Identification and Implications of a Local Temperature Anomaly

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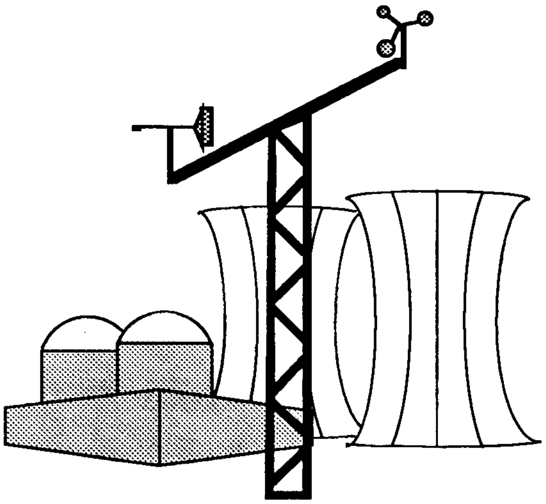

Nuclear Utilities Meteorological Data Users Group Meeting
Boston, Massachusetts

April 1993

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The Tennessee Valley Authority (TVA) Browns Ferry Nuclear Plant is located on the north shore of the Wheeler Reservoir in North Alabama. A 91-meter meteorological tower, located about 1 kilometer east-southeast from the plant (figure 1), provides meteorological data used for both routine and non-routine applications. Unfortunately, two anomalous conditions in the local meteorology impact measurements at this tower.

The first condition is a reduction in the horizontal wind speed at the 10-meter level for winds from the southeast and southwest quadrants (WS anomaly). This WS anomaly is believed to be caused by a tree-covered embankment that rises abruptly from the lake edge south of the tower. After conducting studies of this effect, TVA decided to use the 46-meter level wind data in plume dispersion and transport models for emergency response. A paper presented at the 1984 annual meeting of the Air Pollution Control Association [1] describes the WS anomaly and documents the studies. This anomaly persisted even after trees were cut back to a horizontal distance 10 times tree height above the tower base in 1977.

The second condition (and the subject of this paper) is the unusual temperature profiles identified during some wind conditions (ΔT anomaly). On the basis of the Pasquill stability classification [2], stable classes (E, F, and G) do not occur with wind speeds greater than 5 meters/second (11.2 mph). However, TVA meteorologists have observed these stability classes on the lower (46-10 meters) temperature difference (ΔT) when persistent 46-meter wind speeds are considerably above 5 meters/second. Since this condition is not expected, it was necessary to evaluate the impact of these conditions on atmospheric dispersion algorithms.

Background

Over about the past ten years, TVA meteorologists have noticed unusual temperature profiles on the 91-meter tower at the Browns Ferry Nuclear Plant. During some periods of moderate or strong winds from the south and southeast, a stable condition is readily apparent for the lower ΔT layer. If this condition represents only the local area near the tower, stability conditions affecting the plant area may be incorrectly estimated. However, if this condition is more widespread, some adjustments may be necessary for algorithms that use atmospheric stability information. Therefore, further study of the ΔT anomaly was appropriate to better understand atmospheric dispersion characteristics affecting Browns Ferry Nuclear Plant.

The ΔT anomaly was not studied until recently because of a low frequency of occurrence (less than five percent) and since most of the atmospheric releases go through a 183-meter stack (so low-level data are not normally used). A study of the ΔT anomaly was conducted recently due to increasing interest in improving the accuracy of atmospheric dispersion estimates for TVA nuclear plants. This study isolated the specific circumstances related to the ΔT anomaly and evaluated its effects on the two primary applications for radiological dose calculations from Browns Ferry--routine semiannual reports to the Nuclear Regulatory Commission (NRC) and emergency response support.

Regulatory Guidance

The primary use of meteorological data for nuclear plants is to estimate potential radiation doses to the public. The transport and dilution of radioactive materials released into the atmosphere is highly dependent on the state of the atmosphere along the plume path. The basic meteorological measurements specified in Regulatory Guide 1.23 [3] and ANS-2.5 [4] provide sufficient data for standard atmospheric dispersion models to quantify atmospheric radiation doses.

