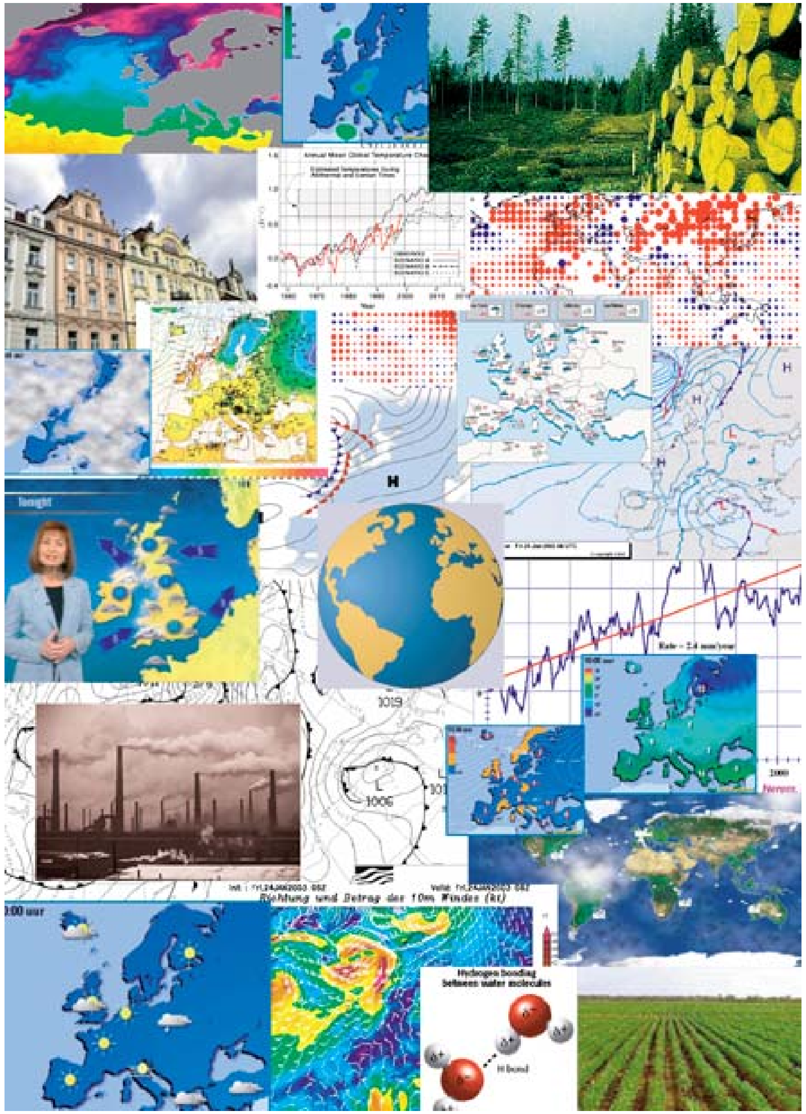


Climatizer Model

Daniel Dekkers, Anton van Hoorn, Miriam Egas (cThrough)

"Ideally, one seeks a balance whereby each component of the climate system is represented at an appropriate level of detail. How to do this is the modeller's "art". Einstein once quipped, that "everything should be as simple as possible, but no simpler". Generations of modellers have agonised over what "no simpler" means. This has been a particularly important issue for assessments of anthropogenic climate change."
Danny Harvey

Introduction

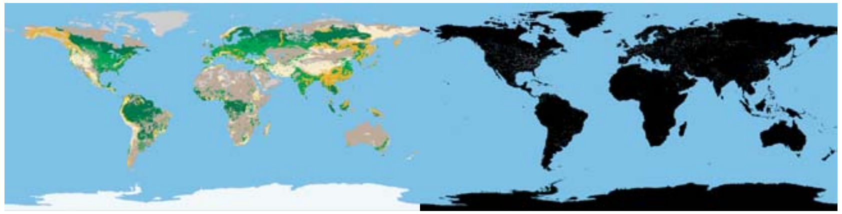
In Cité des Sciences et de l'Industrie a simulation is presented that captures the basics of climate models and projects the results on a large screen display. Finally it is possible to study the climate-parameters and the consequences of changing their values interactively. How is the simulator built up? How does it work?

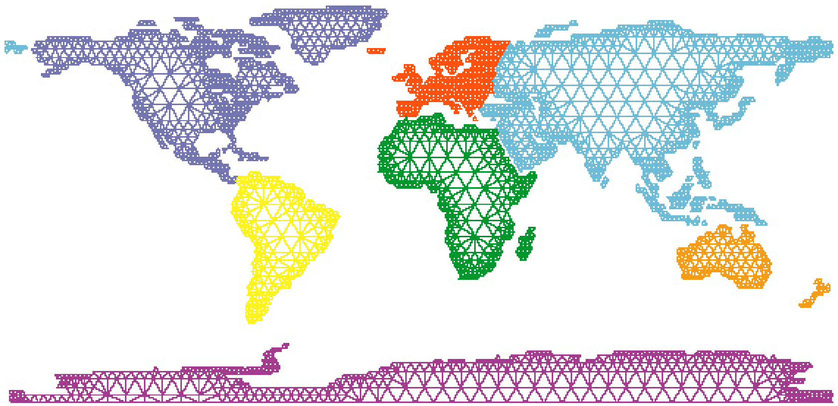
Climate mechanisms on Earth are very complex. There is a large set of parameters that influence temperature, humidity, wind speeds and precipitation, which in themselves also influence eachother. Among the parameters we find natural elements, such as water and forested area and man-made elements, such as city land-use and CO_2-exhaust.

For decades scientists have been struggling to grasp the full complexity of climate-mechanisms, and have succeeded to obtain some fundamental knowledge about parts of the machinery. Also much measurement-data is acquired, making it possible to study in further detail the global weather systems over longer periods in time.

One of the applications of this knowledge is the construction of climate models, which combine vast amounts of measurement-data, parameters and correlation's. It is necessary to use models, we can program into them more and more data and mechanisms, making it ultimately possible to verify our insight in the climate changes, to make predictions and to study alternative actions.

Climate models could eventually help and obtain answers to the many questions now hovering the conferences of Kyoto, Johannesburg and Moscow. How is the climate really changing? How sensitive is it to the external forces of humanity? Can alternative action avoid dramatic changes that would be disastrous for the Earth's biology?





