Echotops for annotation on radar imagery

I. Holleman

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Contents

Chapter 1

Introduction

In 2007 KNMI has performed a technical upgrade of the weather radar systems to extend their operational lifetime with another 10 years. Apart from a mechanical overhaul the upgrade consisted of a renewal of the radar (scan) controller, the signal processor, and the product processor. The radar controller and the signal processor were 10-year-old computer systems which had become outdated and difficult to maintain. As a result of the upgrade the resolution of the operational radar imagery will be increased from 2.5×2.5 km^2 pixels to 1.0×1.0 km^2. Details on the geographical projection of the new high-resolution products are given in Appendix A.

Currently four echotops are derived from the echotop product by the BRAS ("Bliksem Radar Animatie Scherm") display system and the display system of LVNL (Air Traffic Control of the Netherlands). It has been painstaking to harmonize the functionality of the two display systems and thus obtain the same annotated echotops. With the introduction of the new high-resolution radar imagery, new problems are foreseen as the porting of the current annotation algorithm to the high-resolution imagery is not straightforward. Therefore a new algorithm for the selection of the annotated echotops insensitive to a change of resolution is proposed in this technical report. Furthermore it is recommended to run the new algorithm at a central point close to the radar product processor and to add the selected echotops to the operational HDF5 echotop products. In this way all display systems have access to a common list of echotops for annotation on the radar imagery and possible discrepancies are avoided.

The outline of the remaining of the report is as follows:

- In Chapter 2 a description of the current operational method for selection of echotops for annotation is given and an example is discussed.

- The new proposed method for the selection of echotops is presented in Chapter 3. The method is validated on low-resolution and high-resolution imagery and a comparison with the current operational method is made.

- In chapter 4 the storage of the selected echotops and cell properties in HDF5 is discussed.
- In the last chapter the conclusions and recommendations for further application are made.

Chapter 2

Current operational method

Measurement of radar echotop heights and annotation of four echotops in operational radar imagery have a long history at KNMI. In the mid sixties of the previous century regular measurements of echotop heights between 50 and 150 km range started. The tops were indicated by hand on the radar sketches that were distributed by facsimile. In 1988 the facsimile distribution was replaced by a computer display of radar imagery. The manual echotop measurements could be entered as annotation on the radar imagery. One year later automated measurements of the echotops above the four strongest echoes became operational. From 1996 onwards the weather radars are able to record full volume scans and echotop products are derived operationally. At that point an algorithm was introduced to derive the "famous" four tops for annotation from the operational echotop product. More on the historical background of the "four tops" can be found in Wessels (2006).

The current algorithm for determining the four tops is described in Wessels (2006) and the complete description is also given in Appendix B for convenience. Basically all observed echotops above 2000 m are analyzed.

Table 2.1: Output from current echotop annotation algorithm for 21 January 2008 at 0800 UTC. Longitudes and latitudes are given in degrees and the height in km.

Column	Row	Longitude	Latitude	Flight Level	Height
212	79	7.691	53.265	230	7.01
63	38	2.360	54.436	210	6.40
101	135	3.555	52.292	140	4.27
211	140	7.372	51.959	140	4.27

