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Probability of climatic change; identification of key questions

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Abstract

Addressing the question what the probability is of an anthropogenically induced change in the climate, leads to a number of other, underlying questions. These questions, which deal with the characteristics of climate, of climatic change, and of probabilistic statements on climatic change, should be adressed first. The long-term objective of the underlying study, i.e., a quantitative assessment of the risks and opportunities of the predicted climatic change, sets the context against which these questions should be answered. In addition, this context induces extra questions, i.e., about the characteristics of risk.

1. INTRODUCTION

The probability of climatic change, which is due to the anthropogenic enhancement of the Greenhouse Effect, is questioned increasingly in the press. Due to this, interest by both politicians and managers of private enterprises in the predicted climatic change is fading. Policymakers working in the field of climatic change need this interest because they need support for measures aimed at mitigating the risks of, and at adapting to, the predicted global warming, both on a national and an international level. So, they look for ways to renew this interest. The renewal sought for can perhaps be accomplished by founding climate policy on a risk-analysis of the global warming issue. If so, it may also be possible to compare the risks of climatic change with other risks for society. For such a risk-analysis, first of all quantitative probabilistic statements on the expected change are needed. However, information on climatic change is currently almost without exception presented in terms of uncertainty. The project 'Probability of Climatic Change' aims at identifying ways which may result in the probabilistic statements required. This paper identifies the key questions which should be addressed first.

2. UNRAVELLING THE ISSUE

In this section will be shown that there are many possible ways to come to probabilistic statements on climatic change. The issue has in this paper been reduced to linking four categories of information: information on climate, on climatic change, on the foundations of probability, and on risks. Within each category several key questions are presented. The answers to these questions -nine in total- present options which may be focused on when assessing the risks of a change in the climate.

2.1. Characteristics of probabilistic statements

For most climatologists, including myself, this category of information, which deals with the foundations of probabilty, is remote from their daily activities. For this reason, some more background information will be presented on the topic than will be the case for the other three categories.

All probability ideas, which can be traced back to the ancient Egyptians and Greeks, have contributed to the foundations of probability. Three interpretations of probability prevail currently:

1) The interpretation adhered to most often is *the frequentist view, or frequency interpretation, of probability* which is based on a notion of randomness and repeated experiments modelled by the sample space.
2) *The subjective view of probability* describes the strength of belief of an individual concerning the occurrence of events. Strength of belief is determined through a process of introspection and manifests itself through overt choice or betting behaviour,
3) *Logical probability* presents an objective assessment of the degree to which an evidence statement (inductively) supports a hypothesis statement.

A gap may be expected between the foundations of probability, to which these three interpretations belong, and applied statistics; what kind of probability model can be used for which interpretation. Knowledge of the different interpretations of probability, though, can guide the selection of families of probability models (not necessarily numerical ones) so as to better reflect the indeterminate, uncertain, or chance phenomena being treated. Knowledge of the different interpretations may also clarify a choice among the divergent, conflicting statistical methodologies now current. One should realize that different methodologic schools rely on different concepts of modelling probability, albeit this difference is obscured by common agreement on the mathematical structure of probability. Regarding the development of probability models for uncertain events, three different concepts are identified:

1) A model cannot be developed (Neyman-Pearsonians postulate that a class of uncertain phenomena, i.e., the 'unknown parameter', cannot be given a probability model),
2) A choice of models may be developed (Bayesians, personalists and subjectivists insist upon giving the unknown parameter an overly precise numerical probability model, but allow great freedom in the subjectively based choice of the model),
3) Only one, unique model can be developed (structuralists, fiducialists and maximum entropists carry the modelling process one step further by claiming to provide objective, rational grounds for the selection of a unique numerical probability model to describe the unknown parameter).

