Real-time Transport and Dispersion from Illinois Nuclear Power Plants

Thomas E. Bellinger, CCM

Illinois Emergency Management Agency
Springfield, Illinois

1. INTRODUCTION

Meteorological data routinely used in nuclear power plant exercises has given many emergency responders a false sense of being able to accurately depict the transport and dispersion of a radioactive plume released in a real nuclear power accident. To easily predict real-time dispersion and transport, a computer program was developed to automatically display where hypothetical releases might travel from any of the Illinois nuclear power plants. The program was designed to account for the transport and dispersion of any hypothetical release from a nuclear power plant especially when conditions become complex with wind shifts, fronts, speed changes, etc. One regional and seven site-specific nuclear power plant displays have been developed. The site-specific displays also show the location of the 16 gamma radiation detectors surrounding each plant as well as the evacuation sub-areas within the 10-mile emergency planning zone (EPZ). Numerous meteorological conditions, such as near calms, strong winds, frontal passages, Lake Michigan influenced flow, and boundary layer decoupling have been documented. The program has been a useful tool in showing the fundamentals of dispersion and what really can and does happen in the atmosphere.

2. REGIONAL DISPERSION

A display of the regional output of the program is shown in Figure 1. The only information supplied by the user is how many minutes ago to initialize the dispersion and transport. The default time is 2 hours but the program can handle times between 1 minute and 6 hours. Once the time is entered, the program automatically obtains all the required real-time meteorological data from the Illinois Emergency Management Agency (IEMA) Reactor Data Link (RDL) and draws the display. The RDL receives updated raw and averaged meteorological data and other nuclear power plant parameters every minute. Currently, running 15-minute averages are used but the program can be modified to use 1-minute averages or raw data.

The regional display uses several different source heights, each depicted with its own color, to show the transport and dispersion from each nuclear plant. White is used to show transport and dispersion from a ground level source and is derived from the lowest level of meteorological data available, generally 10 meters above ground. The color magenta is used to show transport and dispersion from an elevated source and is derived from the highest level of meteorological data available. The color blue is used to show transport and dispersion using a mid-level source, available at only three nuclear plants, and is derived from the mid-level of meteorological data. Transport and dispersion is accomplished by using *only* the site-specific wind directions and wind speeds and the Pasquill stability classes. Since no other offsite data sources are used, the maximum hypothetical release time of 6 hours was chosen to limit abnormally large and unrepresentative maximum downwind transport distances during strong wind speeds. Beginning and ending hypothetical release times are shown as well as the maximum downwind distance and average transport speed from each source height. Every 3 minutes, the display automatically updates using the current real-time meteorological data from the RDL.

The regional display also shows some other important information. State borders and 10 and 25-mile circles help define the region and the location of each nuclear plant. Red, yellow, and green scalable arrows at each nuclear plant and the IEMA Doppler Sodar represent the wind velocities at various levels in descending order. The red or green scalable arrows not located at the power plants or the Sodar are METAR data that have been downloaded from the National Weather Service (NWS) and National Data Buoy Center (NDBC) via Internet FTP every 20 minutes. If the NWS or NDBC data has a green color, the wind speed is greater than or equal to 5 miles per hour. Missing NWS or NDBC data is depicted with a white plus sign and calms with a red triangle. Any NWS or NDBC data that is less than 5 miles per hour is colored in red and highlights areas where gaussian dispersion modeling assumptions may be invalid. A bilinear interpolation is then performed using all the surface (10-meter) wind

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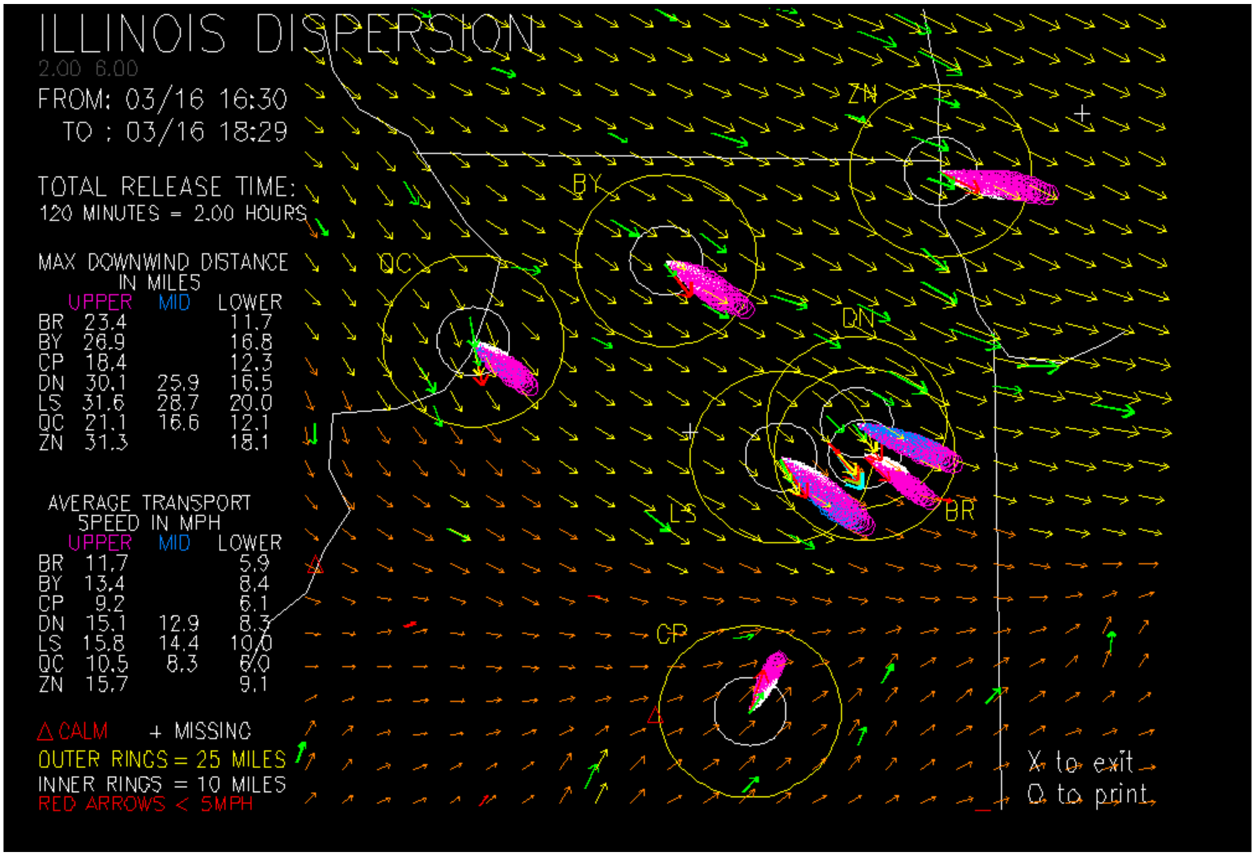
Corresponding author address: Thomas E. Bellinger, Illinois Emergency Management Agency, 1035 Outer Park Drive, Springfield, IL 62704 Email: bellinger@iema.state.il.us



ILLINOIS DISPERSION

2.00 6.00

FROM: 03/16 16:30
TO : 03/16 18:29

TOTAL RELEASE TIME:
120 MINUTES = 2.00 HOURS

MAX DOWNWIND DISTANCE IN MILES

	UPPER	MID	LOWER
BR	23.4		11.7
BY	26.9		16.8
CP	18.4		12.3
DN	30.1	25.9	16.5
LS	31.6	28.7	20.0
QC	21.1	16.6	12.1
ZN	31.3		18.1

AVERAGE TRANSPORT SPEED IN MPH

	UPPER	MID	LOWER
BR	11.7		5.9
BY	13.4		8.4
CP	9.2		6.1
DN	15.1	12.9	8.3
LS	15.8	14.4	10.0
QC	10.5	8.3	6.0
ZN	15.7		9.1

△ CALM + MISSING
OUTER RINGS = 25 MILES
INNER RINGS = 10 MILES
RED ARROWS < 5MPH

Figure 1. Potential dispersion and transport from Illinois nuclear power plants.

data to overlay a regularly spaced wind velocity field on the display. Yellow colored wind velocities show winds greater than or equal to 5 miles per hour and orange colored wind velocities show winds less than 5 miles per hour thus highlighting areas where gaussian dispersion modeling assumptions may be invalid