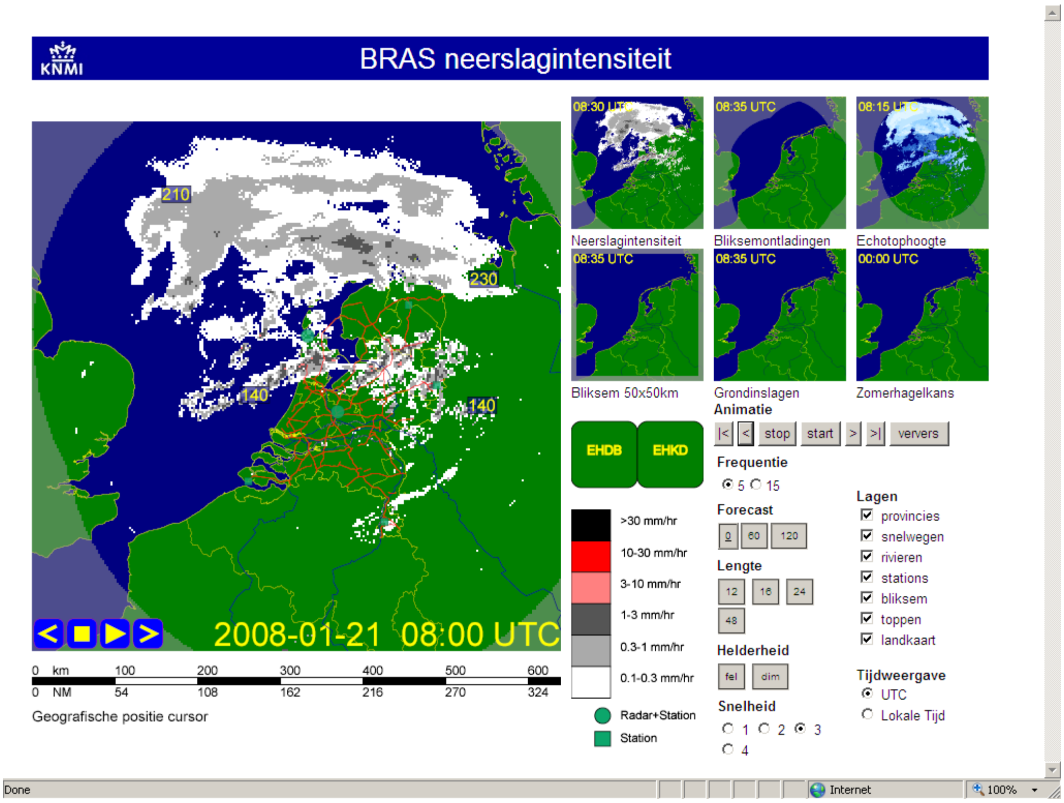

Figure 2.1: Snapshot of the BRAS ("Bliksem Radar Animatie Scherm") radar display used in the operational weather forecasting office. The snapshot is taken on 21 January 2008 at 0800 UTC.

Echotops observed within 70 km range from the weather radar (for single-site radar products) and further than 160 km range from any weather radar are excluded from further analysis. Then all echotops within 10 km from a higher top are removed from the series. Subsequently a speckle filter with a standard deviation criterion is applied to remove spurious isolated echotops near the tropopause. Finally the remaining echotops are sorted for decreasing height and the image quadrant of each echotop is established. The final selection of the four tops starts with the first occurrences in each quadrant, then — if needed — supplemented with the highest remaining tops.

Figure 2.1 shows a snapshot of the BRAS ("Bliksem Radar Animatie Scherm") radar display currently used in the operational weather forecasting office and by a few external customers. The snapshot is taken on 21 January 2008 at 0800 UTC and it shows the radar rainfall and the four annotated echotops labeled with 210, 230, 140, and 140. The labels refer to the height of the observed echotops in flight level, i.e., in units of hundred feet. In

Table 2.1 the properties obtained for the four derived echotops are listed for 21 January 2008 at 0800 UTC. The positions are given in pixel coordinates (column and row numbers) of the radar image and in geographical longitude and latitude. The echotop heights are given in flight level and in kilometers.

Currently the four tops are derived from the echotop product by the BRAS display system and the display system of LVNL (Air Traffic Control of the Netherlands). In the past it has been painstaking to harmonize the functionality of the two display systems and thus obtain the same annotated echotops used for warnings. With the introduction of the new high-resolution radar imagery at KNMI (See Appendix A), new problems are foreseen as the porting of the current annotation algorithm to the high-resolution imagery is not straightforward. Therefore a new algorithm for the derivation of the annotated echotops insensitive to a change in resolution is proposed in this technical report. In addition it is proposed to store the output of the top detection algorithm in the operationally produced radar files and thus make sure that all display systems use the same set of echotops for annotation.

