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QUANTIFYING AIRPORT TERMINAL AREA WEATHER SURVEILLANCE REQUIREMENTS*

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1. INTRODUCTION

The Federal Aviation Administration (FAA) Terminal Area Surveillance System (TASS) research, engineering, and development program was initiated in part to address future weather sensing needs in the terminal area. By the early 21st century, planned systems such as the Terminal Doppler Weather Radar (TDWR) and Airport Surveillance Radar–9 (ASR–9) will be well into their designed life cycles. Any new terminal weather surveillance system should be designed to address existing deficiencies. Key unmet weather sensing needs include detections of: true 3–dimensional winds (vs. radial component), winds in the absence of precipitation, wake vortices, total lightning, hail, icing conditions, clear air turbulence, hazardous weather cells (with adequate time and space resolution), cloud cover and cloud bases (including layers), fog, and visibility (Runway Visual Range), as well as predictions of: the atmospheric conditions mentioned above, wind shifts, microbursts, tornadoes, and snow/rainfall rates (Evans 1991a, McCarthy 1991).

In this paper, we investigate the premise that hazardous weather cells are not currently being measured with adequate time and space resolution in the terminal area. Since a new surveillance system should be based on knowledge of storm dynamics, we have performed a preliminary study of update rate (using rapid scan radar data collected in Orlando), and spatial resolution required to detect rapidly developing thunderstorms and precursors to the low altitude hazards such as microbursts that they produce. Other aspects of a future radar system such as multi–parameter techniques required to discriminate between ice and water phase precipitation, etc. are not considered.

2. APPLICATIONS FOR TERMINAL AREA CONVECTIVE WEATHER INFORMATION

Past studies have shown that weather is the primary cause of serious air traffic delay at the nation's major airports (Weber et al. 1991), and a recent study at Lincoln Laboratory has shown that this delay may even be underestimated with the current reporting system. Thunderstorms and heavy fog account for the largest fraction of weather related delay. Some of this delay can be mitigated by more accurate detection and prediction of weather impacted flight routes, allowing efficient rerouting to take place. This will provide an important economic and safety benefit in the future, as increased air traffic demands maximization of capacity at our existing airports.

The newly deployed TDWRs and ASR–9s will provide a significant increase in safety in the terminal area, but these systems were not specifically designed to reduce weather related aviation system delays. The FAA has recently initiated the Integrated Terminal Weather System (ITWS) program, being developed at Lincoln Laboratory, to provide improved aviation weather information in the terminal area by integrating data and products from the FAA and NWS sensors (Evans 1991b). A key objective of the ITWS program is to increase the effective airport acceptance rate in adverse weather by providing information to support the Terminal Air Traffic Control Automation (TATCA) program. TATCA tools increase the efficiency of individual controller tasks and provide a dynamic, overall plan for traffic management throughout the terminal control region (Andrews and Welch 1989). Thus, reliable analyses and *forecasts* of weather impacted air routes, runway availability, and clear–air winds for direct use by TATCA, traffic managers, and pilots are a major goal of the ITWS system. The design of any future terminal weather surveillance system will have to consider this close coupling of weather sensing and forecasting, and air traffic capacity and efficiency enhancement programs.

The first deployment of the ITWS system will include a Microburst Prediction product, and may also include a storm location prediction based on projection of existing storms according to correlation tracking information. These predictions are performed on existing detectable radar reflectivity regions and thus are necessarily short term. Longer term predictions of weather impacted airspace will require predictions of storms that have yet to develop, and thus will either depend heavily on heuristic rules for convective initiation (Mueller and Wilson 1993) or, perhaps more likely because of accuracy requirements, will require gridded 4–D data assimilation – numerical forecasting techniques such as those being developed at NOAA's Forecast Systems Laboratory (Sherretz 1991). This type of gridded analysis system is already being used in 3–D for an ITWS terminal winds representation (Wilson et al. 1993). With or without gridded numerical forecasting techniques, convective forecasts will be required in a full 60 km radius region around the airport at least.

