CLIMATE CHANGE, Part II:
Models, Uncertainty, Data, and Predictions - *or "Why Climate Models are Like Sausages"*

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EXTENDED ABSTRACT

Climate researchers rely heavily on mathematical and/or stochastic models and modeling of Earth processes in order to pose hypotheses/theories on, or make predictions or projections regarding Climate Change. The validity of these models is often questioned from many standpoints. These questions arise primarily from data errors, bias, imprecision of measurements, stochasticity, incomplete scientific knowledge, and inability to fully characterize the natural processes modeled. Because of these factors, uncertainty is present in all such models and it is worthwhile to examine the causes of uncertainty and how uncertainty affects predictions of future Earth climate.

Understanding how uncertainty enters into climate models and predictions becomes even more important when it is realized that policy makers (as well as the media and general public) often accept these climate models on "face value" alone. Moreover, world leaders are daily using climate models to make decisions relating to climate policies without regard to the resulting and far reaching effects on World economies and standards of living. It is doubtful that these decision makers realize what underlies these models, or that there are missing "error bars" that need to be considered in their interpretation.

An example of the incredible complexity of the natural climate system of Earth is seen in the effort to build credible General Circulation Models (GCMs). In order to begin to describe a GCM for Earth's atmosphere or oceans requires parameterization of over 500,000 variables in which Navier-Stokes equations (non-linear fluid mechanical equations that come out of the process of averaging) on a rotating sphere with thermodynamic terms for various energy sources (e.g., radiation, latent heat) are used to describe the system. Non-linear equations exhibit a peculiar unpredictability in their solutions, not unlike the randomness known as *chaos*. It is thus nearly impossible to develop a full differential/deterministic (i.e., mathematically described) model for the complex processes occurring in the phenomenon being investigated. Notably, these models cannot or often do not include affects from tornados, hurricanes, lightening, etc. (the so-called *"Butterfly Effect"*), which have profound effects on the world's weather. Because of difficulty in describing the inherent complexity of these systems, many modelers have turned to stochastic models relying on *Markov Processes* and/or *Deterministic Chaos* (e.g., Lorenz equations) which may provide better solutions for prediction of changes in Earth's atmosphere and oceans, though there remains danger of error propagation even in these models (paraphrasing Nicolis, 1990).

C. J. Mann (1993) states uncertainty as a simple concept, and gives its meaning as that which is indeterminate, not certain, containing doubt, indefinite, problematical, *non-reliable*, *and/or dubious*. He further divides uncertainty into three categories: Type I – *Deterministic Uncertainty*, and Type II – *Stochastic Uncertainty*, both of which are quantitative in nature; and Type III – *Qualitative Uncertainty*. The three types of uncertainty are not mutually exclusive or statistically independent, and a single source of uncertainty may contribute to different types of uncertainty.

Evidence of presence of the three types of uncertainty was investigated in several recent climate change models which figure prominently in the news and media, and which have been influential in bringing Climate Change to the forefront of today's societal concerns. The purpose of this investigation was to test the validity of the models as good representations of the actual processes occurring in the real systems and predictors of future climate. The approach to model validation requires identifying the factors which contribute to the difference between predictions/projections and observations. The models investigated include the work of M. E. Mann, et al

(1998) on global temperature patterns (i.e., the now famous "Hockey Stick" model); S. A. Marcott, et al (2013), 11,300 year regional and global temperature reconstructions; S. Jevrejeva, et al (2009), on anthropogenic forcing of sea level rise; R. E. Kopp, et al (2016), on temperature-driven global sea-level variability; and lastly, D. Archer (2005), and Archer and Ganopolski (2005), on the fate of fossil fuel CO_2 in geologic time and residence time of CO_2 in the atmosphere. In the case of Mann, et al, the model's uncertainty came not from the method or the scientific approach used, which was sound, but uncertainties introduced through data errors, instrumental and measurement errors, use of *proxies* whose relationship to temperature may not have been well understood, and errors in the application of the Principal Components Analysis statistical procedures. These uncertainties may have also been inadvertently propagated into the later work of Marcott, et al (2013) on the same topic. This points up the extreme necessity for researchers to carefully scrutinize their work and subject it to verification and validation procedures before release to the public.

The basic results of this investigation suggest that in many cases climate models, because of the uncertainty built into them, do not meet the most basic requirements of the scientific method. Many, and possibly most, climate models have not yet been objectively demonstrated to be acceptable descriptions of reality, and therefore may not be valid predictors. The models investigated rely heavily on probabilistic rather than differential methods, due to difficulties in developing deterministic models for such complex phenomena and the paucity of data available necessary to parameterize the models.

In conclusion, results arising from such models should therefore be seen as *possibilities or possible scenarios*, rather than as exact images of realty. Further, these models *should be bracketed by error bars or Probability Distribution Functions (PDFs,) signifying their level of reliability as predictors.* The models themselves should not be accepted at face value, and policy makers as well as the public should be skeptical of a model's validity without objective proof that it is an acceptable portrait of reality. It follows that the acceptance of the model or models as decision making tools should be a measured one.