014.

2. Task T8.1: Designing realistic warming experiments

2.1 Unrealistic air temperatures in warming experiments

The objective of this analysis is to overcome the fact that Ecotrons working with natural light may miscorrelate the relationship between temperature and light intensity found in natura and to which plant are adapted. This is the case in warming experiment as well as in other experiments where temperature is controlled.

2.1.1 Advantage of working with natural light in Ecotron like facilities

Although the specificity of Ecotron is to be able to control the environmental conditions, for many experiments, there is an advantage to work with natural sun light because it is impossible to truly mimic sun light with lamps. Although some new lamp types (i.e. plasma lamps) have a light spectrum very similar to the solar radiations, the intensity they allow to reach (about 500 µmol m-2 s-1 at 30 cm from the lamp) does not match yet the one of the sun (2000 µmol m-2 s-1 at noon in summer). Moreover, lamps provide a very sharp light gradient profile (light intensity decreases with the square of the distance to the lamp) with the result that the leaves at the bottom of canopies receive very low light intensities compared to what they would reach with sun light (the sun is so far from earth that the change in light intensity for a change in distance equal to the height of a canopy is totally negligible).

Working with artificial light results most of the time in plants with a very different physiology compared to plants in natura, either because of the light spectrum is different (and recent papers show that most of the wavelengths of the solar spectrum, including the green ones, are physiologically active) or because the sharp vertical light gradient alter the carbon balance of the older leaves. Papers in the 80's have shown that there is an optimal allocation of nitrogen (mainly in Rubisco) within a canopy profile to maximize photosynthesis. No one tested how far canopies grown under artificial light are from such an optimal allocation of nitrogen due to the mentioned sharp light gradient and its extremely rapidly changing nature due to the vertical growth of most plants.

Additionally, it is costly to run artificial lamps (investment cost and electricity). However, plasma lamps and LED are more efficient than traditional metal haloid lamps to provide photosynthetically active radiations (they produce less heat) and when working with natural light, the cost of cooling to remove the greenhouse effect has to be taken into account.

2.1.2 Problem to be solved when working with natural light in Ecotron like facilities

Ecotrons allows controlling climate in their experimental units, in particular temperature and relative humidity. These parameters can be set constant, or they can follow outside conditions (exactly or with a constant offset, for example a warming of 3 °C), or they can reproduce the climate of a distant location or the climate of a past year or future climatic conditions given by a meteorological model. In the last three cases, a file with the time course of the temperature and relative humidity conditions to be simulated is provided and is used to emulate these conditions in the Ecotron. A potential problem is that, in nature, there is a good correlation between these conditions (especially of temperature) and the light intensity, and plants are adapted to this correlation. The file with the time course of climatic conditions mentioned above may ask to emulate high temperature a given day while that day, the natural light is in a low range, and it could be the opposite the following day. How much plant growth would be affected by such a mismatch between temperature and light is difficult to estimate. There is an interaction between temperature and light intensity on the rate of photosynthesis, but it is variable between species and it also varies according to which portions of the temperature and light gradients are considered. It is then safer a priori to try to match the in natura correlation of light and temperature.

2.1.3 How much light and temperature are correlated in nature?

This will be analyzed in two contrasted climates, a Mediterranean one, with data from the meteorological station of Maugio (near Montpellier, 10 m elevation 43,616 N 4,017 E) and one from mid-altitude mountains in central France with data from St Genes Champanelle, not far from Clermont-Ferrand, but at higher elevation (800 m elevation 45,717 N, 3,017 E).

If data from the 365 days of the year are plotted together, there is a positive relation between radiation and temperature, both in Montpellier and in St Genes ($R^2 \approx 0,40$). There is a temperature variation of about 15 °C between the darker days and the brightest ones in both locations, with a very similar slope.