3. UPDATE RATE

Of all the unmet terminal weather sensing needs, the desire to predict rapidly developing convective weather is a driving factor in the proposed required update rate for a TASS weather sensor. Keeler (1991) assigns a critical time scale of 0.5 – 1.0 min for thunderstorms, and 1.0 – 2.0 min for widespread rain. There is evidence that a 1 min update rate is required for for thunderstorm outflow detection. Study has demonstrated the need for a similar update rate for thunderstorm life cycle predictions (Carbone et al. 1985).

To investigate this, rapid scan measurements were made with the TDWR testbed radar operated by Lincoln Laboratory in Orlando, FL, where the typically very unstable environment leads to rapidly developing and decaying thunderstorms. A special TASS scan was designed to cover a complete volume in 1 min with a set of elevation angles comparable to a true TDWR hazardous–weather mode scan (see Fig. 1). The scan provides uniform coverage up to 14 km AGL for a storm at 20 km range. Suitably long rapid scan datasets on multiple microburst–producing storms were gathered on Aug. 5 , Sept. 22, and Sept. 26 1992. For the identified cells (5 total), parameters

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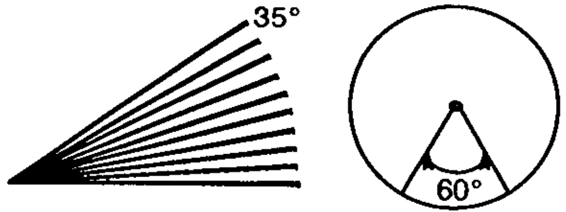

Figure 1. The TASS Rapid Volume Scan consists of 10 elevation angles (0.5, 3.7, 7.3, 10.9, 14.7, 18.6, 22.5, 26.6, 30.7, 35.0°), is 60° wide, and takes 1 min to execute with the TDWR testbed radar.

such as the average vertically integrated liquid water (VIL) and the height of the center of mass (CM) were computed. Trends in these parameters are used in the ITWS Microburst Prediction Algorithm (Wolfson et al. 1993) to identify growing thunderstorms and to predict their collapsing phase, which leads to microburst wind shear at the surface. These parameters measured every minute are compared with the identical parameters derived from hybrid TDWR volume scans made up of 3 TASS scans each, with the lowest elevation angles coming from the first TASS scan, the middle angles from the second, and the highest angles from the third. As an example, the VIL data for Aug. 5 are shown in Fig. 2a. The 3-min VIL lags and peaks later than the 1-min VIL, which shows much more detailed fluctuations. The height of center of mass data show a similar pattern (Fig. 2b).

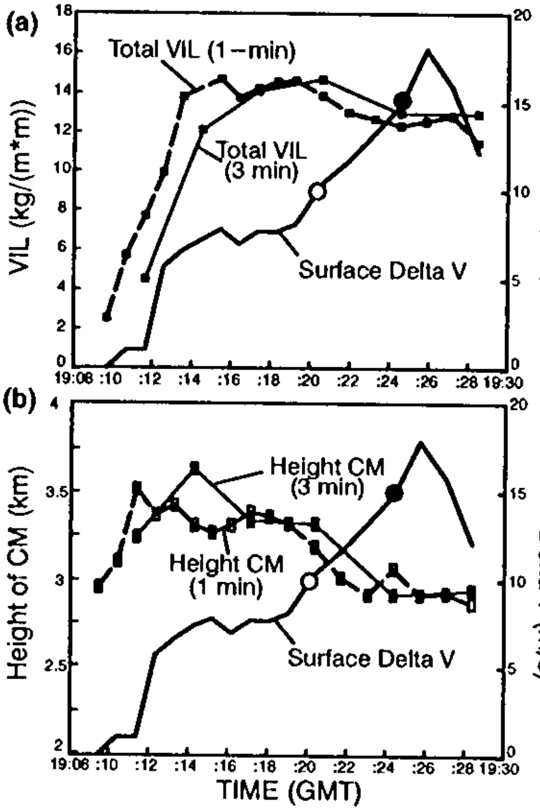

Figure 2. (a) Plot of VIL computed for a storm cell scanned with the TASS Rapid Volume Scan on August 5, 1992, and of VIL and computed from 3-min hybrid scans made from the same data. The surface outflow ΔV derived from the 1-min scans is also shown. The black circle at ΔV=15 indicates the microburst onset and the white at ΔV=10, wind shear onset. (b) As in (a) but for height of center of mass (CM).

