A Critical Evaluation of Post-Normal Science's role in Climate Change Modelling and Political Decision-Making

Una evaluación crítica al rol de la Ciencia post normal en la modelación y toma de decisiones políticas para el cambio climático

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Abstract

Earth System Modelling is a modern approach for studying the complexity of the world and has become integral to the environmental and climate change discourse. It has enabled the possibility of research into areas previously unreachable and has led to the discovery of some of the most complex phenomena on the planet such as Chaos Theory. The exponential growth of computer capabilities has led to an impressive advance in the recognition of complexity and uncertainty. It has also opened up the path for a new scientific paradigm, post normal science. Decisions increasingly have to be made within this framework. Incomplete or poorly understood information provided by models is, despite modelling uncertainties, increasingly dictating the frontiers and interface of science and politics. Modelling, like any tool, has its advantages and disadvantages. This paper critically evaluates, through a comprehensive literature review, some of the benefits, limitations and controversies that surround models and questions their utilisation in the scientific quest for "truth" within the climate change debate. It also looks into the future of climate modelling and post normal science based decision making for a sustainable world.

Keywords: Post-Normal Science; Climate Change; Complexity; Modelling; Policy; Uncertainty

Resumen

El modelado del sistema de la tierra es una herramienta moderna para estudiar la complejidad del mundo y es una parte integral del discurso ambiental y del cambio climático. Se ha habilitado la posibilidad en áreas previamente inaccesibles y ha llevado al descubrimiento de algunos de los fenómenos más complejos del planeta, como la Teoría del Caos. El crecimiento exponencial de la capacidad de la computadora ha causado un crecimiento impresionante en el reconocimiento de la complejidad y la incertidumbre. Igualmente se ha abierto el camino para un nuevo paradigma científico, la Ciencia Post Normal. Las decisiones tienden cada vez más a realizarse en el marco de la Ciencia Post Normal. La información incompleta o mal entendida que proviene de los modelos, a pesar de sus incertidumbres, dictan cada vez más las fronteras y la interfaz de la ciencia y la política. Modelada como cualquier herramienta tiene sus ventajas y desventajas. En este trabajo se evalúa críticamente, a través de una revisión exhaustiva de la literatura, algunos de los beneficios, limitaciones y controversias que rodean a los modelos y las preguntas de su utilización en la búsqueda científica de la "verdad" en el debate sobre el cambio climático. También mira hacia el futuro de la modelización del clima y la toma de decisiones basadas en la Ciencia Post Normal para un mundo sostenible.

Palabras clave: Post-ciencia normal; Cambio Climático; Complejidad; Modelado; Política; incertidumbre.

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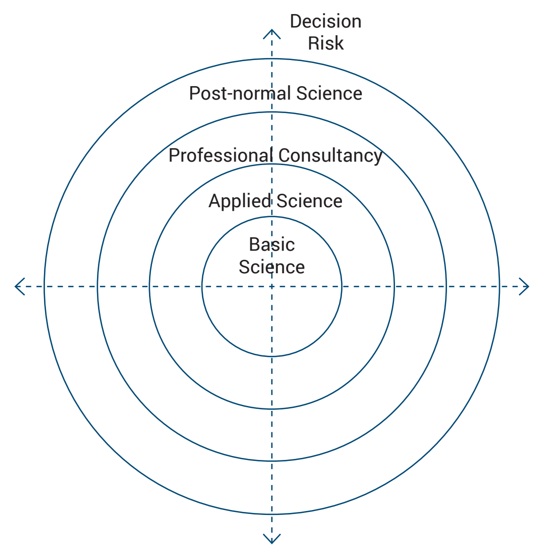
Introduction

Through the development and application of earth system modelling the scientific community has been able to recognise and begin to investigate some of the most complex phenomena of the earth system and uncover new approaches such as post-normal science (Figure 1) with which to study them (Funtowicz and Ravetz [1]).