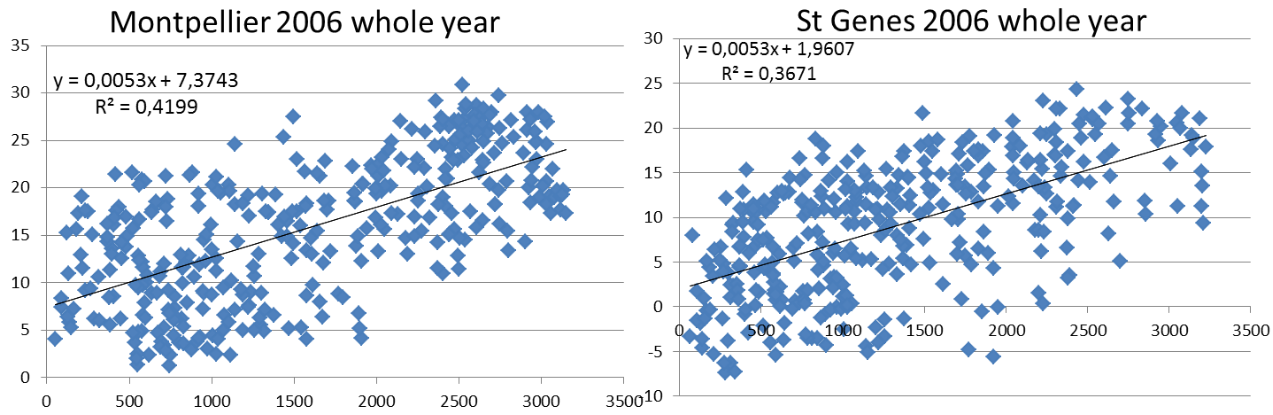

Figure 1 Year round relationship between integrated global radiation and daily average temperature. (In all the graphs, the daily integrated global radiation (Joules / cm²) is on the X axis and the daily average temperature (°C) is on the Y axis.)

However, in the Ecotrons, we are interested in matching light and temperature on a shorter time scale (vegetation has different successive phases and it is the right temperature at each phase which has to be simulated). If the matching is analyzed per period of 3 months, it appears that this matching is absent in the winter months ($R^2 \approx 0,05$) and absent or weak during the fall ($R^2 \approx 0,05$ and 0,14). In spring and summer, there is a variation of about 10 °C between the darkest and brightest days in both climates ($0,18 < R^2 < 0,47$), with a linear relationship in St Genies but not in Montpellier.

From this analysis, it is clear that the relation between light intensity and temperature is climate and season dependent. Only in some seasons (spring and summer for the two climates analyzed) it is worth to try to match temperature and light in the Ecotrons.

Figure 2 The slope (b) of the relationship between light (RG) and temperature (T) is similar in Montpellier (Mtp) and St Genes (StG).

2.1.4 Procedures to match light and temperature in the Ecotron of Montpellier

A first procedure was suggested by INRA. Its principle is that since b, the slope of the relationship between light (RG) and temperature (T) is similar in Montpellier (Mtp) and St Genes (StG) (see figure 2 above), we can apply the relation:

$$T_{ecotron} = T + b\ (RG_{Mtp} - RG_{StG})$$

When the light level in Montpellier (Ecotron) is lower that the light level of the simulated day of St Genes, the simulated temperature in the Ecotron is decreased to the Montpellier temperature expected for the given light level of St Genes and reciprocally. One need also to take into account the fact than in Montpellier the level of radiation is higher than in St Genes. (regarding this point, an alternative is to add some shading on top of the experimental unit to have a similar total radiation inside the experimental units and in natura). Then we applied the following equation for the period April to September 2006.

$$T_{ecotron} = T + b\ (RG_{Mtp} - RG_{StG}) * \sum RG_{St}G / \sum RG_{Mpt}$$

Taking the slope b of the yearly relationship (0,005) resulted in an averaged simulated temperature about 2 °C higher than the St Genes one. Taking the slope of the April to September period (0,0025) still results in a averaged simulated temperature higher (by 0,7 °C) than the St Genes one.
An additional step in the procedure could adjust the simulated temperature so that the cumulative simulated temperature would stay similar to the cumulative StGenes one. The parameter K in the following equation would need to be adjusted daily.

$$T_{ecotron} = T + b\ (RG_{Mtp} - RG_{StG}) + K\ (Cumul\ T_{StG} - Cumul\ T_{ecotron})$$

The improvement of the correlation between T°C and RG with this procedure (without introducing K) is shown on the following graphs (Figure 3). In natura in StGenes, b = 0,0028 with R^2=0,13. Without applying this procedure, b = 0,0011 with R^2=0,02 (no correlation at all). Applying the procedure, b = 0,017 and R^2=0,05.

