Chapter 1

Introduction

All of us who are a part of the present-day society of global information are inundated with a constant flow of news of all sorts, often relevant to events that have taken place a few hours or minutes before, in some remote corner of the world. Among these reports, sometimes we receive some news-flashes about natural events of a meteorological or climatic type, in many cases extreme events (hurricanes, floods, droughts), that, either directly or as an immediate consequence, have spread destruction and death.

Sometimes the news is not so immediately tragic, but brings anxiety about a more remote future. I refer, for instance, to the news of the separation from the Antarctic continent of an enormous iceberg (called Larsen B, larger than the State of Rhode Island), in March 2002. Subsequently other, smaller icebergs broke away, and many people thought it was reasonable to link these events to the world-wide warming of the oceans and lower layers of the atmosphere during the last century (a subject we will discuss further on). Should this trend go on, other icebergs might be expected to break away; and should the ice that melts or is released into the sea come from the cap that covers the Antarctic land, these "plunges" into the ocean would concur in raising the mean global level of the sea and in causing the interface between the land and the sea, i.e. the coasts, to recede.

There are also some pieces of news that rarely reach the western society, because they are not immediately catastrophic and concern extremely remote places. I refer, for instance, to the fact that an entire people, the approximately 11,000 inhabitants of the archipelago of Tuvalu, a small south-Pacific island-state, is negotiating with the governments of other states (in particular Australia and New Zealand), in order to be allowed to take sanctuary in their territory. This application was made necessary by the increasingly frequent flooding of their atolls and by the rising level of the sea, which suggests the possible need for an evacuation within the next few years.

After the immediate, facile stir caused by certain pieces of news, there begins (but not for all of them) a stage of deeper elaboration. In particular, a traditional deterministic analysis leads us to wonder which causes have produced (or are producing) a certain flood, the detaching of a certain group of icebergs or the appearance of "environmental refugees". The rationale behind these questions springs from the common-sense observation that, once the cause of an undesirable effect is removed, that effect disappears as well. At this point scientists come into play.

In the history of science, causal relationships have always been studied carefully. Within the sphere of Greek natural philosophy, whose *summa* is represented by Aristotle's work, there coexist basically two types of physical causes: efficient cause and final cause. The former is the current meaning of the word: it is what comes before a certain phenomenon and determines it; the latter is the goal towards which the caused thing tends, in the future. In modern science, finalistic thinking — according to which a certain phenomenon or process takes place because it tends towards a final situation, its goal — was abandoned[1]. The present-day causal outlook establishes a "time's arrow": all causes come before the effect they produce (they are situated within the light cone of the past, to put it in relativistic terms). Moreover, within the sphere of classical (not quantum) physics, the theoretical approach to evolutionary phenomena is based on differential equations (ordinary or with partial derivatives), more or less implicitly assuming that the future state of the system under consideration is univocally determined starting from a known past state, by means of evolution equations.

[1]In actual fact, in the mathematical physics of the eighteenth century there survives a finalistic explicative concept, with the minimum-action principle or Maupertuis' principle, within the sphere of variational calculus in dynamics: for a critical analysis and a modern outlook that connects it to a causalistic approach, see, e.g., Yourgrau and Mandelstam (1979).

We will analyse this paradigm further on, after having applied it to the atmosphere system, or, more generally, to the Earth system. At present it will be sufficient to point out that, as a rule, in this pattern the scientific explanation of a phenomenon or of the evolution of a process with time involves first of all the identification of its causes, then the analysis of their way of combining to give rise to the phenomenon or process under consideration.

The area that acts as a prototype for these causality analyses is classical mechanics, in particular laboratory-controlled experimental situations[2]. If we recall the simple dynamics problems we had to solve in secondary school and the easy experiments we had to carry out, we notice that in those cases the few forces that act on a material body are easy to identify, and the total effect they produce on the body (e.g. its acceleration) are nothing but the vectorial sum of the effects (accelerations) that each force would produce if it were applied individually. This property of a physical system is called linearity. If the system under examination is correctly described by an equation such as $\vec{a} = \vec{F}/m$, the solution of this equation, in the case of the composition of several forces, is the sum of the solutions of the individual cases in which, each time, only the action of a single force is considered. So once a certain number of concurrent causes has been identified, their composition is quite simple and the problem under examination is easy to solve.

In some systemic ecology studies begun in the nineteen-seventies[3], for the cases that have just been described, linear causality is mentioned, as opposed to a so-called circular causality that is considered typical of living systems, where it becomes essential to consider the intricate relationships and interconnections between the various elements of a system. Though we shall not go so far as to examine the dynamics of living systems, we must point out that also in the atmosphere, and, more generally, when dealing with the overall Earth system, the relationships between causes and effects can no longer be interpreted in terms of the

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[2]These considerations will be resumed and extended in Chapter 5, when we will discuss the Galilean experimental methods.
[3]E.g., see Bateson (1980).

simple linear causality of classical mechanics. In actual fact, what undermines the simple linear pattern is the presence of feedback, i.e. chains of circular two- or multi-element interactions, in which an effect acts in turn on the cause that has generated it, increasing its effect (positive feedback) or decreasing it (negative feedback). In Chapter 4, when we will analyse the current theoretical knowledge of the Earth system, we will consider some concrete examples of these complex cause-effect relationships (which are called non-linear).

