A dynamic statistical experiment for atmospheric interactions

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Interactions among atmospheric parameters exist at different scales. The pristine approach for observational or model data analysis involves changing the input parameters one at a time (OAT) and studying the effect on the system. Limitations of this approach for atmospheric applications are discussed. A fractional factorial (FF) based study is evolved and a methodology is outlined involving dynamic graphical analysis. Observational data from the FIFE and HAPEX-MOBILHY experiments are utilized with a vegetation and soil moisture scheme dynamically coupled in a planetary boundary layer model to demonstrate the robustness of this approach. Both low-resolution and high-resolution designs are considered. Various aspects of the vegetation-atmosphere interactions are delineated. Results obtained from the interaction-based FF approach differ considerably from the earlier OAT-type studies.

Keywords: FIFE, HAPEX-MOBILHY, planetary boundary layer, biospheric analysis, fractional factorial design

1. Introduction

The atmosphere is a dynamic system where various energy transfer mechanisms act simultaneously at different scales. Over the years, our knowledge of this system has evolved from various field experiments and rigorous modeling exercises. Efforts to understand the atmospheric processes started with the assumption of a homogeneous and uniform bare surface. Presently, one of the biggest challenges in atmospheric and climate modeling is to efficiently represent surface features such as vegetation, and soil moisture and associated surface temperature variation [4,20]. This knowledge has helped in understanding and realistically simulating planetary boundary layer (PBL) processes. To study the effect an input parameter has on an entire modeling system, that parameter is generally varied while all the others are held constant. However, we feel that to gain more knowledge of the system, better methods of analysis than the "one-at-a-time" approach must be applied.

Our present study proposes the use of a dynamic graphical statistical method such as main-effect and Pareto plots, which can be efficiently employed for extracting information on various interactions within the atmospheric processes. The effectiveness of the proposed method is demonstrated through a simulation study using the land-surface scheme of Noilhan and Planton [19] (hereafter referred to as NP89) in a columnar version of the North Carolina State University (NCSU) planetary boundary layer (PBL) model [1].

Our overall aim is to show that interaction explicit analysis is useful, if not essential, for atmospheric studies.

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2. Experimental design

Proper experimental design is crucial for any analysis. Presently there are three ways of designing this kind of an experiment, based on the following approaches: (1) one at a time (OAT), (2) factor separation [21], and (3) fractional factorial [6]. To elucidate the bases of these approaches, consider a system with input parameters P_1, P_2, and P_3. In an OAT approach, the effect a parameter P_1 has on the system is treated as

$$E(P_1) = K(P_1),$$

i.e., the changes in the system effect are attributed to the changes in P_1 alone through a function K. P_1 is altered over a possible range in steps and the resulting E (OAT) for each P_1 value is obtained. The same is done for P_2 and P_3, and by comparing the values of $E(P_i)$ the role or significance of each parameter on the entire system is pictured.

The factor separation (FacSep) approach attempts to resolve the effects of P_1 on the system into those that are directly and interactively dependent on P_1. Thus, the setup involves simulating a system with 2^n combinations (see [21]).

In comparing the OAT and FacSep approaches, we find that the OAT approach has the limitations that (1) it is conceptually incorrect, as it assumes an independence of the events, and (2) the outcome exaggerates the significance of the parameter. For example, if vegetal cover is altered in a model, corresponding variations are expected in soil moisture and soil temperature. The net effect due to the vegetal cover change is thus a combined one and not just that due to change in vegetal cover alone (see [3] for a discussion). This could lead to an erroneous hypothesis for the development of parameterizations and for an understanding of the process. The FacSep method is informative, but it may not