5.2 EN ROUTE WEATHER DEPICTION BENEFITS OF THE NEXRAD VERTICALLY INTEGRATED LIQUID WATER PRODUCT UTILIZED BY THE CORRIDOR INTEGRATED WEATHER SYSTEM

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1. INTRODUCTION[†]

The primary cause of national airspace delay is convective weather. A large fraction of these delays is due specifically to en route weather (Allen et al., 2001). Crowded travel corridors such as the Great Lakes corridor from Chicago to New York experience the most significant en route convective weather delays. It is of particular importance within these high traffic regions that traffic managers have access to the most accurate and realistic en route weather depiction products in order to minimize convective weather delays while ensuring safety.

En route weather products from the Corridor Integrated Weather System (CIWS) were first provided for the Great Lakes corridor in July, 2001. As part of this system, CIWS provides a precipitation product created by converting Level II reflectivity data from several NEXRAD radars to vertically integrated liquid water (VIL). It has been previously demonstrated that weather depictions based upon the complete vertical examination of radar echoes fundamentally implied by VIL are more representative of actual weather characteristics than depictions based upon maximum composite radar reflectivity (Crowe and Miller, 1999). Specifically, VIL provides a more accurate portrayal of the severity of convective cells than composite reflectivity because of (1) better indications of storm strength and maturity, (2) improved bright-band contamination mitigation, and (3) indications of turbulence within regions of precipitation (as high VIL values correlate to stronger vertical motions and thus increased turbulence). The CIWS VIL mosaic is computed from the VIL for the individual radars by using a "maximum plausible" value.

The focus of this study is to compare the CIWS VIL precipitation product to the established, widely-utilized Base-Scan Radar Reflectivity Mosaic (BRRM; also called Base Reflectivity or BREF) products used in the Weather and Radar Processor (WARP) and, in the vendor supplied radar mosaic on the FAA Traffic

Situation Display (TSD). Although WARP users have composite reflectivity products available to them, the BREF product is often used operationally due to its higher spatial resolution (2 km versus 4 km for the composite reflectivity products) and the lower latency for the base reflectivity product vis a vis composite reflectivity.

It is demonstrated in this paper that weather depictions in an operational environment based upon VIL provide more meaningful information for en route traffic routing than a BREF product. VIL precipitation proves advantageous in limiting contamination from Anomalous Propagation (AP) ground clutter, biological targets (e.g., birds and insects), and radar artifacts. The extended vertical coverage of VIL sampling also better depicts storm cells as they first develop, further assisting traffic managers achieve more efficient use of tactical airspace when weather occurs unexpectedly.

Differences between the representation of convection by each product are quantified in terms of relative impacts on high-altitude jetways. These analyses, conducted for different developmental stages of convection, illustrate how VIL characteristics help reduce weather impact false alarms during convective events where functional airspace may already be limited.

2. WEATHER DEPICTION COMPARISONS

2.1 Precipitation Data

The primary differences between VIL and BREF en route weather depiction products relate directly to the characteristics of convective weather and the vertical coverage of the NEXRAD beams. The BREF precipitation information is based upon radar reflectivity mosaics that utilize only the lowest elevation angle (0.5°) of NEXRAD volume scan data. Even at a range of 120 nm from the radar, reflectivity data at 0.5° elevation angle are confined below 20,000 feet. Previous investigations of vertical profiles of radar reflectivity have shown that storm cell intensity generally peaks below 20,000 feet (e.g., Zipser and Lutz, 1994; Robinson and Biggerstaff, 1997). This is particularly true when a storm is decaying. The BREF is therefore limited to sampling strong near-surface convective cores which may be unrepresentative and misleading to en route traffic managers concerned with high-altitude air traffic. By integrating full volume-scan NEXRAD radar data, the VIL precipitation provides a more realistic depiction of weather affecting air space of interest to en route traffic managers.