The concept of post-normal science is a scientific approach suitable for environmental policy under conditions of complexity, that is to say, *facts are uncertain, values in dispute, stakes high and decisions urgent. Consequently, the conditions are not normal, neither for science nor for policy* (Deblonde *et al* [2]). Modelling, meanwhile, as a prime means to access natural phenomena (Neugebauer and Simmer [3]), is a very modern approach for studying the complexity of the world (Alcamo et al [4]) but one that has fast become integral to environmental discourse and the study of the multifarious earth system (Oldfield [5]; Figure 2). According to Heavens et al [6] a model organises what humanity thinks it knows about *something in order to predict how it might behave in the present, future, or past as well as how it might respond to external influence*. It therefore plays a significant role within Earth System Science and Post-Normal Science based political decision making, by spearheading the prediction and potential countering of, through mathematical simulation, those phenomena linked to climate change and weather patterns.

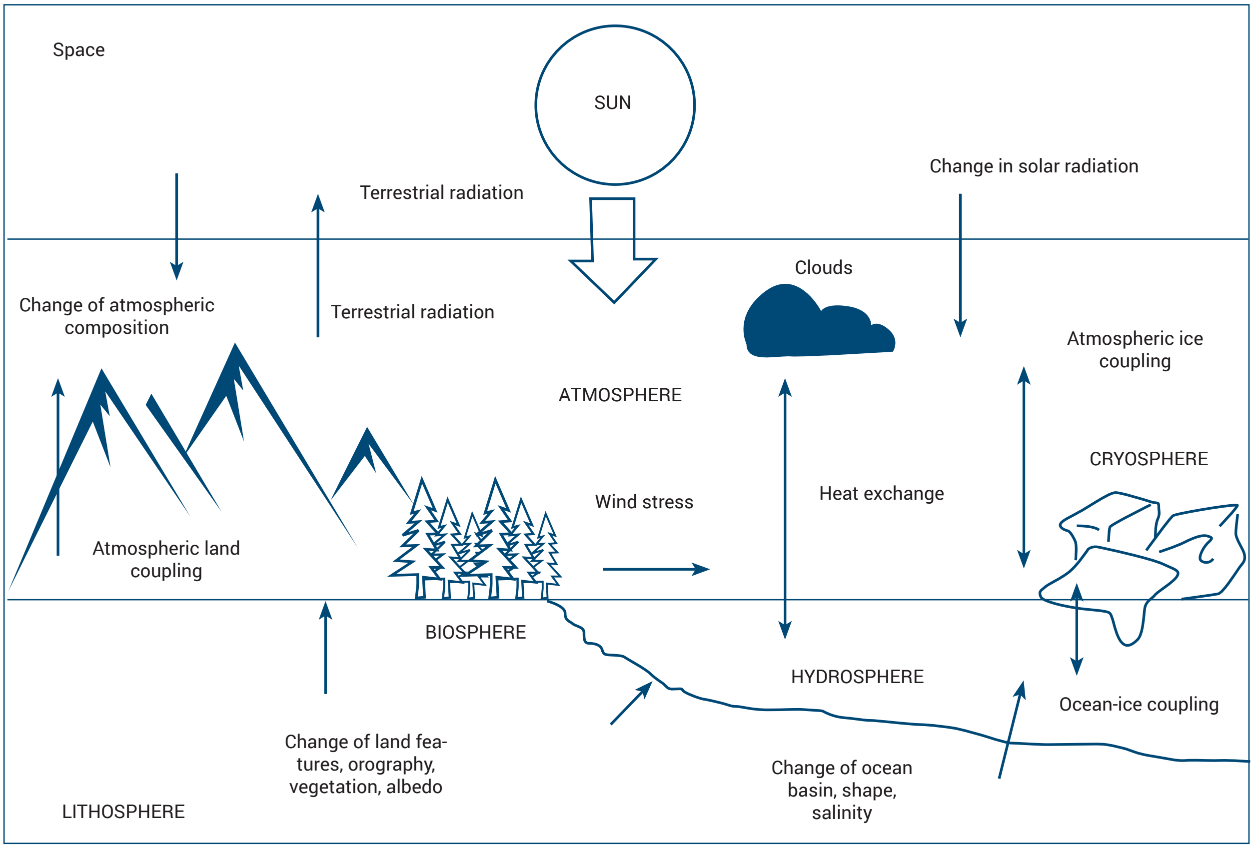
Specifically, Earth System Science views the Earth *as a synergistic physical system governed by complex processes involving the solid Earth, atmosphere, hydrosphere, biosphere etc, their origin and evolution and the changing pattern of Earth through time* (Rollinson [7]; Figure 2). Earth system modelling is therefore an algorithmic representation which attempts to reproduce the observational behaviour of the above and the interactions between them (Leffelaar [8]). Collectively such models have made and continue to make an *increasingly crucial contribution to the science of environmental change in every research area and every scale, from the exchange of moisture and energy between the individual leaf and atmosphere to the whole Earth system* (Oldfield [5]). They can thus be used to help society, at the science-policy interface, understand how and at which speed Earth's climate is changing and facilitate the necessary political decisions to deal with potentially devastating climate events such as the El Niño Southern Oscillation (ENSO), something which affects many countries, including Colombia.