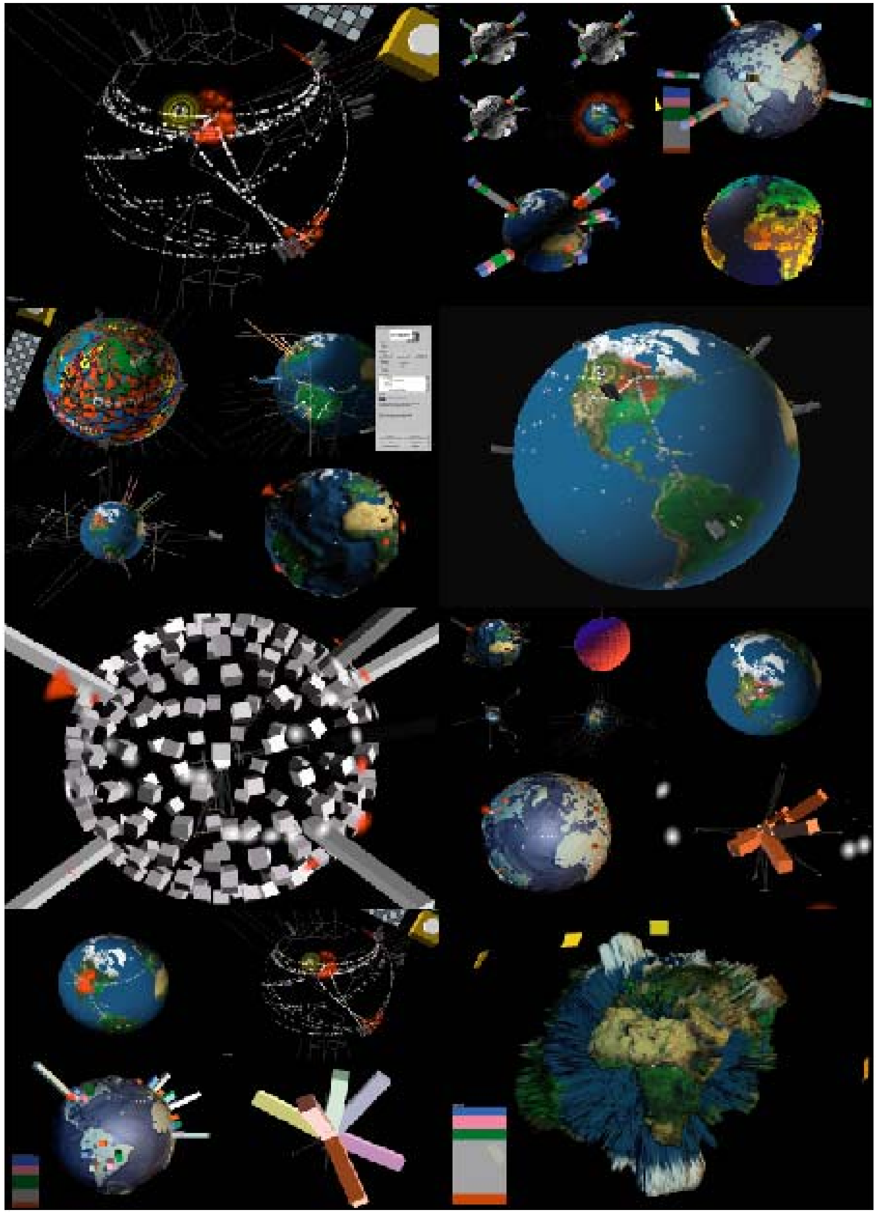
Following Einstein's advise, we search for essentials within the climate system:

- A strong time dependency
  Every process has its own typical time interval, or wavelength. There are the seasonal variations in biomass density, the fast dispersion of CO_2 in the atmosphere, the speed of phase transitions of water (ice melting into water, vapor condensing into rain). The speed in which global average water temperature follows global average temperature in the atmosphere, etc.

- Interdependencies between different processes
  Any process in the climate mechanism influences some other process, but with a delay. Process X influences process Y and process Y might influence process X, but with a different delay. The human mind is not well equipped for predicting the outcomes of processes that show these kind of interdependencies. The ocean water contains 60 times more CO_2 than the atmosphere. If the equilibrium is disturbed by externally increasing the concentration of CO_2, the oceans would absorb more and more CO_2. Algae would thrive, turning our blue planet green. As water warms, it's ability to absorb CO_2 is reduced. If the oceans can no longer keep pace, more CO_2 will remain in the atmosphere. The exact outcomes of these interdependencies on a global scale remain a mystery.

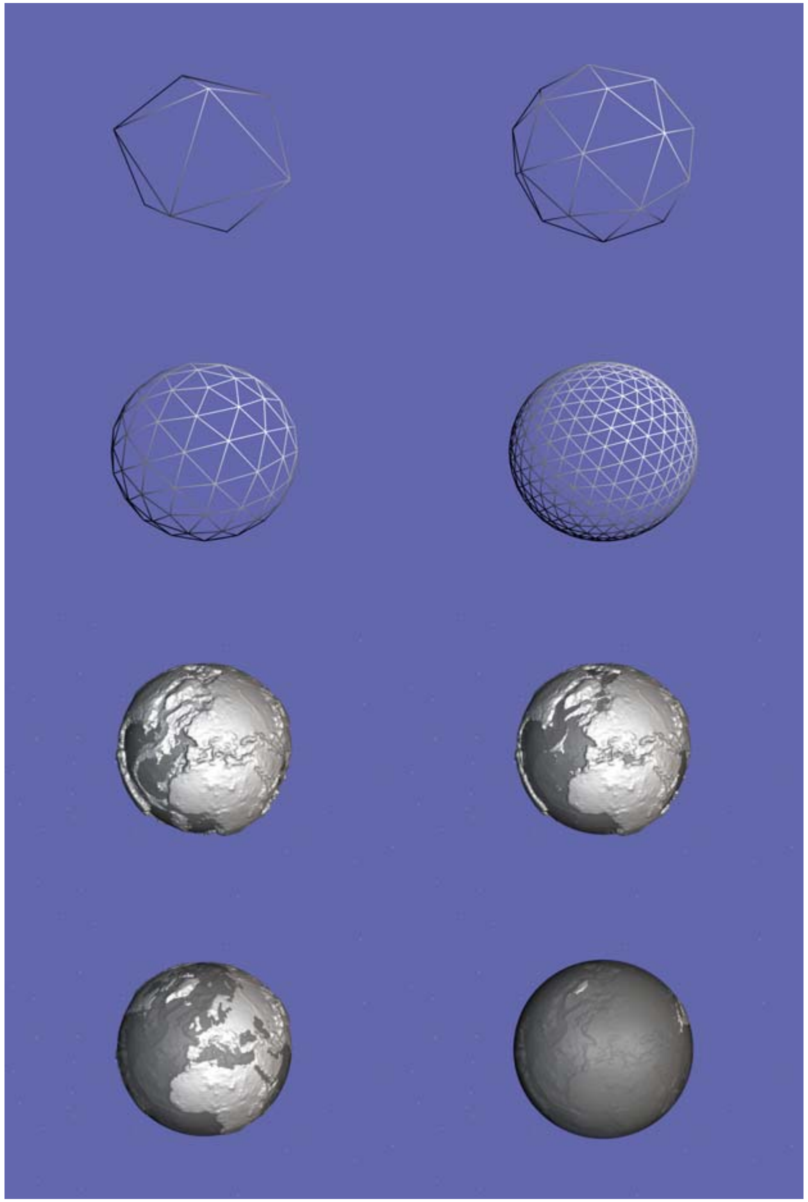
- Uncertainties
  There is little consensus over answers to fundamental questions concerning the climate. For instance, has the climate passed a magic threshold where the system amplifies itself or is it not too late to curb the climate heating process? Or, what is the exact role that water playes in it's different forms ice, water, vapour, clouds, precipitation…

