Points you may want to consider in your discussions:

- What have you learned about EVSs and how different people can view the environment in different ways?
- How do EVSs affect how people respond to environmental issues?
- How have historical events and the development of the environmental movement affected peoples' EVSs around the world?
- What have you learned about your own EVS from this chapter?

1.2 Systems and models

Significant ideas

A systems approach can help in the study of complex environmental issues.

The use of models of systems simplifies interactions but may provide a more holistic view than reducing issues to single processes.

Big questions

As you read this section, consider the following big question:

- What strengths and weaknesses of the systems approach and the use of models have been revealed through this topic?

Knowledge and understanding

- A systems approach is a way of visualizing a complex set of interactions which may be ecological or societal.
- These interactions produce the emergent properties of the system.
- The concept of a system can be applied to a range of scales.
- A system is comprised of storages and flows.
- The flows provide inputs and outputs of energy and matter.
- The flows are processes that may be either transfers (a change in location) or transformations (a change in the chemical nature, a change in state, or a change in energy).
- In systems diagrams, storages are usually represented as rectangular boxes, and flows as arrows with the arrow indicating the direction of the flow. The size of the box and the arrow may represent the size/magnitude of the storage or flow.
- An open system exchanges both energy and matter across its boundary while a closed system only exchanges energy across its boundary.
- An isolated system is a hypothetical concept in which neither energy nor matter is exchanged across the boundary.
- Ecosystems are open systems. Closed systems only exist experimentally although the global geochemical cycles approximate to closed systems.
- A model is a simplified version of reality, and can be used to understand how a system works and predict how it will respond to change.
- A model inevitably involves some approximation and loss of accuracy.

What are systems?

There are different ways of studying **systems**. A *reductionist* approach divides systems into parts, or components, and each part is studied separately. This is the way of traditional scientific investigations. But a system can also be studied as a whole, with patterns and processes described for the whole system. This is the holistic approach, and is usually used in modern ecological investigations. The advantage of using the systems method is that it can show how components within the whole system relate to one another. A systems approach is a way of visualizing a complex set of interactions, which can be applied across a wide range of different disciplines. This course focuses on systems as they relate to ecosystems and society, although the systems approach can equally be applied to other subjects such as economics or politics.

A system is an assemblage of parts and the relationships between them, which together constitute an entity or whole.

A systems approach is a way of visualizing a complex set of interactions which may be ecological or societal.

Diagrams are used to represent systems. Using the systems approach, a tree can be summarized as shown in Figure 1.6.

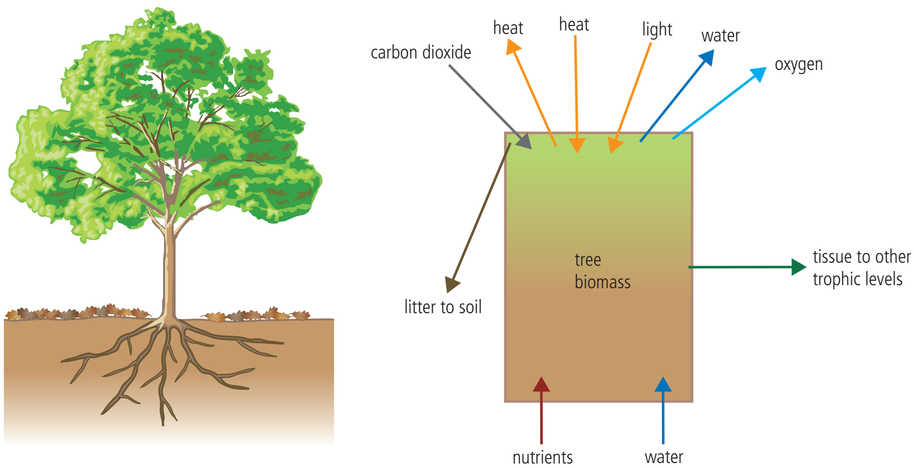


Figure 1.6 Tree system showing storage, inputs, and outputs

The arrows into and out of the tree systems diagram indicate inputs and outputs. In addition, the diagram could be labelled with processes on each arrow. Processes in this example would include:

- **photosynthesis** – transforming carbon dioxide (CO_2), water (H_2O), and light into **biomass** and oxygen (O_2)
- **respiration** – transforming biomass into carbon dioxide and water
- diffusion – allowing the movement of nutrients and water into the tree
- consumption – transferring tissue (i.e. biomass) from one **trophic level** to another.