Figure 1 demonstrates the disparity between the VIL and the BREF precipitation products in depicting

convective events. In this example, a cluster of convective cells embedded in stratiform rain is present south of Detroit, Michigan, near the Ohio-Michigan state border. By utilizing all available vertical radar reflectivity data, the VIL precipitation product is better able to differentiate the relative strength of individual cells. With the BREF product, limited vertical sampling prevents detection of more variable storm characteristics aloft. As is evident with the cluster of cells south of the state border in Figure 1, this limits the ability of the BREF to clearly determine the relatively stronger or weaker convective cores. Specifically, noting the circled storm cell in Figure 1, VIL depicts a much weaker storm cell than the BREF product by tempering strong near-surface storm intensities with measurements of weaker convection aloft. The same cell represented by only near-surface sampling of the BREF precipitation product is approximately 20 dBZ stronger.
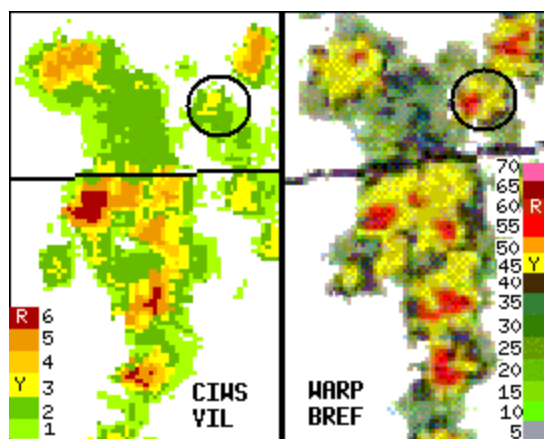

Figure 1. CIWS VIL (left) and WARP BREF (right) precipitation for 09-08-01 2031 UTC. 'R' and 'Y' present in each products' color bar denotes 'yellow' and 'red' threat level precipitation, respectively, discussed in section 3. The circled storm cell is approximately 20 dBZ (3 VIP levels) weaker with VIL. Horizontal line in both weather depiction images denotes MI-OH state border.

2.2 Identifying Initial Convective Development

Earlier detection of developing convection allows for earlier en route traffic reroutes, particularly when weather occurs unexpectedly. The initial radar echo from precipitation often occurs near the freezing level, at heights between 15-20 kft (e.g., Workman and Reynolds, 1949). By integrating full volume-scan radar data, the CIWS VIL precipitation product is able to detect storm cells first developing at these heights. Moreover, incorporation of the complete NEXRAD scanning strategy means that VIL will detect these new cells with high-quality radar data as close as 10 miles from the radar (see Fig. 2).

In contrast, the use of only base-scan radar data makes it difficult for the BREF to detect the initial development of storm cells. Figure 2 demonstrates that BREF is not

able to sample the development region for new cells (15-20 kft) within approximately 90 miles of the radar. Therefore, any sampling by the BREF of convection as it first develops can only be done with lower quality[1], long-range data (Note: WARP takes the maximum of any radar covering a region, so neighboring radars do not have "priority").
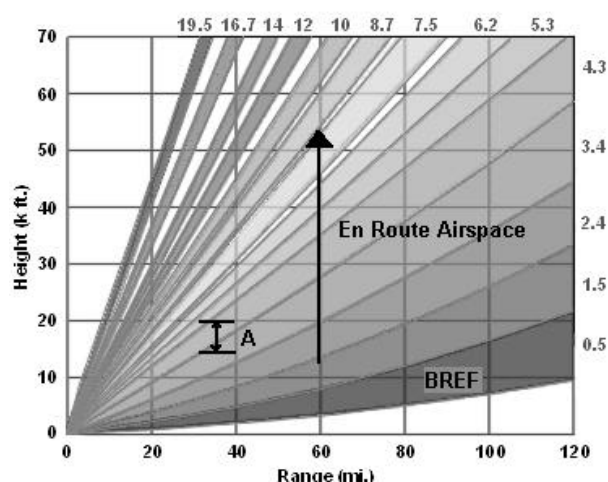

Figure 2. NEXRAD radar scanning strategy used when precipitation is present or expected. Numbers from 0.5 to 19.5 are the degrees of elevation of each tilt comprising a volume scan. Region 'A' denotes heights at which initial radar echoes of developing convection are most common. The lowest elevation angle is labeled as 'BREF', illustrating the limitations of this product in sampling weather within en route airspace. The VIL precipitation product utilizes radar data from all elevation angles.

2.3 Limiting Precipitation Product Contaminants

Contamination within precipitation products from AP ground clutter, biological targets and radar artifacts must be limited to further ensure that reliable weather depiction information is provided to air traffic specialists. VIL demonstrates distinct advantages over BREF in mitigating contamination from spurious or non-meteorological radar echoes.