- Chaos theory
  The reason that the weather can not be predicted more than a few days in advance is that future outcomes depend on fundamentally unpredictable causes in the (near) future. Compare this to the famous example of the butterfly in Peking that flaps it's wings and 'creates' a thunderstorm in New York two months later. The climate is defined as average weather. So by definition, these high-frequent disturbances are not considered but there are medium or low frequent disturbances that need to be considered.



- Level of Detail
  Basic qualities of molecules greatly contribute to the major features of the climate mechanism. For instance, the fact that water freezes at zero degrees and swells between zero and plus 4 degrees is presumed to make the ocean levels rise. So if we wanted to make the perfect climate model, it should contain all these known behaviours for all basic elements contributing to the climate and no assumptions on aggregate behaviours whatsoever. This is an impossible task, not only because the amount of data is too large to be calculated by any computer but also because one could not read and interpreted the data. A photorealistic global high-definition satellite image showing every tree on the Earth is unreadable for the human eye and brain. One wants to read an index number: the amount of trees in North-America, the amounts of trees in Europe. But during this functional zooming-out, information is lost, we no longer know the exact locations of all the individual trees, we only know the quantities. There is a danger that important information is lost during this zoom step.

- Natural processes versus human choice
  The climate process itself follows a set of natural laws $N_i(E_t,t)$, where E_t is a complete history of the world and everything in it until moment t and t is the timecomponent. These laws are, in isolation, well understood. We can melt ice in an aquarium and know how much the water level in the aquarium will rise. The problem is the definition of the composite function $C(E_t,t)$ that defines (and predicts) the climate as a whole: $C(E_t, t+1)=f(\lambda_0 N_0(E_t, t), \lambda_1 N_1(E_t, t),.., \lambda_n N_n(E_t, t))$. This function is unknown, but exists, and shows a behaviour independent from human interference. There would be a climate if there were no humans on the Earth. But once there is human interference, in comes 'free choice'. We can deforest the Earth or not, we can all become vegetarians or not. In the model, the natural process and the human interference should be two different things. The 'world update' is unpolicital, without a preference, without morale or ethics. Humans start to understand this function, start to become conscious and through the method of prediction influence the time line. But what choices are actually made are on a different level, they are political, will follow morale and should be ethical.

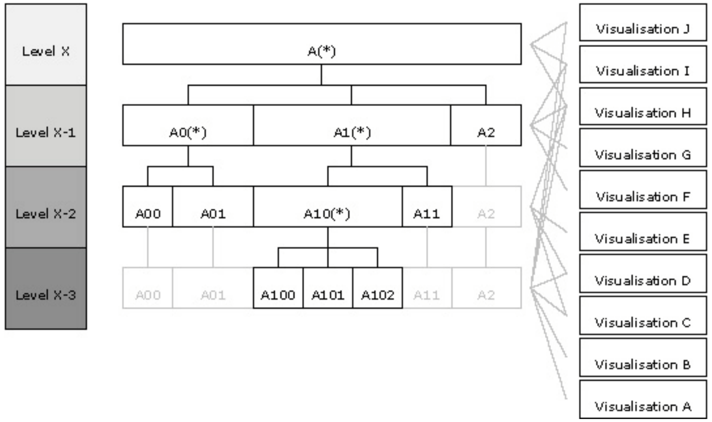


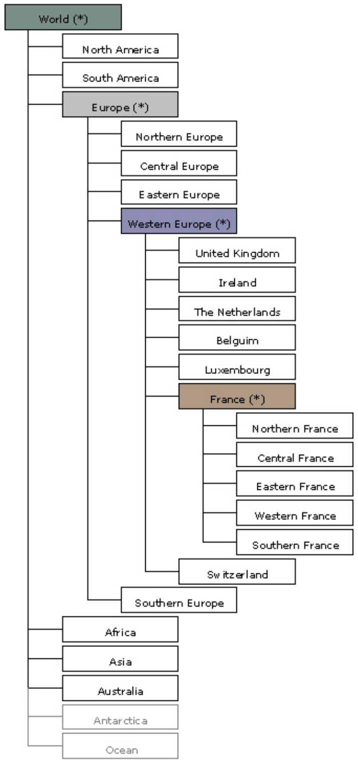
What is Climatizer?

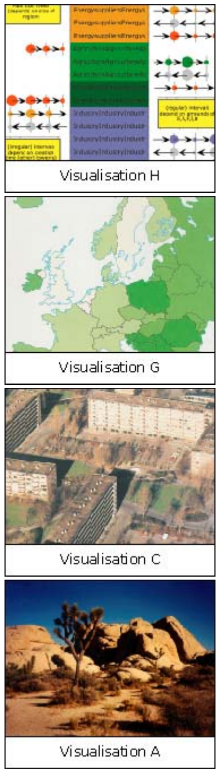
Climatizer is a real-time interactive simulation of the Earth's climate, that focuses on the negotiation of economic output and CO_2 emissions. The simulation allows users to control all economic parameters and thereby influence CO_2 and the climate. As time passes within the simulation, the quantities of so called *actors* (households, industry, forest, agriculture and energy-suppliers) change. Demands are met as the so called *intermediates* (food, energy and goods) are produced, transported and consumed within the limited resources of Earth. In the process, CO_2 is emitted and cumulates to a global average amount. Due to the changing CO_2 level, global average temperature is believed to increase and decrease and the sea-level to rise and decline.