Figure 1. *Post-Normal Science (PNS) is a new conception of the management of complex science-related issues. It focuses on aspects of problem-solving that tend to be neglected in traditional accounts of scientific practice: uncertainty, value loading, and a plurality of legitimate perspectives. Source: Authors - adapted from Funtowicz and Ravetz [1]*



High risk coupled with equally high levels of uncertainty is something which those at the science-policy interface, under the direction of the International Panel of Climate Change (IPCC) for example, are increasingly forced to grapple with. Decisions are increasingly made on uncertain terms - that is to say that they are not based on the pure objectivity of facts but rather subject to intellectual opinion. So, if the basis for political decision making, within the extended scientific community, is based on speculative algorithmic virtual representations not factual physical evidence, it is in the authors' view important to put together a paper that discusses the reliability of climate modelling tools used under the PNS paradigm (Figure 1). It is also vital that one considers in a critical manner the benefits and limitations encountered in the pursuit of "truth". This is in short, through a comprehensive literature review, what the authors attempt to do throughout the length of this paper.

Figure 2. *Diagram of the Earth System Source: Authors adapted from Swinback et al [9]*



Shifting Sands and Forging the Future

Computer simulations have changed the face of many scientific disciplines (Frigg et al [10]) and questions that would not even be asked without the existence of high-speed machine computation and high-resolution computer graphics are now at the forefront of science, politics and culture (Fox Keller [11]; Johnson [12]). As Earth Systems models grow in application and complexity the diversity of scientific disciplines and terminologies will also increase leading to not only advantageous collaborative interactions and discoveries (Kiehl and Ramanathan [13]) but also potentially leading to communication difficulties and additional epistemological and methodological tensions and disagreements (Dahan [14]).

According to Macleod [15], the El Niño and other complex climate phenomena are increasingly set to be managed by scientists, regulators and policymakers with integrated and holistic approaches/tools robust enough to manage right across the spectrum of local (micro) to global (macro) issues. Such approaches include high-powered computerised modelling under the conceptual framework of post-normal science, both of which rely upon robust data collection techniques and the construction of reliable prediction models of the complex Earth system. The accuracy of such models represents *one of the greatest scientific challenges of the 21st century* which is turn compounded by the immense societal and economic benefits at stake (O'Neil and Steenman-Clark [16]).

Models, reliant on appropriate observational data *i.e.* remote sensors, (Kiehl and Ramanathan [13]) are deemed to be "true" if they reflect the observations of the scientific world (Swinbank *et al* [9]). They are according to Schellnhuber [17] nothing short of a second "Copernican" revolution, in that the first enabled us to truly view the heavens and this second one, to "truly" view the Earth. In the last fifty years modelling has uncovered chaos theory (Thompson and Perry [18]) and the non-linear nature of climatic phenomena (Schoeberl *et al* [19]), led to the evolution of Gaia theory (Lenton [20]) through Watson and Lovelock's [21] conceptual *Daisyworld* model (Lovelock [22]) and the identification and estimation of resilience in human-modified natural systems.