Chapter 3

New proposed method

In this chapter a new proposed algorithm for detection of radar echotops is described. It is shown that this new method is insensitive to changes in image resolution and partly resembles the output of the current algorithm. It is stressed here that an exact resemblance of the current and new method is not intended, and a generally applicable and straightforward method is preferred.

3.1 Description of new method

The new proposed method for deriving the echotop heights for annotation in operational radar imagery is based on cell identification. A cell is defined as a group of connected pixels, i.e., pixels above a certain threshold connected via the four direct neighbors or the four diagonal neighbors (Gonzalez and Woods, 1992). First of all, the appropriate threshold for cell finding is determined. Figure 3.1 shows the low-resolution (2.5×2.5 km^2) echotop product for 21 January 2008 at 0800 UTC and thus matching the BRAS display in Figure 2.1. Note that the colors in the image do not represent the rainfall intensity but the heights of the observed echotops. A histogram of these echotop heights is plotted in the left frame of Figure 3.2. In this winter case hardly any echotops above 6 km are observed and most echotop heights are seen between 2 and 5 km. The right frame of Figure 3.2 shows the corresponding cumulative histogram of the observed echotop heights for 21 January 2008 at 0800 UTC. The threshold for cell finding is chosen such that only a certain fraction (default value is 0.25) of the image pixels has a higher value. In this case a threshold of 4.79 km is derived (see dashed lines in the figure).

Using the derived threshold, groups of connected pixels are marked in

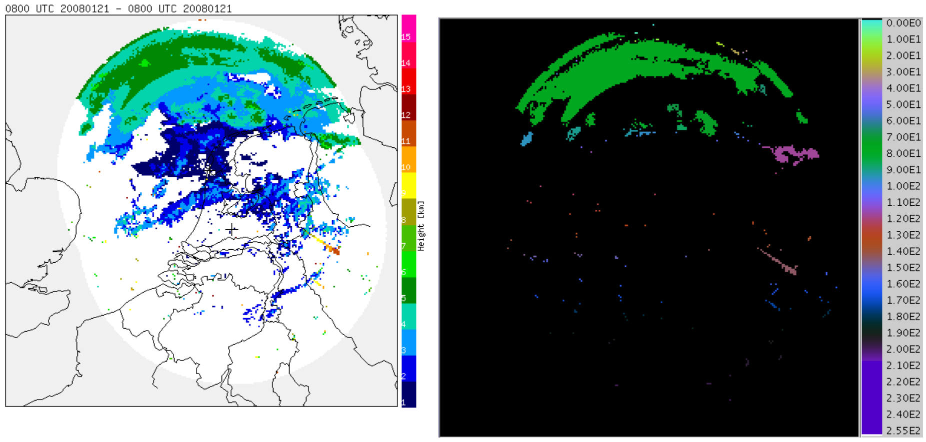

Figure 3.1: The left image shows the low-resolution echotop imagery (2.5×2.5 km^2 pixels) for 21 January 2008 at 0800 UTC (matching the display in Figure 2.1). The pixel colors in the image denote the heights of the observed echotops. The right image reveals the detected cells with connected pixels above threshold (for left image) and the color scale refers to the different cells in this case.