Globe

All climate effects and human action that we are interested in for now, are part of a system that covers the Earth. So a 3D *globe* forms the basic stage for the simulation. Given the globe, a part of the simulation represents different processes in nature: temperature, water and nature as a container for CO_2. A second part represents human behaviour: cities housing people, industry producing goods. In this way, climate and economy are two ever changing dynamic processes, that negotiate through land-use statistics and intermediates.







Regions

To encapsulate the notion of level-of-detail, the globe is divided into *regions.* Regions can be redivided into smaller regions. How to administrate region divisions in different scales on a globe?

For this problem we developed and implemented the concept of a *RegionGraph*. A RegionGraph is a tree-like hierarchical subdivision of space where every element of the graph represents a region. It is similar to the concept of a 'SceneGraph' in computer graphics literature. A RegionGraph starts at a high level (in this case the world) and deconstructs into smaller regions.

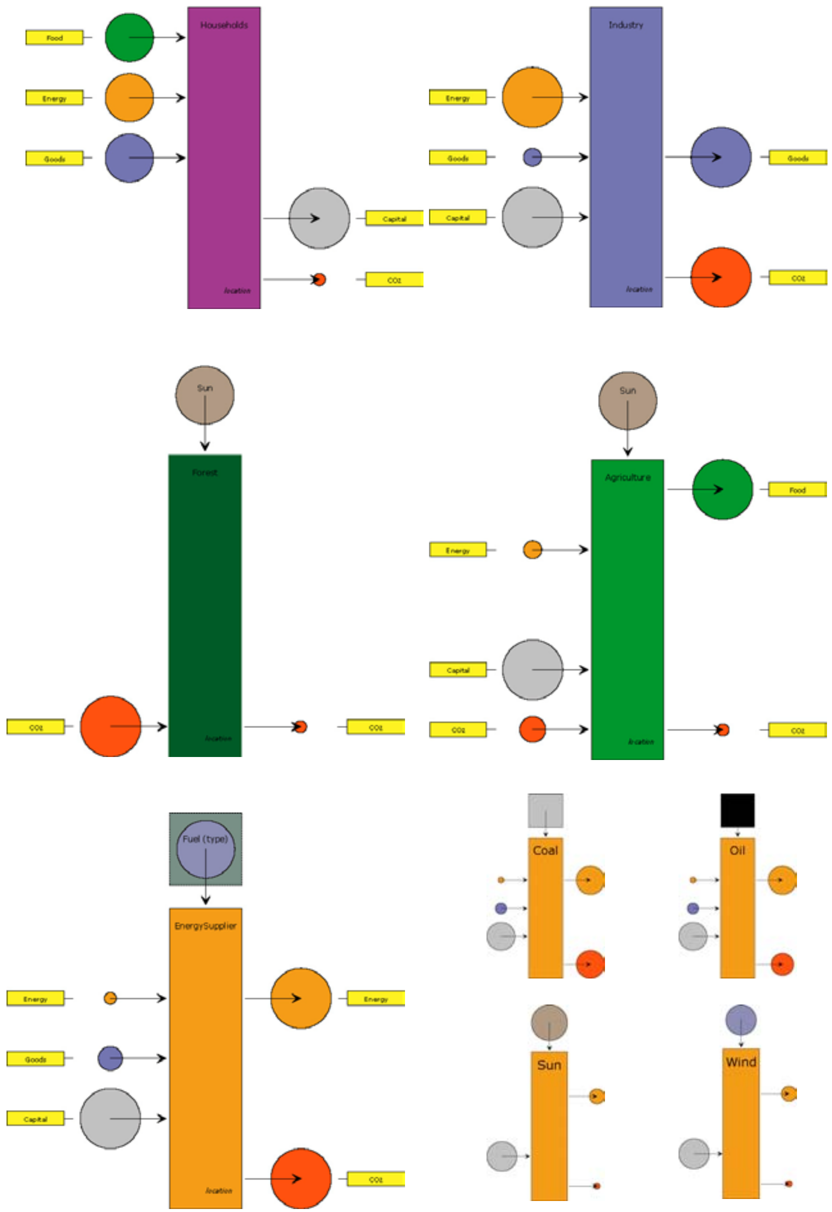
The rules of a RegionGraph:

- The RegionGraph consists of nodes (elements with a (*)) and leaves (elements without a (*)). Nodes are regions that have defined subregions, leaves do not have subregions.
- Every node and leave in a RegionGraph is itself a region.
- There is no spatial subdivision of a region unless the region is a node, subdivisions of regions only appear at level changes.
- A RegionGraph needs not be complete in its deconstruction. Some regions may be deconstructed at a specific level change, others may not, depending on area of interest.
- Interaction on the data of regions is only possible at the leaves of the tree.
- Information flows from bottom to top (leaves to nodes).
- Different regions, even on the same level may have different visualisations. Some visualisations are level-independent, some only make sense on specific levels.

A user of a RegionGraph is able to arbitrarily 'fold' and 'unfold' regions. As a consequence, different levels are visible *at the same time, in the same image*. It is possible to look at all the following information at once:

+- The world is unfolded at continent level, except for:
++- Europe is unfolded at country level, except for:
+++- France is unfolded at provinces level, except for:
++++- La Provence is unfolded at county level, except for:
+++++- Nice is unfolded at city level, except for:
++++++- Vieille Ville is unfolded at tree level, except for:
+++++++- A specific tree is opened at leaves level.
++- South-America is unfolded at country level, except for:
+++- Peru is unfolded at provinces level.

For simulation speed and computer performance, the number of detail levels is kept low. Theoretically, however, the number of levels is unlimited.



Actors

Every region contains a set of *actors*. The actors represent physical static ground usage of a specific type in a region. They mainly reflect human activity of some sort. Households, industry, forest, agriculture and energysuppliers are examples of actors. Think of actors as the fillings of regions. One could even say that actors form regions themselves, since they occupy physical space.

