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A quantitative analysis of short-term precipitation isotopic variability with a Rayleigh-type isotope circulation model

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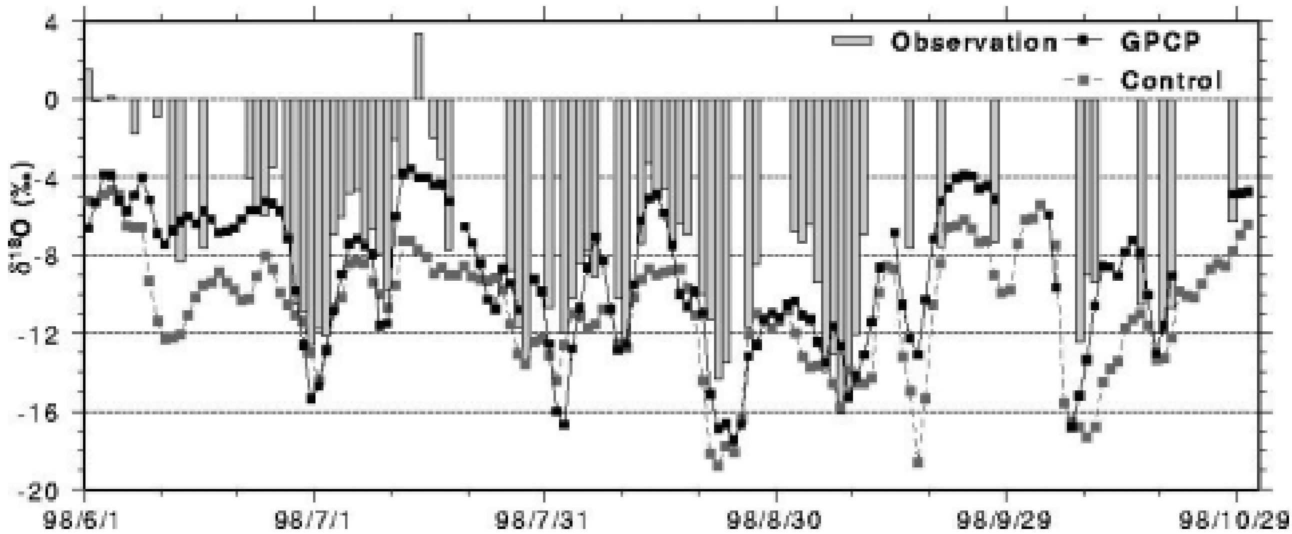
Large spatial and temporal variability of stable water isotopes (D and 18O) in precipitation are widely used to trace the global hydrologic cycle. Rayleigh-type models have first explained the spatial and temporal variability. Subsequently, studies that incorporate the isotopic physics into atmospheric general circulation models (AGCM) have examined the isotopic variability at monthly or annual scales. The causes of short-term (1-10 days) variability in precipitation isotopes, however, remain unclear. This study seeks to explain isotope variability quantitatively at such scale.

Thus, a new water isotope circulation model on a global scale that includes a Rayleigh equation and the use of external meteorological forcings is developed. Transport and mixing processes of water masses and isotopes that have been neglected in earlier Rayleigh models are included in the new model. A control simulation of 18O for 1998 is forced with data from the GAME (GEWEX Asian Monsoon Experiment) reanalysis. The forcing variables from the dataset are precipitation P, evaporation E, precipitable water W, and vertical integrated moisture flux Q (2 horizontal components). The results are validated by GNIP (Global Network of Isotopes in Precipitation) monthly observations with correlation R=0.76 and a significance level exceeding 99%. The short-term isotopic variability is well reproduced comparing with daily observations at three sites in Thailand with similar correlation and significance. The present study also confirms that the impact of the amount of precipitation at the site, i.e., 'amount effect,' is insufficient to explain the short-term isotopic variability. The control factors of short-term variability are quantitatively revealed for the first time in this study. The contributions from each of the three factors have clear geographical distributions: moisture flux is most important in arid regions, precipitation dominates in regions of persistent rain, and evaporation is important in warm maritime regions. However, the contribution of moisture flux is the largest, accounting for 37% at Chiangmai, and 46% in the global average. This highlights the importance of transport and mixing of airmasses with different isotopic concentrations.

Moreover, a sensitivity analysis of the temporal and spatial resolution required for each variable is also made, and the model is applied to two additional datasets. The more accurate GPCP (Global Precipitation Climatology Project) precipitation dataset yields improved model results at all three observation sites in Thailand. For example at Chiangmai, Thailand, the correlation increases to 0.80 from 0.76, and the root mean square error decreases to 2.9 permill from 4.2 permill comparing with the control simulation. In addition, data from the NCEP/NCAR (the National Centers for Environmental Prediction and National Center for Atmospheric Research) reanalysis allow the simulation to cover two years, reproducing reasonable interannual isotopic variability. In particular, the model reproduces the downward arch in seasonality over Thailand in 1998, and the upward arch in seasonality in 1999. The improved results from GPCP and the reasonable interannual reproduction from NCEP/NCAR support that the study appropriately models isotope circulation in an area influenced by the Asian Monsoon.

This study reveals that the moisture transport system at large scales (more than 100 km) generates most of the short-term isotopic variability, and regional rain-forming processes, that include in-cloud microphysics and temperature variations of condensation and evaporation in convective activities, are not a primal factor. Further, more validations with daily observations in various sites are required for further improvement of the model reliability.



Observation
GPCP
Control
δ¹⁸O (‰)
4
0
-4
-8
-12
-16
-20
98/6/1
98/7/1
98/7/31
98/8/30
98/9/29
98/10/29