The basic principles of atmospheric dispersion are well established, but it is also well known that local effects can significantly influence the actual dispersion patterns. Regulatory Guide 1.23, ANS-2.5, and Regulatory Guide 1.111 [5] specify that such localized effects should be identified and impacts on actual doses quantified.

An error in the classification of atmospheric stability class can significantly impact estimates of both plume rise and downwind dispersion. Consequently, it is important to examine the circumstances and effects of the ΔT anomaly. Specific items that need to be addressed include the frequency of occurrence, the physical extent of the ΔT anomaly (both horizontal and vertical), and the effects on plume dispersion. Finally, recommendations are needed concerning handling the ΔT anomaly in both routine and nonroutine applications.

Identification

The primary characteristic of the ΔT anomaly is a low-level stable layer (based on the 46-10 meter ΔT) that is not consistent with other meteorological conditions. For example, the ΔT anomaly exists when the lower layer indicates stable conditions (E, F, or G stability class) while the upper layer (91-46 meter) ΔT and other meteorological data (wind speed, solar radiation, and general weather) are consistent with neutral or unstable conditions (A, B, C, or D stability class).

A historical data set for 1986-1987 was used to conduct this study. The identification of the ΔT anomaly consisted of four steps.

1. Confirm Anomaly. Joint frequencies of wind speed and wind direction by stability class were constructed for both the upper layer and the lower layer by month. The hours were classified into a "night" set (2100-0600) and a "day" set (0900-1700) to reduce the complications associated with diurnal transition periods. A review of the results confirmed that the lower layer had a bias of stable classes with winds from the southeast and southwest quadrants during daytime in the cooler months.

2. Select Data For Analysis. All days were identified during which at least one "day" hour had a ΔT stability class of E, F, or G in the lower layer and/or at least one "night" hour had a ΔT stability class of F or G. For each identified date, 46-meter wind direction and wind speed, three levels of air temperature, upper and lower ΔTs and stability classes, precipitation, solar radiation, and reservoir water temperature were obtained.

3. Synoptic Weather Review. Daily Weather Maps [6] and Climatic Summaries [7] for Huntsville, Alabama (approximately 30 kilometers east of Browns Ferry) were used to obtain information about regional meteorological effects on Browns Ferry. Positions of weather map features (air mass boundaries, high and low pressure areas, etc.), pressure gradients, wind information, cloud information (types, heights, and amounts), visibility, and occurrences of weather phenomena (showers, rain, snow, fog, etc.) were identified for the dates selected in step 2.

4. Case Identification. Synoptic data and observed conditions for each date identified in step 2 were reviewed to determine if the stable ΔT was really anomalous or was due to some other weather effect. The "night" data primarily duplicated the "day" data but did enable identification of a few cases. In addition, "night" data were useful in determining end times for many of the cases.

A total of 36 ΔT anomaly cases (table 1) was identified in the two-year data base. These cases covered 582 hours (about 3 percent of the total hours).

Analysis

The first significant observation is the large degree of variability from year to year in the occurrence of the ΔT anomaly. During 1986, virtually all the cases occurred during January through March (case 15 being the only exception). During 1987, most cases (12 of 21) occurred during October through December. No cases of the ΔT anomaly occurred during the warm months of May through September. In addition, the strength of the ΔT anomaly differed from year to year. About 80 percent of the cases during 1986 were characterized as "strong" (low-level layer was dominated by F and G stability classes) during at least part of the case. About 52 percent of the cases during 1987 were characterized as weak (low-level layer was predominately E stability class).

In addition to these overall observations, several specific features were noted.

A. Relationships between the occurrence of ΔT anomaly cases and other measurements (table 2).

- Except for only two hours (less than 0.4 percent of all ΔT anomaly hours), the wind speeds are moderate to strong (greater then 5.0 mph). The two hours that were an exception occurred during the passage of the remnants of a squall line over the Browns Ferry site during case 15.

  Since stable Pasquill stability classes (classes E, F, and G) do not occur with wind speeds greater than 5 meters/second (11.2 mph), this highlights the unusual nature of the ΔT anomaly.

- All the cases occur with winds from the east-southeast through southwest directions. About 65 percent of the case hours are for winds from the south-southeast and south.

  This directional dependence is extremely significant in isolating the anomaly.