Every actor has default settings for it's growth rate and internal behaviour. Behaviours are the production and consumption of food, goods, energy and CO_2. The latter four are called *intermediates*. These are mobile elements, that travel the globe following generic paths of demand and supply between regions. What actors do we need on the climate stage:

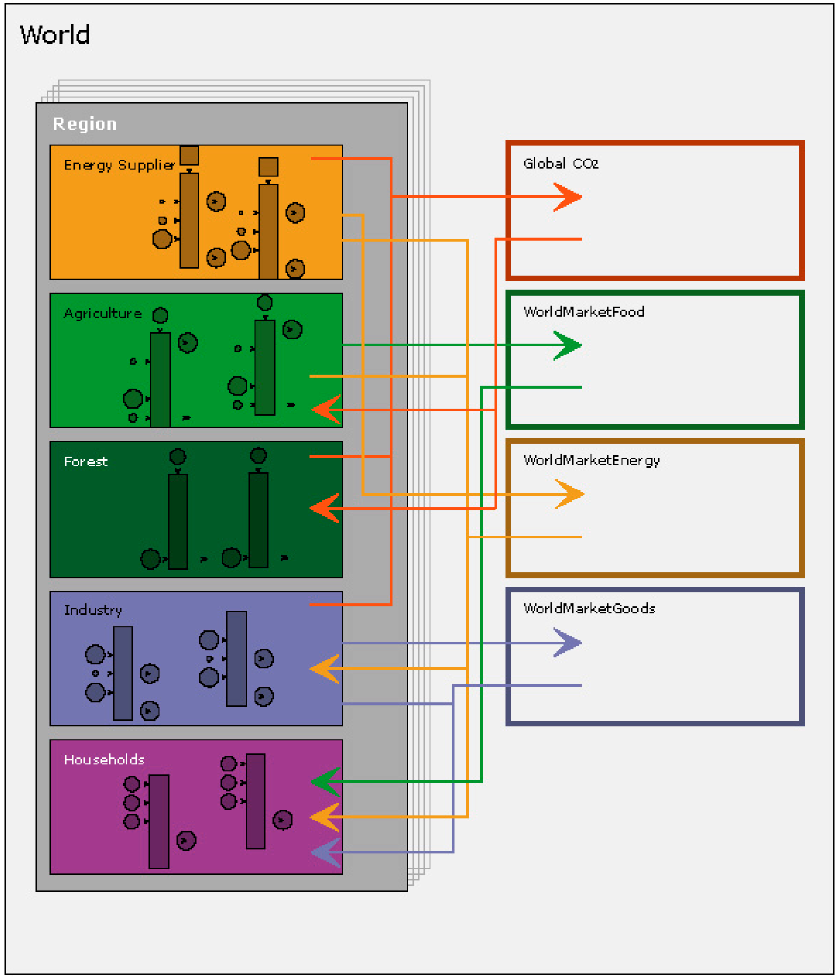
- Households
  Households represent the population living in a region. Households are the main consumers of food, goods and energy. They produce a relatively small amount of CO_2, mainly as a by-product of ‘consuming'.

- Industry
  Production of goods in general is represented by Industry. All Industry types ranging from heavy to light are contained in this category. Industry generates goods and CO_2 and consume energy, goods and capital.

- Forest
  Forests are a container of CO_2. The higher the amount of forest in a region, the higher the consumption and production of CO_2 by photosynthesis. Little capital is needed (negligible), but high quantities require lots and lots of space.

- Agriculture
  Agriculture represents livestock as well as crops. Agriculture produces food. Food could be anything: beef, potatoes, corn, wheat, rice, bananas, chewing gum, pork, coffee and beer. All these kinds of food have their specific land-usage and CO_2-exhaust. This is generalised into an average efficiency. That can be changed according to the world population's diet. Agriculture (or at least the crops part) is also a container of CO_2, just like forests.

- Energysuppliers
  Energysuppliers represent physical objects that generate energy (electricity). Both suppliers based on the combustion of fossil fuels and the use of renewable energy are contained in this category. The category's efficiency relies strongly on the proportions of the sources used. If only fossil fuels are used as a source, the CO_2-exhaust is huge.



Intermediates

For a large part of the climate model, the producer/consumer-metaphor fits well. Most of the actors are both producer and consumer. The *intermediates* are the elements that are produced and consumed. Food, goods, energy, and CO_2 are all examples of intermediates. Note the difference between an intermediate and an actor. An actor is a static physical element, an intermediate is a non-static moving element. A rice field is an actor, a bag of rice is an intermediate.

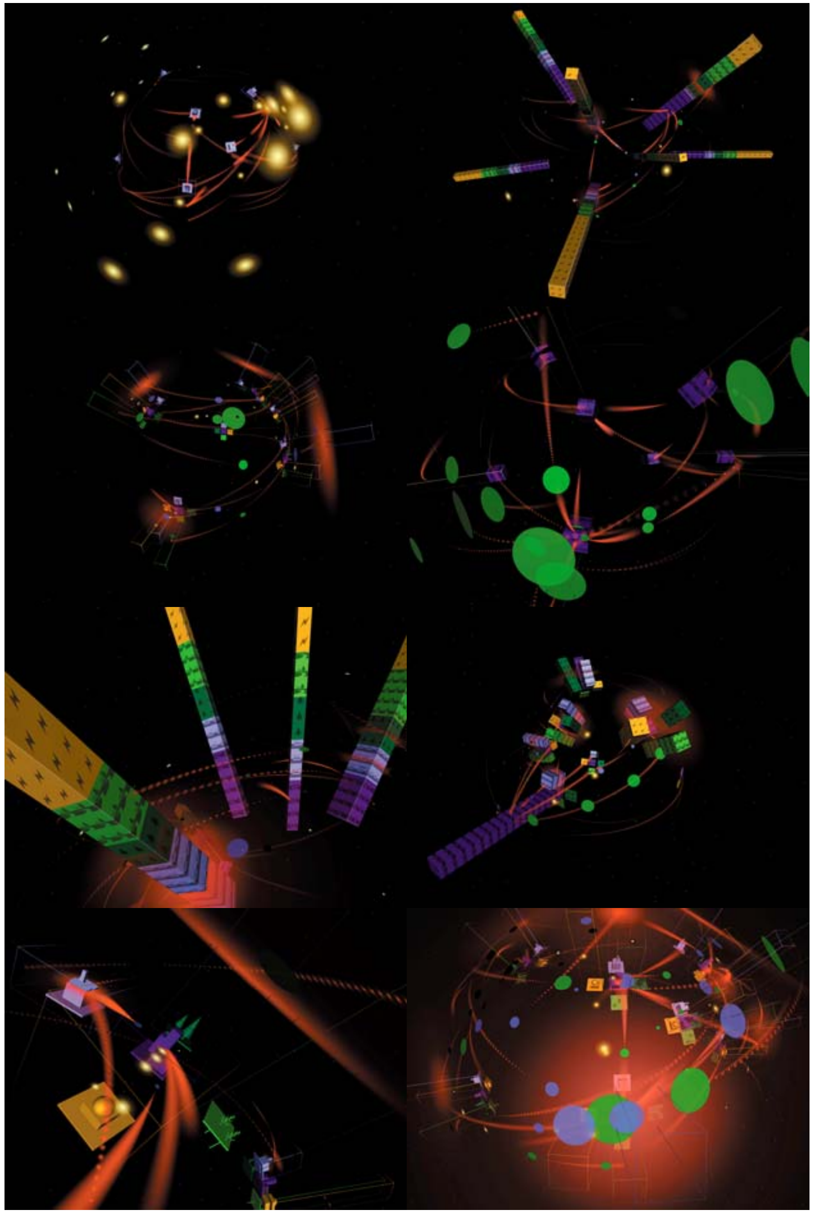
- Food
  Food is an intermediate generated by agriculture. All households rely on the production of food by there own, or other regions.