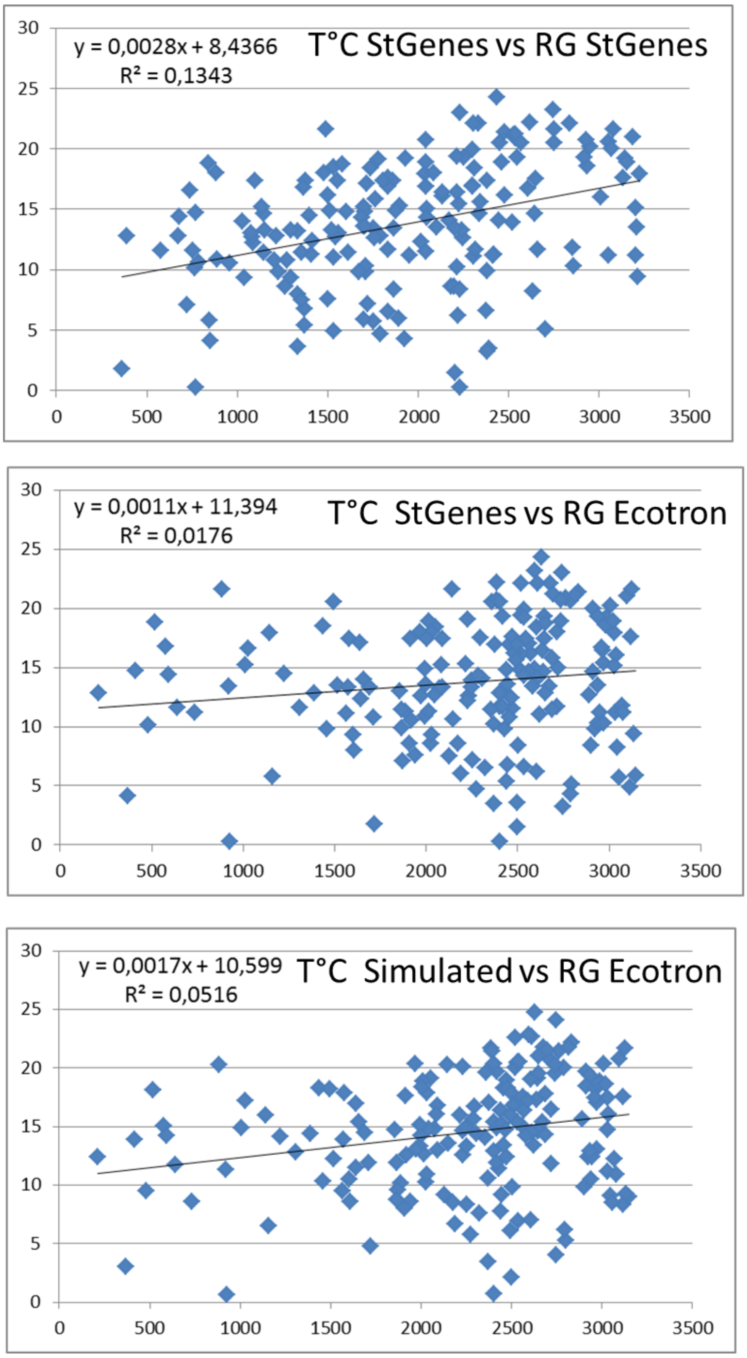

Figure 3 The improvement of the correlation between T(°C) and RG (without introducing K).

This procedure improves the correlation of the simulated temperature in the Ecotron and the natural light at the Ecotron, but not enough to come close to the StGenes in natura correlation. In addition, such a procedure to be applied on line and not retrospectively would need the knowledge of the expected RG for the day which has to be simulated. It would also require transforming the daily average temperature to be simulated in the adequate values for all the individual temperature steps to be simulated during the course of the day.

This procedure is not simple and requires getting radiation at the soil level forecast for the day to come. Since such a forecast was needed, we developed a simpler procedure using radiation forecast for 5 days. Such a forecast is available on-line from Météo France at a cost of about 800 € per year. The procedure is based on the comparison of the in natura averaged daily radiations of the 5 next days to be simulated and the forecasted radiations in Montpellier for the next 5 days to come. Then we interchange the days to be simulated so that their radiations become closer to the radiations that will occur in Montpellier. The match is good at the beginning of the 5 days period and may deteriorate at the end of the 5 days (there is no possible interchange, the days not yet simulated have to be simulated!).

Let's take an example with simple figures. The first column of the table below is the radiations of 5 days in natura that we want to simulate in the Ecotron. The second column is the radiation forecast for the 5 days to come. The third column is the order in which the 5 in natura days will be simulated in the Ecotron.

Radiation in natura		*Montpellier expected radiation*		*Sequence of simulated days*	
July 1st	1000	July 1st	600	July 2nd	600
July 2nd	600	July 2nd	400	July 4th	400
July 3rd	200	July 3rd	800	July 1st	1000
July 4th	400	July 4th	800	July 5th	600
July 5th	600	July 5th	1000	July 3rd	200

Without this procedure, the radiation mismatch would have been (arithmetic sum of in natura – Montpellier) (1000-600)+(600-400)+(800-200)+(1000-600) = 1600

With the procedure, the mismatch would be (600-600)+(400-400)+(1000-800)+(800-600)+(1000-200) = 1200

The simulated temperature is exactly the in natura one, only the order of the days has been changed. A script has been developed to find the optimal sequences of days to be simulated once the radiation forecast is known and to feed the Ecotron machinery with these sequences. The procedure has not been tested yet and its full evaluation is not available.

2.1.5 Conclusion

To fully take advantage of working with natural light in Ecotrons, an improved matching of the simulated temperatures with the natural radiations conditions in the Ecotron location at the time of the simulation is needed. However, a specific analysis of the relationship between radiation and temperature at the site which is being simulated is needed since the correlation between the two is very variable and may not exist at some seasons.
Applying a corrective procedure based on the slope of the radiation/temperature correlation only partially improve the match between simulated temperature and local radiation and alter the average simulated temperature. An alternative procedure based on changing the sequence of the days to be simulated so that they would be closer to the forecasted radiation level is proposed.

