RESEARCH STUDY:
SEVERE STORMS DOPPLER LIDAR SIGNAL PROCESSING

Final Report

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I. Introduction

Contract NAS8-33834 includes four tasks related to the signal processing aspects of the severe-storms Doppler lidar program. Tasks A and B involve the development of algorithms for windfield retrieval from Doppler lidar measurements made during the severe storms program. Tasks C and D provide for support during signal processor installation and in post-flight data analysis.

This final report will summarize the work performed in support of these tasks. Reference will be made to the detailed descriptions of this work contained in the nineteen monthly progress reports generated during the life of the contract.

II. Tasks A and B: Algorithm development and simulation

Task A called for the development of windfield retrieval algorithms based upon least-squares surface fitting techniques. The presence of bad or missing data points in the measurements requires an analysis method with two important properties: it must be tolerant of large measurement errors, and it must fill in gaps in the data. In addition the technique should make the best possible use of weak measurements, and should provide resultant wind fields on arbitrary analysis grid points. Task B provided for evaluation of the proposed algorithms by use of windfield and data-acquisition simulations.

Such simulated windfields were presented in MPR 4 (Nov. 10, 1980). Numerical filtering of random data sets was used to produce flow fields with realistic spatial spectra. These random fields were sampled with a lidar simulation, with appropriate amounts of introduced measurement noise. Examples of the degraded windfield estimates are shown in MPR 4.

Since the proposed analysis technique relies upon least-squares operations with the measurement data set, it is important that realistic estimates of measurement reliability be available. An editing algorithm has been developed and described in MPR 5 (Dec. 10, 1980) to examine the measurements and assign probable errors. This assignment is made on the basis of signal strength, measurement context, and knowledge of the error characteristics of the Doppler estimator. Examples shown in MPR 5 demonstrate the rather good agreement between the actual data errors (as introduced into the synthetic wind field by the simulated lidar system) and the error estimates produced by the editor.

Also shown in MPR 5 are the first results of windfield smoothing by the use of quadratic surface fitting. The two scalar velocity measurements are separately fitted to quadratic surfaces, with the surface coefficients determined by local least-squares fitting. Such a fitting process tends to eliminate weak or erroneous measurements, and the continuous surface makes interpolation to any grid system trivial.

The next step was to make the surface-fitting process adaptive to the quality of the data. Where measurement errors are low smoothing is minimal (to preserve spatial resolution); where large errors are present smoothing is increased, with spatial resolution compromised to the degree necessary to achieve the desired velocity accuracy. Many examples of such adaptive smoothing are shown in MPR 6 (Jan. 10, 1931). Useful velocity fields are obtained in regions where the raw data was nearly impossible to interpret.

Extension of the algorithm to compensation for advection is treated (with examples) in MPR 7 (Feb. 10, 1981). Local estimates of average translation velocity are used to estimate the location of measurement points at a time common to the forward and aft measurements (which may themselves be separated in time by 60 seconds). In the simulation studies considerable success was obtained in correcting for advection, but with field data considerable judgment must be used before applying such a correction.

The final step in algorithm development was estimation of divergence and circulation from the velocity fields. It was found best to estimate these parameters analytically from the coefficients of the quadratic surfaces (see description and examples in MPR 8, Mar. 10, 1981).

Algorithm descriptions (EDIT, ADVECT and SMOOTH) were delivered in March 1981. A description of these algorithms was presented in December 1981 at the 20th Conference on Radar Meteorology (Boston, American Meteorological Society). A copy of this paper as printed in the proceedings of the conference was appended to MPR 18 (Jan. 10, 1982).

III. Task C: Processor installation

Support for signal processor installation and systems integration was provided on three occassions in 1981. During April Lassen Research personnel provided assistance during systems integration at Raytheon and

Advanced Computer in the Boston area. During June support was provided for processor installation on the CV-990 aircraft at Ames Research Center. This support included participation on the June 12 initial flight of the system. Lassen Research personnel again visited Ames Research Center during July to assist in the resolution of several data interpretation problems. This support resulted in the discovery and correction of software problems, as verified by the excellent data acquired during flight 10.

IV. Task D: Analysis of flight data

This task was included in the contract since it was anticipated that some revision of the analysis algorithms would be required when the characteristics of the flight data were known. That this was the case was confirmed by the first flight results (MPR 14, Sept. 10, 1981). These examples contained velocity errors which were systematic. While the algorithms developed earlier perform well with random data errors, they are unable to correct systematic data errors.

The suspicions noted in MPR 14 that these systematic errors were due to errors in the aircraft attitude measurements (and hence in the pointing of the lidar beam relative to the flight vector) were confirmed in MPR 15 (Oct. 10, 1981). Examples in MPR 15 demonstrate that the major part of the systematic errors can be explained by errors in aircraft drift angle on the order of a few tenths of a degree. The examples also show clearly that the error is due to a delay of approximately two seconds in the drift angle measurement.

The presence of such a delay in the drift angle measurement was confirmed through an investigation of the data acquisition software timing. It was found that about 75% of the systematic error could be removed through interpolation of the drift-angle measurements to remove the time delay (MPR 16, Nov. 10, 1981). Examples in MPR 16 show dramatic improvement with the interpolation scheme, particularly when the aircraft is experiencing turbulence (as in the boundary layer).

Also noted in MPR 16 are errors in the pointing angle of the laser beam (due to a 0.84-second delay) and errors in the vertical elevation of the beam. The elevation angle of the beam is nominally zero degrees, but since delays are present in the aircraft attitude information the actual elevation angle may be in error by up to one degree. In addition there appear to be biases in the elevation angles: perhaps -0.4 deg in the aft beam and +1.0 deg in the forward beam (estimated through terrain returns from known topography, see MPR 16).

V. Recommendations for further work

Recommendations can be made in two areas. The first area includes suggestions for changes in procedures on future data flights. Clearly an effort should be made to revise system software to minimize the time delay between the measurement of aircraft attitude and data acquisition. Since this delay cannot be made equal to zero, it is further suggested that the various important angles be measured more frequently than once per scan, so that interpolation for delay correction can be more effective.

The second area concerns the data already taken. More accurate interpolation techniques can be developed to compensate for time delays. Such interpolation should also be developed to estimate the vertical angle of the beam: while the vertical angle cannot be compensated for, it should be known so that excessive vertical errors can be used to flag questionable data. These interpolation technques take into account the fact that the data is not obtained at a uniform rate.

Finally, there is a limit to the accuracy of interpolation due to a number of sources. Unknown and random delays are present in the angular data due to the non-synchronous sampling of the INS unit relative to the lidar data acquisition; unknown errors are present in the INS angles. When aircraft dynamics are high (as in the turbulent boundary layer) these second-order errors may reduce the utility of the data to near zero even after interpolation. It is suggested that continuity of the mean radial velocity be constrained to recover this data. This may be accomplished by least-squares fitting of mean radial velocities to a function with constrained smoothness, and adopting the resulting function as the "true" mean radial velocity. Such a procedure may be defended by arguments depending upon the spatial spectra of velocity fields.