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On the use of variational analysis for determining the motion, growth and decay of radar echoes over complex orography

A dissertation submitted to the Swiss Federal Institute of Technology, Zurich for the degree of Doctor of Natural Sciences

presented by

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Abstract

The idea using radar data for nowcasting of severe storms has been the topic of many investigations in radar meteorology since the advent of the digital weather radar. In recent years, the research interest on this topic has been increased together with a remarkable progress in computer technique and with increasing public needs for nowcasting products. Over the last three decades, a number of techniques have been developed for extrapolation of the motion, shape and intensity of radar echoes into the future. In principle, most of these techniques can be classified as pattern recognition techniques. A common property of these techniques is that they determine the movement of storm systems or, at best, of individual cells. As a consequence, the effect of small-scale evolution within radar echo is not considered adequately. In addition, the lack of considering the growth and decay processes of radar patterns is one of the reasons for a not yet optimal performance of these nowcasting schemes.

The TREC method (Tracking Radar Echoes by Correlation) was originally proposed to track small scale features of radar echoes in order to retrieve the internal motion within radar patterns. However, the TREC vectors appear to represent the airflow only in case of clear-air echoes in the boundary layer, whereas in precipitation situations, the sources, the sinks and sedimental effects of precipitation can affect the TREC vectors in a significant manner. In addition, ground clutter, shielding effects and random fluctuations of the radar patterns have a disturbing influence on TREC vectors. In spite of these factors, TREC provides a potential base for nowcasting the evolution of radar patterns since the method is able to detect small scales of motions of radar echoes.

In this thesis, based on a specific constraint and a variational technique, an efficient objective analysis method is proposed for smoothing the motion vectors and forcing them to fulfil the continuity equation. This method (COTREC hereafter) is an extension of TREC and allows us to obtain the motion, growth and decay of small scale radar patterns. The continuity equation is used as a strong constraint in the variational analysis. The use of this constraint is motivated by the need 1) to isolate the divergent component of the retrieved motion field, 2) to correct the apparently wrong vectors that often turn out due to the influences of ground clutter, shielding effects and failures of TREC and 3) to detect the region of echo growth and decay within the observed radar echoes.

The behavior of this method has been investigated with a series of real radar data samples. Doppler radar data of convective and widespread precipitation were collected in complex orography and used for an evaluation of the sensitivity of the method to different types of precipitation patterns. Comparisons with Doppler radar measurements have shown that COTREC can drastically reduce the scatter of the differences between Doppler velocity and the radial component of the TREC-derived motion vectors in situations that are characterized by a weak vertical wind shear in the layer of precipitation. This scatter is attributed to failures of TREC that are caused by clutter and by rapid morphological changes of the radar patterns. The remaining RRMS errors are on the order of 3-4 m/s after application of COTREC. The sedimentation effect is one possible source for systematic differences between the Doppler velocities and the COTREC-velocities in high-shear weather situations.
A contribution of the thesis is the description of a retardation effect of the COTREC motion vectors in orographic precipitation. This retardation effect may be caused by two phenomena: a tendency of radar patterns to become stationary (triggered) on upsloping orography and by the influence of ground clutter and shielding, also highly correlated by orography. While the first one reflects the fact that propagation of echoes does not necessarily occur with the wind (which would produce a simple translation of the echoes), the second one is an artifact, caused by the method of observation (radar), but mitigated with Doppler techniques by suppressing the stationary part of ground clutter.

Quantitative agreement between COTREC-velocity and wind velocity is of minor importance when the patterns of echo growth and decay are of interest. It has been shown in several case studies that the patterns of echo growth and decay are useful: 1) for detection of orographic rainfall, 2) for quantitative detection of echo growth and decay within convective storm complexes, 3) for identification of the internal structure of severe convective storms and 4) for an investigation on climatology of the growth and decay patterns of radar echoes in complex orographic regions.

It has been demonstrated that COTREC can predict the patterns of echo growth and decay up to about 20 min in advance, which is about half of the characteristic lifetime (30-45 min) of ordinary convective cells. Based on long-term radar data of all precipitation events of July 1993, averaged patterns of the growth and decay of radar echoes were obtained. These patterns represent a geographic distribution of enhanced precipitation associated with topography. Strong relations between the formation and dissipation of radar patterns and topography are found in Swiss pre-alpine regions. Grossversuch IV data with a high spatial and temporal resolution are used to retrieve the internal motion within radar patterns. A box size of 4 km, a grid size of 2 km and a time lag of 2 min are selected for calculation of the motion fields. The results explain some of the dynamical processes within the given storm case. Cyclonic vorticity is indicated from the flow pattern in the centre of the storm. The COTREC analysis is consistent to animation loops of the radar pictures of this storm, which show cyclonic rotation.

COTREC may become a tool for the analysis and visualization of the temporal and spatial evolution of radar patterns. The method is especially useful in orographically complex areas. It is suggested that COTREC may become part of a more integrated nowcasting procedure. This can improve nowcasts of the future radar echo coverage. One advantage of the method is that only two consecutive PPI-scans within a short time interval (typically 2 min) are sufficient for application of the method. The computer time needed to calculate the resulting fields of echo motion, growth and decay is negligible. Thus, application of COTREC may become attractive in any research or operational activity where the assessment and analysis of radar patterns is of interest.