The interdependent components of systems are connected through the transfer of energy and matter, with all parts linked together and affecting each other. Examples of systems, with increasing levels of complexity, include particles, atoms, molecules, cells, organs, organ systems, communities, ecosystems, biomes, the Earth, the Solar System, galaxies, and the universe.

The systems approach emphasizes similarities in the ways in which matter, energy and information link together in a variety of different disciplines. This approach, therefore, allows different subjects to be looked at in the same way, and for links to be made between them. Although the individual parts of a complex system can be looked at using the reductionist approach, this ignores the way in which such a system operates as a whole. A holistic approach is necessary to fully understand the way in which the parts of a complex system operate together. These interactions produce the emergent properties of the system.

SYSTEMS APPROACH

The concept of systems has been used in science for many years, especially in biology where the functioning of the whole organism can be understood in terms of the interactions between various systems, such as the breathing and circulatory system. The reductionist approach often used in traditional science tends to look at the individual parts of a system, rather than the whole, so that the 'big picture' is missed (TOK Chapter, page 445). The nature of the environment and how we relate to it demands a holistic treatment. A systems approach emphasizes the ways in which matter, energy and information flow, and can be used to integrate the perspectives of different disciplines to better represent the complex nature of the environment.

The systems concept can be applied across a range of scales, from global-scale biomes to the small scale of life contained within a bromeliad in the rainforest canopy.

The systems concept on a range of scales

Bromeliads are flowering plants found in abundance in the canopy of the rainforest. They capture rainwater, which enables a small ecosystem to exist containing tree frogs, snails, flatworms, tiny crabs and salamanders. Animals within the bromeliad may spend their entire lives inside the plant.

An ecosystem is a community of interdependent organisms and the physical environment they inhabit. Different ecosystems exist where different species and physical or climatic environments are found. An ecosystem may, therefore, be of any size up to global.

For example, a tropical rainforest contains lots of small-scale ecosystems, such as the complex web of life that exists within a single bromeliad in the canopy (Interesting fact box, page 21). As you have just learned (page 11), systems have inputs, outputs, and storages. The rainforest can be viewed as an ecosystem with particular inputs (e.g. sunlight energy, nutrients, and water), outputs (e.g. oxygen, soil litter, and water), and storages (e.g. biomass within trees and plants; nutrients within soil). Such ecosystems can be viewed on the local scale (i.e. within one country) or more widely (in many different countries where the same climatic conditions apply). On the global scale, ecosystems with similar climatic conditions in different parts of the world are called **biomes**. Examples of different biomes include tundra, tropical rainforest, and desert (Chapter 2, pages 102–103).

Biosphere refers to the part of the Earth inhabited by organisms that extends from upper parts of the atmosphere to deep in the Earth's crust.

At the largest scale, our entire planet can be seen as an ecosystem, with specific energy inputs from the Sun and with particular physical characteristics. The Gaia hypothesis, formulated by scientist James Lovelock in the mid-1960s (page 6), proposes that our planet functions as a single living organism. The hypothesis says that the Earth is a global control system of surface temperature, atmospheric composition, and ocean salinity. It proposes that Earth's elements (water, soil, rock, atmosphere, and the living component called the biosphere) are closely integrated in a complex interacting system that maintains the climatic and biogeochemical conditions on Earth in a preferred homeostasis (i.e. in the balance that best provides the conditions for life on Earth).

TOK

The holistic approach and the reductionist approach used by conventional science use almost identical methodologies: the difference between them may, therefore, be only one of perspective.

Dendrobates pumilio, the strawberry poison dart frog, is common in the Atlantic lowland tropical forests of Central America, especially Costa Rica. The female typically lays 3–5 eggs on the forest floor in a jelly-like mass that keeps them moist. Once the eggs are ready to hatch, one of the parents steps into the jelly surrounding the eggs: the tadpoles respond to the movement and climb onto the parent's back, where they stick to a secretion of mucus. The parent carries the tadpoles up to the canopy where they are deposited in water caught by the upturned leaves of a bromeliad. Each tadpole is put in a separate pool to increase the likelihood that some offspring will survive predators. The bromeliad ecosystem is a vital part of the frog's life-history.