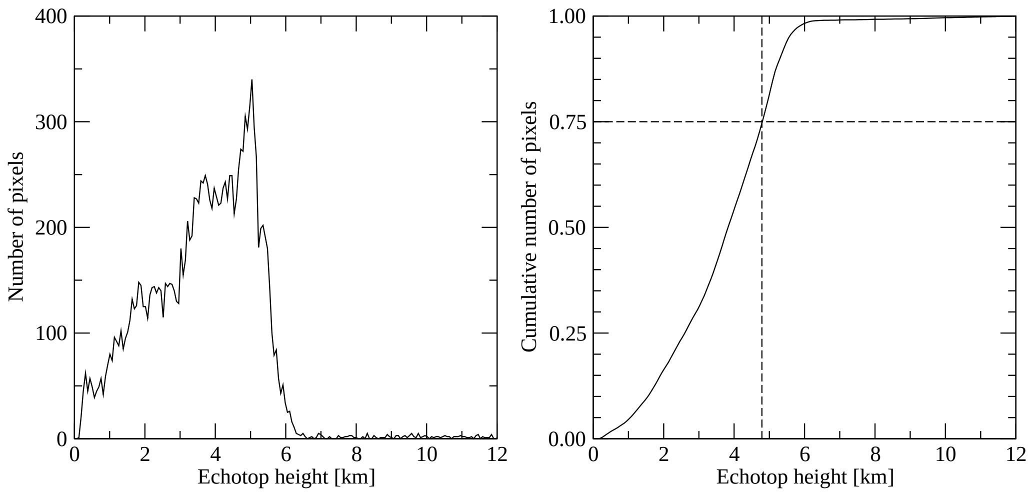

Figure 3.2: The left plot shows a histogram of the image pixel values of the radar echotop product displayed in Figure 3.1. The horizontal axis refers to the echotop height and the vertical axis to the number of pixels. The right plot shows the cumulative histogram scaled to one with the derived echotop threshold for cell finding (dashed lines). A threshold of 4.79 km is derived in this case.

1	1	0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0
0	0	0	2	2	2	0	3	3	0
0	0	0	2	2	2	0	0	3	0
0	0	0	0	2	0	0	0	0	0
0	0	0	0	2	0	0	0	0	0
0	0	0	2	0	0	0	0	4	0
0	0	0	0	0	0	0	4	4	4

Figure 3.3: A schematic example of a cellmap denoting groups of connected pixels. In this example for a 10×10 image, pixels below threshold are marked with 0 and groups of connected pixels are marked with the same number 1...4.

the image using for instance the non-recursive algorithm found in Gonzalez and Woods (1992). The basic output of such a cell finding algorithm is a so-called "cellmap" denoting the groups of connected pixels. In Figure 3.3 a schematic example of such a cellmap for a 10×10 image is shown. Pixels below the threshold value are marked with 0 and groups of connected pixels are marked with the same number (1...4). In the right image of Figure 3.1 the cellmap obtained for the low-resolution echotop product of 21 January 2008 at 0800 UTC is visualized. Clearly black is used to mark the echotop pixels below the derived threshold of 4.79 km. Several small and larger groups of connected pixels with different colors (referring to different cellmap numbers) can be seen in the image.

By combining the original echotop product and the derived cellmap, a variety of echotop cell properties can be deduced. The geographical area of a cell, the mean echotop height for a cell, the maximum echotop value observed in the cell, and the image coordinates of the maximum are calculated for all cells. Table 3.1 lists the derived echotop cell properties for 21 January 2008 at 0800 UTC. The cells are sorted by area and an area threshold of 100 km^2 is applied to select valid cells, and thus only larger cells appear in the table. If a user prefers to sort the cells according to maximum echotop value this can easily be done. The two largest cells (green and purple) in the right image of Figure 3.1 evidently correspond to the top-two of the table. In addition a number of smaller cells is found and obviously more than four cells are listed. The user can make the final selection for annotation of the echotops in the radar imagery. A comparison with the output from the current algorithm is presented in Section 3.3.

Table 3.1: Output from new proposed echotop annotation algorithm for 21 January 2008 at 0800 UTC on low-resolution imagery. Longitudes and latitudes are given in degrees, area in km^2, and the height in km.

Column	Row	Longitude	Latitude	Area	Height	Flight Level
63	38	2.360	54.437	19549.3	6.43	196
212	79	7.691	53.263	1018.7	6.87	209
163	69	5.965	53.605	718.7	8.00	244
217	156	7.506	51.601	318.7	11.84	361
83	67	3.050	53.785	225.0	5.48	167
52	74	1.903	53.662	225.0	5.54	169
143	52	5.295	54.016	206.2	5.73	175
90	59	3.323	53.950	200.0	5.17	158
224	61	8.213	53.614	181.2	5.17	158
147	64	5.401	53.747	106.2	5.61	171

3.2 Application to high resolution imagery

As KNMI is currently increasing the resolution of the operational radar imagery from 2.5×2.5 km^2 pixels to 1×1 km^2 pixels, it is of crucial importance that the new proposed method for selection of the echotops for annotation is insensitive to resolution changes. From the description of the method given in the previous section it is probably clear that the new proposed method should be insensitive to these changes.