- With the exception of 10 hours (less than 2 percent of all ΔT anomaly hours), the reservoir water temperature (as measured at the -0.5 foot level) is colder than the corresponding air temperature (as measured on the tower 10-meter level).

  This is consistent with the time of year that the ΔT anomaly is observed, when air from the south is often warmer than reservoir water.

- The air is generally dry (less than 65-70 percent relative humidity) as indicated by air temperatures exceeding the dewpoint temperature by 5.0°F or more. The hours when the difference between the air temperature and the dewpoint temperature is less than 5.0°F (approximately 16 percent of all case hours) are either in relatively weak cases (stability classes D and E versus classes F and G) or are associated with weather influences.

  This is significant since it shows a greater potential for evaporative cooling of the air near the water surface as it moves across the reservoir.

B. Synoptic conditions:

- Invariably, moderate to strong pressure gradients existed between high pressure to the east or southeast and low pressure to the west or northwest. This is consistent with the moderate to strong wind speeds from the south.

- While more than a third of the days in which the ΔT anomaly occurred had relatively high solar radiation values, few of the cases had fair skies. Most high solar radiation days had thin broken or thin overcast with high and sometimes middle clouds. All other cases had broken to overcast cloud cover with mostly low and/or middle clouds and sometimes middle and/or high clouds.

- All cases involved warm advection by moderate to strong winds with trajectories across Wheeler Reservoir.

- Often the air mass was quite dry, particularly during the beginning hours of a ΔT anomaly event.

C. Geographic considerations:

- The overwater trajectory of the air arriving at the meteorological tower is significant in these ΔT anomaly cases (figure 2). First, the water is cooler than the air. Second, the water warms more slowly than the land. Third, evaporation of the surface water removes heat from the air as it passes over the water. Consequently, as the air moves over the cooler surface and is cooled from below, a surface-based temperature inversion develops. The effect at the Browns Ferry site is believed to be the creation of a surface-based temperature inversion over the reservoir that is deep enough to envelop the 10-meter level on the meteorological tower as the air moves off the reservoir. The same conditions are believed to occur at the stack base and the reactor and turbine buildings.

- The travel distance of the air over the reservoir is not the most critical factor in the number of hours with the ΔT anomaly at the tower (table 3). Specifically, the number of hours is highest when the wind is from the south with overwater travel distances of 2.5 to 5.0 kilometers and drops off dramatically when the winds are from the southeast, even though the overwater travel distance increases to more than 10 kilometers.

- The travel distance of the air over land from the reservoir to the meteorological tower is much more closely related to the hours of occurrence (table 3). The number of hours is highest when the winds are from the south and overland travel is about 200 meters. However, the number of occurrences drops off as the overland distance increases, and no cases occur when the distance is more than 400 meters (figure 3). This would indicate a limited horizontal extent for the ΔT anomaly.

Implications

Chi/Q (X/Q) values increase when the atmosphere becomes more stable. The ΔT anomaly will generally cause higher accident X/Q values to be calculated when using the 46-10 meter ΔT, resulting in higher dose estimates. In addition, since the ΔT anomaly is associated with moderate to high wind speeds, releases from building vents are more likely to have a lower plume rise, become entrained in the building wake, and be treated as ground-level releases.

Unlike the WS anomaly, which is believed to be due to factors that affect the meteorological tower site but not the plant itself, the ΔT anomaly is believed to affect both the meteorological tower and the plant in the same way. Therefore, it is important to understand the effects that the ΔT anomaly may have.

A sensitivity analysis of TVA's routine dose assessment model [8] shows that use of a G stability instead of a D stability could cause an increase of up to a factor of 10 in the X/Q for ground-level releases. A sensitivity analysis of TVA's emergency dose model [9] shows that use of an F stability instead of a D stability could cause an increase of up to a factor of 10 in the X/Q for a ground-level release, while use of an F stability instead of a C stability could cause an increase of up to a factor of 100. Therefore, the ΔT anomaly has a significant potential to impact dose estimates, especially for accidental releases of radioactive materials.

For routine operation reports to the NRC, both the ΔT anomaly and the WS anomaly result in higher X/Q values for building releases and thus higher dose values than would otherwise be computed. However, since virtually all routine releases are from the stack, slightly conservative dose estimates may be reported to the NRC only if significant building releases occur.