2.2 Unrealistic canopy temperatures in warming experiments

2.2.1 IR heaters

Despite the apparent growing popularity of infrared heating in ecological research, an issue which is still unresolved is the manner in which to control canopy temperatures. In many studies, temperature control is based on canopy (surface) temperatures, by maintaining a set difference between the heated canopy and the control (e.g. Marchand et al. 2004). A problem with this kind of control method is that the canopy temperatures are no longer allowed to freely vary, as they would do naturally. Kimball (2005) stressed the sensitivity of canopy temperatures under infrared heaters to the canopy conductance, noting that the power needed to warm the canopy by 1 °C is drastically reduced at night and in water-stressed canopies (i.e. when stomatal conductance is low). Marchand *et al.* (2006) also stated that the reduced soil water contents observed in their heat wave experiment likely reinforced the temperature increment, and that a heating treatment with the same soil moisture as in the ambient plots would therefore experience a less intense heat wave. Applying a control which fixes the warming at a certain level compared to the controls does not take into account effects of the plant water status, and as such the natural plant response is restricted.

A method where the warming is independent of plant responses is the application of a constant energy flux (e.g. Saleska *et al.* 2002). However, the resulting warming (i) increases temperature variability due to the dependence on fluctuating environmental conditions (mainly air temperature, wind and radiation) (ii) is uncontrolled – no target temperatures can be set. Also, the amount of energy that needs to be applied is unclear, as for example merely adding the extra radiative forcing from climate projections to simulate a future climate will hardly affect temperatures (Kimball 2005). The use of a constant energy flux therefore seems an inadequate solution for many experiments, especially those testing specific scenarios of average temperature increases or extreme deviations from normal (heat waves).

What is needed is an adjustable amount of warming that avoids the artefacts associated with the plant response and does not rely on the uncontrolled constant flux approach. To achieve this, the amount of heat that is added should be independent of plant responses. We propose to accomplish this by (i) calculating theoretical canopy temperatures associated with given (target) air temperatures, under fluctuating meteorological conditions, and (ii) simultaneously computing the energy output of the IR heaters required to achieve this theoretical canopy temperature. Step (i) can be done with an energy balance equation in the form of:

$$T_{canopy} = T_a + \frac{R_{abs} - \varepsilon_s \sigma T_a^4 - G - \dfrac{\lambda g_\upsilon D}{p_a}}{c_p (g_r + g_{Ha}) + \lambda s g_\upsilon}$$

where R_{abs} is absorbed radiation, ε_S the surface emissivity (which can be regarded as a constant), σ the Stefan–Boltzman constant, λ the latent heat of vaporisation for water (=-42.575 T_a + 44994, in kJ mol^{-1}), G the heat flux from or into the soil (measurable with heat flux plates), g_ν the canopy conductance (see later), D the vapour deficit of the air (which can be derived from relative humidity and air temperature), p_a the atmospheric pressure, c_p the specific heat of air (a constant), g_r the radiative conductance (=$4\varepsilon_S \sigma T_a^3/c_p$), g_{Ha} the canopy (boundary layer) conductance (which is dependent on wind speed) and finally s the slope of the saturation mole fraction = Δ/p_a with Δ = $bce_s(\mathrm{T})/(c+\mathrm{T})^2$ and $e_s(\mathrm{T})$ = a exp$(bT/(T+c))$, where a, b and c are constants. However, the input air temperature should be the target air temperature: preferably a predefined increment above the fluctuating ambient (measured) air temperature (e.g. + 3 °C), as this reflects the natural daily temperature course (see below). In other words, the formula calculates what the future canopy temperature would be under the prevailing conditions of irradiation, wind speed, humidity, etc., given a prescribed warming scenario. With the target canopy temperature computed, the control device of the IR heaters should then modulate their output (e.g. by altering the voltage, see Nijs et al. 1996) to generate this temperature, whilst calculating the amount of radiation (or power) needed to achieve this. A crucial input parameter is canopy conductance, which has to reflect reference conditions. Canopy conductance should therefore be based on the study's controls by entering the current environmental conditions measured in those plots and solving the energy balance equation for stomatal conductance. As such, the only temperature input is the target air temperature, with the actually measured canopy and air temperatures being the result of the applied energy addition in the form of IR radiation as well as of the plant and whole-system response to this. This method allows plant responses to freely affect temperature levels, without these responses in turn affecting the applied warming, hence creating artefacts (De Boeck & Nijs, 2011). A control system to test all the algorithms is currently being assembled and programmed, and will be ready for testing in 2014.

