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A Fast Inverse Algorithm based on Multigrid Technique for Cloud Tomography

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The spatial distribution of liquid water content (LWC) in clouds is a very important physical quantity. Existing techniques to observe LWC, such as in situ measurement and radar, have limitations. Microwave radiometer (MWR) becomes an effective way to quantitatively measure the LWC since its detected brightness temperature is independent of the particle size distribution. But as a passive remote sensing way, it has poor spatial resolution. Cloud tomography was proposed to improve the spatial resolution of MWR. In order to avoid the model error caused by the linearization in previous algorithms, L-BFGS-B algorithm was used to solve this nonlinear optimization problem. This method is called NHV for short hereafter. But the convergence of this iterative method can be very time-consuming because of its smoothing property. This smoothing property represents that the algorithm spends much time to converge the short waves and the long waves are hardly improved until the short waves are done.

In this study, a fast inverse algorithm (HV) based on Half-V cycle scheme of multigrid technique is developed for cloud tomography, so as to save computing resources and ensure its real time application in wider fields in the near future. In HV algorithm, objective function built on the coarsest grids is optimized and then the solution is projected to the finer grids as an initial value. This procedure is repeated until the finest grid level is reached. The effectiveness of HV algorithm and its essential cause that accelerates the convergence have been investigated by numerical simulations.

Fourier analysis shows that, the slow convergence problem caused by smoothing property of NHV can be even more serious in cloud tomography. Because the observations are insufficient to retrieve the short waves in vertical direction, whereas the smoothing property of NHV makes the long waves be converged very slowly before the short waves are done. This problem can be greatly alleviated by HV algorithm where long waves are always retrieved ahead of short ones. Thus long waves contained in observations can be well retrieved on coarse grids and leave only the unresolved short waves as errors on finer grids.

The comparison of these two algorithms shows that the retrieval accuracy of HV is quite close to that of NHV algorithm on all the cases. But the runtime can be significantly reduced by 89%-96.9%. As for a currently feasible two-level flight scheme for a 20km wide target area, the convergence can be accelerated from 407 sec in NHV to 13 sec in HV. This reduction in time will be multiplied several times if the target area is much wider and segmental retrieval is required to avoid exceeding the time limit of cloud tomography.