The use of earth system modelling in building understanding of resilience and using subsequent knowledge in the management of real systems is considered by Fletcher and Miller [23] *as perhaps the most vital step towards averting disaster and collapse of many of the social-ecological systems that form the foundation of our societies*. Likewise, according to Van der Sluijs [24] practitioners of post-normal science, a scientific paradigm which recognises that *claims based on conceptual models go beyond the competence of present-day (normal Kuhnian) science*, argue that the aforementioned situations can only be addressed at the science-policy interface by the integration of scientific understanding and modelling over a wide range of spatial and temporal scales. These models, however comprehensive, with their advantages and disadvantages, do however hold a considerable degree of uncertainty when it comes to creating algorithms that accurately reflect the way climate phenomena forms, behaves and "acts". And it is this element of uncertainty, which places climate change in the wake of post-normal and beyond the realm of Kuhnian scientists.

The Advantages of Post-Normal Science Modelling: Fighting on the Frontiers of Science

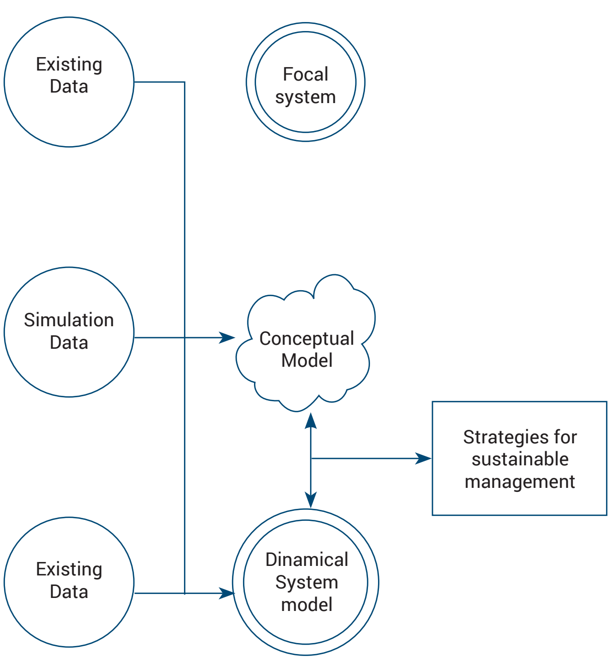
One key benefit of modelling phenomena is its ability, with every successful simulation adding to the scientific and political body of knowledge, to become an important, even didactic, tool for understanding (USNRC [25]). Indeed, Kiehl and Ramanathan [13] identify earth system modelling as the most comprehensive tool in the understanding of current and past/future variations of climate. It has also proved, under the post-normal paradigm, an essential means of communicating across the science-policy interface (Gallopin [26]). This is because the introduction of the Earth System Model has enabled scientists *to harness powerful computer technology to provide a more solid theoretical footing* (Beerling [27]). It has meant that the testing of hypothesises, elucidation of cause and effect (Swinback et al [9]), and the simulation and prediction of events in a virtual laboratory (Wainwright and Mulligan [28]) have played an important role in the fabric of society and the exchange of knowledge. In short, such methods have significantly improved access to climate phenomena, and yielded the possibility of research into and success in tackling problems *which were not treatable otherwise or would have taken unsustainable efforts to pursue* (Heymann [29]). This is something which in the authors' opinion has placed climate policy and actions firmly in the political landscape of the 21st century.