In order to validate this expectation the new proposed method has also been applied to the high-resolution echotop products from 21 January 2008 at 0800 UTC. The corresponding high-resolution echotop product and the derived cellmap image are visualized in Figure 3.4. When comparing this high-resolution echotop product with that in Figure 3.1 the sharper structures due to smaller pixels are most appealing. When comparing the two corresponding high- and low-resolution cellmaps, it is evident that the shapes of the cells match but that the colors are different. The different colors refer to different cell numbers given by the connection-finding algorithm but they do not have a physical meaning.

In Table 3.2 the echotop cell properties derived with the new proposed method are listed. Again the cells have been sorted according to decreasing cell area and cells smaller than 100 km^2 have been removed from the list. The two largest cells (light blue and dark blue) in the right image of Figure 3.4 evidently correspond to the top-two of the table. A comparison with the

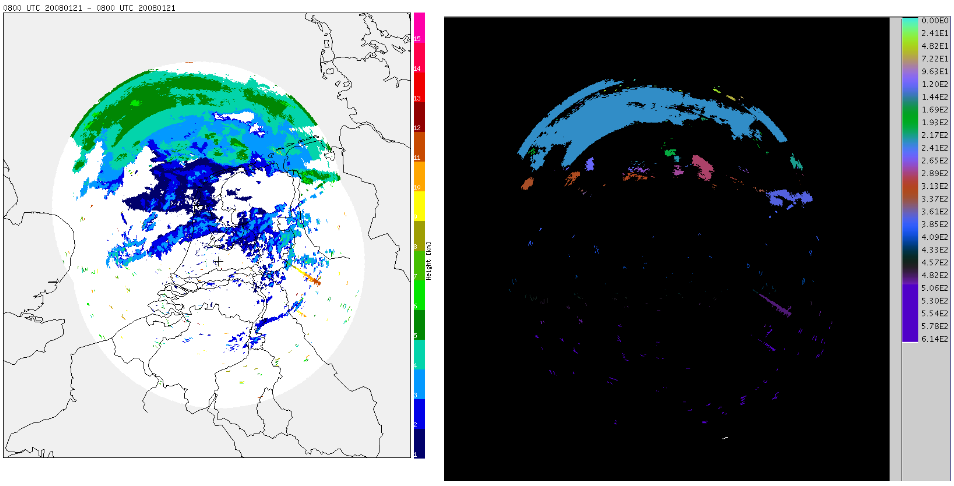

Figure 3.4: The left image shows the high-resolution echotop imagery (1×1 km^2 pixels) for 21 January 2008 at 0800 UTC (matching the display in Figure 2.1). The pixel colors in the image denote the heights of the observed echotops. The right image reveals the detected cells with connected pixels above threshold (for left image) and the color scale refers to the different cells in this case.

Table 3.2: Output from new proposed echotop annotation algorithm for 21 January 2008 at 0800 UTC on high-resolution imagery. Longitudes and latitudes are given in degrees, area in km^2, and the height in km.

Column	Row	Longitude	Latitude	Area	Height	Flight Level
157	173	2.352	54.429	19491.1	6.43	196
530	273	7.694	53.276	949.0	6.93	211
412	245	6.038	53.640	715.0	9.70	296
545	464	7.546	51.624	300.0	11.84	361
130	262	1.903	53.663	221.0	5.54	169
223	226	3.293	53.939	198.0	5.17	158
563	236	8.244	53.555	197.0	5.17	158
208	244	3.058	53.790	189.0	5.48	167
289	248	4.240	53.710	164.0	5.61	171
361	206	5.348	54.022	145.0	5.73	175
372	233	5.472	53.779	136.0	5.73	175

