Three-Dimensional Mosaic of the Eddy Dissipation Rate Fields from WSR-88Ds

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1. INTRODUCTION

A national 3-D mosaic of in-cloud turbulence, represented as Eddy Dissipation Rate (EDR), is being developed and prototyped through collaboration between the National Center for Atmospheric Research (NCAR) and NOAA’s National Severe Storms Lab (NSSL) under the auspices of the FAA Aviation Weather Research Program’s Turbulence and Advanced Weather Radar Techniques (AWRT) Research Teams (RTs). The EDR field is an indicator of in-cloud turbulence intensity derived from WSR-88Ds’ spectrum width data by the NEXRAD Turbulence Detection Algorithm (NTDA, Williams et al. 2006), which was developed at NCAR by the Turbulence RT. The NTDA software has been delivered to the National Weather Service Radar Operations Center and will be implemented operationally on all WSR-88Ds beginning in the spring of 2008, providing EDR and the associated confidence field, called EDC, as polar-grid Level III data for each radar elevation tilt. A national 3-D mosaic of the EDR field will provide a high-resolution, rapid update, in-cloud turbulence product for use in aviation safety decision support processes. In particular, the Turbulence RT plans to incorporate it into a new rapid-update version of the Graphical Turbulence Guidance product, which will directly address convective turbulence for the first time.

An initial 3-D EDR mosaic capability has been developed using NTDA data from 20 radars covering the Chicago to Washington DC region. The NTDA data are generated at NCAR (see Craig et al. 2008) and transferred to NSSL in real-time. A mosaic scheme previously developed by the AWRT RT for creating 3-D reflectivity mosaics (Zhang et al. 2005) was used as a starting point, and a number of adjustments were made to accommodate differences between the physical characteristics associated with EDR and reflectivity fields. In addition, the EDC data, which reflect the estimated quality of the associated EDR, should be incorporated into the 3-D mosaic weighting scheme, whereas no comparable confidence field exists for the reflectivity data. Presented in this paper are some preliminary results from the initial 3-D EDR and EDC mosaics. Further adjustments and enhancements to the system are still underway.

2. THE REAL-TIME TURBULENCE MOSAIC SYSTEM (RTTMS)

Real-time EDR and EDR confidence (EDC) fields for 20 radars (Table 1) are currently being transferred from NCAR to NSSL through FTP in real-time. The RTTMS ingests these real-time single radar, single elevation tilt data fields and generates 3-D EDR and EDC mosaics on a regional domain (Fig. 1). The northwest corner of the RTTMS domain is at (44.1N, -96.7W), and the southeast corner is (33.6N, -74.6W). The horizontal resolution of the RTTMS grid is 0.02° latitude × 0.02° longitude (~2km × 2km), and there are 31 vertical levels (Table 2) in the 3-D turbulence mosaic grid.

Table 1 List of radars from which EDR and EDC fields are transferred from NCAR to NSSL in real-time.

<table>
<thead>
<tr>
<th>Radar ID</th>
<th>Lat (°N)</th>
<th>Lon (°W)</th>
<th>Radar ID</th>
<th>Lat (°N)</th>
<th>Lon (°W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KAKQ</td>
<td>36.984</td>
<td>-77.007</td>
<td>KJWX</td>
<td>41.359</td>
<td>-85.700</td>
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<tr>
<td>KCCX</td>
<td>40.923</td>
<td>-78.004</td>
<td>KJKL</td>
<td>37.591</td>
<td>-83.313</td>
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<tr>
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<td>41.413</td>
<td>-81.860</td>
<td>KLOT</td>
<td>41.604</td>
<td>-88.085</td>
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<tr>
<td>KDMX</td>
<td>41.731</td>
<td>-93.723</td>
<td>KLSX</td>
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<td>-90.683</td>
</tr>
<tr>
<td>KDVN</td>
<td>41.612</td>
<td>-90.581</td>
<td>KLVX</td>
<td>37.975</td>
<td>-85.944</td>
</tr>
<tr>
<td>KEAX</td>
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<td>-94.264</td>
<td>KILX</td>
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<td>-77.478</td>
</tr>
<tr>
<td>KFCX</td>
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<td>-80.274</td>
<td>KPAH</td>
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<td>-77.478</td>
</tr>
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<td>KRLX</td>
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</tr>
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<td>KILX</td>
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<td>-89.337</td>
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<td>37.235</td>
<td>-93.400</td>
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<tr>
<td>KIND</td>
<td>39.708</td>
<td>-86.280</td>
<td>KVWX</td>
<td>38.260</td>
<td>-87.724</td>
</tr>
</tbody>
</table>
Fig. 1 The domain (white area) for the experimental real-time EDR mosaic system.

The RTTMS consists of four modules. An overview flowchart of the system is shown in Fig. 2.