- Energy
  Energy is produced by energysuppliers and is interpreted in this model as an exchangeable product. Compare this to Scandinavian countries that sell electricity to other countries as eco-energy. It is convenient to think of energy as electricity particles.

- Goods
  Goods are produced by industry. All households rely on the production of food by there own, or other regions. Goods are: consumer electronics, cars, pens, raw fabrics, clothes and furniture.

- CO_2
  CO_2 (carbon dioxide) can be interpreted as a product as well. We do not have to model the actual transport of CO_2 because in real life it distributes very fast in the atmosphere. It is not important where it is created, only the total amount of produced and consumed CO_2 is considered.

- H_2O
  H_2O (water) is an important green house gas since, in the form of clouds, it absorbs and reflects sunlight. It can hardly be influenced by human activity (only indirectly). Water evaporates from the oceans, forms clouds, and is released again in the form of rain. Water also features in the climate mechanism as a carrier of warmth energy. It does so for instance by conveying internal-energy when traveling as clouds.



Processes

The behaviour of the actors results in production and consumption intermediates, the intermediates have to be transported across the globe. This economic activity results in pollution and changes in the climate. How does the actual administration of the climate and the negotiation of resources take place?

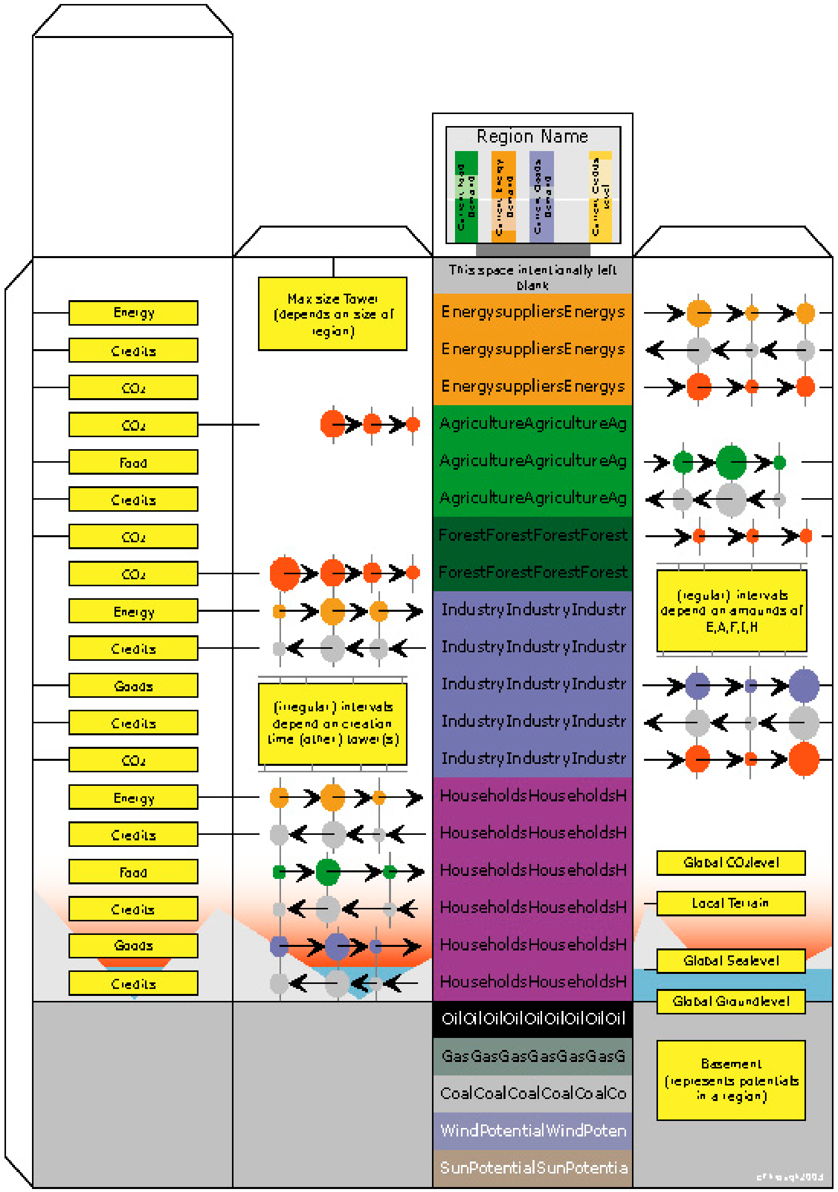
The smallest time interval in the model is a week. So, for instance, we don’t consider the Earth circumnavigating the sun. During one iteration step every actor performs a step in their behaviour pattern.

Internal actor behaviours

- Households
  Households consume food, energy and goods. There is a notion of current demand per region per intermediate category: *CurrentDemandFood*, *CurrentDemandEnergy* and *CurrentDemandGoods*. Depending on the amount of households and the average consumption patterns in that region: *HouseholdsFoodConsumptionAmountPP*, *HouseholdsEnergyConsumptionAmountPP* and *HouseholdsGoodsConsumptionAmountPP*, the current demands are increased every time interval. Households produce a small amount of CO_2: *HouseholdsCO2ProductionAmountPP*. The bulk of the CO_2 production of households is done indirectly: during the creation of food, energy and goods in agriculture, energysuppliers and industry. This of course does not imply that households can not influence global CO_2 production. By lowering their demands, agriculture, energysuppliers and industries can produce less.