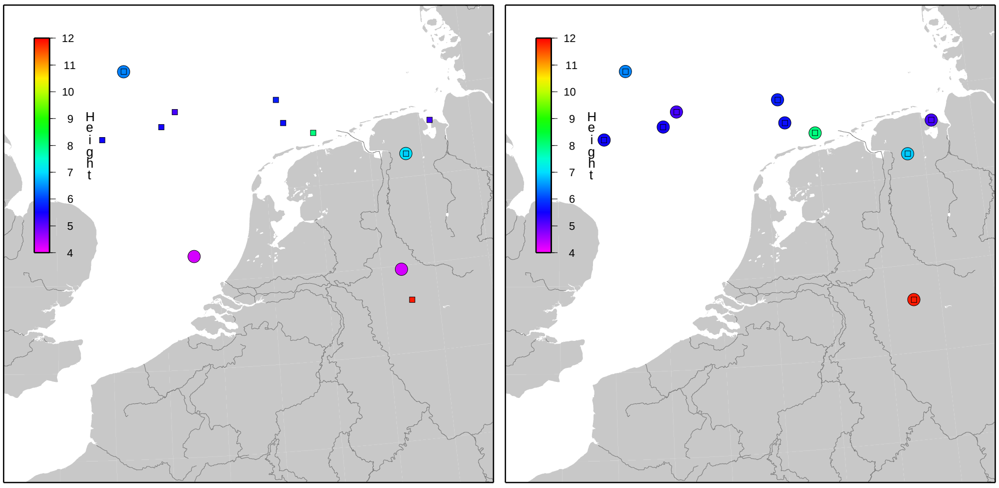

Figure 3.5: The left frame presents a graphical comparison of the output of the current method for annotation of echotops (large circles) to that of the new proposed method on the low-resolution imagery (smaller squares) for 21 January 2008 at 0800 UTC. The right frame presents a similar comparison between the output of the new proposed method on low-resolution imagery (large circles) to that on high-resolution imagery (smaller squares) for the same case. The colors represent the echotop values.

output from the current algorithm and the output on the low-resolution imagery is presented in the next section.

3.3 Comparison of methods

A graphical comparison of the current operational method for selection of echotops for annotation and the new proposed method on low-resolution imagery is presented in the left frame of Figure 3.5. The map shows the positions and values of the selected echotops. The echotops obtained from the current method are indicated by the large circles and those from the new proposed method by the smaller squares. The echotop values are indicated by the colors. The two highest echotops (blue circles) found by the current algorithm are also found by the new proposed method. The other two echotops (purple circles) are not found by the new algorithm as the heights are below the applied threshold of 4.79 km. It is evident that the new proposed algorithm has selected a number of other tops. Comparing Tables 2.1 and 3.1 it appears that the two matching echotops correspond to the largest cells. The highest echotop found by the new method (red square) is due to a solar interference (see Figure 3.1).

In the right frame of Figure 3.5 a graphical comparison of the new proposed method for low-resolution (large circles) and high-resolution (smaller squares) imagery is shown. Obviously the output of the new proposed method is insensitive to a resolution change from 2.5×2.5 km^2 pixels to 1×1 km^2 pixels. Tables 3.1 and 3.2 can be used for a detailed numerical comparison.

Chapter 4

Storage in HDF5

At KNMI all operational weather radar, satellite, and lightning detection data are stored and distributed to (real-time) users in HDF5. The HDF5 technology suite is designed to organize, store, discover, access, analyze, share, and preserve diverse, complex data in continuously evolving heterogeneous computing and storage environments (`www.hdfgroup.org`). HDF5 supports all types of data stored digitally, regardless of origin or size. Petabytes of remote sensing data collected by satellites, terabytes of computational results from nuclear testing models, and megabytes of high-resolution MRI brain scans are stored in HDF5 files, together with metadata necessary for efficient data sharing, processing, visualization, and archiving.