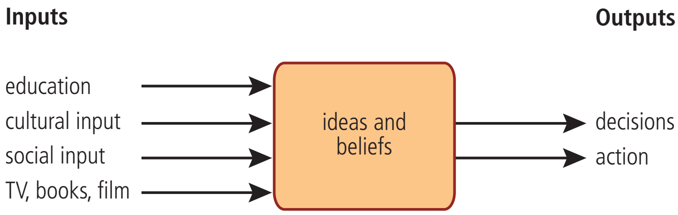
Strawberry poison-dart frog

The characteristics of systems

A system consists of storages and flows. **Storages** are places where matter or energy is kept in a system, and **flows** provide inputs and outputs of energy and matter. The flows are processes that may be either **transfers** (a change in location) or **transformations** (a change in the chemical nature, a change in state or a change in energy).

Systems can be represented as diagrams (page 19). In these **systems diagrams**, storages are usually represented as rectangular boxes, and flows as arrows with the arrow indicating the direction of the flow. Figure 1.7 shows flows and storage for the social system discussed on page 11.

Figure 1.7 A social system, showing flows and storage. Flows are inputs and outputs, and storage is the ideas and beliefs of the society.



A diagram can show several storages and the flows between them, and show the relationship between the parts of a complex system. For example, Figure 1.8 shows a systems diagram for the movement of energy and matter in a forest ecosystem.

Boxes in Figure 1.8 show storages, such the atmosphere and biomass (i.e. biological matter). Arrows show flows – inputs to and outputs from storages. The arrows are labelled with different processes, either transfers or transformations.

Transfers include:

- harvesting of forest products
- the fall of leaves and wood to the ground.

TOK

The systems approach gives a holistic view of the issues, whereas the reductionist approach of conventional science is to break the system down into its components and to understand the interrelations between them. The former describes patterns and models of the whole system, whereas the latter aims at explaining cause-and-effect relationships within it.

- **Transfers flow through a system and involve a change in location.**
- **Transformations lead to an interaction within a system in the formation of a new end product, or involve a change of state.**

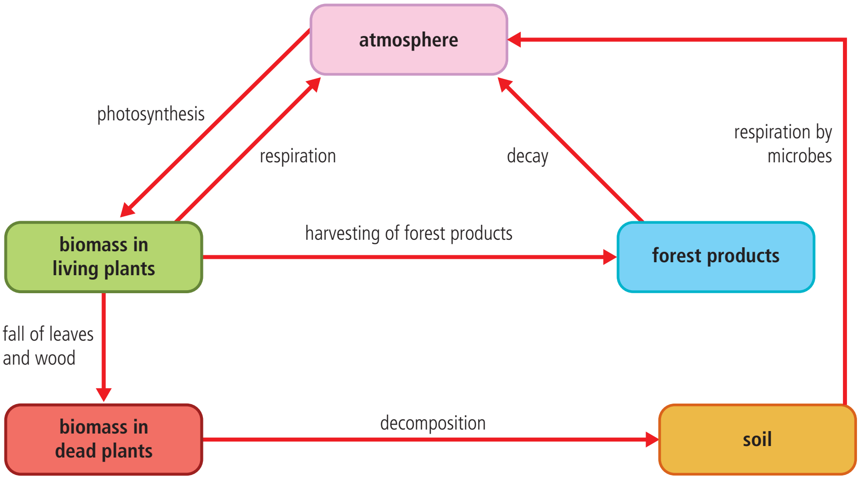
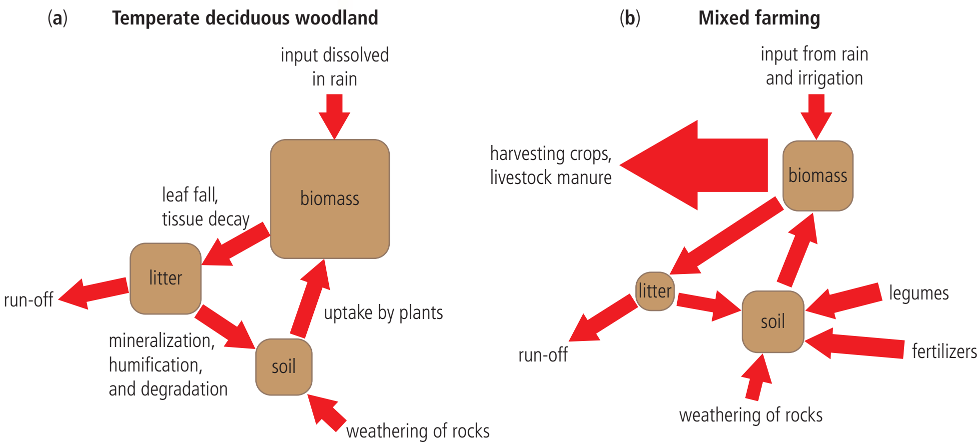