For emergency response, undue conservatism in dispersion estimates could alter protective action recommendations in certain instances, particularly building wake situations. Therefore, both the WS anomaly and the ΔT anomaly must be addressed in the emergency preparedness meteorological data input procedures. For the WS anomaly, the 10-meter wind speed is replaced by the 46-meter wind speed. For the ΔT anomaly, emergency team meteorologists can substitute appropriate replacement stability class values so that predicted doses are more realistic. Currently, this substitution is highly subjective, but with more knowledge about the ΔT anomaly, more objective approaches could be developed.

Future Activities

A better understanding of the ΔT anomaly is necessary to properly assess the impact on the data applications. The vertical and horizontal extent of the ΔT anomaly downwind from the reactor building location should be identified. Confirmation that the ΔT anomaly is not detectable beyond the downwind plant boundary would be helpful in decisions about data applications. In addition, it would be extremely useful to confirm the assumption that the WS anomaly does not affect the reactor building.

Two future actions are under consideration:

1. Field Study--A field study of both the ΔT anomaly and the WS anomaly should be conducted to reduce uncertainties about the effects on the data applications.

2. Statistical Evaluation--A statistical evaluation of a long-term (10-15 years) data set could be done to improve confidence in the data relationships and the nowcast aids applications.

References

1. "Effects of Nearby Surface Features on Wind Speed at a Nuclear Plant Meteorological Station"; by N. A. Nielsen, R. J. Goodwin, and D. E. Pittman; Presented at the 77th Annual Meeting of the Air Pollution Control Association in San Francisco, California; June 24-29, 1984.

2. "Workbook of Atmospheric Dispersion Estimates," D. B. Turner, U.S. Public Health Service Pub. No. 999-AP-26, 1967.

3. NRC Regulatory Guide 1.23, "Onsite Meteorological Programs," Revision 0, February 17, 1972.

4. ANSI/ANS-2.5-1984, "Standard for Determining Meteorological Information at Nuclear Power Sites," September 1984.

5. NRC Regulatory Guide 1.111, "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors," Revision 1, July 1977.

6. "Daily Weather Maps," Weekly Series for January 6, 1986 through January 3, 1988; U. S. Department of Commerce, NOAA, NWS, NMC, Climate Analysis Center; Washington, D.C.

7. "Local Climatological Data--Monthly Summary, January 1986-December 1987," for Huntsville, Alabama; U. S. Department of Commerce, National Climatic Data Center; Asheville, North Carolina.

8. "A Sensitivity Analysis of the Gaseous Effluent Licensing Code (GELC)," Tennessee Valley Authority, October 1991 [Table GRND-2]

9. "A Sensitivity Analysis of the Radiological Emergency Code (RED)," Tennessee Valley Authority, December 1991 [Table STAB-1]