- Industry
  Industry consumes energy: *IndustryEnergyConsumptionPP* and a (small) amount of goods: *IndustryGoodsConsumptionPP*. Industry produces goods and CO_2: *IndustryCO2ProductionPP* and *IndustryCO2ProductionPP*. As is the case with food from industry and energy from energysuppliers, the destination of these goods is chosen at the moment the goods are created; the goods are placed on the world market. Depending on current demands in the regions, capital levels and a randomiser, a destination region is designated and the goods are shipped.

- Forest
  Forest typically has two cycles of binding CO_2. In the first process, the *amount* (surface area) of nature changes (quantity dependent): *ForestAbsoluteCO2ConsumptionPP*. New nature is created and CO_2 is taken up from the atmosphere. The reversed process is called deforestation and results in the emission of CO_2. So if the forests are a part of a CO_2-sink strategy, the amount of forest should continue to expand... The second process is season and Earth-location dependent and represents the creation



of new leaves in the spring by photosynthesis: *ForestSeasonalCO2ConsumptionPP*. Like in the first process, CO_2 is taken up, but this CO_2 will be emitted again in autumn in the form of leaf deposit.

- Agriculture
  A (small) amount of energy and goods is consumed by agriculture: *AgricultureEnergyConsumptionPP* and *AgricultureGoodsConsumptionPP*. The CO_2 production and consumption process is similar to forest. Agriculture creates food. Food is expressed in KiloJoules. Depending on the fraction vegetarian/non-vegetarian, different amounts of food are created *with the same amount* of agriculture (the same surface area).

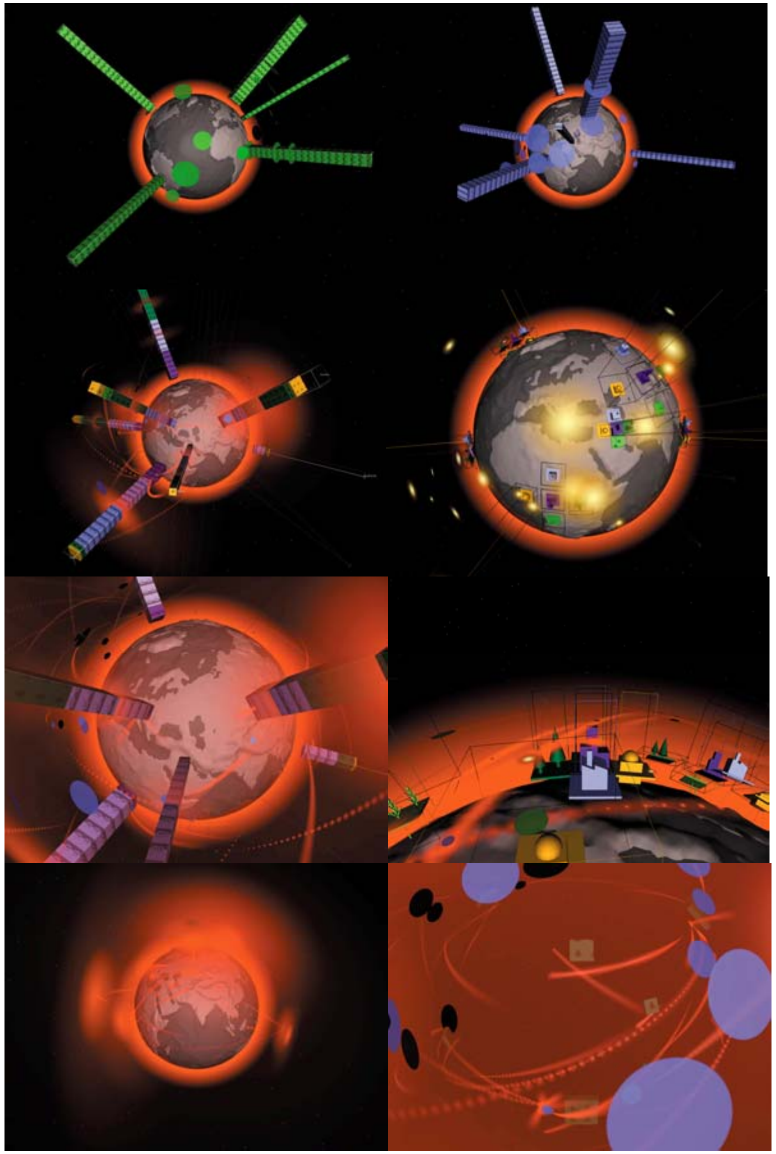
- Energysuppliers
  Energysuppliers activity results in an output of energy (electricity) and greenhouse gasses (mainly CO_2). Inputs are 'fuel' (depending on the type of supplier, this may be coals, oil, wind, sun, water movement, etc.) and capital. The factors of the inputs and outputs differ according to the type of the energysupplier. For instance: solar panels create a relatively small amount of energy while they need a lot of capital, the 'fuel' is practically unlimited, and no CO_2 is produced. An coal power plant is relatively cheap, produces a lot of energy but has a fixed, limited amount of 'fuel' and produces a large amount of CO_2.

Transport of intermediates

Produced food and goods have to be transported from source regions to destination regions. Energy is interpreted as electricity, so the transport of energy is not considered to be a CO_2 emitter in this model. For food and goods, the emitted CO_2 during transport depends on the amounts of the transported intermediates, the means of transport (ship, train, car, plane) and the distance from source to destination.