The vast majority of intense AP and detections of biological contaminants such as birds and insects occurs within the lowest tilt elevation of a radar volume scan. The BREF, utilizing only base-scan radar data, is more apt to possess erroneous measurements due to AP and biological targets, despite the employment of contaminant-mitigating algorithms. VIL precipitation, by using complete volume scan radar data to integrate through a much larger vertical column, is less affected by spurious AP and contamination from biological targets.

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[1] For example, surface tilts at long range are more likely to have unedited AP (because there is no velocity data). Also, the surface tilt may be blocked by terrain.

Radar artifacts such as strobes, starbursts, and bull's-eyes can also adversely impact the validity of weather depiction products. These artifacts will effectively be removed from CIWS VIL data by way of a Data Quality Assurance (DQA) algorithm developed at MIT Lincoln Laboratory (Smalley and Bennett, 2002). DQA is being developed for the Build 3 cycle of the NEXRAD radar network's new Open Radar Product Generator (ORPG) architecture (slated for release in March 2003). DQA will be employed by CIWS in 2002. WARP will eventually benefit from DQA as well, but must wait until its NEXRAD ORPG release for incorporation into its system.

3. JETWAY IMPACT ANALYSES

3.1 Defining Threat Level Precipitation

Convection impacting a specific high-altitude jetway is deemed significant by its intensity level. It is a common empirical practice to consider yellow and red color-coded precipitation intensity levels as distinct, first-order threat levels for convection. Yellow threat level precipitation often depicts the intensity level at which radar echoes are generally considered convective and therefore of concern to pilots. Red threat level precipitation is often the visual representation of severe or extremely hazardous convection.

A six-level Video Integrator and Processor (VIP) level intensity scale represents CIWS VIL precipitation. The VIL algorithm is applied to NEXRAD radar reflectivity data and precipitation is depicted in terms of VIP level intensity by way of a linearly-regressed conversion applied to the available vertical column (Troxel and Engholm, 1990). Table 1 illustrates the relationship between VIL, radar reflectivity, and VIP level intensity. Precipitation of VIP level 3 intensity in VIL data is depicted at the "yellow" threat level, corresponding with pilots' widely-quoted VIP 3 rule-of-thumb for the minimal intensity for weather avoidance (e.g., Rhoda et al., 2002). "Yellow" threat level precipitation for the BREF reflectivity data used in this investigation begins at 43 dBZ which is similar enough to the equivalent reflectivity threshold value of VIP 3 intensity VIL (41 dBZ) for meaningful comparisons (see Table 1). Color bar settings for WARP BREF data used in this study denote "red" threat level precipitation beginning at 53 dBZ. This value is 4 dBZ lower than the reflectivity equivalent of VIL "red" threat level precipitation assigned to VIP 6 intensity (57 dBZ). Because of this disparity, WARP BREF "red" threat level precipitation is defined to begin at 58 dBZ, allowing for more meaningful jetway impact comparisons with CIWS VIL data.

3.2 Jetway Impacts During Squall Line Event

The number of high-altitude jetways impacted by yellow and red threat level precipitation from both CIWS VIL and WARP BREF weather data were tabulated during the maturation and eventual decay of an organized squall line across portions of Michigan and Indiana on September 7-8, 2001 (Fig. 2). Squall lines are probably the most disruptive weather phenomenon to affect the Great Lakes Corridor as these predominantly north-south oriented lines of storms can cover an incredibly large area with only a few (if any) gaps in significant weather available for the heavy volume of east-to-west air traffic. Therefore, it is crucial that the number

Table 1. VIL to VIP Conversion

VIL (Kg/m^2)	Reflectivity (dBZ)	VIP Level
0.05	< 18	0
0.14	18	1
0.7	30	2
3.5	41	3
6.9	46	4
12.0	50	5
32.0	57	6

Conversion used to convert VIL to corresponding VIP levels (Troxel and Engholm, 1990).

and size of gaps in significant weather be as accurate as possible to allow for the most efficient tactical management of impacted airspace.

Figure 3 demonstrates that the tendency of the BREF to exaggerate the intensity of convection by sampling only the more intense near-surface cores directly translates into the unnecessary closing of additional en route traffic routes. CIWS VIL, representing a much larger vertical column of convection, portrays a more meaningful and less intense convective weather field throughout the entire life cycle of the mesoscale convective event. En route traffic managers utilizing VIL precipitation as their weather depiction product of choice would note less weather-impacted jetways and more functional airspace than implied by the BREF depiction. Specifically, by 2128 UTC, when the squall line matures and increases in coverage, 30% fewer high-altitude jetways are impacted by "yellow" or "red" threat-level convection with a VIL precipitation product than a BREF precipitation product.