Figure 1
Browns Ferry Nuclear Plant ΔT Anomaly Cases
1986-1987

Location of Power Plant and Meteorological Tower

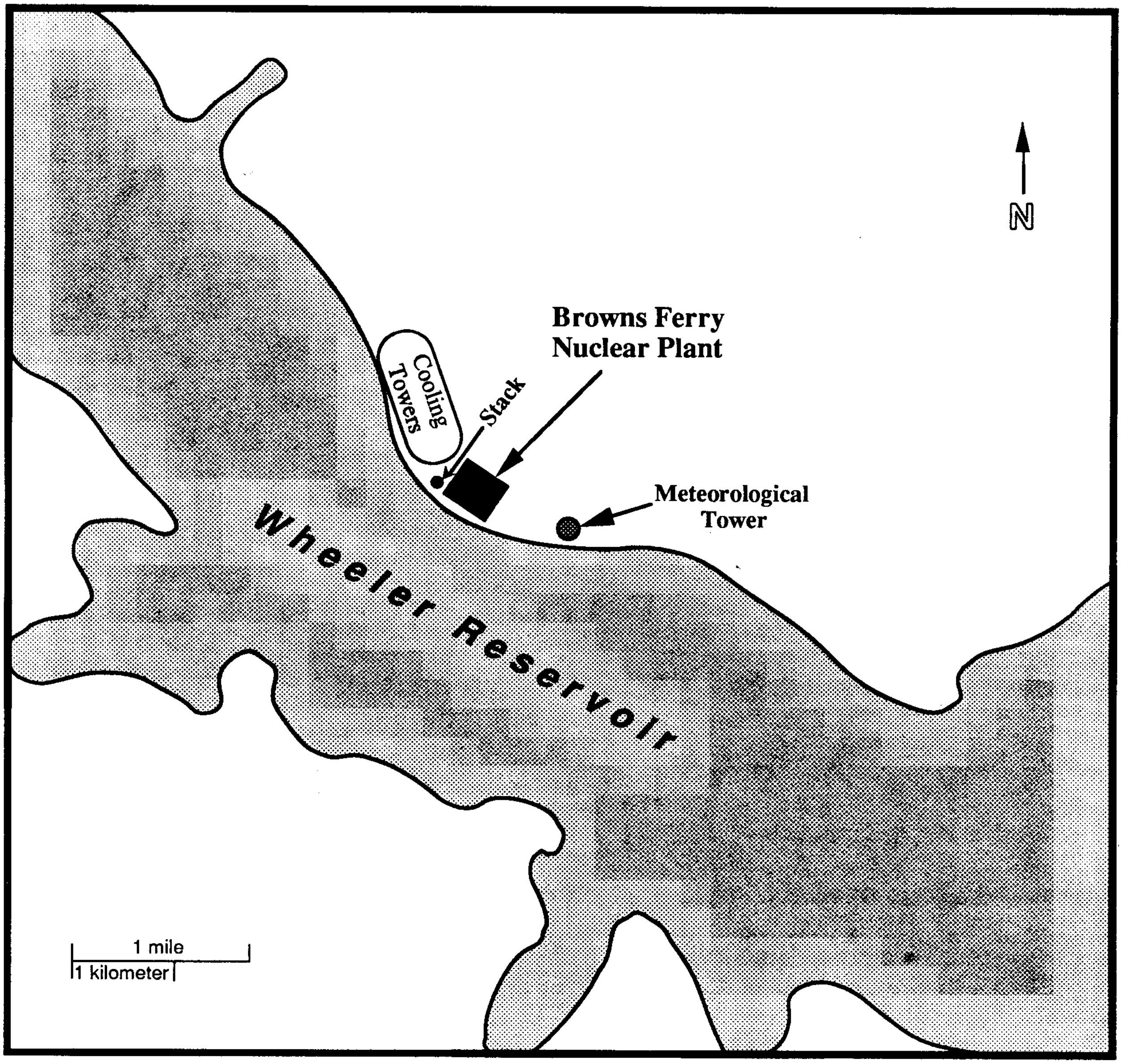


Figure 2
Browns Ferry Nuclear Plant ΔT Anomaly Cases
1986-1987

Relationship between Air Parcel Travel Distances and the Number of ΔT Anomaly Hours

