

## A Scientific Function Test Framework for Modular Environmental Model Development: Application to the Community Land Model

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Environmental system modeling presents a variety of challenges. Through the past several decades, along with strong interests of understanding the large-scale environmental phenomena and the rapid development of computing technologies, many computer models have been developed to capture our knowledge on numerous facts of environmental systems, and to explore better options for system-wide management. Therefore, environmental models generally embrace multiscale and multidisciplinary integration. Recently, many high performance, integrated environmental modeling systems have been developed to address new challenging problems. It is challenging to redesign environmental models and to validate model results under new configurations, because the software system of these environmental models quickly becomes complicated. Therefore, we need new tools to analyze and verify model projections, to expedite integrated model developments, and to facilitate the collaborations among broad scientific communities including field scientists, environmental system modelers and computer scientists

From a software engineering perspective, a lot of effort has been placed on software structure analysis to improve software quality and computing performance. We think it is the time to develop new computational frameworks to analyze complicated environmental modeling system with emphasis on hypotheses, scientific workflow, and numerical methods inherited from existing model development. Herein, we present our new effort on scientific function test framework for modular environmental model development. Evolved from the traditional concepts on software unit testing, our framework is designed to provide innovative and convenient (piece-by-piece) ways for process-based multiscale model verification and validation, covering both model structure and scientific workflow. It expedites model modification and enhancement; it also enables environmental model reconfiguration, reuse and reassembly. We have applied these methods to the Community Land Model with three typical scenarios: 1) benchmark case function validation, 2) observation-constraint function validation, and 3) a virtual root module generation for root function investigation and evaluation. We believe that our strategies and experience in scientific function test framework can be beneficial to many other research programs that adapt integrated environmental modeling methodology.