We used the prototype ITWS Microburst Prediction algorithm to quantify the advantage of the TASS scan (1 min) over the hybrid TDWR scan (3 min). In the algorithm, a region is first identified and tracked based on a significant rise in VIL, among other features. This rise must persist for 2 volumes for a track to be established. If the region has been tracked twice, a prediction can be issued as soon as a drop in center of mass is detected, assuming the quantity of VIL present at that time is sufficient to produce a microburst-strength outflow. Table 1 shows the achievable prediction lead times for the TASS and hybrid TDWR scans. The TASS strategy allows an average ~3 min greater prediction lead time, extending the TDWR average of 2-4 min for these (weak) cases to 5-6 min. (These results may change as the Microburst Prediction algorithm evolves from its prototypical to its final form.)

4. SPATIAL RESOLUTION

High spatial resolution is required to detect microbursts, tornadoes, etc. at very low elevation angles, but it may be possible to trade resolution for a more rapid update rate at upper levels. To investigate this, we created a model storm ellipsoid 10 km high, 6 km wide, with a central core reflectivity of 65 dBZ at 5 km AGL, which decreased linearly to the outer edges of the ellipsoid. We compared the TDWR scan to an experimental low resolution fan beam scan consisting of 6 beams, each 5° in elevation, centered at 5, 15, 25, 35, 45, and 55°. By using only 6 broad beams to scan the volume instead of 11 narrow beams (TDWR), the update rate could theoretically be improved.

Since VIL and CM measurements are crucial to the ITWS Microburst Prediction algorithm, these parameters as a function of range were compared. The ellipse was moved in range from 0 to 25 km, and "scanned" every km with both strategies. Figure 3 shows that, although the cone of silence over the radars leads to incorrect values inside of 4 km range, the values for the two strategies are not dramatically different at near range. (Even the TDWR VIL falls short of the true VIL because interpolation cannot recreate unsampled peak reflectivity regions, and the 1 km influence radius can include distant low VIL values.) At longer range, our studies have shown that the large variability of the fan beam VIL is due to the gaps in elevation, and the large rise in fan beam CM is due to the rising center height of the 15° beam, which dominates the CM calculation. For microburst prediction, the apparent changes in CM with range have far greater potential for causing false alarms than do the changes in VIL.

Since future algorithms and especially any numerical forecasting techniques will undoubtedly use gridded radar data, we also investigated the effect of Cartesian grid resolu-

Table 1. Microburst prediction lead times for 5 cells scanned with TASS scan and hybrid TDWR scan. For cases with 2 entries, first is lead time for onset of 10 m/s outflow, second for 15 m/s.

Date 1992	TDWR lead (min)	TASS lead (min)	Outflow DV (m/s)
August 5	3 – 6	6 – 9	17.5
September 22A	5	7	11.6
September 22B	3	5	14.8
September 22C	0 – 1	2 – 3	19.3
September 26	0	6	12.0
Average 10 m/s:	2.2	5.2	5 cases
Average 15 m/s:	3.5	6.0	2 cases