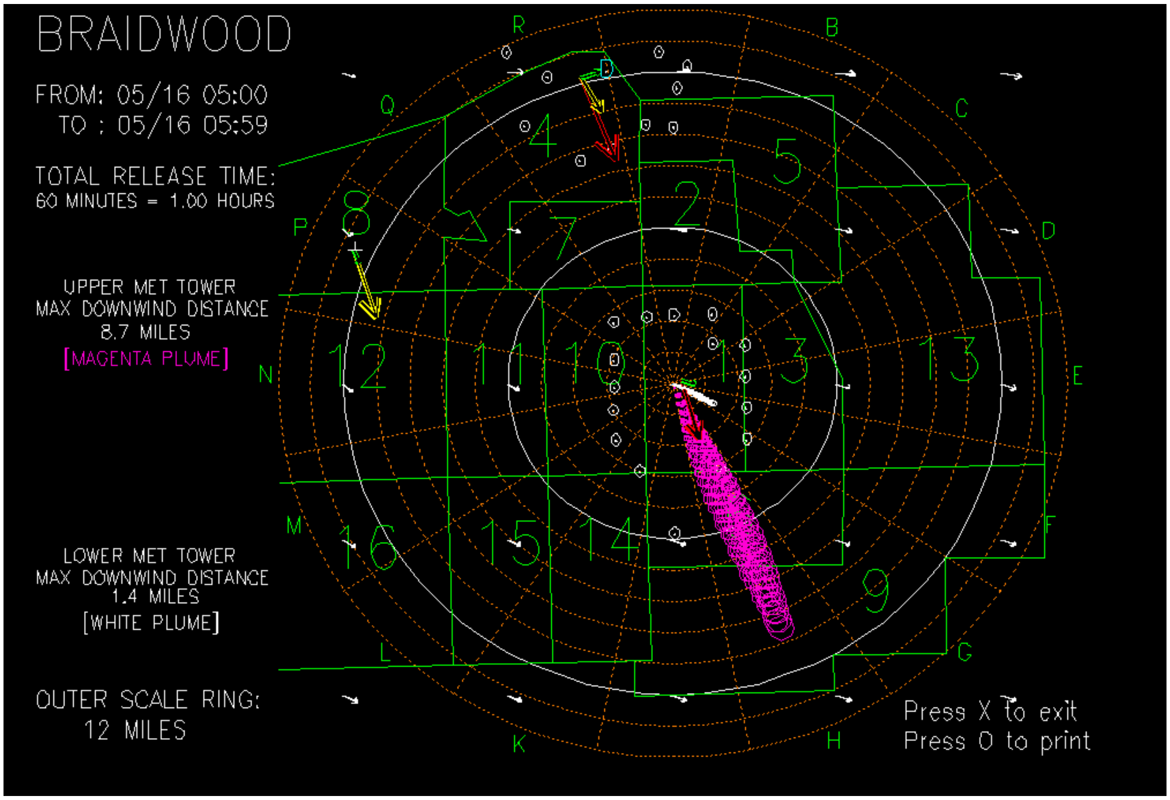
3. SITE-SPECIFIC DISPERSION

Displays of the site-specific output of the program from the Braidwood, Byron, Clinton, Dresden, LaSalle, Quad Cities, and Zion nuclear power stations are shown in Figures 2 through 8, respectively. The only information supplied by the user is the number of minutes ago to initialize the dispersion and transport. The default time is 15 minutes but the program can handle times between 1 minute and 6 hours. Once the time is entered, the program automatically obtains all the required meteorological data from the IEMA RDL and draws the display.

The site-specific displays contain the same information as the regional display with a few exceptions. To better highlight where gaussian dispersion modeling assumptions may be invalid, white arrows are used instead of orange arrows to indicate wind speeds less than 5 miles per hour. The site-specific displays show the 16 meteorological sectors, the locations of the 16 offsite gamma radiation detectors, and the various evacuation sub-areas within each EPZ. The display also provides automatic scaling with radial rings to indicate downwind distance in miles. State borders and average transport speed information are not displayed. The site-specific display refreshes itself every minute. It is important to note that transport and dispersion is accomplished by using *only* the site-specific meteorological data, not the offsite NWS and NDBC data.

4. PROGRAM CALCULATIONS

It is important to note that this combined Fortran and PV~Wave program provides a qualitative view rather than quantitative view of dispersion and transport and this view is developed using only the meteorological data from each nuclear plant. The Fortran side of the program obtains the real-time meteorological data and the PV~Wave side provides calculations and graphics. Raw data, 1-minute



BRAIDWOOD

FROM: 05/16 05:00
TO : 05/16 05:59

TOTAL RELEASE TIME:
60 MINUTES = 1.00 HOURS

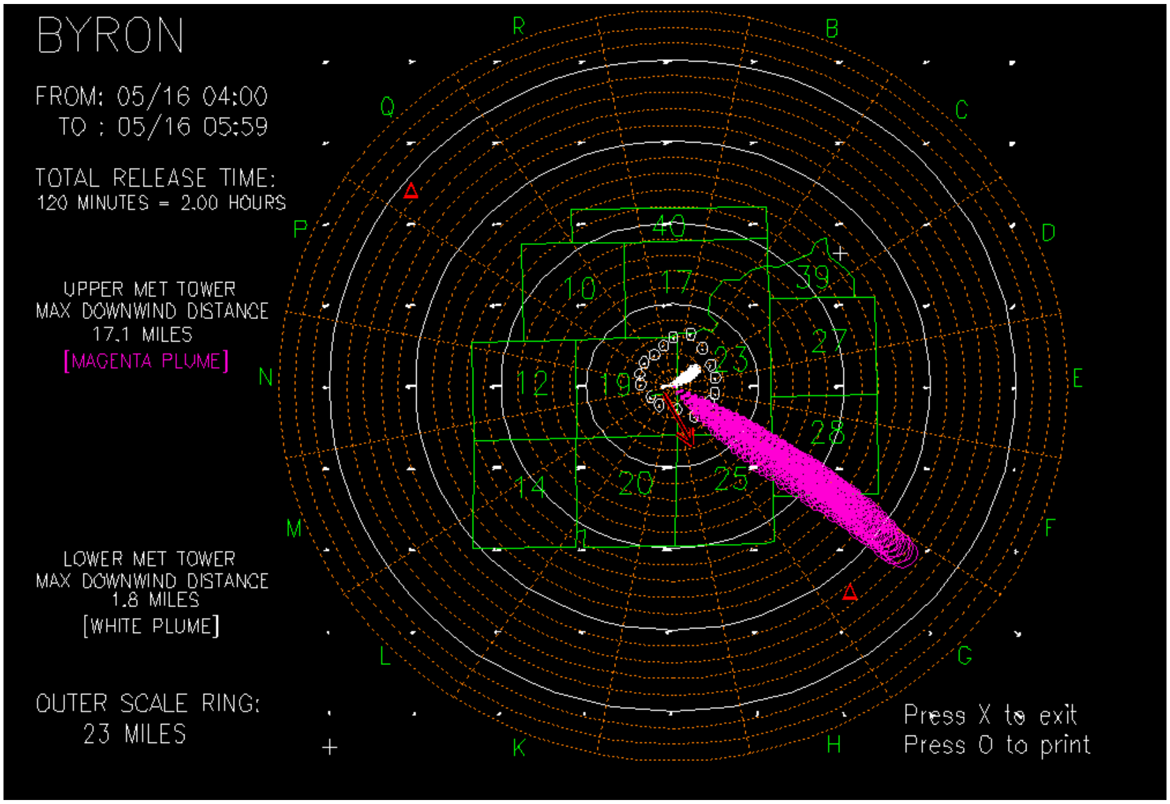
UPPER MET TOWER
MAX DOWNWIND DISTANCE
8.7 MILES
[MAGENTA PLUME]

LOWER MET TOWER
MAX DOWNWIND DISTANCE
1.4 MILES
[WHITE PLUME]

OUTER SCALE RING:
12 MILES

Press X to exit
Press O to print

Figure 2. Potential dispersion and transport dispersion from the Braidwood nuclear station.



BYRON

FROM: 05/16 04:00
TO : 05/16 05:59

TOTAL RELEASE TIME:
120 MINUTES = 2.00 HOURS

UPPER MET TOWER
MAX DOWNWIND DISTANCE
17.1 MILES
[MAGENTA PLUME]

LOWER MET TOWER
MAX DOWNWIND DISTANCE
1.8 MILES
[WHITE PLUME]

OUTER SCALE RING:
23 MILES

Press X to exit
Press O to print

Figure 3. Potential dispersion and transport from the Byron nuclear station.

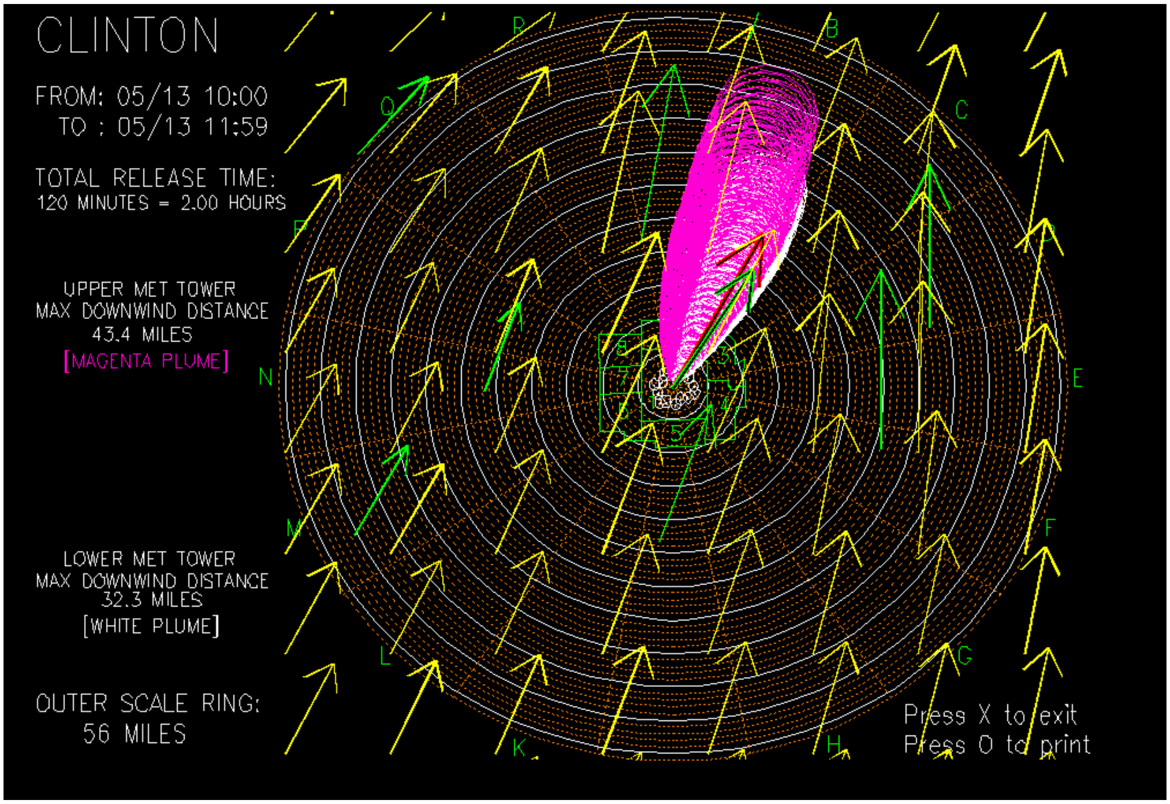


Figure 4. Potential dispersion and transport from the Clinton nuclear power station.