The HDF5 data model used by KNMI is described in Roozekrans and Holleman (2003) and it will be extended in the near future (Holleman et al., 2008). This data model includes a structure for storing 8-bit and 16-bit images and corresponding metadata, including geographical projection information. In addition the model includes structures for storing processed and raw lightning detection data and radar volume scan data. Finally also metadata on radars, satellites, and detection stations can be stored and color palettes can be attached to imagery for visualization purposes.

An extension of the HDF5 data model is proposed to store the selected echotops for annotation on radar imagery (Holleman et al., 2008). Table 4.1 lists the proposed HDF5 attributes that will be added to the "statistics" subgroup of the repeated "image" group in the existing HDF5 data model. The first attribute contains the number of selected cells (in echotop imagery) and it fixes the length of the five array attributes. The second attribute contains the threshold used for finding the groups of connected pixels. The arrays describe different properties of the selected cell, i.e. the area of the cell in km^2, the mean value of the geophysical quantity over the cell area, the maximum value of the geophysical quantity, and the column and row coordinates of

Table 4.1: An overview of the HDF5 attributes that will be used for storage of the selected echotops for annotation on radar imagery. The first attribute indicates the number of selected echotops and it marks the length of the subsequent array attributes (five). The attributes will be added to the "statistics" subgroup of the repeated "image" group in the KNMI HDF5 data model.

HDF5 Attribute	Type	Description
stat_cell_number	Integer	Number of cells detected in the image for which properties are stored
stat_cell_threshold	Float	Threshold value of geophysical quantity for cell finding.
stat_cell_area	Float array	Areas of the detected cells in km^2
stat_cell_mean	Float array	Mean value of geophysical quantity stored in image over cell area in units of the parameter
stat_cell_max	Float array	Maximum value of geophysical quantity stored in image over cell area in units of the parameter
stat_cell_column	Integer array	Column coordinate (pixel number) in image of maximum value detected in cell area
stat_cell_row	Integer array	Row coordinate (pixel number) in image of maximum value detected in cell area

the maximum. When these attributes are added to the operational echotop product, the display systems have access to a common list of echotops for annotation on the radar imagery.

Chapter 5

Summary and Recommendations

In this report a new method is proposed for selection of echotops for annotation on operational weather radar imagery. This new method is straightforward and insensitive to changes in image resolution. Currently the four echotops are derived from the echotop product by the BRAS ("Bliksem Radar Animatie Scherm") display system and the display system of LVNL (Air Traffic Control of the Netherlands). It has been painstaking to harmonize the functionality of the two display systems. With the introduction of the new high-resolution radar imagery, new problems are foreseen as the porting of the current annotation algorithm to the high-resolution imagery is not straightforward. Therefore it is recommended to replace the operational method by the new proposed algorithm.

Moreover it is recommended to run the new algorithm at a central point close to the radar product processor and to add the selected echotops to the operational HDF5 echotop products. In this way all display systems have access to a common list of echotops for annotation on the radar imagery and possible discrepancies are avoided. It is left to the user to make the final selection of the echotops for annotation, e.g., the highest values, the values for the largest cells, or the four values for the image quadrants (mimicking the current algorithm), could be used. Finally it is suggested to run the new algorithm on all radar products as preliminary results indicate that it can provide useful information on extreme values in other products as well.

Acknowledgments

Hans Beekhuis and Ernst de Vreede (KNMI) are gratefully acknowledged for reviewing the draft Technical Report.

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Appendix A

Geographical projection of high-resolution KNMI radar images

In this appendix the details of the geographical projection of the high-resolution KNMI radar images, both single site data and the national composite, are listed. The radar images are projected according to a stereographic projection with the north pole in the projection origin. A stereographic projection also uses a so-called alignment meridian (Greenwich) which is equal to the longitude of the projection origin and a latitude of true scale (60N). The stereographic projection is a conformal projection which implies that the angles are conserved during the projection. The meridians are projected into straight lines starting from the north pole and latitude circles are projected as circles centered at the north pole. It is important to stress that the KNMI radar images are projected using an ellipsoid earth model (WGS-84). This makes the projection equations substantially more complex, but it enables a more accurate overlay of the radar echoes with the topographical data. The parameters of the geographical projection of the KNMI radar images are listed in the table below:

