Using short-term physical tendencies to study the dynamical balance of atmospheric models

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Dynamical imbalances between the physical processes included in an atmospheric model can have an impact on the realism of the climate of a model and its variability. It is often observed that the climate of a model may differ from that of observations and detailed diagnostics are necessary to assess whether adjustments in the physical parameterizations used for convection, radiative and dynamical processes lead to a state that is close to observations. Rodwell and Palmer (2007) have proposed to use diagnostics based on short-term physical tendencies of the model when analyses are used as initial conditions. Such diagnostics provide useful information about the consistency of the physics as it relaxes to the model's own climatology in the first moments of the integration. On the other hand, it is well known that analyses can themselves create spin-up problems that need to be addressed by using normal mode initialization or digital filtering to remove spurious gravity waves. Gauthier and Thépaut (2001) showed that 4D-Var analyses provide initial conditions that are better balanced and do not require as much the application of other constraints to maintain this equilibrium. In this study, using the model that produced the analyses, the difference in the impact of using 3D or 4D-Var analyses on the diagnostics of the physical tendencies is shown to be significant in the Tropics and results in differences in the ITCZ. In another set of experiments, integrations with this model started from its own 4D-Var analyses were compared to integrations using ERA-interim analyses as initial conditions. While the two analyses are similar, the diagnostics revealed huge imbalances which persist even after 5 days of integrations. This reflects the differences between the two models as analyses embed the dynamics of the model used in the assimilation.

For global climate models, a long integration is done to spin-up the model to its own climatology and this imbalance is of little consequence except for model validation comparing a climate run against reanalyses. The problem however is more serious for regional climate models which are driven by either reanalyses or a global climate run often obtained from another model. In a third set of experiments, short integrations were performed with the Canadian Regional Climate Model (CRCM), a limited-area configuration of the global model used by the 3D and 4D-Var assimilation. Short integrations were done with initial conditions based on the 3D and 4D-Var analyses described above, and the diagnostics revealed imbalances, in both cases, slightly more important than in the previous experiments. Using ERA-interim reanalyses led also to a significant imbalance comparable to those of the previous experiment with the global model. Other experiments were also conducted in which the model boundary conditions driving the model are provided every 6-h as is usually done for the CRCM climate simulations. In experiments using 4D-Var analyses and ERA-interim reanalyses to define the boundary conditions, the results showed more important imbalances for the ERA-interim integrations as was observed in the other experiments with the global model. We conclude from these results that the diagnostics used by Rodwell and Palmer (2007) are very useful to detail the nature of the imbalances in climate models. Our results show that differences between the model driving a regional climate model and the RCM can create imbalances that could artificially alter the model's internal variability.

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