A domain contains both events whose occurrences are of interest to a reasoner and a setting identified by the reasoner as informative about the occurrence of events and as relevant to achieving its goals. In some fashion, the reasoner decides that it can perhaps identify which of the events are probable, or which events are more probable than other events, or even assign a numerical probability to each event. Implicit in this process is an initial determination as to what provides the evaluative basis for the probability concept being invoked (e.g., what climatic records and theory can we use to calculate the probability of a climatic change in the next century). The evaluative basis largely fixes the meaning of the probability concept, which must have meaning extending beyond its evaluative basis if it is to serve a role other than that of data summarization.

Question 1: What *evaluative basis* should we choose for the probabilistic statements on climatic change sought for? Possible evaluative bases are:

1) Past occurrences of other events of the same type (the palaeo-analogue method),
2) Experiments generating the events (output from simple climate models, e.g., autoregression models, or complex climate models, e.g., coupled-GCMs),
3) The strength of belief of an expert concerning the events (surveys of expert opinion or statements by individual experts),
4) The inductive relation between a formally presented amount of information and the event (due to the complexity of the climatic systm this method is not usually applied and, if so, often patronizingly called 'hand-waving').

1 and 2 belong to the frequency interpretation of probability, 3 belongs to the subjective interpretation of probability, and 4 belongs to the logical interpretation of probability.

Once the reasoner has adopted a concept of probability supported by a domain of application, he then wishes to move this empirical relational system into a formal mathematical domain so as better to determine the implications of the position. The events of interest in the domain are represented either by sets or by propositions. It is generally not possible to enumerate all possible events (complex systems occasionally surprise us by behaving in unforeseen ways) and therefore the sample space is at best a list of practical possibilities.
The recognition that probabilistic reasoning must confront a wide range of domains and levels of information, knowledge, belief, and empirical regularity can lead us to an acceptance of an hierarchy of increasingly precise mathematical concepts of probability. This hierarchy has been little explored, as almost all of the effort has been devoted to numerical probability. That numerical probability may be inadequate to the full range of uses of probabilistic reasoning is suggested by the following observations:

1) For some categories of empirical phenomena (e.g., climate) there is no obvious stability of relative frequency for all events of interest.
2) An ensemble of events may lack information; the resulting indeterminacy should be respected and not be obscured by applying dubious hypotheses (e.g., "If you know nothing about the parameter, then adopt a uniform maximum entropy for it").
3) Self-knowledge of individuals is intrinsically limited, and attempts to force belief or conviction to fit the mold of a particular 'rational' theory can only yield results of unknown value.

Question 2: *What precision* should the probabilistic statements have? An attempt to accommodate to the preceding observations leads to the following hierarchy of concepts:

1) Possibly, the globe will warm by between 1 and 3 °C in 2050,
2) Probably, the globe will warm by between 1 and 3 °C in 2050,
3) That the globe will warm by between 1 and 3 °C in 2050 is at least as probable as that the globe will warm by between 0 and 1 °C in 2050,
4) That the globe will warm by between 1 and 3 °C in 2050 has a probability of between 4 out of 10 and 8 out of 10,
5) That the globe will warm by between 1 and 3 °C in 2050 has a probability of 6 out of 10.

Conditional versions of each of the foregoing concepts are also available and will in reality be the versions dealt with. An example of a conditional version of the foregoing concept is established when the following phrase is put before each concept: If atmospheric greenhouse concentrations continue to increase according to the IPCC IS92a scenario, then....(for this, see question 5).
The probability concepts just introduced must then be given structure through a set of axioms and definitions of significant terms (e.g., independence, expectation).

While it is the role of interpretation to co-ordinate the mathematical, axiomatically constrained concept with the domain of events of interest to the reasoner, this co-ordination is typically idealized and not itself a working basis for probabilistic reasoning. Statistics is the discipline that supplies the working basis for numerical probability with a frequentist interpretation. Statistics is also of value in supplying the basis for numerical probability in the subjective setting.
Little is yet known about the practical issues connected either with formal concepts of probability other than the numerical one or with the logical interpretation of probability.