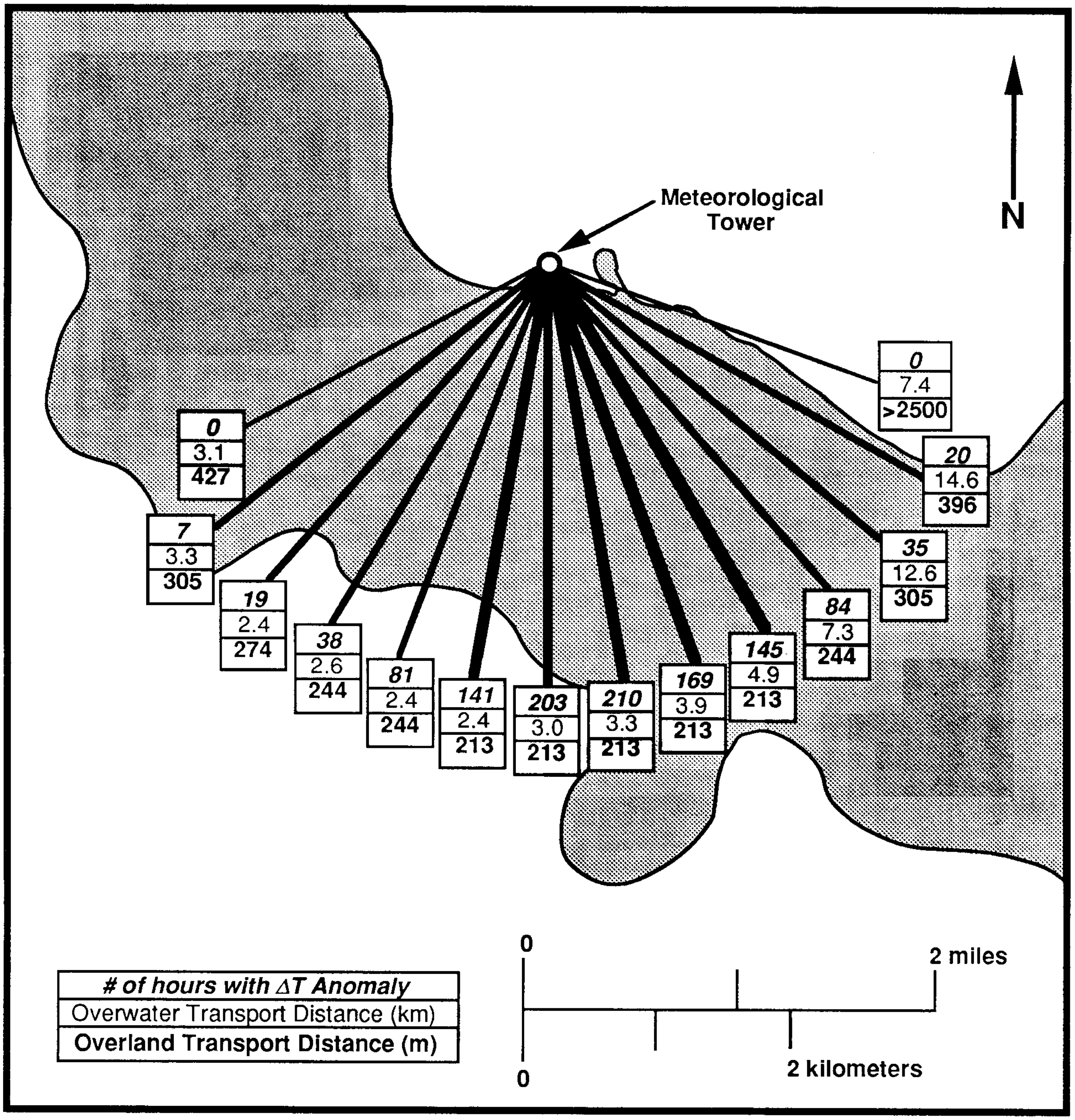
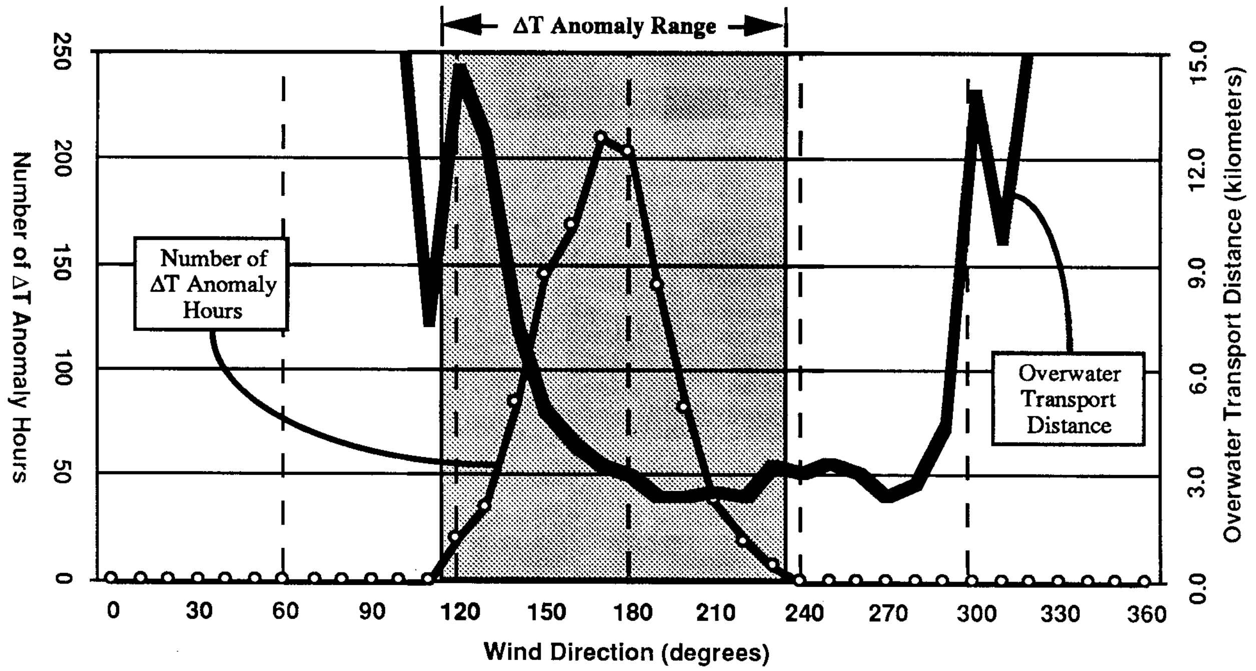