The first module converts each tilt of the EDR and EDC data from a NetCDF format produced by the NCAR Turbulence RT software into a binary format used by the NSSL AWRT RT software, and then squares the original EDR value (the reason for this is described later). Before converting the data format, the EDR and EDC files in a same volume scan are grouped together according to their sequence in a volume scan for use in Module 2. The sequence of the files was determined using the time stamps included in the NetCDF filenames.

Table 2 Heights (km above Mean Sea Level) of the vertical levels in the RTTMS grid.

<table>
<thead>
<tr>
<th>Level</th>
<th>Hgt (km MSL)</th>
<th>Level</th>
<th>Hgt (km MSL)</th>
<th>Level</th>
<th>Hgt (km MSL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>21</td>
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<tr>
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<td>12</td>
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<td>1.25</td>
<td>14</td>
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<td>24</td>
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<td>15</td>
<td>5.0</td>
<td>25</td>
<td>11.0</td>
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<tr>
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<td>5.5</td>
<td>26</td>
<td>12.0</td>
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<tr>
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<td>2.0</td>
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<td>27</td>
<td>13.0</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>31</td>
<td></td>
<td></td>
<td>18.0</td>
</tr>
</tbody>
</table>

Fig. 2 An overview flowchart of the real-time turbulence mosaic system.

The squaring of the EDR values is necessary for two reasons. Firstly, the EDR field produced by the NTDA is really the cubed root of eddy dissipation rate, $\varepsilon^{1/3}$, which has the unit of $\text{m}^{2/3}\text{s}^{-1}$; the turbulent kinetic energy is directly related to $\varepsilon^{2/3}$, not $\varepsilon^{1/3}$. Secondly, assuming that turbulence is three dimensionally isotropic, Labbit (1981) used the Kolmogorov energy spectrum, and Comman and Goodrich (1996) used the von Karman energy spectrum to show that $\varepsilon^{2/3}$ relates to the expected squared radar spectrum width due to turbulence. Therefore the weighted mean calculations associated with the interpolation and mosaic processes in a later module (Module 3) should operate on the squared spectrum width or $\varepsilon^{2/3}$, not the cubed root eddy dissipation rate provided in the EDR field.

Module 2 generates spherical-to-Cartesian coordinate transformation lookup tables, one for each VCP (Volume Coverage Pattern). This module only runs once for each new VCP. Once the table for a specific VCP is generated, the coordinate transformation information is stored in the table and the same information can be used for next volume scan with the same VCP without computing the coordinate transformation again. The tables help to speed up the real-time process of interpolating radar data from their native spherical coordinates onto the 3-D Cartesian mosaic grid because the complex calculations involving the coordinate transformation are already done a priori.

Module 3 performs the interpolation and mosaicking of the squared EDR and EDC fields from
their native grids in spherical coordinates to the three-
dimensional mosaic grid in a Cartesian coordinate
system. The interpolation and mosaicking schemes
are described in the following section.

Module 4 converts the 3-D mosaicked squared
EDR field back to the cubed root eddy dissipation rate
and outputs the final 3-D EDR and EDC mosaic grids.

The initial version of RTTMS has been running in
real-time at NSSL since September 29, 2007. In the
system, a main program calls these four models and
runs in real-time on clock, currently at every 5 min.

The update cycle for the 3-D turbulence mosaic is
eventually expected to be reduced to every 2.5 min,
and the NetCDF files will be replaced with NEXRAD
Level III NTDA data once the operational NTDA
products are available from the NEXRAD ORPG
(Open Radar Product Generator).

3. INTERPOLATION AND MOSAICKING
ALGORITHMS

The 3-D radar reflectivity mosaic scheme
developed by Zhang et al. (2005) was adapted for the
interpolation and mosaicking of the turbulence field.
There are three interpolation schemes for transforming
single radar data fields from spherical coordinates to a
3-D regular grid in Cartesian coordinates. The first
scheme, Nearest Neighbor mapping, assigns the value
from the nearest radar bin (i.e., measurement location)
to each Cartesian grid cell. The distance between a
radar bin and a given grid cell is calculated from the
center of the radar bin to the grid cell’s center.

The second scheme, Vertical Interpolation,
applies a linear interpolation in the elevation (vertical)
direction while taking the nearest neighbor approach in
azimuth and range directions. The vertical
interpolation is performed between all pairs of adjacent
tilts.

The third scheme, Vertical and Horizontal
Interpolation, is the vertical interpolation approach
combined with a horizontal interpolation. The horizontal
interpolation is only applied between adjacent tilts within certain range limits, where
horizontal distance between centers of the adjacent tilts
are less than a user-defined threshold (default value =
25 km).