It is thus perhaps not surprising that the IPCC or any other research body or institution, favours modelling and post-normal science, at least symbolically, as a research method or theoretical framework given that it *is faster to get a result by modelling than through the acquisition and analysis of more data (in the field) which suits managers and politicians …staff scientists and professors* (Klemes [30]) who want to reap the benefits of new insight into long term, large scale changes in politically and economically important issues such as water use and land cover (Alcamo *et al* [4]).

Model based studies are thus of particularly high importance to those members of the public and policymakers who wish to address areas of science with high risk, complexity and uncertainty such as climate change (Washington *et al* [31]), damaging events with huge socio-economic and political consequences such as the Deepwater Horizon Spill (Bhattacharyya *et al* [32]), Hurricane Katrina and the droughts or floods of El Nino years. For the latter two it is hoped that "forecasts" that come from earth simulation models will continue to push the frontiers of understanding sufficiently that such projections *may be useful in helping certain populations manage climate variability* (Stute *et al* [33]) and develop resilience (Figure 3). Models have been successfully used in the UK, for example, to decrease vulnerabilities by appraising, in the form of a cost-benefit analysis, further coastal development proposals against managed retreat strategies (Hemingway et al [34]). Other applications of modelling to prevent coastal catastrophe include advanced flood warning systems in Holland (Hollingsworth et al [35]) and Tsunami warning models in Indonesia which were developed to protect citizens from a repeat of the 2004 Indian Ocean tsunami that killed 168,000 people in Indonesia alone (Mackinnon [36]). Simulations of the El Nino Southern Oscillation (ENSO) have also led to successful identification of direct correlations between climate variables and disease outbreaks (Murtugudde [37]). All of these models help support hard policy decisions that steer the Earth system toward a more sustainable existence for the benefit of all society (Clark and Holliday [38]; Mitchell and Romero [39]). Post Normal Science, then provides a theoretical framework for scientists and politicians using modelling tools to proceed urgently in the decision-making process, in the midst of polarised interests, when the facts uncovered are diverging and inherently uncertain (Saloranta [40]). In addition, post-normal science, although not without its disadvantages, offers:

> A means of winning legitimacy for science on contentious issues, creating consensus from diverse views and can potentially package science in ways amenable for policymaking and public discussion – Glover [41].

Figure 3. *Developing an Earth system model in order to Build Ecological Resilience into the System which serves Protect Communities against the severity of the El Nino/ La Nina Oscillations. Source: Authors adapted from Fletcher and Miller [23].*



