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Hydrology and Earth System Sciences Discussions

Interactive comment on “*HESS Opinions* “A random walk on water”” *by* D. Koutsoyiannis

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GENERAL COMMENTS

The key contribution of the paper by Demetris Koutsoyiannis (DK), with the imaginative and inventive title “A random walk on water”, is the analysis of the ’predictability’ of natural processes and of the behaviour of hydro-systems. Prediction is a core issue in hydrology and in water resources engineering; to quote Harleman (1986), “the prediction by models of effects and benefits, in advance of the construction of a facility, is the essence of engineering.” This view is mirrored in DK’s statement (6619: 7-9) that prediction “is a crucial target of science – with even higher importance in engineering.” DK argues that the traditional decomposing of natural phenomena into two mutually exclusive components, a deterministic and a random one, is artificial. Following a favourite approach of his, DK uses a caricature hydrological system and its toy model to illustrate that (Abstract, 6612: 11-17) “it is possible to shape a consistent stochastic representation of natural processes, in which predictability (suggested by deterministic laws) and unpredictability (randomness) coexist and are not separable or additive components. Deciding which of the two dominates is simply a matter of specifying the time horizon of the prediction. Long horizons of prediction are inevitably associated with high uncertainty, whose quantification relies on understanding the long-term stochastic properties of the processes.” In my opinion, DK presents his viewpoint credibly; I would only like to add two ideas of how this study could be extended or complemented.

SPECIFIC COMMENTS

First, I want to congratulate DK for the intelligent design of his illustrative example. The simplicity of the caricature system and its toy model allows conveying difficult notions lucidly, e.g., deterministic dynamics, chaotic behaviour in response to uncertainty in the initial conditions, stochastic representation of system evolution, estimation of the prediction uncertainty and of the skill of a deterministic versus a naïve statistical projection in relation to the forecast horizon. This paper is thus interesting scientific reading, but it is also written in such a way that it can be useful in the classroom as well (for example, the “steam tube” analogy and the rationale for ensemble forecasting in flood hydrology). Section 4, entitled “The power of data” [6626-6636], conveys effectively the message of the value of data. Perhaps, the hydrologic community, and particularly the competent government agencies, should rethink the ongoing dismantling of monitoring networks. The importance of data connects very well with the discussion in section 6, entitled “From the toy model to the real world” [6636-6638], regarding the properties of an appropriate model (among other issues, detail in the modelling of the physics and in the discretisation, and modelling parsimony).

Let us now return to the toy model of the caricature system to reconsider the solution approach. Suppose (i) that Eqs. 1-2 used to advance the solution in time were numerical approximations of two differential equations (DEs), finite difference schemes,

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say, and (ii) that it were possible to solve those DEs by exact integration and to obtain analytical expressions. Of course, nonlinear DEs in general, and those describing chaotic systems in particular, rarely can be integrated exactly, yet the existence of their analytical solutions is useful for our present argument, allowing to pose the following questions: Were the temporal evolution calculated analytically, instead by an approximate numerical scheme, would the exact solution behave as the numerical one? If not, how would the two differ? These questions have practical value, because, in hydrological applications, calculations are carried out by means of numerical approximations of the governing DEs. Obviously, these questions cannot be answered without conducting a new study (for, contrary to assumption (i), DK uses Eqs. 1-2 as 'exact' solutions), yet they seem worth pondering.

The two methods of calculation would differ. The analytical one (continuous-time dynamics) would always start from the slightly perturbed initial condition and would advance the solution directly to any future time; in contrast, the numerical one (discrete-time dynamics) would use successively the result from time i-1 to advance the solution to time i, carrying forward any inherited imprecision (the first one being any imprecision in the initial condition) due to the approximate solution. Formulating the problem also in continuous time (analytically) has the merit that the system's intrinsic unpredictability could be separated from the uncertainty caused by the propagation of the numerical error. However, the nonlinearity of the DEs would not permit the (instructive) analytical tracing of the error propagation in continuous time (hence DK's numerical calculation of the system evolution). An error analysis, as applied to schemes for the numerical solution of linear DEs, seems also impossible; in that analysis (e.g., Roache, 1976), a small error is introduced at the initial time and its propagation is traced via the numerical scheme, yielding the stability (and additional) conditions. I surmise that the nonlinearity of Eqs. 1-2 would also lead to error equations non-separable from the numerical scheme containing only solution values. Therefore, in the expectation that a simpler – still chaotic – model hydrological system could be devised that would be amenable to analytical treatment, the equations would have to be simplified, in particular the parent

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DE of Eq. 2.

