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Assessment of the fluctuation-dissipation theorem as an estimator of the tropospheric response to forcing.

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The Fluctuation-Dissipation Theorem (FDT) predicts the response of a stochastic dynamical system to a small applied forcing given data on the unforced behaviour of the system. The applicability of the FDT to predicting the zonally averaged response of the tropospheric circulation to an external forcing is investigated, with particular emphasis on quantitative accuracy. The latter requires consideration of the statistical problem of estimating the linear operator, expressing the response in terms of the applied forcing, from the available data. Two different forms of this estimated operator are considered, one (the Gaussian FDT) resulting from a quasi-Gaussian assumption and the other (the linear FDT) resulting from a linear inverse modelling approach. Both forms include a parameter that needs to be chosen on practical grounds. Analysis of the behaviour of a simple two-dimensional stochastic model shows how statistical uncertainty needs to be taken into account in choosing the optimal form for the estimated operator. The same principles are shown to be relevant when applying the FDT to a simple general circulation model. The additional question of how many spatial degrees of freedom it is useful to include in the calculation is also considered. Other aspects of the application of the FDT which are also important to consider include whether or not a linearised approach valid for small forcing is justified and also the calculation of an 'effective forcing' that is required when the FDT is applied to a reduced system in which some of the degrees of freedom of the original system have been discarded. Having taken all these aspects into account, it is concluded that the Gaussian FDT and linear FDT are not useful quantitative estimators of the zonally symmetric circulation response.