Parameter	Value
Projection	Stereographic
Projection origin (lon,lat)	0E, 90N
True scale (lat)	60N
Earth radius (equator,polar)	6378.137 km, 6356.752 km
Pixel size at true scale (x,y)	1.000 km, −1.000 km
Offset of image corner (i,j)	0.0, 3650.0
Number of rows	765
Number of columns	700

The geographical projection of the radar data from the azimuthal equidistance projection ("radar projection") to the polar stereographic projection can be done using the "proj.4" library (Evenden, 1990). This library has been developed at the USGS and is used world-wide in numerous applications. The geographical projection of the KNMI radar images is described by the following "proj.4 string":

```
"+proj=stere +x_0=0 +y_0=0 +lat_0=90 +lon_0=0 +lat_ts=60 +a=6378.137 +b=6356.752"
```

After the geographical (re)projection the resulting image only has to be scaled and shifted linearly using the given pixel sizes and offsets of the image corner. The pixel size in y-direction is negative because the images lines are plotted from north-to-south and the y-axis is pointing in the opposite direction. The projection parameters define the geographical corners of the KNMI radar images. The corners of the KNMI radar image are:

Corner	Lon [deg]	Lat [deg])
north-west	0.000E	55.974N
north-east	10.856E	55.389N
south-east	9.009E	48.895N
south-west	0.000E	49.362N

Appendix B

Selecting cloud tops for annotation in PPI displays

In this Appendix the description of the current operational algorithm by Wessels (2006) is reproduced.

Once the complete ETH product is available, it is transmitted to the CRIS, where the following actions take place:

- selection of high tops for annotation of (old) remote displays
- conversion to KNMI-PIF file for display at the MWS
- creation of combined product from more radars for MWS display.

The second and third item are treated in the next section, the first is documented in the following algorithm for selecting individual tops from ETH-product.

The first selection of high tops consists of pixels with higher value than the surrounding ones. Tops below a minimum value (set to 2000 m, default 0) are excluded. The tops inside an inner circle (d_2, set to 70 km, default 15) or outside an outer circle (d_1, set to 160 km, default 120) around x_r,y_r are deleted from the series. A number of N tops is remaining.

Next all tops within a 10 km (d_3, default 10) from a higher top are discarded. An additional selection criterion is needed to discard spurious isolated echoes near the tropopause: a so-called “speckle filter”. For each pixel the surrounding 8 pixels are evaluated. If the central value is a certain amount X higher than the average of the surrounding pixels, that central value is discarded as echo top. The critical difference X is based on the standard deviation of the values of the 8 surrounding pixels with respect to their average:

$$\min(X_1, X_2 \cdot \text{stddev}(\text{surr.8})) \quad \text{(B.1)}$$

Default values for the X-parameters are: X_1=1.8 km, X_2=5.

In the next step the remaining tops are sorted for decreasing height and N is updated. For each of the N remaining tops the quadrant number 1-4 is established. Then the series of quadrant numbers - in order of decreasing top height - is searched for the first occurrence (highest top) of each quadrant number. Finally the required number M of tops is selected, starting with the first occurrences in each quadrant, then - if necessary - supplemented with the highest remaining tops (independent of quadrant).

The result is a number of tops with pixel coordinates x,y and height. Parameters are: d_1, d_2, d_3 (pixel units, resp. about 150, 50 and 20 km) and M (number of tops searched for) The displayed identification A...D has to be maintained for nearby tops in subsequent pictures. This number tracking has been specified in the KNMI 1987 radar program.

NOTE: The distance parameters proved on first inspection to be internal, any change requiring a new compilation.

NOTE: Initially the height scale was fixed at 100 m per bit value. The maximum height was 25.5 km in stead of about 16 km (label V4 in the extended file header). Preferably the height scale should be read from the input file header.