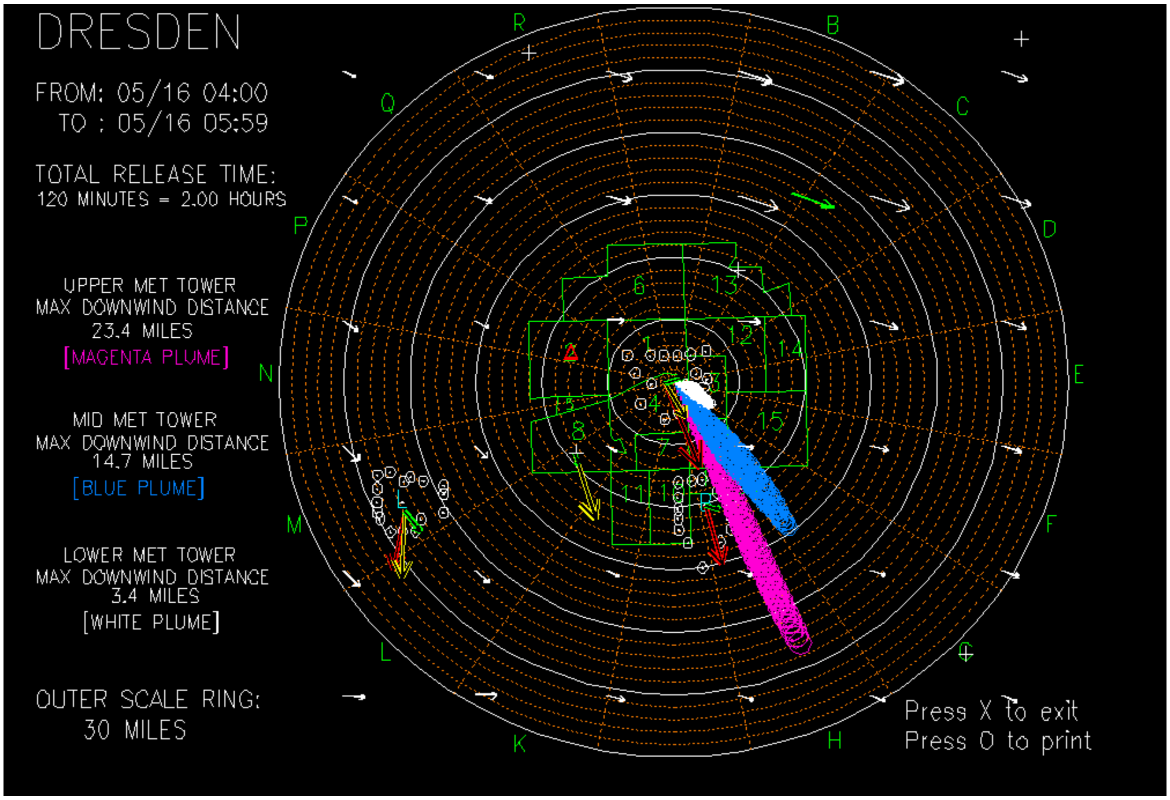


Figure 5. Potential dispersion and transport from the Dresden nuclear power station.

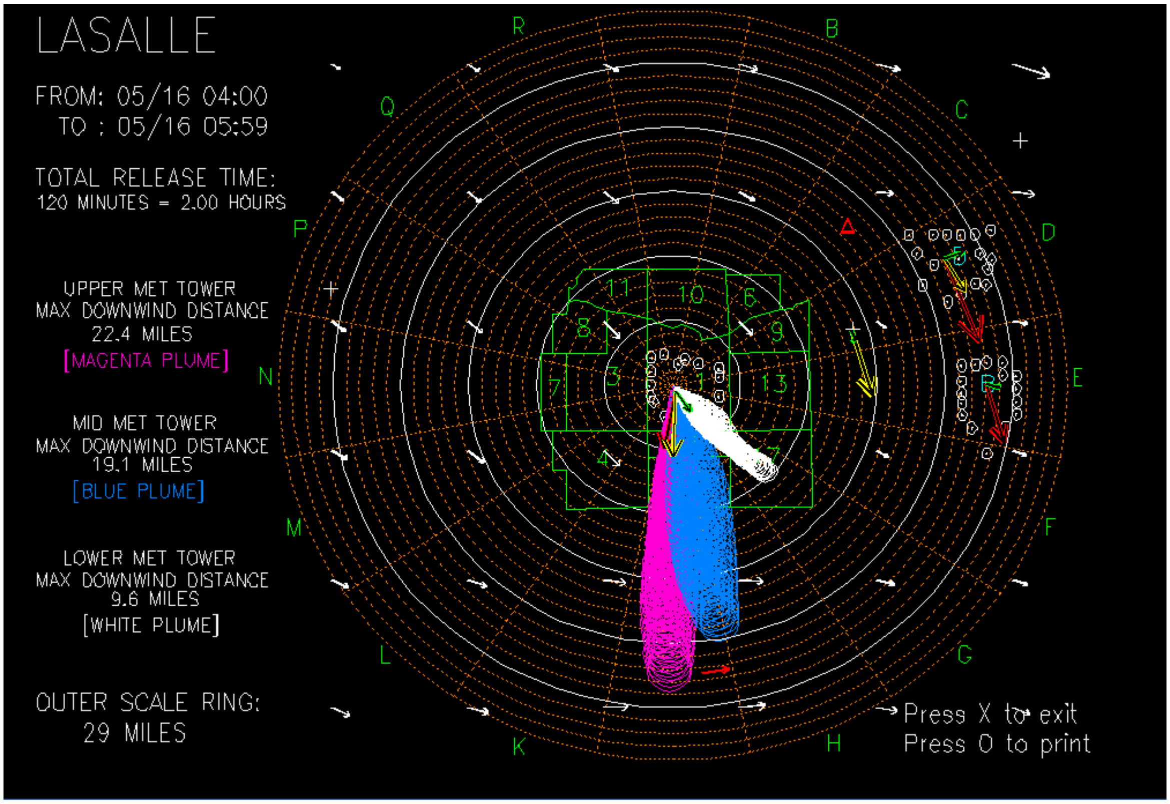


Figure 6. Potential dispersion and transport from the LaSalle nuclear power station.

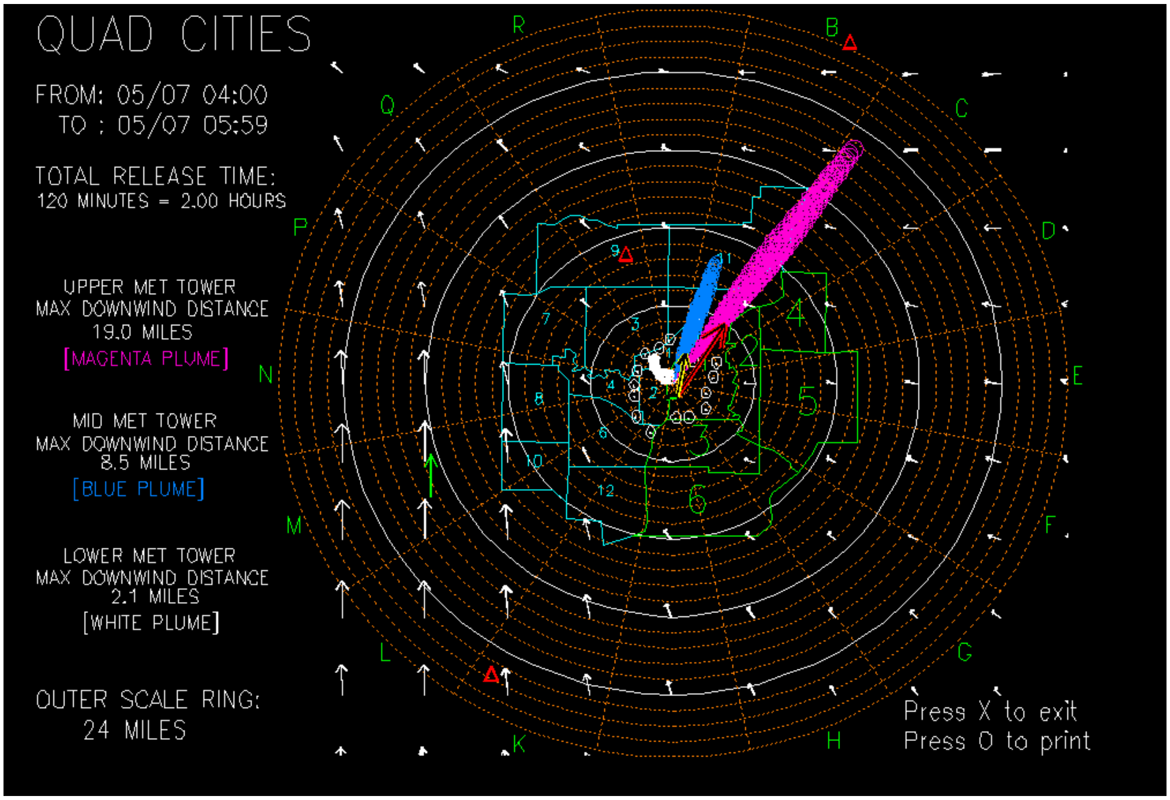
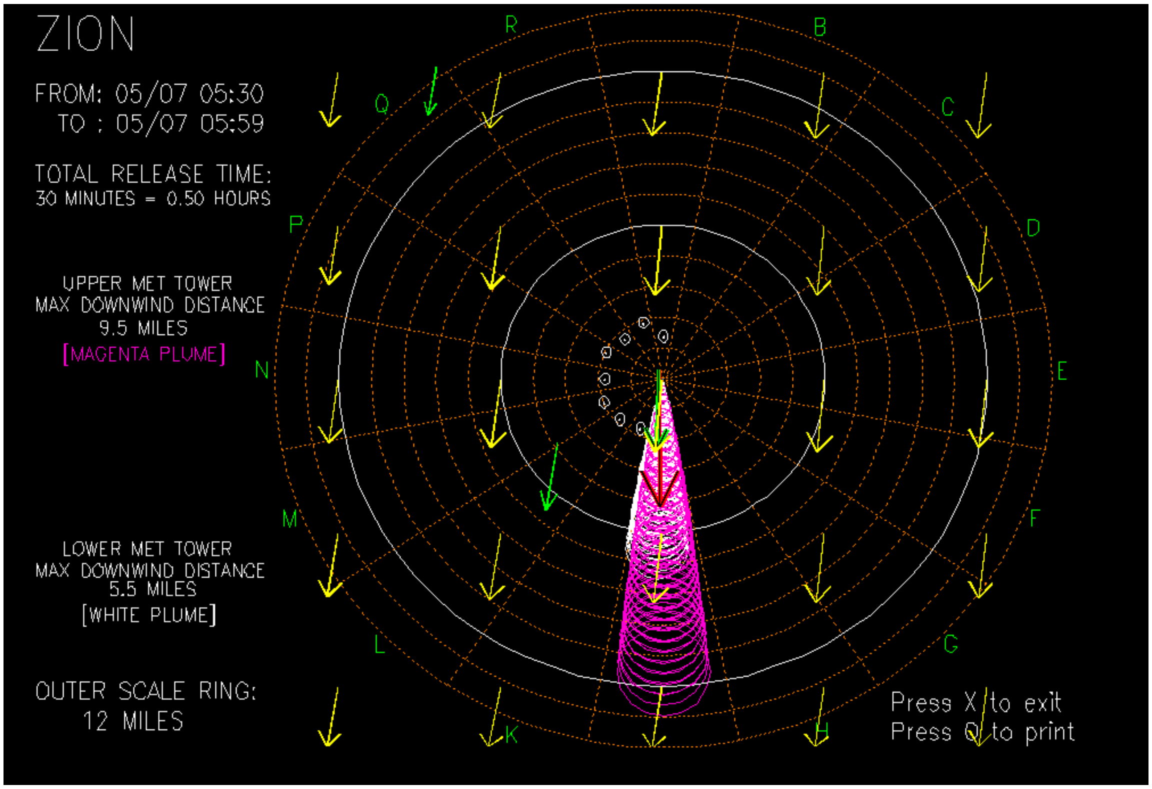