As the squall line begins to weaken (2230 UTC), decaying convection represented by VIL more quickly declines below threat level intensities compared to BREF. Near-surface convection that is emphasized by a BREF depiction tends to maintain strong reflectivity properties longer than the region of decaying storm cells above approximately 15,000 feet (Toracinta et al., 1996). BREF representations of dissipating convection may therefore be misleading to en route traffic management applications as strong convective signatures at lower levels do not necessarily indicate significant weather aloft. An accurate portrayal of dissipating convection is as important for en route traffic routing applications as accurately representing developing storm activity. (For example, an [unpublished] FAA/airline review of summer 2000 national airspace operations emphasized the importance of reopening routes as soon as significant weather had dissipated.) As the squall line weakens and convection decays, functional en route airspace no

longer affected by hazardous weather is larger and becomes available sooner based upon VIL weather depictions.
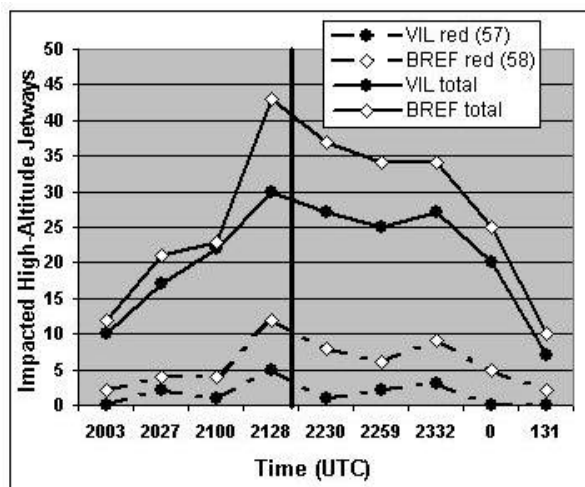

Figure 3. High-altitude jetways impacted by threat level precipitation from both VIL and BREF products during the developing and dissipating stages of a squall line present within the Great Lakes Corridor on September 7-8, 2001. VIL and BREF totals are sums of jetways impacted by both red and yellow (not shown) threat level precipitation. Numbers in parentheses represent reflectivity thresholds used for red. Vertical line denotes transition in squall line evolution from growing to decaying.

4. SUMMARY

A suite of weather products from the Corridor Integrated Weather System (CIWS) was first provided for the Great Lakes air traffic corridor during the 2001 summer storm season. As part of this system, CIWS provides a VIL precipitation product created from vertically integrated full-volume NEXRAD radar reflectivity data. Comparisons of VIL precipitation as an en route weather depiction product are made with the established, widely-utilized WARP BREF precipitation product.

Weather depictions based on VIL precipitation have the benefit of improved mitigation of contamination from AP ground clutter and biological targets. Unlike the BREF storm intensity depiction, VIL is not limited to near-surface measurements where contaminants are most prevalent. These shallow spurious or non-meteorological echoes are effectively removed as the VIL product integrates though an extensive vertical column.

The extended vertical coverage of the VIL precipitation products accounts for both strong near-surface cores as well as weaker convection aloft, thus providing more realistic relative and complete depictions of the convective weather field for en route traffic applications. By using only base-scan NEXRAD data, the BREF is limited to sampling strong near-surface cores which may be unrepresentative to traffic managers concerned with high-altitude air traffic.

By utilizing full volume-scan radar data, VIL is also able to detect the initial development of storm cells at heights generally between 15-20 kft. Conversely, limited base-scan sampling of BREF data precludes any detection of new cell growth within 90 miles of the radar.

The relative impact of hazardous convective weather represented by each weather depiction product on high-altitude jetways is compared. Exaggerated storm intensities from WARP BREF data result in significantly more en route jetways being impacted by storms of threat-level intensity than CIWS VIL, particularly in the decay phase of storm evolution. The results of this investigation suggest that by reducing the number of travel routes closed by unrepresentative weather information, the CIWS VIL precipitation product may allow air traffic personnel to more efficiently manage functional en route airspace during times of hazardous weather, leading to reduced convective weather delays.

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