Disadvantages of Post-Normal Modelling: Truth, Tensions and Tradeoffs

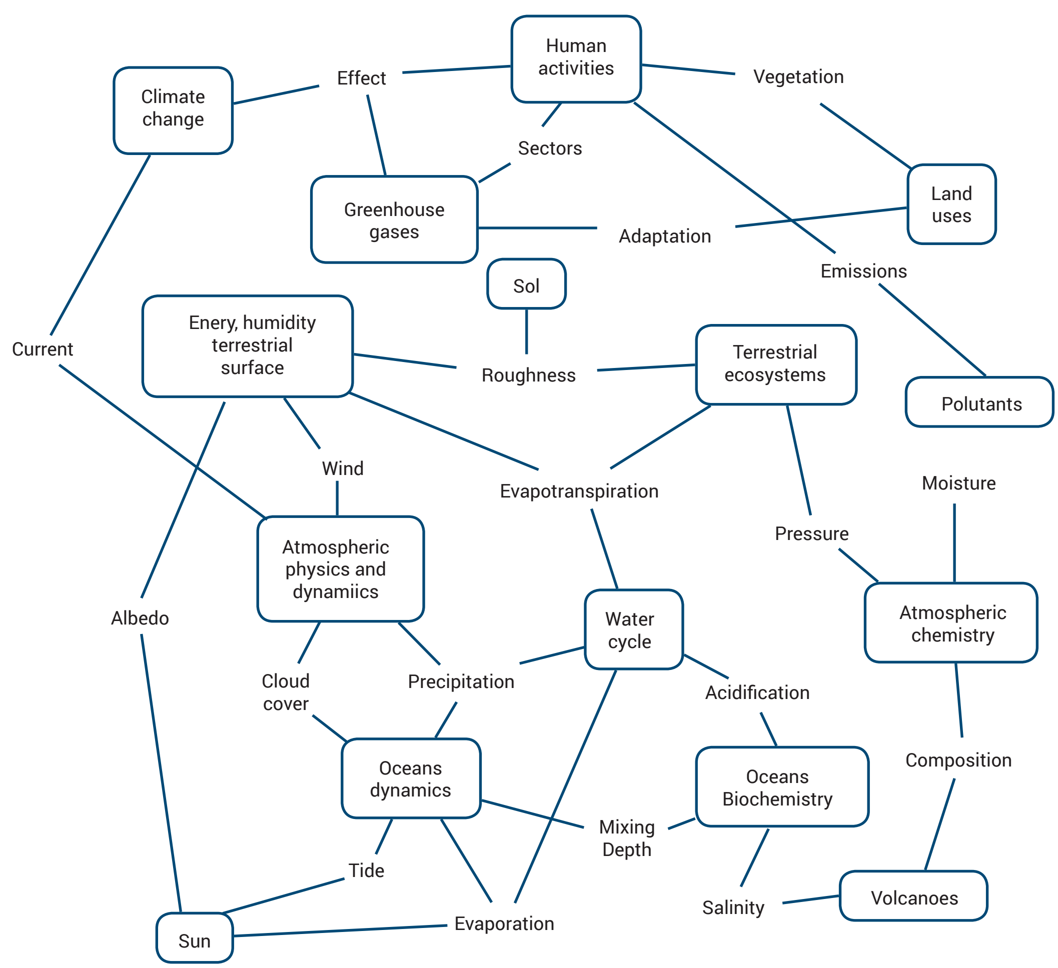
Climate scientists, aligned with Post-Normal Science, have according to Friedrichs [42], the difficult balancing act of invoking scientific objectivity and some sort of convention, by stating and supporting factual knowledge, upon which their authority and profession is based, while at the same time being forced by the circumstances to engage in political interventions as framed by post-normal science. This is of particular concern in emotive issues with uncertain "truths" because modelling itself is only a reflection of reality and subject to various data errors and subjective judgements.

The level of complexity, for instance, of an Earth System Model is determined by various factors including computing power (Claussen [43]), the nature of the scientific questions to be addressed (Kiehl and Ramanathan [13]), developments in science and scientific disciplines such as an increased demand to study systems in an integrated manner with greater extrapolation in time and space (Wainwright and Mulligan [28]) and the natural tension *between the scientists desire to understand the system and the policy makers desire for useful predictions* (Cox and Nakicenovic [44]). All of these entities, much like the phenomena the model attempts to emulate, influence the nature of the computer simulation and its ability to accurately represent reality and communicate "truth".

Truth in information systems, any combination of information technology and people's activities using that technology to support decision-making (of which modelling forms an integral part) is not neutral nor value free (Stahl [45]). In fact the biggest problem *with models is the fact that they are made by humans who tend to shape or use their models in ways that mirror their own notion of what a desirable outcome would be* (Firor [46]). Given that model simulations, due to the infeasibility of empirical methodology, are central tools in global change science (Edward [47]) and the global warming debate which some believe has left the realm of pure science (Lanzerotti [48]) and *become a euphemism for a political agenda* (DeWeese [49]). Scientists also tend to develop models within parameters (assumptions) which means any knowledge produced is also confined to such parameters and subject to the imperfect understanding of natural phenomena and misreading of their observation (Lahsen [50]). Further issues are the linking of models of system parts that operate at different rates such as atmospheric and oceanic processes and feedbacks and spatial resolution limitations which prevent important factors such as the Gulf Stream to be adequately simulated (O'Neil and Steeman-Clark [16]; USNRC [25]; Figure 4)). There is also a real lack of models considering those feedbacks between socio-economics and Nature – currently, they undertake a dual assessment but at the expense of *drastic simplifications in the submodels e.g.* climate may only be represented by global mean temperature (Steffen *et al* [51]). Such issues go some way to explaining how the choice of model can influence the result in more than the choice of scenario (Lomborg [52]).