With the results of DK's toy model for the caricature system as backdrop (especially the relevant for climatic processes persistent behaviour displayed in Figs. 15 and 16 – HK processes), it is hard not to doubt the reliability of projections by climate models for time horizons from one hundred to multi-thousand years. Some of the pathologies of GCM projections, and of their post-processing (downscaling), have been highlighted in the literature, e.g., Rougier (2007) and Koutsoyiannis et al. (2008), and make planning for water resources management under future climate scenarios seem a questionable, or even futile exercise. However, as W. Soon (2009) points out, we should be concerned with finding alternatives to the deterministic GCM projections (a problem that DK and his co-workers also discuss elsewhere, e.g., Koutsoyiannis et al. (2007, 2009b)).

Next, I would like to refer to four points from the penetrating discussion of S. Weijs (2009): (1) [section 1, C2735] "Maybe we just have to conclude that randomness and determinism can emerge from each other and which one dominates depends on scale in general and not just on time, as is stated in (6612:14-15)." (2) [section 3, C2736] "I would rather see hydrological systems as high-dimensional complex systems, with surprising predictable macroscopic behaviour." (3) [section 5, C2741] "Modeling relations between macro-states is what we mainly try to do in hydrology (referred to by Koutsoyiannis as 'overstanding'),. . ."; and (4) [section 5, C2742] "Another distinction that can be made is the prediction of simple systems of few states (like in particle physics) and prediction of the macro-states in far larger systems (like in hydrology). In the paper by Koutsoyiannis this difference is referred to as the difference between understanding and "overstanding"."

Based on the aforementioned four points of Weijs and on his plausible assumption [section 3, C2737] "that the states used in the caricature system are in fact macro-states of a more complex system", a study of the predictability of the macroscopic behaviour of a system could be carried out following the consistent stochastic representation of DK, but generalised to use scale in addition to time. DK acknowledges [6636: 14-20] a

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multitude of sources of uncertainty in real-world systems, one of which is high dimensionality. Such a study would be complementary to the one presented by DK, which focuses on chaotic system dynamics. It would evaluate the system response due to the uncertainty in a more realistic (> 2 state variables), yet still relatively small number of state variables (to keep the computational effort manageable), in order to assess the predictability of the macroscopic behaviour of real systems. We may then see whether real systems (at their macro-states) are more, or less predictable than a simple toy system, considering also persistence in space, i.e., Hurst-Kolmogorov behaviour in the spatial evolution.

SUMMARY ASSESSMENT COMMENTS

Taking “A Random walk on water” with Demetris Koutsoyiannis has been enjoyable. It is stimulating and thought-provoking reading, guaranteed to enrich one’s thinking about and “overstanding” of predictability in hydrology, in the context of theory and praxis alike (even for non-specialists in random processes and the maximum entropy principle) – its etymological excursions and historical references adding the salt so often missing from our techno-texts.

EGU’s awarding of the Henry Darcy Medal for 2009 to Demetris Koutsoyiannis “for his outstanding contributions to the study of hydrometeorological variability and to water resources management” is a well-deserved distinction of excellence in hydrological science. One can agree or disagree with certain of DK’s positions, although I admit that I could not find much to dispute in this HESS Opinion paper. But DK should be recognised not only for the inquisitive intellect that his innovative work manifests, but also for his courage and strength of character to challenge accepted wisdom, for, as history teaches, and the recent “Climate-Gate” affair confirms, it is not easy being an iconoclast.

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