Figure 7. Potential dispersion and transport from the Quad Cities nuclear power station.



ZION

FROM: 05/07 05:30
TO : 05/07 05:59

TOTAL RELEASE TIME:
30 MINUTES = 0.50 HOURS

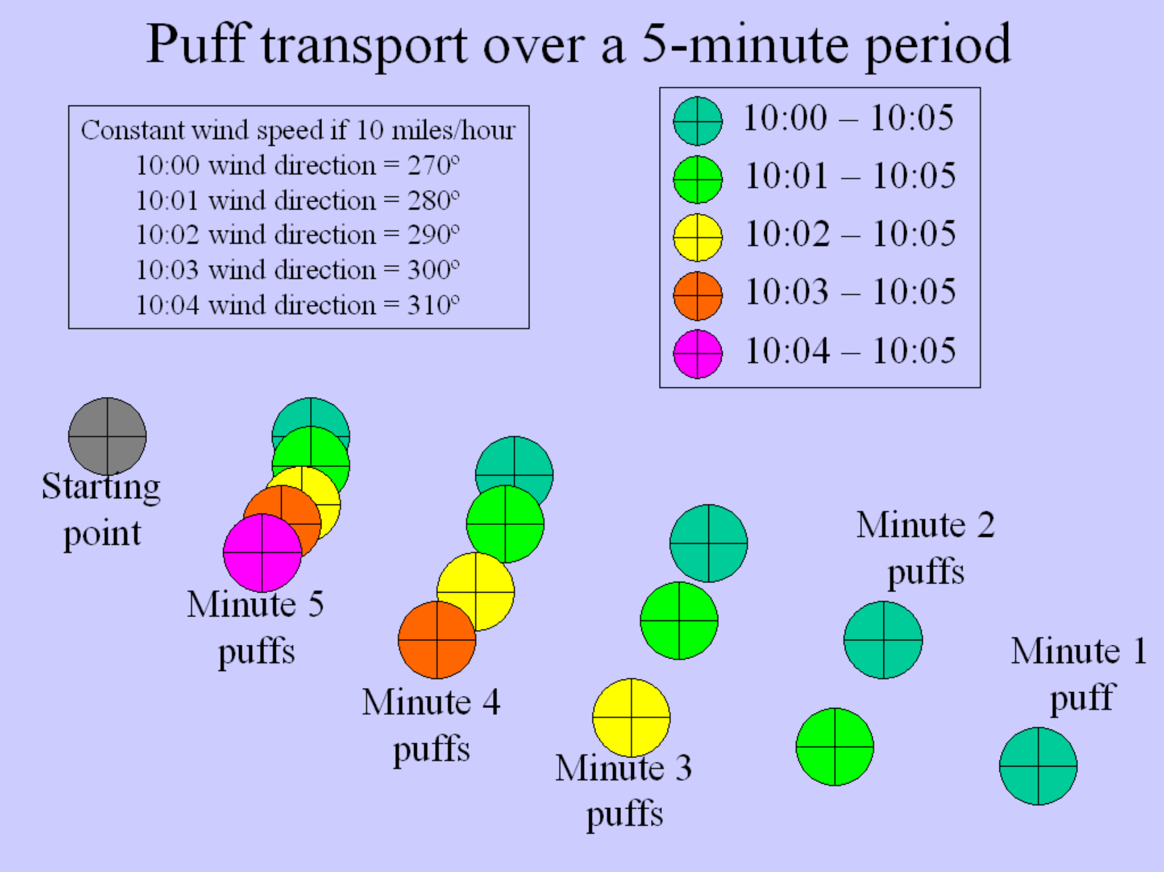
UPPER MET TOWER
MAX DOWNWIND DISTANCE
9.5 MILES
[MAGENTA PLUME]

LOWER MET TOWER
MAX DOWNWIND DISTANCE
5.5 MILES
[WHITE PLUME]

OUTER SCALE RING:
12 MILES

Press X to exit
Press Q to print

Figure 8. Potential dispersion and transport from the Zion nuclear power station.



Puff transport over a 5-minute period

Constant wind speed if 10 miles/hour
10:00 wind direction = 270°
10:01 wind direction = 280°
10:02 wind direction = 290°
10:03 wind direction = 300°
10:04 wind direction = 310°

Figure 9. Schematic of puff transport over a 5-minute period.

averages or running 15-minute averages can be used as used as input. The program assumes hypothetical puffs are introduced every minute from various heights during the user specified time interval. The most complex calculations are undertaken to determine puff transport and puff growth.

Puffs are transported each minute using the various site-specific levels of wind direction and wind speed data. A simple accounting method is used to keep track of the center of each puff every minute. Figure 9 shows a schematic of puff transport over a 5-minute period. The total number of puffs available for any given initialization time in minutes can be calculated by this equation:

Total number of puffs = ((minutes+1)/2) * minutes

Due to the length of time it takes to plot every puff for larger initialization times and PV~Wave graphics limitations, the number of puffs that are displayed are reduced using these rules:

0 to 59 minutes = all puffs plotted
60 to 119 minutes = every other minute plotted
120 to 179 minutes = every third minute plotted
180 to 239 minutes = every fourth minute plotted
240 to 299 minutes = every fifth minute plotted
300+ minutes = every sixth minute plotted

Reduction in the number of minutes plotted, thus the number of puffs, does not cause any adverse effects in visualizing the transport and dispersion and it also greatly decreases program execution time.

Calculating puff growth, or σ_y, is a function of downwind distance and horizontal or vertical Pasquill stability class. Puff growth is determined using these modified equations from reference 1:

Class A $\sigma_y=0.17*x(1+.1x)^{-1/2}$
Class B $\sigma_y=0.14*x\ (1+.1x)^{-1/2}$
Class C $\sigma_y=0.11*x(1+.1x)^{-1/2}$
Class D $\sigma_y=0.08*x(1+.1x)^{-1/2}$
Class E $\sigma_y=0.06*x(1+.1x)^{-1/2}$
Class F $\sigma_y=0.04*x(1+.1x)^{-1/2}$
Class G $\sigma_y=0.02*x(1+.1x)^{-1/2}$
Where x is downwind distance (km)

To account for stability class changes during transport, the rate of puff growth is calculated by obtaining a difference from minute to minute using the above equations. In this manner, growth of σ_y becomes an accounting process growing larger with distance. Displayed puff width is then set to $6\sigma_y$. In terms of the normal gaussian distribution, each puff then represents where 99 percent of any effluent disperses. This method of puff growth compares favorably other algorithms for calculating σ_y.

The wind field developed through bilinear interpolation is accomplished using the PV-Wave GRID_3D routine. All the IEMA, NWS, and NDBC 10-meter wind data is used in this step. The NWS and NDBC data are downloaded by FTP every 20 minutes from the following locations, respectively:

ftp://weather.noaa.gov/data/observations/metar/cycles/
ftp://www.ndbc.noaa.gov/data/realtime2/

GRID_3D uses an inverse square of distance averaging technique to interpolate 10-meter wind data into a 230x230 mile grid with grid points every 5 miles. Calms or missing data values are not used in this technique. To provide a more uncluttered site-specific display, the number of grid points displayed is limited using the following rules:

Outer scale ring ≤ 25 miles - all grid points
Outer scale ring ≤ 40 miles – every other grid point
Outer scale ring ≤ 70 miles every third grid point
Outer scale ring ≤ 100 miles every fourth grid point
Outer scale ring > 100 miles every fifth grid point

To also minimize cluttering, the regional display shows every other grid point.