Once single radar fields from each radar are
interpolated to the Cartesian grid, each grid cell
covered by multiple radars is examined. The final
mosaicked value is computed from a weighted mean of
the multiple radar values using the weighting function
of \( w = \exp\left(-\frac{d^2}{D_0}\right) \) for each. Here \( d \) is the
distance from the grid cell to a given radar site, and \( D_0 \)
is a constant which is set to \((50 \text{ km})^2\).

4. CASE STUDY

A playback version of the RTTMS has also been
developed for rerun of historical events. Using the
playback system, 3-D turbulence mosaic fields for two
squall line cases were analyzed.

Fig. 3 shows example 3-D EDR and EDC mosaic
fields from the RTTMS on October 1, 2007. The
vertical interpolation scheme was used to obtain the
results. A squall line associated with a cold front runs
north-south from western Wisconsin to the northeast
corner of Oklahoma (Fig. 3a). The large values in the
EDR and EDC mosaic fields (Figs. 3b and 3c)
corresponded well with the most intensive reflectivity
in the squall line. There were also some notable
differences between the turbulence and the reflectivity
fields. For instance, there were some circle-shaped
gaps in the mosaicked EDR and associated confidence
fields (Figs. 3b and 3c). These gaps are due to factors
such as the gaps between adjacent tilts, the insufficient
signal in the 2nd trip echo recovery procedure and the
limited coverage (230 km) of the WSR-88D’s Doppler
fields. Mitigating these artifacts is a challenge because
a large-scale smoothing/gap-filling that works well for
the radar reflectivity would not be appropriate for EDR
because of the typically small scales of turbulence
patches. Additional radars could provide better
coverage and fill in some of the gaps (e.g., by running a
version of the NTDA on TDWR radars), and use of a
scan strategy with more sweeps and smaller elevation
increments would be very helpful as well. In
addition, the Turbulence RT has proposed a new
spectrum width estimator for NEXRADs that should
produce usable spectrum widths in regions of lower
SNR than the current estimator (Meymaris and
Williams 2007), and is also working on a second
version of the NTDA that should provide improved
coverage, particularly at lower altitudes.
Fig. 3a. Composite reflectivity from the RTTMS valid at 01:00UTC on 10/01/2007.

Fig. 3b. Horizontal cross section of the EDR mosaic field at 7 km (MSL) valid at 01:00UTC on 10/01/2007.

Fig. 3c. Horizontal cross section of the EDC mosaic field at 7 km (MSL) valid at 01:00UTC on 10/01/2007.

Fig. 4 shows example results from a severe storm event that occurred on August 24, 2007. The relatively large values of EDR (Fig.4b) on the squall line correlated well with the strong convection (e.g., areas with reflectivity higher than 40 dBZ, Fig.5a). For the data displayed in Figs.4b and 4c, the Nearest Neighbor interpolation scheme was used to remap the single radar EDR and EDC from spherical system onto the three dimensional Cartesian grids. There are circle-shaped “cone of silence” regions around radars (Figs.4b and 4c); these holes appear more prominent in the EDR than the reflectivity field because they are less likely to be filled in using data from adjacent radars. Figs. 5 and 6 show mosaicked EDR fields using the Vertical Interpolation and the Vertical and Horizontal Interpolation schemes, respectively. Comparing Fig. 5 with Fig. 4b one can see that the Vertical Interpolation alleviated the circle-shaped “ring” artifacts around KSGF and KLSX radars significantly. The Vertical and Horizontal Interpolation did an even better job (Fig. 6).

Fig. 4a. Composite reflectivity for a squall line event that occurred on 24 August 2007. The images are valid at 22:55UTC.
Fig. 4b. The EDR mosaic field at 8 km (MSL) height corresponding to Fig 4a. The Nearest-neighbor algorithm was used to remap the single radar data from spherical coordinates to the three dimensional Cartesian grids.

Fig. 4c. Same as in Fig. 4b except showing the EDC field.

Fig. 5. Same as Fig. 4b, but with the Vertical Interpolation scheme.

Fig. 6. Same as Fig. 4b, but with the Vertical and Horizontal Interpolation scheme.

5. FUTURE WORK

In the future, we will use *in situ* turbulence reports from commercial airplanes (Cornman et al. 2004) to evaluate the accuracy of the turbulence mosaic grids, and to quantitatively compare alternative mosaic schemes based on both their accuracy and coverage. In particular, we will continue to evaluate the algorithms that remap single radar data from spherical coordinates to three-dimensional Cartesian grids as well as the weighting function for mosaicking EDR and EDC fields from multiple radars. We will also explore ways of using the EDC field in the weighting scheme for the 3-D EDR mosaic.

6. ACKNOWLEDGEMENT

This research is in response to requirements and funding by the Federal Aviation Administration (FAA). The views expressed are those of the authors and do not necessarily represent the official policy or position of the FAA.

7. REFERENCES


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