2.2. Characteristics of climate

Question 3: Which *climatic variables* are of most importance when assessing the risks of a change in the climate? Four categories of variables could be identified, of which two comprised variables which were considered to be strongly related. These are:

1) Precipitation (intensity, surplus, i.e., precipitation minus evapotranspiration),
2) Temperature (extremes, averages, freezing days or 'tropical' days),
3) Cloud coverage and irradiance (of both short-wave and long-wave radiation),
4) Storms, tidal amplitude and sea-level.

It should be added that risks may also be due to changes in several variables, which do not necessarily have to be of climatic origin, occurring at the same time, which are not significant by themselves but which are significant when occurring in ensembles. This is called multi-stress.

Question 4: What *statistics* should be used? Climate can be defined as 'the characteristics of weather seen over longer periods'. But depending on the statistical processing of weather information, one and the same climate could be presented in different forms. Eight categories of statistical representation were identified. These are:

1) Extreme values,
2) Averages,
3) Trends,
4) Variability,
5) Spatial and temporal correlation,
6) Run events,
7) Distribution,
8) Timing.

2.3. Characteristics of climatic change

Question 5: What *reference* should we take if we talk about climatic change? When discussing climatic changes, it is implicitly assumed that the climatic issue of interest shows a temporal evolution or trend. However, climate does not change due to time, but because processes influencing climate directly or indirectly change in time -the internal climatic variability is disregarded at this point. Processes influencing climate directly are changes in land-use influencing the hydrological cycle (e.g., changes in run-off due to deforestation influencing in turn rain patterns and groundwater levels) and temperature (e.g., via albedo changes and by creating so-called islands of urban heat). *The direct effect is primarily regional,* i.e., only extending to neighbouring areas. Processes changing climate indirectly via perturbation of the Earth's radiative balance are absorption and emission of long-wave or short-wave radiation by gasses, reflection and absorption of short-wave radiation by the Earth's surface and scattering of short-wave radiation by particles in the air, e.g., aerosols. *The indirect effect is primarily global.* Two references were identified:

1) Changes in the concentrations of atmospheric constituents influencing the radiative balance (affecting climate globally, with regional variation due to uneven distribution of emissions of some short-living constituents like, for example, sulfur dioxide and soot),
2) Changes in land use (affecting the climate globally via changes in emissions and albedo. Land-use changes have a regional influence because they may influence the local heat-balance by the heat produced directly, e.g., by cities, and by changes in the albedo which influences the amount of incoming solar radiation used for surface warming. Changes in land use may also influence the hydrological cycle regionally).

Question 6: What *geographical scale* should we consider if we discuss climatic change? It can be observed that when people or the press discuss climatic change, global or hemispheric values are presented if any. The same can be said of many scientific reports and of the policymakers summaries, for instance of the IPCC. In general it can be said that 'the global climate' is an empty concept; there is no such thing as a global climate. This is made clear by the following example, which at the same time links the question of geographical scale and risks of climatic change. Four coupled models predict that the global temperature will have increased by between 1.3 and 2.3 °C at the time of CO_2 doubling. All four models show local heatings of up to 2.5 °C, one of up to 5 °C, one of up to 6 °C, and one of up to 7 °C. Two models also show regions which will *cool*, one of these even up to -6 °C. Two geographical scales of interest for the underlying study were identified:

1) Regional (a region with a specific climate as defined by a climatic classification system, e.g., the Köppen System or the Holdridge Classification. Such a region may be very large indeed)
2) Local (an area within a climatic region).

Question 7: What *temporal resolution* should we strive for when studying climatic change? If one is interested in studying climatic changes in the past then the temporal resolution of the records tells us what changes can be resolved. The Nyquist-theorem indicates that the sampling frequency should be at least twice as high as the highest frequency that should be resolved. So, if we have measurements with 50 year intervals than changes over 100 years can be resolved. If we, on the other hand, are interested in seasonal changes in the future, then we need model output -if we wish to rely on model output, that is- with monthly resolution. Climatic risks are often associated with changes in agricultural production. If so, even higher resolutions are required. The cultivation of rice is, for example, highly dependent on maximum daily temperatures. Prediction of sea-level rise due to thermal expansion of the water allows climatic information with a lower temporal resolution. Taking future societal risks as boundary condition for the question of temporal resolution, the following hierarchy is identified:

1) Annual values,
2) Seasonal values (by definition seasonal values should be climatological homogeneous, this implies that the number and location of seasons should be chosen appropriately),
3) Values of Julian days,
4) Day-time or night-time values.