Furthermore, behind every quantitative earth system model lies a more qualitative patchwork of compromises (NASA [53]) because any modeller is reduced to representing the process based on his/her best understanding of how the atmosphere works which may capture the essence of the systems but ignore the nuances (Lupo [54]). Clouds for instance, one of the least understood and accurately modelled components, have shown to negate the effects of global warming (Spencer [55]) and are according to the IPCC *a significant source of potential error in climatic simulations* (Houghton *et al* [56]). Identifying model errors is very difficult due to the complexity and uncertainties of the Earth system whilst the biases (assumptions) introduced are s*urprisingly difficult to correct* (Reichter and Kim [57]). Edwards [58] found that in the absence of data, models are used to "massage" the very data sets they are attempting to analyse. Similarly a

Figure 4. *Complex processes, dynamics and feedbacks – some of which at different rates that make up a "simple" computer model. Source: Authors*



model's accuracy is determined by comparing it against that of another model but they are generally based on *the same equations and assumptions, so that agreement among them may indicate very little about their realism* (Lahsen [50]). It is after all *much easier to get a model to behave unrealistically than to get it to behave realistically* (Spencer [55]). Thus whilst models may represent a great intellectual accomplishment, none have been or can be validated given that there is no standardised protocol to do so (Guillemot [59]; Carter [60]). The authors would also like to point out that it is this very lack of "provability" which places modelled phenomenon under the scope of Post-Normal Science, in the first place.

Should Climate Scenarios be Modelled or Observed?

The question is therefore, although there have been a number of advantageous developments in the field of modelling which have led to benefits that could not have been made in their absence, given the issues just described, "Should climate change be *modelled* or should science simply *observe?*

In answering such a question, one most recognise that models are limited not only by lack of understanding but by computer power (Schoeberl *et al* [19]) which is always improving and generating more and more capabilities (Claussen *et al* [61]). They are certainly not gospel and should not be treated as such (Farber [62]) but are according to Dr Pope [63] of the Met Office *the only way to predict the day-to-day weather and changes to the climate over longer timescales.* The scientific community must, in the authors' opinion, if this is indeed the case, rather than abandon them, strive to improve models through comprehensive data gathering and monitoring of higher resolutions (Gallopin [26]). More complete models, developed through greater attempts to observe, will provide a more realistic estimate of the uncertainty in the behaviour of the real Earth System (Steffen et al [51]). *Sustained observations expose our ignorance of important natural processes, and force improvements in the science of forecast models and products* (Hollingworth et al [35]) which *will help constrain projections of the future and will support the testing and development of models in a way model development alone is unlikely to achieve* (Gallopin [26]). *Thus there is an urgent need to maintain and develop the monitoring of the Earth System i.e. historic records, utilisation of new satellites* (Steffen *et al* [51]) precisely because it is against such observation that the "truth" of a model can be evaluated and the assumptions "validated" (Swinbank *et al* [9]). Modelling is and never can be an alternative to observation. Instead it must be but an accompanying tool, used within the theoretical framework to aid understanding of those observations and their theory (Wainwright and Mulligan [28]). The two go hand in hand and are not polar opposites because models have only limited value at the science-policy interface if one does not have a deep understanding of a system process or feedback (Betts [64]).

Conclusion

There are clearly both advantages to be obtained and disadvantages to be overcome in the future success of climate change modelling with every advance requiring new and improved methods and theories. Future modellers must not only promote continued observation but a truly interdisciplinary effort so that the disadvantages of do not outweigh the potential successes of models. Models are not gospel but are revolutionary and the prowess of science and politics to understand the Earth System would be greatly diminished if they were not embraced and utilised, despite their clear limitations and the disadvantages and controversies that accompany them.

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