2.2.2 Greenhouses

In greenhouses, the radiative environment is different from outside. The temperature of clear skies is often well below 0°C (Nobel, 2005), while the 'sky' inside the greenhouse consists of the cover materials which in most circumstances will be warmer than the outside sky. Sky temperatures determine the downward longwave radiation and therefore directly affect the energy balance and thus canopy temperatures. Other properties of the greenhouse such as the total light transmission and the reflectance of long-wave radiation could also affect the leaf temperatures. Using an energy balance model, we investigate possible effects of greenhouses on leaf temperatures. The model applies standard energy balance formulae, supplemented with data on optical properties of greenhouse materials. Results show that the different radiation environment inside temperature-controlled greenhouses did not produce large leaf temperature deviations compared to outside (De Boeck et al. 2012). Poor greenhouse design with significant radiation blockage by the structure or with insufficient ventilation did affect tissue temperatures more significantly. To prevent unrealistic canopy temperatures inside greenhouses, the ventilation system should be designed in such a way that it can follow the outside wind conditions, at least up to 1.5 m s^{-1} (effects of wind speed on canopy temperatures decrease exponentially with increasing speed). Furthermore, the greenhouse structure and covering material should be designed to block and filter as little radiation as possible.

2.2.3 Open top chambers

Unlike greenhouses, open top chambers (OTCs) do not prevent convection. They do, however, drastically reduce the wind speed inside (Dalen 2004). This inevitably has implications for the energy balance. Using the same energy balance model as for our study on the influence of greenhouses (see above), we ran a number of simulations to test the effect of the reduction in wind speed on the canopy temperatures inside OTCs (De Boeck et al. 2012). The results demonstrate that the warming effect generated by OTCs is likely to have been underestimated. For the widely used ITEX chambers, reported increases in air temperature range from less than half a degree in forests (De Frenne *et al.*,

2010) to approximately 1.5 degrees in tundra (Marion *et al.*, 1997). Our results suggest that the effective warming for plants (via the canopy temperature) could well be twice that in many ecosystems, caused by the much reduced wind speed inside OTCs. This would counter the criticism that OTC generated temperature rises are only minor. It also means that OTC studies that have extrapolated their findings on warming responses should be treated with caution. The fact that we show that OTCs create a larger increase in temperatures than previously assumed, may be considered an advantage rather than an unwanted artefact. As such, measures to minimise it seem unnecessary. However, we do advocate that researchers using OTCs to warm vegetation should provide clear data on both the amount of wind reduction in their chambers and the exact warming experienced by the plants and soils. This would allow more accurate use of the results in predicting the responses of tundra and other small-statured ecosystems (for which OTCs are being used) in a warming world.

2.3 Unrealistic biosphere-atmosphere exchange in monoliths

After finalizing evaluation of applicable insulation techniques test lysimeter were replaced by fully instrumented ‘real’ TERENO in-situ lysimeter for long term monitoring of complex biosphere-hydrosphere-atmosphere interactions under Global Change. Data gathered from test phase and from long term monitoring were used to quantify temperature deviations between lysimeters and field and to identify the drivers causing them. With installation of shields at the upper boundary (0-10 cm) of the lysimeter deviation in mean annual temperature could be reduced down to 0.2 to 0.3 °C with maximum values in summer of about 3°C. Seasonal courses of soil temperature in lysimeter and field agreed well. Deviations at lower boundary (140 cm) were in the same order of magnitude resulting in mean annual difference of 0.3 °C to 0.5 °C. Contrary to upper boundary significant difference in seasonal courses of temperature were observed, with accelerated cooling/warming of soil in autumn/winter and in spring/summer in lysimeter, respectively. Active ventilation of the lysimeter housing with air of the service unit or installation of a continuously circulating serpentine coil has the greatest potential for further reduction of temperature deviation at the lower boundary. Installation of an actively watered fleece at the top of the lysimeter has a great potential to further reduce temperature deviations at the upper boundary. Testing of these installations is scheduled for 2014.

3. Task T8.2: Using Computational Fluid Dynamics (CFD) to design CO_2 enrichment technologies

3.1 A PID (Proportional Integral Differential) control algorithm for FACE unit

When adjustments are required in any automatic control system, whether it is simple or complex, actions of control and correction are always required. In extreme synthesis, a proper control algorithm must therefore perform a series of operations and also verify their effectiveness, in a dynamic sequence of successive events. In essence, a FACE (Free Air CO_2 Enrichment) unit requires three basic control components:

- Define the reference value of a variable to be controlled (set-point or target)
- Measure the size of interest and compare it with the set-point
- Use the differences between the two values to determine an action that includes the value of the interest to the set-point

The basic components of this system are:

- A sensor that detects the value of the quantity to be controlled which is, in the case of a FACE system a relatively fast-response Infra-Red gas analyzer which is located at the center of the FACE ring (enrichment area)
- A controller that performs the comparison of the magnitude of interest and the reference value and based on this set a signal to send the organ final adjustment
- A final hardware component that allows the effective action

Such a regulation system is defined as "closed" as opposed to open ones that performs a direct action in response of a measured variable. As far as the control algorithm of a closed/open system is concerned, this can be divided into:

- Systems of ON / OFF
- Systems of floating control
- Systems of proportional (P)
- Systems of proportional -integral (PI)
- Systems of proportional - integral-derivative (PID)

The ON/OFF systems control to monitor the magnitude of interest between two positions, a minimum and a maximum, whose difference defines the hysteresis band, determining a series of oscillations of the controlled variable . An example of this type of system is the thermostat of the heating of a dwelling that switches on and off control of the boiler.

