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Consistency of airborne wind measurements with aircraft dynamics –Tests for DEEPWAVE cases

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Accurate wind measurements are important for gravity wave and other atmospheric research. Here, we describe an extended Kalman filter method to post-process airborne measurements including a six-degree-of-freedom (6-dof) model of the aircraft dynamics. We describe the concept and show test results for flights during the DEEPWAVE research project (https://doi.org/10.5065/D6BG2M1H). The results indicate that inclusion of the aircraft dynamics allows assessing and improving the accuracy of the position data and related wind analysis. Moreover the analysis confirms the presence of strong mountain waves in the cases measured.

The famous Kalman filter belongs to a class of algorithms to estimate the state of a system (such as the position and velocity of an aircraft versus time) from measurements, given a system model, a measurement model, measurement data, and measurement and model error covariance statistics. The method is efficient by using a step-wise approach. By combining a traditional extended forward Kalman filter with a backward Rauch-Tung-Striebel filter, the method uses the measurements over the whole observation time period. The method is attractive because it can provide optimal solutions for ideal conditions (linear, fully known error statistics, complete models). An adaptive filter approach is used to improve error covariance estimates.

Commonly, Kalman filters are applied for airborne navigation with a kinematic model of the system 6-dof position and attitude vectors as a function of linear and rotation velocities. In such a kinematic model, the linear and rotation velocity changes are estimated from the observations. Here we estimate the velocity changes from a model of aircraft dynamics for given air flow data. The model is designed to approximate the dynamics of the aircraft of types Gulfstream V or 550, such as the NSF-GV used by NCAR during the DEEPWAVE campaign and HALO used by DLR in similar experiments. Aircraft dynamics models require input data which are only partly known. Added model information can improve the results of a Kalman filter only when sufficiently accurate. The aircraft dynamics depends strongly on the inertia and the aerodynamic properties of the aircraft and on the autopilot used. Hence, it was not clear from the beginning whether such an approach is worthwhile.

This contribution presents a short summary of the method developed. We will present results of aircraft position based on 25 Hz data with and without aircraft dynamics and autopilot model. The errors of the data sources are estimated using various model versions. We find considerable changes in the related wind results when varying the model parameters but the uncertainty is small enough to confirm that previously measured mountain waves are realistic within reasonable error bounds. The method offers the potential to be useful in routine post-processing of airborne measurements.

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