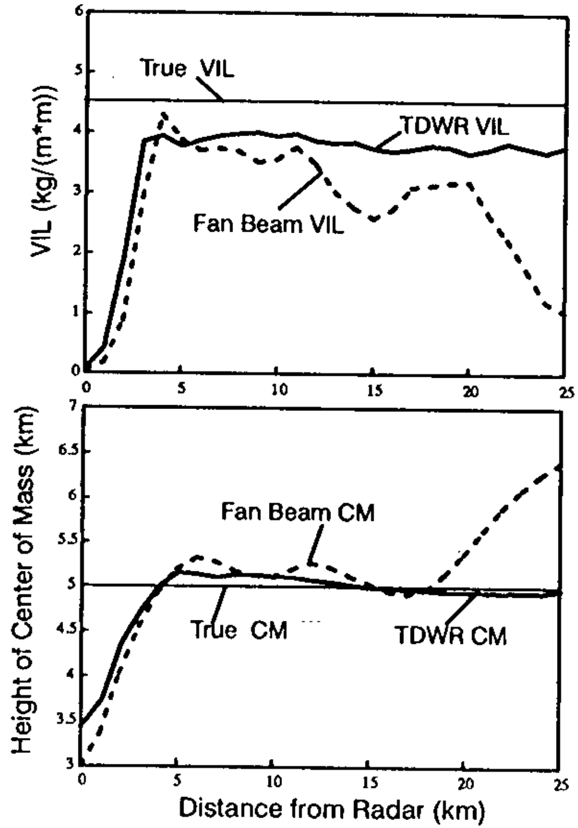

Figure 3. Apparent VIL and height of CM of model ellipsoid scanned with TDWR and fan beam strategies.

tion. We discovered that there was very little difference between 0.1 km and 0.5 km for the TDWR scan (Fig. 4). At 1.0 km, the measured parameters were still very close to their 0.1 km values, but the variability of CM with range increased. The ITWS prototype Microburst Prediction algorithm currently uses 1 km resolution (although 0.5 km vertical resolution is being considered), and the gridded Terminal Winds product uses 2 km horizontal resolution at 50 mb height intervals.

5. SUMMARY AND CONCLUSIONS

We have considered here the key unmet needs in the airport terminal area of adequate coverage both in time and space for detection and prediction of hazardous weather cells. Because thunderstorms evolve on such rapid time scales, this requirement may be a driver for the design of any new terminal weather surveillance system. It is our contention that requirements for update rate and spatial resolution must be developed in the context of likely use of the data – in gridded prediction systems, data assimilating numerical models, and for specific improvements in flight route planning, weather avoidance, and terminal air traffic capacity and efficiency.

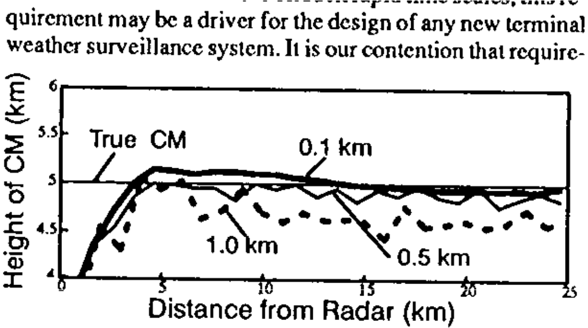

Figure 4. Apparent height of center of mass of model ellipsoid scanned with TDWR strategy, and gridded at 0.1, 0.5, and 1.0 km resolution. A 1.0 km interpolation radius was used at each resolution.

We have developed a methodology towards quantifying the weather surveillance requirements for update rate and coverage of convective storms. By making special radar measurements at high volume update rates, and comparing them with derived lower update rate scans, the benefit with respect to some detection or prediction algorithm or model can be quantified. Likewise, by sampling idealized or actual high resolution numerical model data of storms, trade–offs on required coverage resolution can be made. Based on these studies and other research performed at Lincoln Laboratory for the TDWR and ITWS programs, we can draw several conclusions.

1. Whole volume coverage to at least 4 km altitude in the terminal area is required every 1.0–2.5 min. The actual selected update rate will depend on the perceived cost/benefit ratio. State–of–the–art algorithms and numerical models should be used to calculate this ratio.

2. A "cone of silence", i.e. an unscanned region over the radar, is not acceptable over the airport.

3. Surface updates of 0.5–1.0 min are required over the airport and approach/departure corridors for timely outflow detection.

4. High resolution data (100–250 m range gate spacing, 1–1.5° azimuthal resolution) are required in the boundary layer, i.e. the lowest ~2 km. Contiguous beam coverage is desirable since wind speed changes rapidly with height near the surface. It is crucial to determining new areas of convection that boundary layer forcing (convergence) be adequately measured, and this requires low altitude coverage even at the far ranges of the terminal area.

5. Above ~2 km, resolution requirements can be relaxed. Wider beam widths can be tolerated, but the desired resolution at long range must still be taken into account.

ACKNOWLEDGEMENTS

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