Figure 1.8 A forest ecosystem shown as a systems diagram

Transformations include:

- photosynthesis – transforming carbon dioxide (CO_2), water (H_2O), and light into biomass and oxygen (O_2)
- respiration – transforming biomass into carbon dioxide and water.

Figure 1.9 Nutrient cycles for (a) a temperate deciduous woodland and (b) an area nearby where the woodland has been cleared for mixed farming. Biomass is all the living material in the ecosystem. Arrows are proportional to the amount of energy present (i.e. larger arrows show greater energy flow than smaller ones).



The size of boxes and arrows in systems diagrams can be drawn to represent the size (i.e. magnitude) of the storage or flow. The system diagrams in Figure 1.9 offer information about the different systems by drawing flows and stores proportionally (e.g. biomass store is larger in the woodland; litter store is larger in the woodland; and there is a large output in mixed farming due to the harvested crops and livestock). The diagrams also show that legumes and fertilizers are additional inputs in mixed farming. Extra value can be given to systems diagrams, even simple ones, by showing data quantitatively.

You are expected to be able to apply a systems approach to all the topics covered in this course. You should be able to interpret system diagrams and use data to produce your own for a variety of examples (such as carbon cycling, food production, and soil systems). These ideas are explored in subsequent chapters.

Open, closed, and isolated systems

Systems can be divided into three types, depending on the flow of energy and matter between the system and the surrounding environment.

- **Open systems** – Both matter and energy are exchanged across the boundaries of the system (Figure 1.10a). Open systems are organic (i.e. living) and so must interact with their environment to take in energy and new matter, and to remove wastes (e.g. an ecosystem). People are also open systems in that they must interact with their environment in order to take in food, water, and obtain shelter, and produce waste products.

- **Closed systems** – Energy but not matter is exchanged across the boundaries of the system (Figure 1.10b). Examples are atoms and molecules, and mechanical systems. The Earth can be seen as a closed system: input = solar radiation (Sun's energy or light), output = heat energy. Matter is recycled within the system. Although space ships and meteorites can be seen as moving a small amount of matter in and out of the Earth system, they are generally discounted. Strictly, closed systems do not occur naturally on Earth, but all the global cycles of matter (e.g. the water and nitrogen cycles) approximate to closed systems. Closed systems can also exist experimentally (e.g. Biosphere II).
- **Isolated systems** – Neither energy nor matter is exchanged across the boundary of the system (Figure 1.10c). These systems do not exist naturally, although it is possible to think of the entire universe as an isolated system.

An open system exchanges both energy and matter with its surroundings, a closed system exchanges energy but not matter, and an isolated system does not exchange anything with its surroundings.

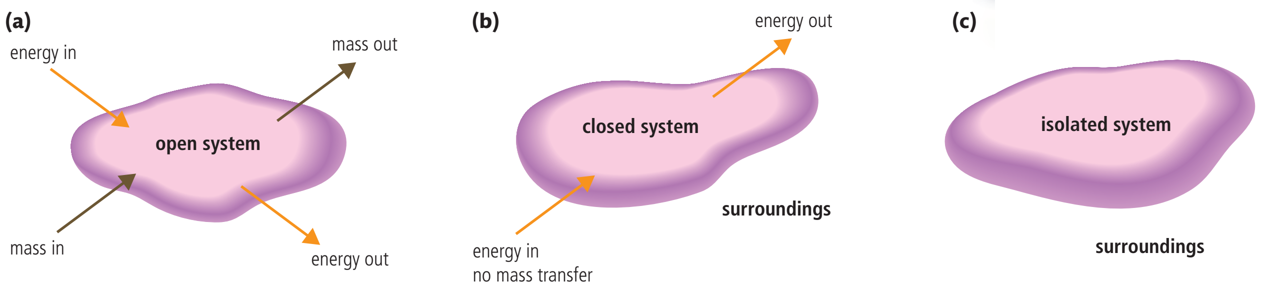


Figure 1.10 The exchange of matter (mass) and energy across the boundary of different systems. Open systems (a) exchange both; closed systems (b) exchange only energy, and isolated systems (c) exchange neither.

