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Stable water isotope simulation by current land-surface schemes: Results of iPILPS Phase 1

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Abstract

Phase 1 of isotopes in the Project for Intercomparison of Land-surface Parameterization Schemes (iPILPS) compares the simulation of two stable water isotopologues ($^{1}H_2{}^{18}O$ and $^{1}H^{2}H^{16}O$) at the land–atmosphere interface. The simulations are offline, with forcing from an isotopically enabled regional model for three locations selected to offer contrasting climates and ecotypes: an evergreen tropical forest, a sclerophyll eucalypt forest and a mixed deciduous wood. Here, we report on the experimental framework, the quality control undertaken on the simulation results and the method of intercomparisons employed. The small number of available isotopically enabled land-surface schemes (ILSSs) limits the drawing of strong conclusions, but, despite this, there is shown to be benefit in undertaking this type of isotopic intercomparison. Although validation of isotopic simulations at the land surface must await more and much more complete, observational campaigns, we find that the empirically based Craig-Gordon parameterization (of isotopic fractionation during evaporation) gives adequately realistic isotopic simulations when incorporated in a wide range of land-surface codes. By introducing two new tools for understanding isotopic variability from the land surface, the isotope transfer function and the iPILPS plot, we show that different hydrological parameterizations cause very different isotopic responses. We show that ILSS-simulated isotopic equilibrium is independent of the total water and energy budget (with respect to both equilibration time and state), but interestingly the partitioning of available energy and water is a function of the models' complexity.

Keywords: water isotopes; land parameterization; model intercomparison; Craig-Gordon scheme; PILPS

1. iPILPS introduction

1.1. Background and timing

The goals of iPILPS are to (1) offer a framework for intercomparison of isotope-enabled land-surface

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schemes (ILSSs) and (2) encourage improvement of these schemes by evaluation against high-quality (isotope) observations. When iPILPS was approved by the GEWEX Land–Atmosphere System Study (GLASS) in September 2004 (Henderson-Sellers, 2006), it was agreed that its first stage (Phase 1) would focus on the stable water isotopes $H_2{}^{18}O$ and ${}^1H^2H^{16}O$.

Phase 1 of this international project tests the hypothesis that: observation and analysis of the diurnal fluxes of ${}^1H_2{}^{18}O$ and ${}^1H^2H^{16}O$ between the soil, plants and atmosphere can accurately determine the partitioning of precipitation into transpiration, evaporation and total runoff (surface plus soil drainage). Although this hypothesis is not fully tested in this paper, the direction such testing could take is described in Henderson-Sellers (2006). The iPILPS effort will contribute (1) to improving the accuracy with which land-surface schemes partition net available surface energy into latent and sensible heat fluxes and thus (2) to decreasing uncertainty in hydroclimate modelling and water resource vulnerability predictions. Phase 1 of iPILPS exploits novel stable water isotopes (SWI) and analysis techniques in the development and evaluation of ILSSs. To achieve the project aims, it is necessary to:

(1) identify and test ILSSs which already (or plan soon to) incorporate SWIs;
(2) appraise SWI data applicable to hydroclimatic and water resource aspects of ILSSs;
(3) identify observational data gaps required for evaluating ILSSs and resolve them; and
(4) apply SWI data to specific predictions of well-understood locations simulated by available ILSSs.

The timeline for Phase 1 of iPILPS began in late 2004 with the distribution of the Phase 1 plan and call for participants (see Henderson-Sellers, 2006). The simulations were conducted over the period February to April 2005. The inaugural iPILPS Workshop from 18 to 22 April 2005 was held in Sydney and focussed on the first intercomparison results. Throughout Phase 1 of iPILPS, an interactive website is being used to manage the ILSS simulations from participants (http://ipilps.ansto.gov.au). This allows quick-look intercomparisons by the ILSS owners and rapid community-wide dissemination of results.

1.2. Forcing meteorology and isotopes

Offline simulations need appropriate boundary conditions. The ILSSs require either measured forcing meteorology and isotopes or the same variables derived from a model representing atmospheric and isotopic processes as closely as possible to actual meteorological conditions. The meteorological and isotopic variables need to be coherent; deriving one from observations and the other from a model is not adequate.

For iPILPS Phase 1, it was determined that the only way of supplying adequately good forcing was to use an isotope-enabled atmospheric model. The REMO (REgionales MOdel, developed by the Max Planck Institute for Meteorology, Hamburg) had been shown to generate high-quality simulations for two of the three selected locations (Sturm et al., 2005, submitted for publication). The spatial resolution of REMO is 1/2 degree (~54 km) with a model timestep of 5 min. REMO is nested into the European Centre Hamburg GCM (ECHAM) and the iPILPS Phase 1 forcings were derived from nesting into the 'climatological' version of ECHAM, which had a constant annual cycle in sea-surface temperatures—see Fischer and Sturm (2006-this issue) for further details.

Even though weather systems are better represented in REMOiso than in a global model, running in a climatological mode does not permit reproduction of specific meteorological situations. Global reanalyses, which assimilate all available meteorological observations, are believed to provide the best estimation of the actual state of the atmosphere (e.g. Kistler et al., 2001), but no isotopic information is yet available in any reanalysis.

The simulations of REMOiso have been thoroughly analysed in its first domain, which covers the European continent, encompassing temperate, Mediterranean and subpolar climates (Sturm et al., 2005). Following this success, REMOiso was moved to the South American continent, including the Amazon, the arid grassland regions such as Brazil's Nordeste and the Andes glaciers (Sturm et al., 2006-this issue). Most recently, REMOiso has been integrated over Australia spanning tropical monsoons in the north, the arid centre and to Mediterranean climates in the south (Fischer and Sturm, 2006-this issue). All these model evaluations have been successful for simulated precipitation and humidities and their isotopic signature and REMOiso parameterizations have been proved to be elaborate enough to adequately represent secondary effects such as the deuterium excess. Based on these experiments, we are confident that REMOiso performs well in all climatic environments selected for iPILPS.

The forcing data include magnitudes of each isotope (i.e. ${}^1H_2{}^{18}O$ and ${}^1H^2H^{16}O$) in precipitation and in water vapour at the atmospheric lowest level