5. METEOROLOGICAL PROCESSES SEEN

The program has been a useful tool in showing the fundamentals of dispersion and what really can and does happen in the atmosphere. In nuclear power plant exercises, these displays have been useful in developing protective action recommendations, determining where to send field monitoring teams, and when to expect increased activity on any of the 16 offsite gamma radiation detectors. The following discussion highlights some of the more interesting, challenging and complex dispersion and transport regimes seen while developing, testing and using the program.

5.1 *Boundary Layer Decoupling*

On clear nights with weak winds, surface cooling creates an inversion that leads to the suppression of turbulent mixing that results in a decoupling of the atmosphere from the surface. Due to the lack of surface friction, the air aloft responds in a rather sensitive fashion to the pressure gradient force and can ultimately develop into a low-level jet. Figures 2, 3, 5, 6 and 7 each show some measure of boundary layer decoupling. Dispersion and transport during these times is very dependent upon the source height.

5.2 *Fronts and wind shifts*

The location of fronts, frontal passages, general wind shifts and the timing of these events are very important to the emergency responder concerned about transport and dispersion of effluents. The program allows the user to get a better understanding of the synoptic meteorology and the timing of events in the next few hours. Figure 10 shows the regional display where a warm front has stalled across the south central portion of the display. This front was stalled across the state of several days. Figure 11 shows a cold front recently passing the Quad Cities nuclear plant and the resulting smeared transport and dispersion. Smeared transport and dispersion is also seen in Figure 12 where a wind shift occurs during light winds.

5.3 *Lake Michigan induced flow*

Lake Michigan can often impact the transport and dispersion in northern Illinois. Transport and dispersion during lake breezes is shown in Figure 13 and 14. Lake breezes and their remnants often make remarkable penetration inland impacting Braidwood, Byron, Dresden, and LaSalle nuclear plants many times every year. Although not shown, Lake Michigan can often modify the local wind flow and serve as a conduit for strong winds pushing down the lake.

5.4 *Development of "hot spots"*

Transport and dispersion always causes effluent concentrations to decrease with increasing distance. However, given the right meteorology, some "hot spots" can develop over short period of time. In order for this to occur, an oscillating wind direction with nearly constant wind speed is needed. Figure 15 shows data from such a situation from the Byron nuclear plant. The wind direction oscillates about 40 degrees approximately every 45 minutes while the wind speed is fairly constant. This causes the center of every puff to pass directly over certain locations or nodes downwind. Since puff centers always have the highest effluent concentration, these locations will develop a "hot spot". Figure 16 shows the transport and dispersion using the data from Figure 15. Note that there appears to be a pinching or concentrating in the transport and dispersion at about 6, 11, and 16 miles downwind.

5.5 *Horizontal vs. Vertical stability*

The program can be modified to select dispersion based on vertical stability classes via the delta T method or horizontal stability classes via the sigma theta method. Both methods have their strengths and weaknesses. Suffice it to say that both methods are approved by the Nuclear Regulatory Commission. Given the rather flat topography in Illinois and the fact that IEMA provides protective action recommendations using large sub areas around each nuclear plant EPZ, it is unlikely that IEMA emergency responders would arrive at different conclusions using the two different methods. Since IEMA does not receive sigma theta data from all nuclear plants via RDL, the delta T method is the default method for dispersion. The delta T method also seems to have a higher availability since the sigma theta method is based on the wind direction sensors that fail more often and are susceptible to icing. Figure 17 shows the same data as Figure 16 only using horizontal stability class for dispersion. For this case, using horizontal stability classes leads to more dispersion. Figures 18 and 19 show the regional displays using vertical stability class and horizontal stability class for dispersion, respectively. For this case, using vertical stability classes leads to more dispersion.

6. CONCLUSIONS AND FUTURE WORK

The program has been well received at IEMA. Output from the program is reviewed and archived to document what really can happen in the real world of dispersion meteorology. Numerous changes and upgrades to the program have been identified. These include: obtaining a NOAAport or Local Data Manager to obtain current METAR data as soon as possible, utilizing other sources of wind data from other state agencies, installing more wind sensors in Illinois leading to an Illinois mesonet, calculating transport and dispersion downwind using the gridded wind field, allowing an option to enter a stop time to simulate when a hypothetical release has terminated, and providing a statewide view. It is also desired to have the ability to view the vertical transport and dispersion in a sideways view as well as the current view from above.

7. REFERENCES

Pasquill F., and F.B. Smith, *Atmospheric Diffusion, Study of the dispersion of windborne material from industrial and other sources*. Third edition, Ellis Horwood Limited, 1983, pp339.

METAR data downloaded from the National Weather Service at: ftp://weather.noaa.gov/data/observations/metar/cycles/.

National Data Buoy Center, Southern Lake Michigan Buoy 45007 downloaded at: ftp://www.ndbc.noaa.gov/data/realtime2/ .

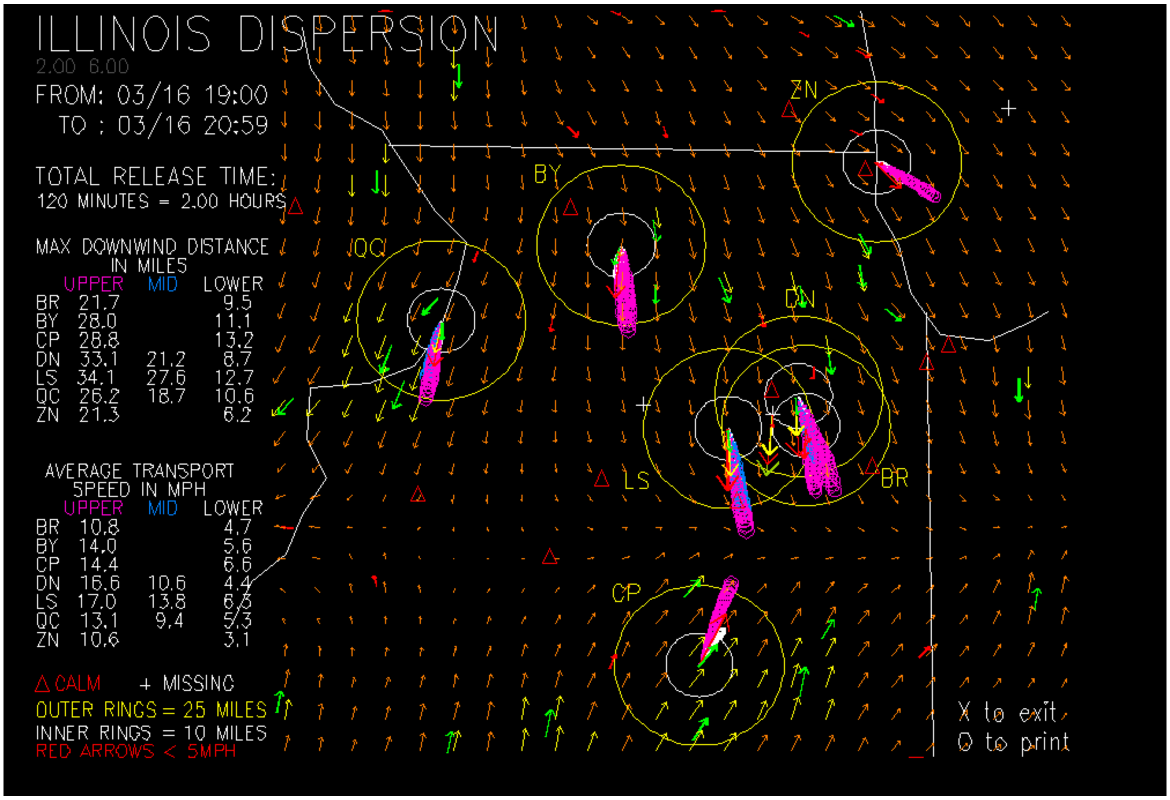


Figure 10. Regional dispersion and transport with warm front is stalled across central Illinois.