Figure 3
Browns Ferry Nuclear Plant ΔT Anomaly Cases
1986-1987

Number of ΔT Anomaly Hours versus Air Parcel Transport Distances

OVERWATER TRANSPORT



OVERLAND TRANSPORT

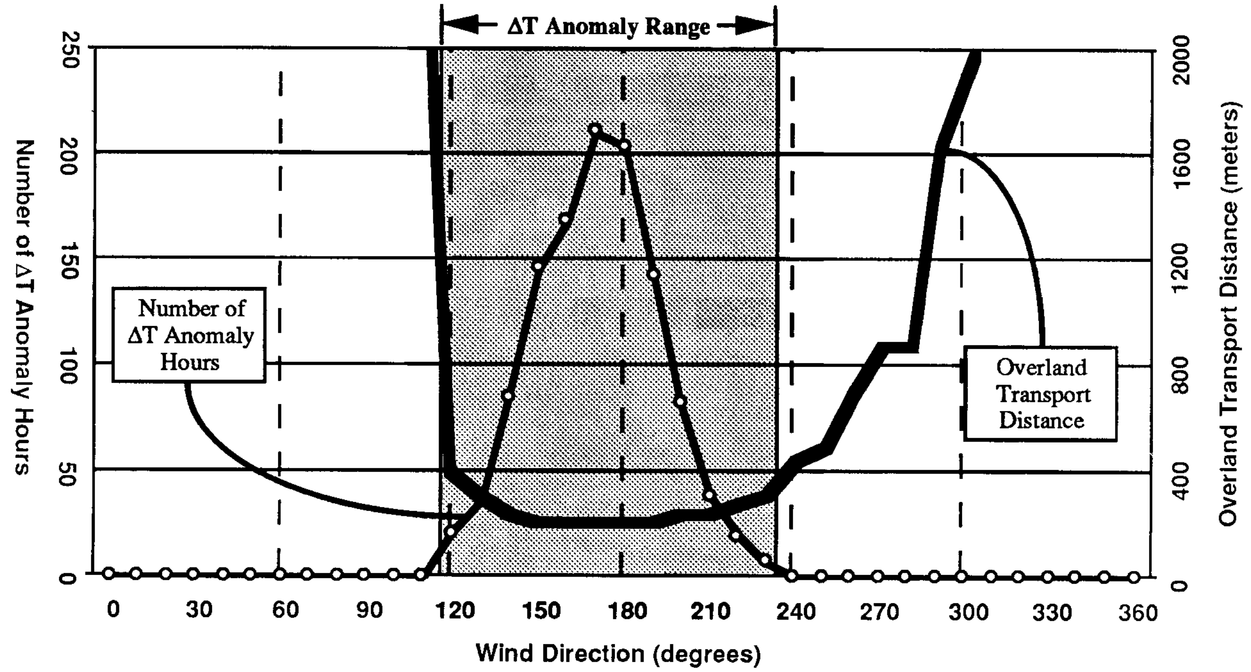


Table 1
Browns Ferry Nuclear Plant ΔT Anomaly
1986-1987

List of Cases

Case No.	Start Date and Hour	End Date and Hour	Duration (hours)
1	01/02/86 - 1300	01/02/86 - 2100	9
2	01/16/86 - 1100	01/16/86 - 2100	11
3	01/17/86 - 1300	01/17/86 - 1700	5
4	01/21/86 - 1000	01/22/86 - 0300	18
5	02/01/86 - 1100	02/02/86 - 1400	28
6	02/02/86 - 2000	02/02/86 - 2400	5
7	02/03/86 - 1300	02/04/86 - 1700	29
8	02/16/86 - 1000	02/17/86 - 1600	31
9	02/20/86 - 1100	02/21/86 - 0300	17
10	03/08/86 - 1600	03/09/86 - 0300	12
11	03/09/86 - 1000	03/10/86 - 2300	38
12	03/12/86 - 1300	03/12/86 - 1800	6
13	03/18/86 - 1300	03/18/86 - 2200	10
14	03/25/86 - 1200	03/26/86 - 0100	14
15	11/07/86 - 2200	11/08/86 - 2200	25
16	01/06/87 - 1300	01/06/87 - 2100	9
17	01/09/87 - 1200	01/09/87 - 1600	5
18	01/29/87 - 0800	01/29/87 - 2400	17
19	02/01/87 - 1100	02/02/87 - 0100	15
20	02/11/87 - 1400	02/11/87 - 2300	10
21	02/28/87 - 1600	02/28/87 - 2400	9
22	03/15/87 - 1400	03/15/87 - 2300	10
23	03/29/87 - 1100	03/29/87 - 1600	6
24	04/13/87 - 1200	04/13/87 - 2300	12
25	10/26/87 - 1100	10/26/87 - 1500	5
26	11/08/87 - 1400	11/08/87 - 1900	6
27	11/15/87 - 1400	11/15/87 - 1500	2
28	11/15/87 - 2400	11/16/87 - 2000	21