2.4. Characteristics of risks in the context of climatic change

It should be noted first that climatic change will also have beneficial effects. Indeed, as risk-assessments on the global warming issue have not yet been done, it cannot be said in advance that the risks will be smaller or larger than the opportunities.

Question 8: What *kind of risks* are we talking about. One may think of:

1) Damage to, or loss of, ecosystems (leading to an increase of the 'natural debt'),
2) Direct economical loss (which may also be expressed by changes in discount rate),
3) Damage to the physical and mental health of people,
4) Political instability due to indirect socio-economic effects (climatic change may indirectly lead to migration of large groups of people. It may also lead to tension between neighbouring countries if, for example, the agricultural production increases in the first country and decreases in the second),
5) Food production (including agricultural production and fishery).

Question 9: *Whose risks* are we talking about. From an anthropogenic point of view can be defended that the answer on this question is dependent on the people who, or institutions which, decide over, or are in power in, a specific area: the decisive bodies. The following hierarchy is proposed:

1) Bodies operating intercontinentally (e.g., UN, OESO, and OPEC),
2) Bodies operating continentally or transboundary (e.g., EU, USA, and BENELUX),
3) Bodies operating nationally (e.g., nations and states),
4) Bodies operating locally (e.g., cities, towns, and municipalities),
5) Individuals, families, households, offices, shops, communities, et cetera.

Ideally, the bodies one to four should comprise of politicians only. The politicians in turn should ideally represent the interest of institutions like NGO's, industries, trade associations, organisations, et cetera, as promised to all individual voters before the elections. In reality one may often have the impression that in certain regions some institutions have more power than the politicians in charge.
Another point which should not be overlooked is that the climatic risks for a specific country may partly depent on the climatic risks of another country with which is has a physical, economical, or some other relationship (for this, see question 8).

3. DISCUSSION AND CONCLUSION

Several options within nine categories representing four categories og information have in this paper been presented. These options may be focused on when assessing the risks of a change in the climate. However, when it is decided that the focus should be on one or more of the options given, this may effectively exclude that other relevant information can be extracted from the study results. For instance if the focus is on local risks of a temperature increase on the agricultural sector, one may not reveal information on the risks of changes in precipitation patterns for the ecosystems within a nation. Shortly, starting with a decision in one category will have consequences for decisions to be taken in the other categories. So, first of all decisions should be taken on the value of the different approaches that can be considered. The value of different possible approaches will be elaborated on in the course of the project and has, thus, not been discussed in this paper.

The assessment of quantitative probabilities on the risks and opportunities of the predicted climatic change should be started with an analysis of the problem. According to this study, the problem analysis should consist of addressing at least nine keynote questions which deal with four different types of information.
It is acknowledged here that even more fundamental approaches to the different types of information may be required. For instance, addressing the question which climatic variable should be studied, as has been done in this paper, may by some be interpreted as that changes in all climatic variables are predictable. From the work of Lorenz and others follows that if we are also interested in the chronological order in which these changes take place the answer should be 'no'. Addressing the question 'whose risks' implies that there is a common perception about risks. This seems improbable and should thus be accounted for when pursuing the long-term objective mentioned.

The differences in character between the key questions identified leads to the conclusion that a risk-assessment of climatic change will be the result of a common effort by many specialist, among which experts from both the natural and the social sciences, policymakers, and politicians. This also stresses the need for NRP projects aimed at communication.

4. REFERENCE AND ACKNOWLEDGEMENTS

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