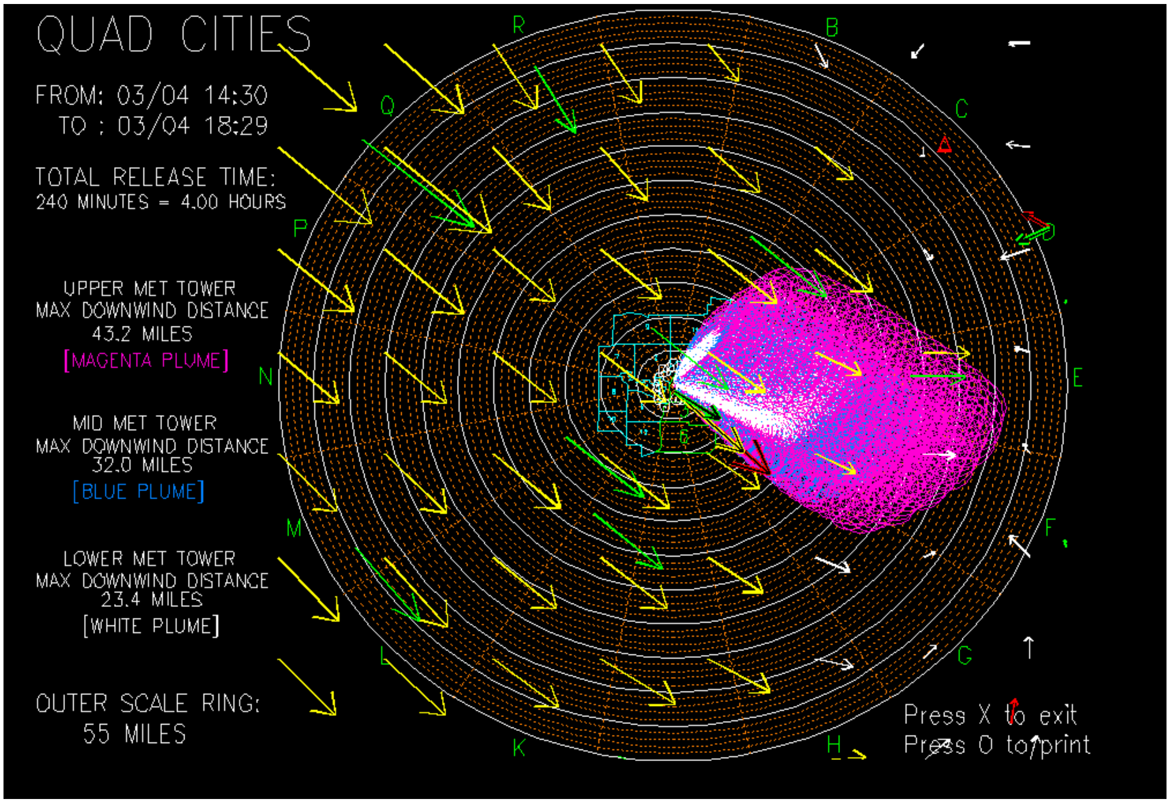
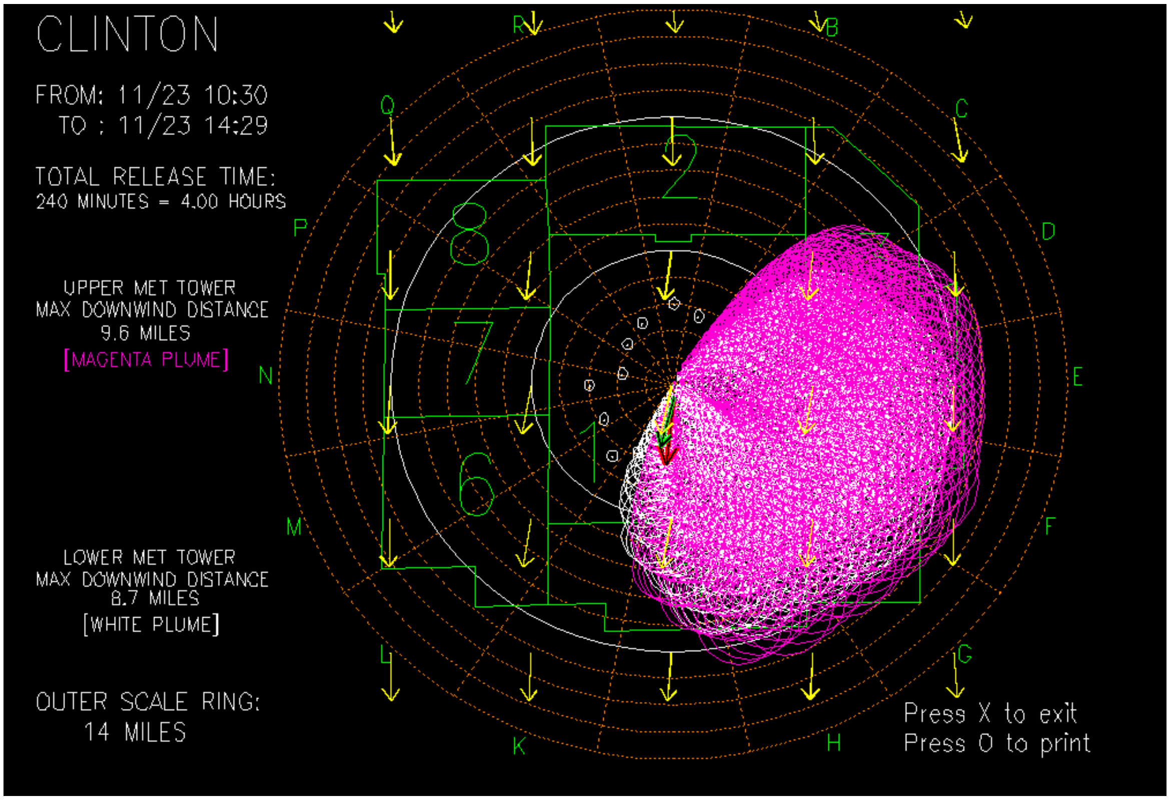


Figure 11. The dispersion and transport just after a cold front passes the Quad Cities nuclear plant.



CLINTON

FROM: 11/23 10:30
TO : 11/23 14:29

TOTAL RELEASE TIME:
240 MINUTES = 4.00 HOURS

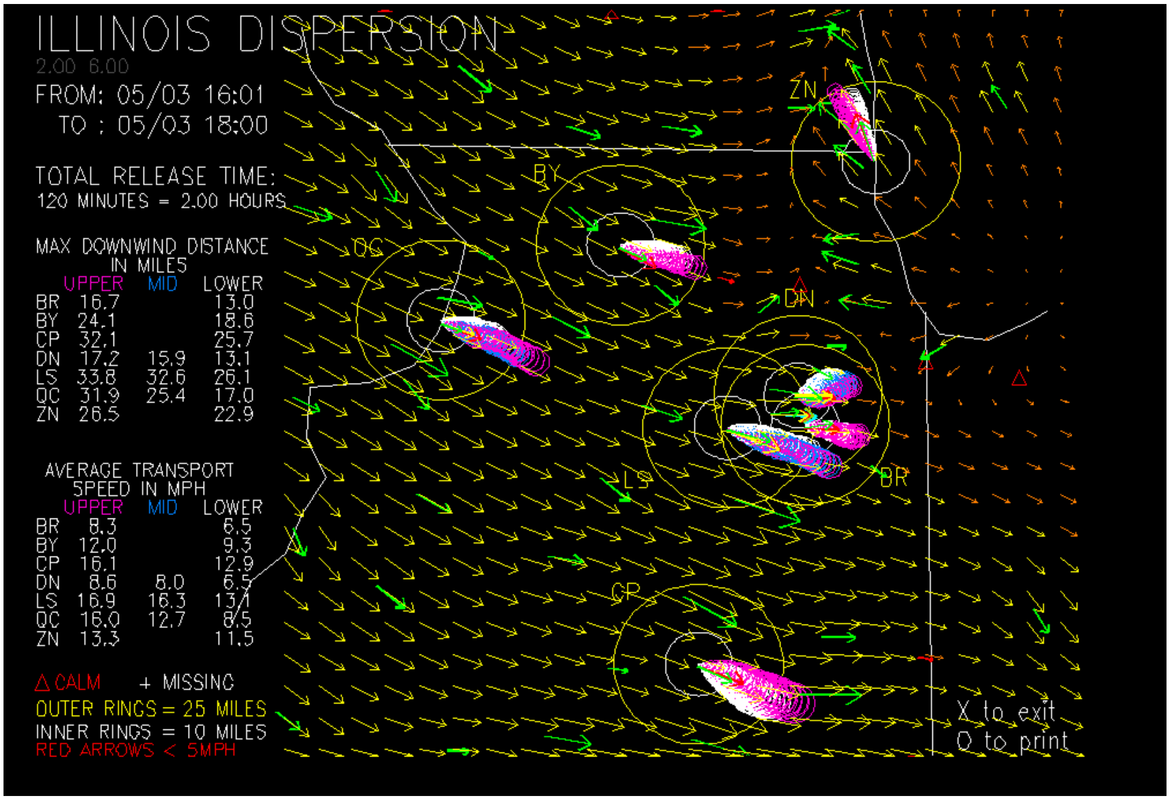
UPPER MET TOWER
MAX DOWNWIND DISTANCE
9.6 MILES
[MAGENTA PLUME]

LOWER MET TOWER
MAX DOWNWIND DISTANCE
8.7 MILES
[WHITE PLUME]

OUTER SCALE RING:
14 MILES

Press X to exit
Press 0 to print

Figure 12. Smeared transport and dispersion from a wind shift during light winds.



ILLINOIS DISPERSION
2.00 6.00
FROM: 05/03 16:01
TO : 05/03 18:00

TOTAL RELEASE TIME:
120 MINUTES = 2.00 HOURS

MAX DOWNWIND DISTANCE
IN MILES

	UPPER	MID	LOWER
BR	16.7		13.0
BY	24.1		18.6
CP	32.1		25.7
DN	17.2	15.9	13.1
LS	33.8	32.6	26.1
QC	31.9	25.4	17.0
ZN	26.5		22.9

AVERAGE TRANSPORT
SPEED IN MPH

	UPPER	MID	LOWER
BR	8.3		6.5
BY	12.0		9.3
CP	16.1		12.9
DN	8.6	8.0	6.5
LS	16.9	16.3	13.1
QC	16.0	12.7	8.5
ZN	13.3		11.5

△ CALM + MISSING
OUTER RINGS = 25 MILES
INNER RINGS = 10 MILES
RED ARROWS < 5MPH

X to exit
O to print

Figure 13. The Lake Michigan lake breeze begins to penetrate inland and affect transport and dispersion.