The floating control systems allow two operations aimed at final adjustment , modifying its position from that of completely closed to completely open by maintaining a fixed intermediate position as long as the magnitude of interest remains in the neighborhood of the set-point

In proportional systems (P) a change of the controlled variable corresponds to a proportional change of the manipulated variable . There is only one position in which the system is in equilibrium , in which the value of the controlled variable is equal to the set-point.

Proportional-integral systems (PI) can overcome a limitation of the systems of regulation only proportional to the deviation that is generated in the presence of any disorder of action between the value of the controlled variable and the value of the set-point. In the presence of any deviation a correction term is added which tends to cancel it.

Finally, proportional-integral-derivative systems (PID) add an additional correction term, which depends on the speed of the variation of the difference between the value of the controlled variable and the set-point: such correction term allows to reduce the oscillations of the controlled variable which is actually regulated, while simultaneously reducing the time necessary to achieve proper stability conditions.

The proportional control does not allow to get down to below a certain value of the difference between the controlled variable and the setpoint, as well as determing a rather long period of adjustment. The proportional-integral adjustment allows, through the integral component , to eliminate the deviation between the controlled variable and the set reference value and to reduce the time of adjustment. The proportional -integral - derivative allows, through the derivative part , to reduce or eliminate system overshooting by reversing, in some case, the action due to the excessive rate of change of the control.

A classical implementation of a PID control requires configuration parameters such as:

Setpoint

The value that must be kept the size configured as input checked: eg can be a constant value (not modified except by a change of configuration), or variable, in which case it must be set to the reference input or an analog variable. If it is variable, the setpoint is typically the result of processing carried out in another control block.

Startup time

The time that remains on the limitation of the transient phase of the start of the regulation (both activation of the enable inputs control and enable control), useful to avoid oscillations of the output adjustment at the start. The limitation may be of constant or ramp. If a time zero is set, the transition phase is skipped and control work immediately with the only limitations set the maximum and minimum values.

Proportional Band

The scale of variation of the input (input control) because the output proportional theoretical steps from 0 to 1. In practice the band corresponds to the width of the field theory of regulation. It can be a constant value (not modified except by a change in the configuration), or a variable, in which case it must be set to a reference of an input or an analog variable. An increase in the proportional band value is equivalent to having a milder rule action. A decrease is instead equivalent to having an stronger adjustment action, with the risk of being reduced to a setting of ON/OFF type , with consequent oscillations of the controlled variable

Cycle time

The time that elapses between two consecutive control cycles which is typically set to a value equal to or less than half the theoretical time of significant variability of the input.

Full- time

The accumulation time of the error to the error correction proportional. It can easily enabled/disabled. The integral action of the algorithm is inversely proportional to the value of the time integral: when the integral time increases, the integral action decreases and vice versa.

Derivative time

The time used for the correction and the damping of the overshoot of the magnitude of output. In practice this parameter allows to predict and compensate as the input variable go over the value of selected setpoint. The derivative action is directly proportional to the value of the time derivative

Initial value output

The output value taken when the control is switched off or just started.

Minimum output

The minimum value that can take the output variable in any condition when the enable input is active control. It can have a value between 0 and 1, but it must have a value less than or equal to that of the value set in the field "Maximum Output".

Maximum output

The maximum value that can take the output variable in any condition when the enable input is active control. It can have a value between 0 and 1, but it must have a value greater than or equal to that of the value set in the field "Minimum output."

Offset action

The theoretical value of the output variable being proportional control when the input variable takes a value equal to the setpoint, ie when the condition is satisfied adjustment: it can take a value between -1 and 1. The following figure shows a window screen of the basic control algorithm (PID) and the required adjustments which has being developed and is currently under test for the CO2 set-point of the FACE systems developed by CNR.

