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Summary

Applications of linearized physics - Marta Janisková

Adjoint models (transpose of the linearized models) are powerful modeling tools that enable many problems to be solved efficiently. They have several applications in numerical weather prediction (NWP). In variational data assimilation for instance, they are used as a tool for efficient determi- nation of the optimal solutions. Without this tool, the optimization problem could not be solved in a reasonable time for real-time forecasting. Another application is for singular vector computa- tions, which can be employed in Ensemble Prediction System (EPS) to generate perturbations to the initial conditions. Furthermore, adjoint models can be used for sensitivity studies or objective estimation of physics parameters. Though initially only the adiabatic linearized models were used in NWP, the significant role of physical processes was soon recognized and they were gradually included in adjoint models with the different level of complexity.

Variational data assimilation

Using physical processes in the assimilating model can reduce the so-called spin-up problem, pro- duce an initial atmospheric state more consistent with the physical processes and provide a better agreement between the model and data. Furthermore, it is an important step towards the use of observations that are directly related to the physical processes, such as rain, clouds or soil moisture.

In variational data assimilation, linearized physical parametrizations have two main applications. Firstly, they are used during the assimilation to link the models prognostic variables (typically temperature, wind, humidity and surface pressure) to the observed quantities (e.g. radiances, reflectivities, backscatters). Secondly, in the particular context of four-dimensional variational (4D-Var) data assimilation, the model with physical parametrizations is needed to evolve the model state from the beginning of the assimilation window to the time of the observation.

Over the years physical parametrizations become important components in current variational data assimilation systems. The direct relative improvement of analysis and subsequent forecast coming from including the linearized physics in the 4D-Var system (i.e. impact on the evolution of the model state in time during the assimilation) was illustrated in Janiskov´a and Lopez (2013). How- ever, further improvement in producing more realistic initial atmospheric states can be achieved by assimilation of observation related to the physical processes as demonstrated, for instance, by operational assimilation of microwave radiances in all sky conditions (Bauer et al., 2010; Geer et al., 2010) or surface rain data from ground-based NCEP Stage IV rain radars and gauges over the Eastern US (Lopez, 2011), as well as by experimental assimilation of spaceborne cloud opti- cal depths from MODIS (Benedetti and Janiskov´a, 2008), synoptic station (SYNOP) rain gauge observations (Lopez, 2012) or cloud radar data from CloudSat (Janiskov´a et al., 2011).

Singular vector analysis

The adjoint models have also application in singular vector (SV) analysis. Singular vectors repre- senting the fastest-growing perturbations over a finite time interval, can sample the dynamically most relevant structures to dominate the uncertainty sometime in future. They can be used to generate perturbations to the initial conditions in EPS.

Including linearized physical parametrization schemes into SV computations can lead to more of the SV structures to be associated directly with some atmospheric processes (such as processes in planetary boundary layer, tropical instabilities or development of baroclinic instabilities) and subsequently to a better spread in EPS. For instance, study of Lang et al. (2012) has shown that using diabatic processes in SV calculations result in stronger growth being associated with the tropical cyclone compared to other flow features and generate larger spread of wind speed, track and intensity of cyclone when such SVs are used to initialize ensemble forecast.

Adjoint sensitivities

Since adjoint models allow to compute the gradient of one output parameter of a numerical model with respect to all input parameters, they can also be used for sensitivity studies. Using the physical processes in these models improves the sensitivity analysis thanks to a more consistent description of atmospheric processes. When adjoint technique is applied to a particular physical parametrization scheme, it can provide information on the meteorological variables to which the parametrization scheme is the most sensitive. This can be used as a different, more effective tool for the validation of parametrization scheme since the sensitivity of one output variable to a number of input variables can be obtained in one run instead of multiple runs required by other standard approaches (e.g. Li and Navon, 1998; Janiskov´a and Morcrette, 2005).

More generally, an adjoint can be applied to sensitivity of a forecast error to initial conditions or any forecast aspect (e.g. precipitation, cyclone,) to the model control variables. The adjoint method can also be used to measure the sensitivity with respect to any parameter of importance of the data assimilation system. In recent years, adjoint-based observation sensitivity techniques have been used as a diagnostic tool to monitor the observation impact on short-range forecasts (e.g. Lagland and Baker, 2004; Zhu and Gelaro, 2008; Cardinali, 2009). Since this technique is influenced by simplified adjoint model used to carry the forecast error information backwards, more sophisticated adjoint model leads to more flow dependent and more realistic sensitivities. Results obtained when using a too simplified adjoint model with large inaccuracies or adjoint models without a proper treatment of nonlinearities and discontinuities, can be incorrect.

Objective optimization of physics parameters

Adjoint of physical processes can also be used for efficient determination of model parameters. This is similar to the problem of data assimilation, except that instead of or in addition to tuning model initial conditions, the best fit of forecasts with respect to the model parameters is determined. The goal is to adjust the value of (some) physics parameters by cycling 4D-Var data assimilation (over one or two months), under the constraint of all routinely available observations as demonstrated by Lopez (personal communication). There are some limitations for this application. Only pa- rameters that are present in both the forecast model and the linearized simplified physics (used in the minimization of cost function) can be treated in this way. Discrepancies between these two parametrization sets might lead to suboptimal results. This method is also uncertain for parame- ters associated with more non-linear processes (e.g. condensation) or less well constrained by the observations.

Summary

A positive impact from including linearized physical parametrization schemes into the assimilating model and singular vector computations has been demonstrated in the experimental and opera- tional runs. The adjoint of physical processes has also application in sensitivity studies and model parameter estimations. However, all these applications of the linearized physics have some require- ments and limitations to be considered. One of them is linearity of physical parametrization and observation operator. Non-linearities could cause convergence problems in variational assimilation which is based on strong assumption that the analysis is performed in quasi-linear framework. They could also lead to spurious unstable modes in computation of singular vectors. The relevance and usefulness of adjoint sensitivity can be limited by the degradation of the linearity assumption. Ac- curacy of physical parametrization and observation operator is also important in order to provide realistic enough sensitivities and model equivalent to observations. Moreover, one needs to consider a computational cost for practical applications.

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