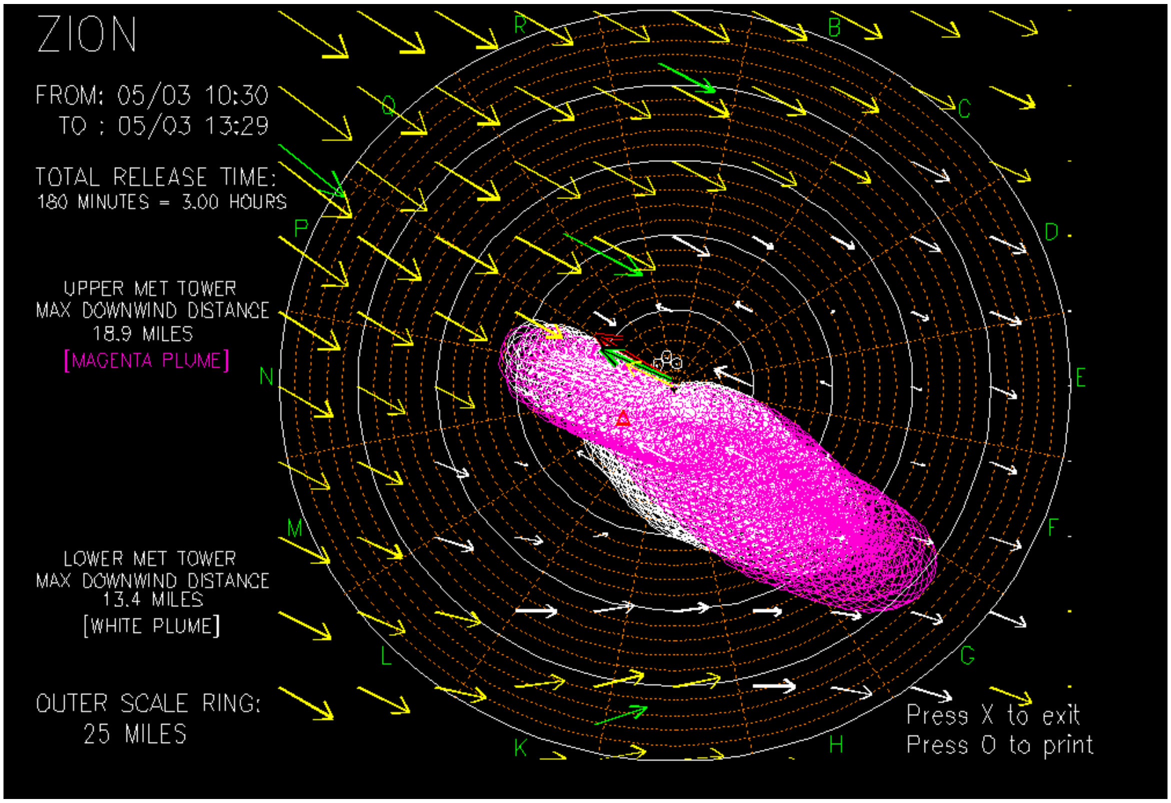


Figure 14. The Lake Michigan lake breeze causes wind reversals that affect dispersion and transport.

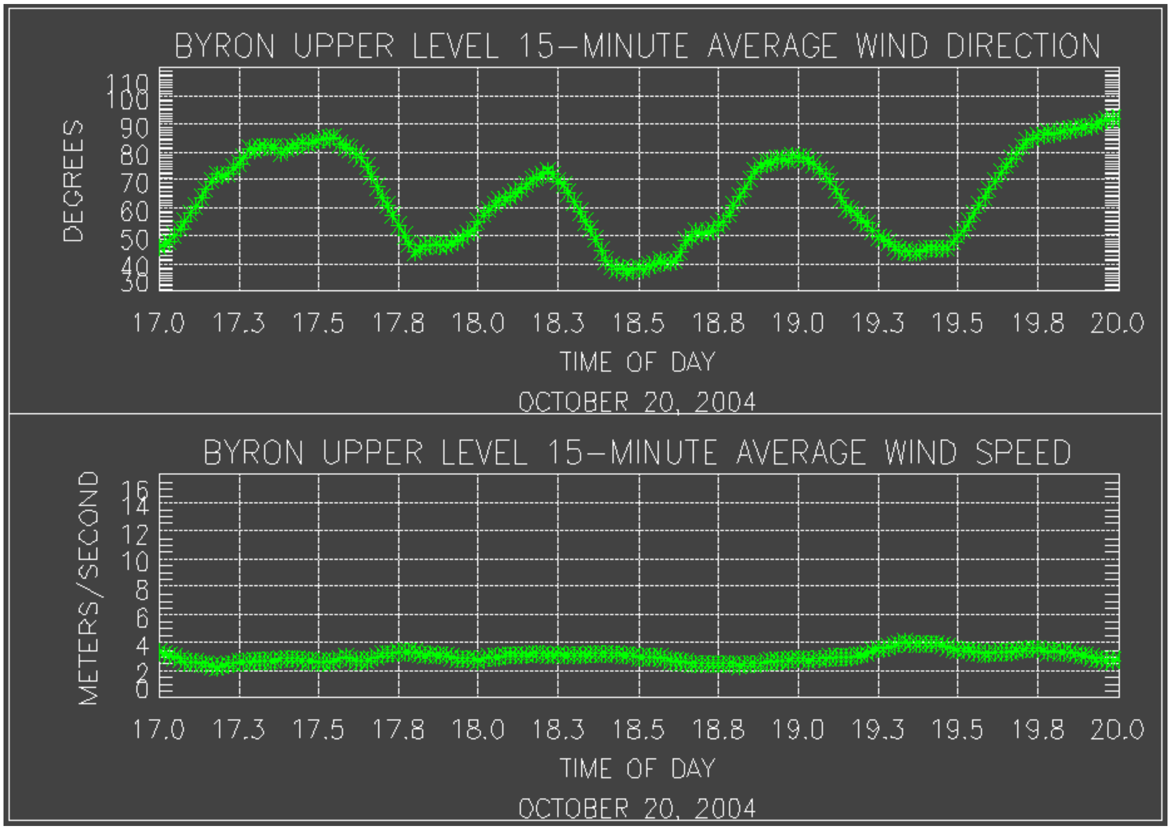


Figure 15. Byron meteorological data that results in the development of ”hot spots”.

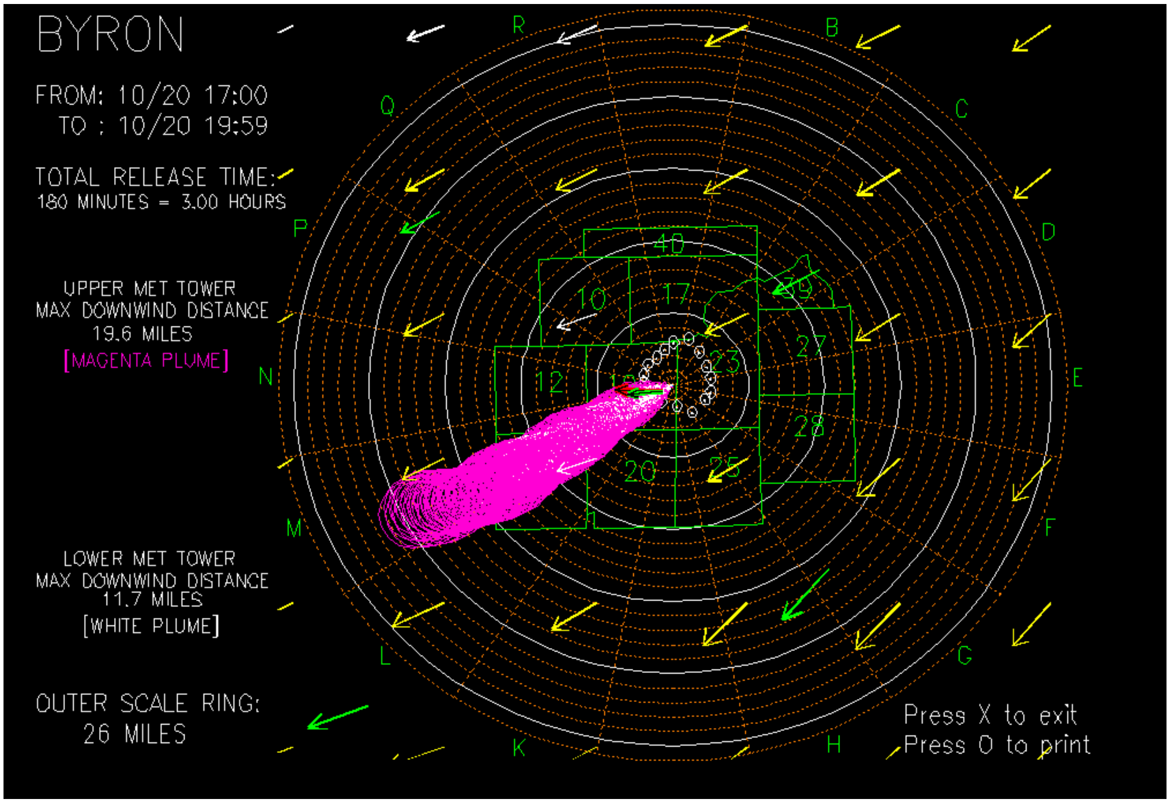


Figure 16. Using the data from Figure 15, "hot spots" develop. See text for discussion.