Cumulative global effects

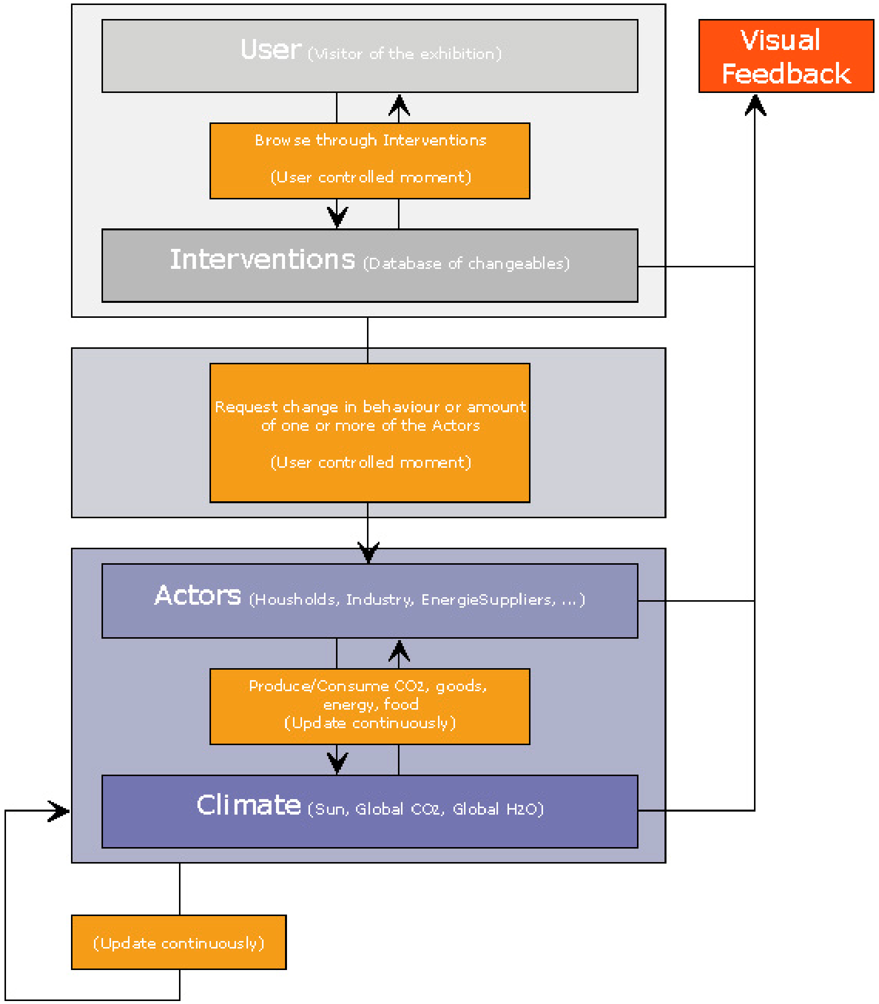
During a single time step all economic activity concerning production, transport and consumption of intermediates is performed. All CO_2 contributions and absorbtions are added to the current global average CO_2 level. Depending on the average ocean temperature a very large amount of CO_2 is extracted from the atmosphere. The remaining CO_2 particles are contributors to global warming. From the new global average CO_2 level, the average global temperature can be calculated, this again has an effect on the average ocean temperature, resulting in a difference in sea level.



Interventions

The simulation can run as a stand-alone simulation independently of interference by exhibition visitors. Factories will produce, CO_2 will diffuse continuously. However, visitors can change the economy settings, indirectly influencing the way the climate evolves over time. These so-called *interventions* consist of predefined changeables in the configuration of the system. In theory, an uncountable number of interventions exist, Climatizer interventions are a select few that have a high impact on the climate, some examples:

- Growthrate Change
  Every actor in every region has an attached parameter that represents growth/decline of that specific actor in that specific region. For instance: growth/decline of industry in Africa. This would be a slider with a minimum (say -5%) and maximum (say 10%) where the slider is in a default position of 2%. This default position is based on current data, the average growth rate in the last 5 years. The intervention consist of changing the rates.
- Autarcticity
  In the default setting, every region is allowed to export and import food, energy and goods from all other regions. With this intervention, one can experiment with self sufficient regions. If import and export is not allowed and the region does not produce (enough quantities of) some type of intermediate, demands of that specific category will rise instantly.
- Consumption pattern households
  If consumption patterns of food, energy and goods are changed, demands grow less rapidly and less intermediates have to be produced to meet demands. Compare the different consumption patterns of rich countries and third world countries
- Technology level industry
  Increasing efficiency levels of industry in a region, larger amounts of goods can be created with lower CO_2 emission rates.
- Biodiversity forest
  Some biomass variations and placements are more efficient in binding CO_2 as others. A more conscious strategy on the choice of species and planting increases CO_2 binding per surfaceareaunit.
- Diet change agriculture
  Agriculture contains crops as well as live-stock. Per surfacearea unit a non-vegetarian instead of a vegetarian production of food (expressed in KiloJoules) results in higher produced amounts.
- Changing energysuppliers categories
  Changing energysuppliers categories from fossil-based to renewable results in an enormous change of emitted CO_2, energy amount and costs.



Scenarios

So far we described the elements of which the model is built up. Once it is running, it performs on it's own. One option of course is to do nothing, all behaviours remain as if fixed the way they are in 2003. This is similar to what the Attentiste-scenario is proposing. But visitors can also decide to turn all Europeans into vegetarians or to concentrate all the world's energy suppliers in Africa.

In the model, scenarios are not fixed. During the simulation, at arbitrary moments in time, arbitrary choice-variables can be changed by the user. The user creates the scenario. In general we can define a scenario as:

> *A scenario is a complete enumeration of completed interventions together with the outcomes of all intervention-dependent processes within a certain time interval.*

So for a scenario, we place the user of the system in a central position. The user has the responsibility to complete all 'free choice' questions that exist withing a certain time interval. Once all these answers are given, the simulation calculates the unique outcomes.

The general formula for the number of distinctive scenarios that could exist is:

$$\#statesperintervention^{(\#regions*\#interventions*\#timeintervals)}$$

For 2 regions, 4 interventions with 3 states each, a total time frame divided in 3 intervals, there are $3^{(2*4*3)}$ = 282429536481 different scenarios possible.
For 20 regions, 10 interventions with 5 states each, a total time frame of a year divided in 52 intervals, the total number of different scenarios would be: $5^{(20*10*52)}$, approximately 2.0e7269 (a 1 followed by 7269 zero's). This is a seemingly unlimited set.

Following scenarios, attentiste or active ones, dramatic events could happen. Cities may submerge in ocean water, entire continents may disappear. The economy influences the climate, that much is what we are sure of. The Climate influences the economy. But how? You need a lot of money to evacuate or elevate a flooded country like Bangladesh. On the other hand, a flooded Paris would attract more tourists than it has ever done before. A CO_2 suffocated, clouded Earth would perhaps produce the most curious species of plants ever to have unfolded in the shade. Didn't stranger things already happen? We won't really know until something dramatic happens. And so it seems hardly possible to calculate the best action to follow. The predictions in this simulations show us, that climate effects can be huge. But people will adapt.