Biosphere II encloses an area equivalent to 2.5 football pitches, and contains five different biomes (ocean with coral reef, mangrove, rainforest, savannah, and desert). Further areas explore agricultural systems and human impact on natural systems.

Biosphere II is an experiment to model the Earth as a closed system. It was constructed in Arizona between 1987 and 1991 and enables scientists to study the complex interactions of natural systems (e.g. the constantly changing chemistry of the air, water, and soil within the greenhouses), and the possible use of closed biospheres in space colonization. It allows the study and manipulation of a biosphere without harming the Earth. The project is still running and has resulted in numerous scientific papers showing that small, closed ecosystems are complex and vulnerable to unplanned events, such as fluctuations in CO_2 levels experienced during the experiment, a drop in oxygen levels due to soils over-rich in soil microbes, and an over-abundance of insect pests that affected food supply.

TOK

An isolated system does not exchange matter or energy with its surroundings, and therefore cannot be observed. Is this a useful concept?

TOK

Systems are hierarchical, and what may be seen as the whole system in one investigation may be seen as only part of another system in a different study (e.g. a human can be seen as a whole system, with inputs of food and water and outputs of waste, or as part of a larger system such as an ecosystem or social system). Difficulties may arise as to where the boundaries are placed, and how this choice is made.

Models

A model is a simplified description designed to show the structure or workings of an object, system or concept.

You are expected to be able to construct a system diagram or a model from a given set of information.

A **model** is a simplified version of reality. Models can be used to understand how systems work and predict how they will respond to change. Computer models use current and past data to generate future predictions. For example, they are used to predict how global surface temperatures will change during the 21st century (Chapter 7). All models have strengths and limitations and inevitably involve some simplification and loss of accuracy.

Some models are complex, such as the computer models that predict the effect of climate change. Other models, even of complex systems, are simpler (Figure 1.11).

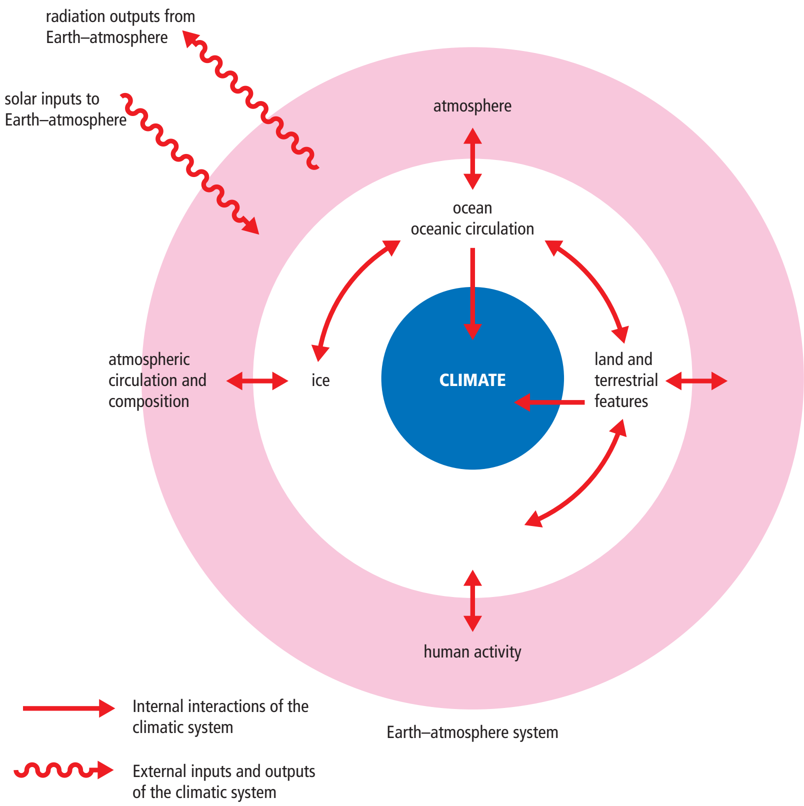
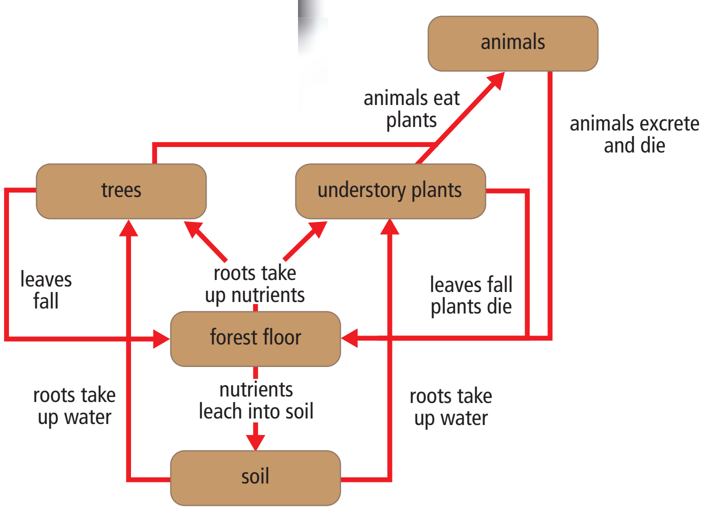