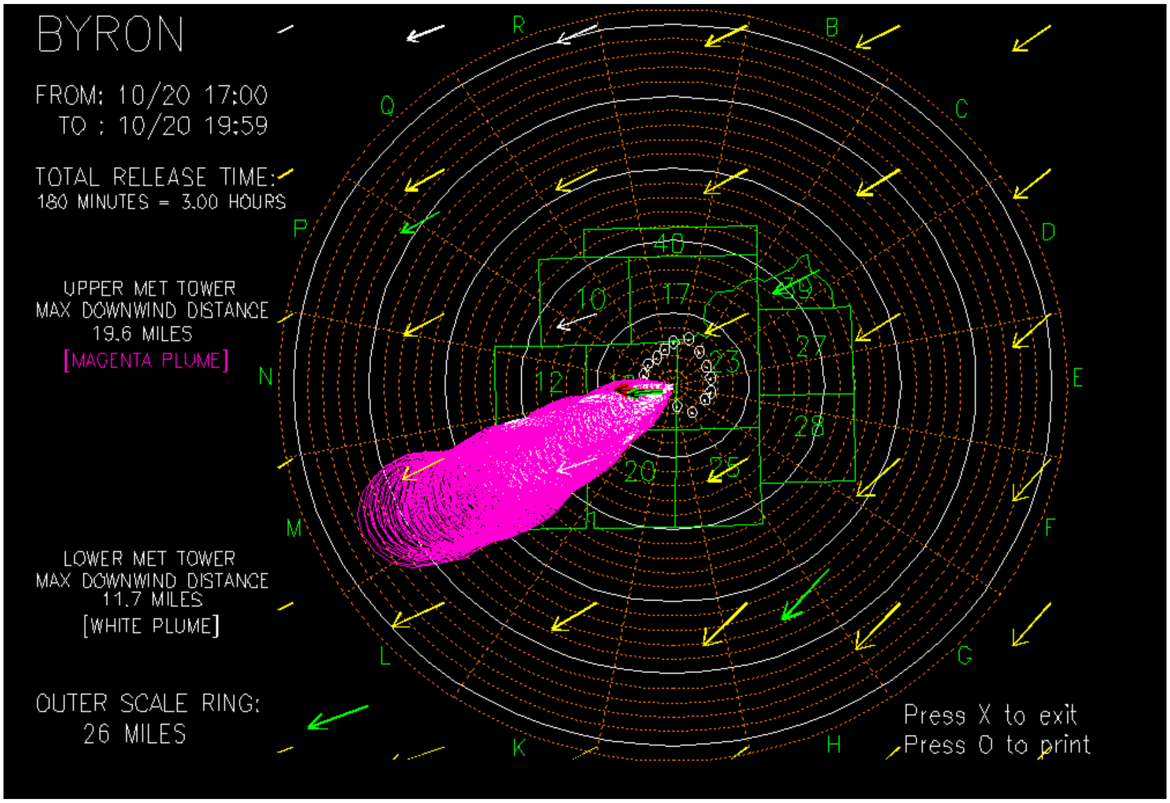
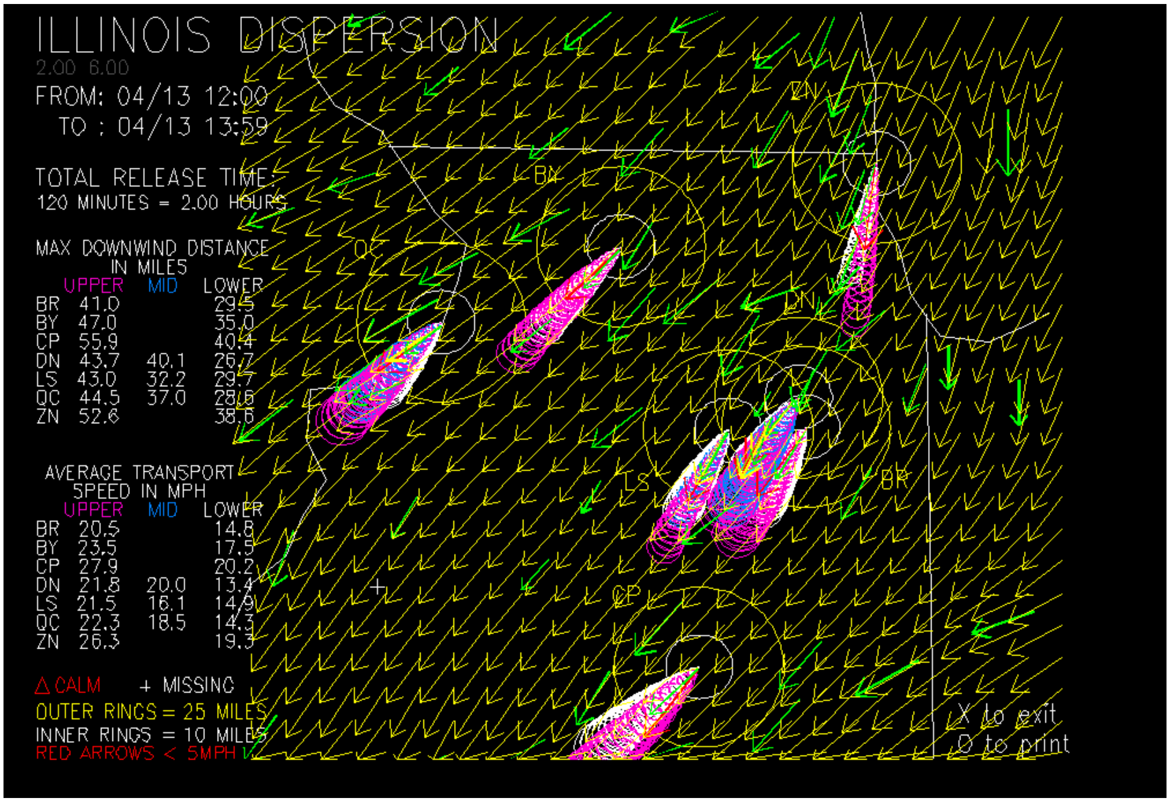


Figure 17. Same as Figure 16 only using horizontal stability class to calculate dispersion.



ILLINOIS DISPERSION

2.00 6.00

FROM: 04/13 12:00
TO : 04/13 13:59

TOTAL RELEASE TIME:
120 MINUTES = 2.00 HOURS

MAX DOWNWIND DISTANCE IN MILES

	UPPER	MID	LOWER
BR	41.0		29.5
BY	47.0		35.0
CP	55.9		40.4
DN	43.7	40.1	26.7
LS	43.0	32.2	29.7
QC	44.5	37.0	28.6
ZN	52.6		38.6

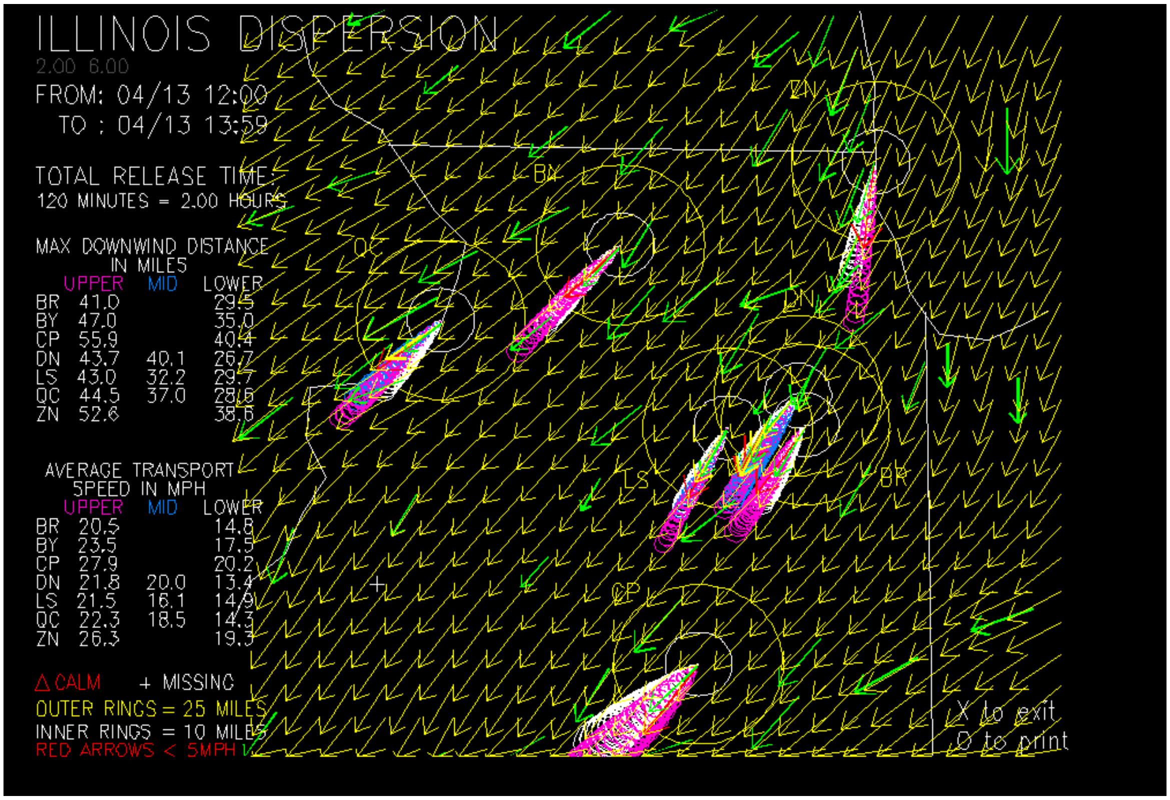
AVERAGE TRANSPORT SPEED IN MPH

	UPPER	MID	LOWER
BR	20.5		14.8
BY	23.5		17.5
CP	27.9		20.2
DN	21.8	20.0	13.4
LS	21.5	16.1	14.9
QC	22.3	18.5	14.3
ZN	26.3		19.3

△ CALM + MISSING
OUTER RINGS = 25 MILES
INNER RINGS = 10 MILES
RED ARROWS < 5MPH

X to exit
Q to print

Figure 18. A regional view of transport and dispersion using vertical stability class for dispersion.



ILLINOIS DISPERSION

2.00 6.00

FROM: 04/13 12:00
TO : 04/13 13:59

TOTAL RELEASE TIME:
120 MINUTES = 2.00 HOURS

MAX DOWNWIND DISTANCE IN MILES

	UPPER	MID	LOWER
BR	41.0		29.5
BY	47.0		35.0
CP	55.9		40.4
DN	43.7	40.1	26.7
LS	43.0	32.2	29.7
QC	44.5	37.0	28.6
ZN	52.6		38.6

AVERAGE TRANSPORT SPEED IN MPH

	UPPER	MID	LOWER
BR	20.5		14.8
BY	23.5		17.5
CP	27.9		20.2
DN	21.8	20.0	13.4
LS	21.5	16.1	14.9
QC	22.3	18.5	14.3
ZN	26.3		19.3

△ CALM + MISSING
OUTER RINGS = 25 MILES
INNER RINGS = 10 MILES
RED ARROWS < 5MPH

X to exit
Q to print

Figure 19. A regional view of transport and dispersion using horizontal stability class for dispersion.