From what we have just explained, it is evident that there does not exist an answer, in terms of a linear composition of concurring causes, to the questions we had previously posed about the floods, icebergs and "environmental refugees". If to this we add the fact that our theoretical knowledge of atmospheric phenomena is linked to a description in terms of systems of equations that can be solved analytically only in very particular, simplified cases, we can understand why, up to a few years ago, giving sensible answers to these questions was quite unthinkable. To make the situation even more complicated, in many cases these phenomena should be regarded as "extreme events", that is statistically improbable events, and this makes it difficult also to approach their description and prediction in terms that are not dynamic but statistical.

Within the picture we have just given of the situation, whose elaboration lends itself to be carried out from various angles, we must now delimit the goals that this book has set out to achieve.

When discussing phenomena relevant to meteorology, the climate and its changes during the last few decades or centuries, the subject can be tackled from the viewpoint of our scientific knowledge in this area (essential for any other discussion of the problem), from the viewpoint of the impact of these phenomena on nature and mankind (including studies on the vulnerability of the latter and on possible adaptation strategies), and — if there seems to be the possibility of acting in a concrete manner to reduce the causes of the most negative phenomena — from the viewpoint of mitigation studies relevant to what is usually called sustainable development (a possible example is the development of energy production methods that have a lower impact on the environment). The third viewpoint is the one where the decisions to be taken are the most delicate, because they affect the world-wide social, economic and political sphere[4].

The viewpoint adopted in this book belongs to the first of these three areas. In brief, we will begin by analysing the current scientific knowledge of meteorological and climatic phenomenology, both from the angle of observations (Chapters 2 and 3) and from that of the theoretical description of the Earth system and its atmosphere subsystem (Chapter 4). In doing this, we will pay attention particularly to the conceptually relevant aspects that reveal the complexity of the system under examination and make it so different from the physical systems that our school education has made familiar to us. This first part of the book is somehow preparatory to what follows, because it supplies the grounding required to understand the change of paradigm in the researches in this field that is described in the second part of the book.

Chapter 5, which at first sight may seem a digression, discusses the Galilean experimental method. The motivation of this brief excursus into the physics of the seventeenth century is that the application of this method was precisely what allowed physics and other so-called "hard" scientific disciplines to achieve extremely important results and a very evident progress in the understanding of nature. In the meantime, meteorology and climatology, as described in the first three chapters, remained observational disciplines, and had much trouble in attempting a theoretical description, because of the complexity of the system that was being studied. At this point it is natural to think that, if we could recover a Galilean way of carrying out scientific researches, other disciplines that up to now were purely observational might achieve important progresses in understanding the phenomena within their province.

Chapter 6, in which simulation models are introduced, analyses precisely the entrance of some observational disciplines into the category

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[4]It is not fortuitous that this schematisation follows, rather faithfully, the one proposed by the IPCC (Intergovernmental Panel on Climate Change) in the three reports it has recently published on the state of climatic research in the world. The IPCC was established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) with the main purpose of periodically drawing up technical reports (and résumés for policy-makers) about the state of the art of scientific, technical, social and economic knowledge of climate changes and their consequences. Further on we will refer to one of these reports.

of Galilean-type sciences. Here a new paradigm in the way of performing a scientific research, simulation, is discussed, particularly as regards the possibility of constructing a "virtual laboratory" for the study of complex systems.

In Chapter 7, we will describe the structure and operation of the models for weather forecasts, highlighting their strong points and weaknesses. In particular we will discuss the appearance of what is called deterministic chaos, which leads to a revision of the concept of deterministic prediction for complex systems, such as the atmosphere.

In Chapter 8, the system that is being studied in its dynamic evolution is extended to fully include the oceans and some phenomena that are neglected or not dealt with dynamically, for instance the so-called carbon cycle (photosynthesis, respiration, storage). The purpose here is not to predict the weather during the next few days, but to correctly reconstruct the climates of the past and make it possible to analyse future scenarios in relation to important climatic variables such as the mean temperature and the precipitations in a certain area of the world. The positive results and current limits of the models are evaluated.

The last chapter contains a general discussion of the importance of the simulation-based approach to the study of the weather and climate. This approach is evaluated from a conceptual and epistemological[5] point of view, and the prospects of future development within this paradigm, and out of it, are presented.

The great importance that meteorology has in everyday life and the enormous publicity that is given to the debate about climate change, essentially based on the results of predictive models, are accompanied by a general lack of information on the scientific practice (of which simulation-based modelling is an integral part) that characterises these disciplines. I hope, on the one hand, that my book will be able to bridge this gap, on the other hand that the conceptual and epistemological

[5]In the literature relevant to this area, the adjective "epistemological" is used with meanings that sometimes differ from each other, depending on the exact meaning ascribed to the noun "epistemology" (e.g., see Greco (1998)). Here "epistemology" is understood as the critical and philosophical study of nature and of the procedures of scientific activity.

reflections by which it is accompanied will explain the intellectual appeal of a change of paradigm that has recently allowed these disciplines to be included in the category of Galilean-type sciences. Furthermore, there is a lot of talk about complexity and chaos, and one is led to believe that the phenomena relevant to them are confined in some obscure sector of physics. On the contrary, the study of the atmosphere as a subsystem of the Earth system is an ideal and very concrete case study of complex system, and makes it possible to evaluate the conceptual and practical scope of a model-based approach to these themes.