Figure 1.11 A model of the climatic system

Figure 1.12 Models are simplified versions of reality. They can show much about the main processes in an ecosystem and show key linkages. This is a model of a forest ecosystem.



Models can be used to show the flows, storages, and linkages within systems, using the diagrammatic approach (pages 21–22). For example, Figure 1.12 shows a model of an ecosystem. While unable to show much of the complexity of the real system, Figure 1.12 still helps us to understand basic ecosystem function.

Evaluating the use of models

Strengths of models

- Models allow scientists to simplify complex systems and use them to predict what will happen if there are changes to inputs, outputs, or storages.
- Models allow inputs to be changed and outcomes examined without having to wait a long time, as we would have to if studying real events.
- Models allow results to be shown to other scientists and to the public, and are easier to understand than detailed information about the whole system.

Limitations of models

- Environmental factors are very complex with many interrelated components, and it may be impossible to take all variables into account.
- Different models may show different effects using the same data. For example, models used to predict the effect of climate change can give very different results.
- Models themselves may be very complex and when they are oversimplified they may become less accurate. For example, there are many complex factors involved in atmospheric systems.
- Because many assumptions have to be made about these complex factors, models such as climate models may not be accurate.
- The complexity and oversimplification of climate models, for example, has led some people to criticize these models.
- Different models use slightly different data to calculate predictions.
- Any model is only as good as the data used. The data put into the model may not be reliable.
- Models rely on the expertise of the people making them and this can lead to impartiality.
- As models predict further into the future, they become more uncertain.
- Different people may interpret models in different ways and so come to different conclusions. People who would gain from the results of the models may use them to their advantage.

You need to be able to evaluate the use of models as a tool in a given situation, for example climate change predictions.

The need for models to summarize complex systems requires approximation techniques to be used: these can lead to loss of information and oversimplification. A model inevitably involves some approximation and therefore loss of accuracy. The advantage of models is that they can clearly illustrate links between parts of the system, and give a clear overview of complex interrelationships.

Exercises

1. How does the holistic approach to systems differ from the reductionist approach of conventional science? What are the advantages of the holistic approach compared to the conventional approach?
2. Draw a table comparing and contrasting open, closed, and isolated systems. Comparisons should be made in terms of the exchange of matter and energy with their surroundings. Give examples for each.
3. What is meant by transfer within a system? How does this differ from transformation processes?
4. Draw a systems diagram showing the inputs, outputs, and storages of a forest ecosystem.
5. Draw a table listing the strengths and weaknesses of models. Your table could summarize the issues regarding one particular model (e.g. climate change) or be more generally applicable.

Big questions

Having read this section, you can now discuss the following big questions:

- What strengths and weaknesses of the systems approach and the use of models have been revealed through this topic?

Points you may want to consider in your discussions:

- How does a systems approach facilitate a holistic approach to understanding?
- What are the strengths and weaknesses of the systems you have examined in this section?
- What have you learned about models and how they can be used, for example, to predict climate change? Do their benefits outweigh their limitations?