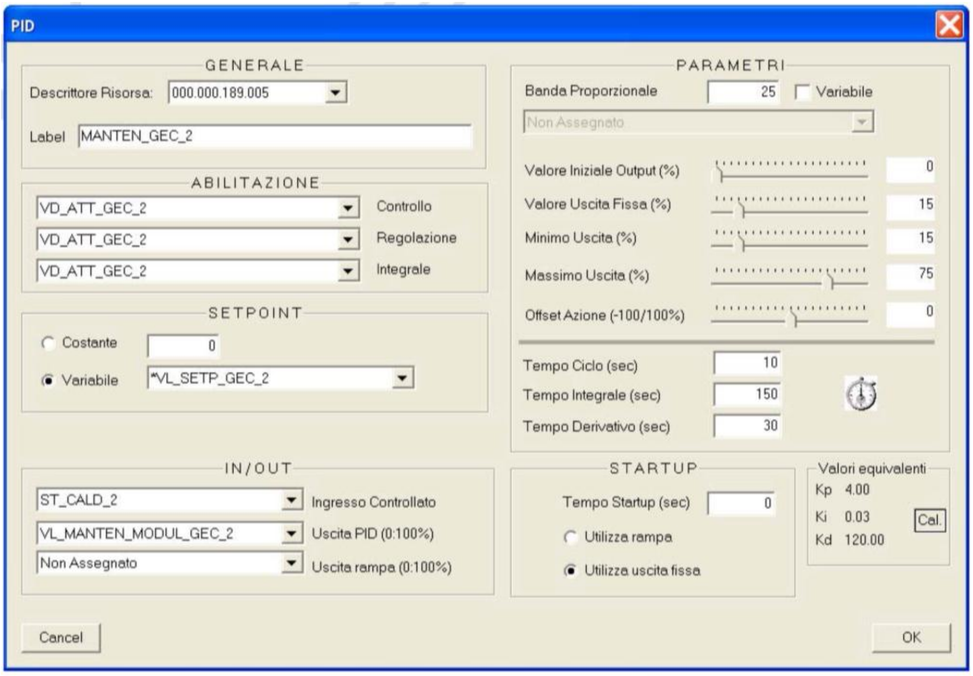

Figure 4 A window screen of the basic control algorithm (PID)

4. Task T8.3: Designing new approaches for experimental ecosystems

4.1 Lack of reproducible model systems in ecosystem science

4.1.1 Model ecosystems and their relevance in ecology

Model systems (*e.g. Escherichia coli, Caenorhabditis elegans, Drosophila melanogaster, Arabidopsis thaliana*, mouse, chicken …) are used in many fields of biology. The use of such model systems allows concentrating the efforts of a large number of research teams worldwide on a small number of well-defined organisms in order to have a larger knowledge of their characteristics which accelerates the deciphering of subsequent properties.

In ecology, the complexity of the studied systems is very large compared to other disciplines with ecosystems being composed of genotypes within populations within species within communities with all these biotic components interacting between them and with a vast array of combinations of environmental factors. Despite this infinite variety of ecosystems, there has been no attempt to define and use a model ecosystem, although there have been a few attempts to use standard artificial soil (Ellis, 2004; Guenet et al. 2011). The study of the diversity within and between ecosystems is central to ecology, but to establish laws of ecosystem functioning or to test ecological theories, the use of a model ecosystem with well-defined biotic and abiotic characteristics could accelerate the progressive accumulation of knowledge on this ecosystem and the achievement of a deeper understanding of ecosystems properties. In practice, each time a new experiment is done in ecology, even within a given laboratory, it is done on a somehow different ecosystem with new characteristics.

The first part of the study is to test the feasibility and the relevance of a model ecosystem. The relevance refers to the capacity to test hypotheses in some main domains of ecology (for example biogeochemical cycles or the role of biodiversity in ecosystem functioning). The feasibility refers to the practicality of assembling such a model ecosystem and to its capacity to provide repeatable results. The model ecosystem has to be practical in term of experimentation: easily assembled, small size (small stature herbaceous vegetation), rapid development (short cycles of the component species). Accumulated knowledge on some of the biotic components or availability of specific variants of some components would be a plus for the tests of given hypotheses. To test how repeatable the cultivation of such a model ecosystem would be, it has to be cultivated in a well-defined and easily reproducible controlled environment like the one provided by climate controlled growth chambers.

4.1.2 Reproducibility vs. repeatability: how much standardisation is needed ?

Using such a model ecosystem is conducive to running experiment in highly standard conditions in term of the environmental conditions and in term of the composition of the model ecosystem itself. Such a high standardization is needed to insure replicability of the experiment and to increase the statistical power of the experimental design.

Repeatability is classically thought of as being the corner stone of scientific method, and in some disciplines, especially medicine, specific funds are given to replicate experiments. The very poor replicability of medicine experiments, together with other not optimum research practices (lower power of experiment, lack of reporting negative results, publication of only innovative results by top journals) have recently put a discredit on current science (The Economist, 2013). However, while it is a strong issue in some scientific domains, replicability of experiments has not been addressed in ecology. Standardization of ecological experiments is difficult due to the complexity of ecosystems, their natural changes of characteristics driven by environmental variability, especially of the biotic components whose composition changes through the dynamics of populations and communities. The ecologists do not have the possibility to order a specific well defined ecosystem likes colleagues in other discipline order given strains of mice for their experiments. The development of model ecosystems has the potential to open such a possibility.

