A nonlinear descent method without inversion of the background error variance-covariance matrix in variational analyses

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A new descent method is developed for adopting sophisticated background statistics in nonlinear variational analyses (i.e., analyses adopting a non-quadratic cost function). The general consensus holds that it is essential to include the term of constraint on the difference between background and analyzed values in the cost function in variational analyses. If including the background term, optimization with a conventional descent method requires the inversion of the large matrix called background error variance-covariance matrix. Fourier transformation with homogeneous and isotropic assumption is often adopted for avoiding this difficulty in atmospheric assimilation systems. This method is, however, not suitable for ocean analysis because of its lateral boundaries and the non-homogeneity of the correlation fields. Thus, the conjugate gradient method that allows us to avoid the inversion is widely adopted in oceanic three-dimensional variational (3DVAR) analyses. The method can, however, not be adopted in nonlinear problems: it cannot minimize a non-quadratic cost function. We, therefore, developed a new nonlinear preconditioned quasi-Newton method, which can be adopted in nonlinear problems without the inversion of the variance-covariance matrix. The method is named Preconditioned Optimizing Utility for Large dimensional analyses (POpULar). It should be noted that inhomogeneous correlation fields can be easily employed with the new descent scheme. The methods allow us to handle the correlations among the deviations of control variables from the background in nonlinear problems. For example, the methods allow us to handle the correlations in adjoint analyses. The effect considering the correlations is illustrated in an experiment using the Burgers' equation. The experiment shows that considering the correlations significantly improves the accuracy of adjoint analyses. We also examine the feasibility of POpULar in the 3DVAR and adjoint ocean data assimilation systems. In the 3DVAR system, we can easily introduce nonlinear observation functions associated with ocean surface dynamic height by using POpULar, resulting in the improvement of the assimilated fields. In the adjoint system, handling horizontal correlations of the analysis increment improves the analysis field especially around the equator compared to conventional adjoint system in which the correlation is ignored. The methods are, thus, powerful tools for sophisticated oceanic and atmospheric data assimilation systems.