Replicability of experiments requires a standardization of all the steps of the experiment and their detailed reporting. However a debate developed on the possible negative consequences of such a high standardization aiming at improving test sensitivity and replicability. The argument is that the higher the standardization (and hence the narrower the range of local experimental conditions), the lower the external validity of that experiment (the lower the generality of the conclusions). This debate took place in the field of animal science (physiological behavior, Richter et al. 2009, 2010) as well as in machine learning science (Drummond 2009). The concept of reproducibility of an experiment (capacity to reach similar general conclusions) has been opposed to the concept of replicability (capacity to reproduce precisely the results of an experiment). Reproducibility requires local variation (which increases generalization) while replicability calls for absence of variation (which gives rise to higher tests sensitivity) (Figure 5 below). What is then the level of standardization desirable for working with model ecosystems? Is the use of model ecosystems contradictable with reaching general conclusions? The reproducibility of results obtained with model ecosystems has to be tested along with the standardization of the experimental protocol (standardization of the model ecosystem and of the environment).

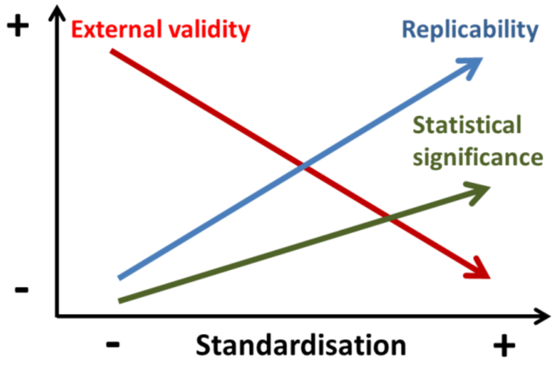

Figure 5 Trade-off along a gradient of standardization between reproducibility of the general results of an experiment (its external validity) and its statistical power and the replicability of the time-course of individual ecosystem characteristics.

4.1.3 Experimental protocols

CNRS is launching experiments using ecosystem models in controlled conditions to sort out with which complexity to build these models and to test their feasibility and relevance and also to address the trade-off between replicability and reproducibility. A protocol describing how to build model ecosystems along a gradient of complexity has been written. Two experiments testing i) their feasibility, replicability and relevance and ii) trade-off between replicability and reproducibility have been designed.

4.2 Miniaturised analogues/physical models of larger scale systems

The Ecotron facility at Imperial College is closing down and the work on miniaturised analogues/physical models of large scale systems could not be pursued. However, Imperial College, through Alex Milcu, contributed to the development of the ideas of the above section on model ecosystems.

5. Task T8.4: New generation biodiversity/climate change experiments

UA lead subtask

UA organized a workshop on 4 October 2012 to publish a review/perspectives paper on 'choices and pitfalls in global change experiments'. The workshop involved ExpeER and external participants. The resulting manuscript, led by UA, discusses approaches of manipulation experiments that deal with global change, as artefacts and inherent limitations can lead to misinterpretations. Technical and non-technical solutions or workarounds are proposed when available, and limitations in interpreting and extrapolating experimental results are outlined. Of particular relevance is the inherent trade-off between experimental realism (facilitating extrapolation) and simplicity (improving process understanding), which resonates throughout all the issues addressed in the manuscript. It explains why not any single experiment can provide all the answers and why bringing together experiments across this trade-off would avoid many issues associated with a singular approach. The paper is currently in review at the journal 'Methods in Ecology and Evolution'.

De Boeck H., Vicca S., Roy J., Nijs I., Milcu A., Kreyling J., Jentsch A., Campioli M., Chabbi A., Callaghan T., Beierkuhnlein C., Beier C. Submitted. Choices and pitfalls in global change experiments

UA also developed protocols for two novel experimental approaches in biodiversity research. The first is aimed toward investigating species richness - ecosystem functioning relationships using the natural variation in species richness at the microsite scale. The second is a quick method for characterizing species interactions in multispecies systems in the field. Both protocols have been tested in a pioneer study in the summer of 2013. Further testing and publication is planned for 2014.

UFZ lead subtask

UFZ is leading the preparation of an opinion paper entitled:

Biotic interactions and feed-back effects in manipulative experiments in ecology

Biotic interactions trigger community structure, energy flow and element cycles in ecosystems. Several studies showed that the outcomes of ecological experiments (e.g. diversity effects, climate change effects) depend on the manipulation/presence of trophic interactions. Interaction motifs are extracted from complex networks to extract basic information on the type of interaction and underlying mechanisms. Great part of ecological theory and concepts bases on manipulative experiments.

Numerous studies showed that the influence of global change factors is importantly mediated by their effects on biotic interactions like pollination, herbivory, symbioses etc. However, biotic interactions have been turned out to be one of the sources of uncertainty in predicting the consequences of global change since it has been shown that these indirect interaction-mediated affects may overwhelm direct effects. Experiments documented strongly interacting effects between global change and trophic interactions for a wide range of systems ranging from vertebrate grazing system and invertebrate herbivores to soil food webs. Moreover, t was also showed that plants under global change may benefit from associations with the interacting soil microbial communities due to their ability to adapt and respond to global change.

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