29	11/22/87 - 1500	11/25/87 - 1800	76
30	11/27/87 - 1100	11/27/87 - 1400	4
31	12/08/87 - 0800	12/09/87 - 0900	26
32	12/14/87 - 1500	12/15/87 - 0200	12
33	12/19/87 - 1000	12/20/87 - 0800	23
34	12/23/87 - 1400	12/23/87 - 2300	10
35	12/24/87 - 2200	12/25/87 - 2400	27
36	12/31/87 - 0500	12/31/87 - 2300	19

Table 2
Browns Ferry Nuclear Plant ΔT Anomaly
1986-1987

Frequency Tabulations for Key Variables
(missing data not included)

46-meter Wind Speed (mph)

Interval	Hours
≤ 5.0	2
5.1-10.0	62
10.1-15.0	198
15.1-20.0	190
20.1-25.0	82
> 25.0	43

45- to 10-meter Stability Class

Class	Hours
D	22
E	177
F	219
G	158

Joint 46-m Wind Speed & Stability Class (hours)

Interval	D	E	F	G
≤ 5.0	1	1	0	0
5.1-10.0	6	15	31	10
10.1-15.0	6	55	63	73
15.1-20.0	3	56	74	57
20.1-25.0	3	35	29	15
> 25.0	3	15	22	3

46-meter Wind Direction (degrees)

Interval	Hours
001-120	0
121-130	20
131-140	15
141-150	69
151-160	76
161-170	93
171-180	117
181-190	86
191-200	55
201-210	26
211-220	12
221-230	7
231-360	0

Joint 46-m Wind Direction & Stability Class (hours)

Interval	D	E	F	G
001-120	0	0	0	0
121-130	0	13	7	0
131-140	0	2	13	0
141-150	4	17	33	14
151-160	3	19	29	25
161-170	3	22	28	40
171-180	4	30	35	48
181-190	2	32	35	17
191-200	3	22	20	10
201-210	0	12	12	2
211-220	2	4	5	1
221-230	0	4	2	1
231-360	0	0	0	0

10-meter Air Temp. and -0.5-foot Water Temp. Diff. (Ta-Tw) [°F]

Interval	Hours
< -5.0	0
-5.0 to 0.0	10
0.1 to 5.0	90
5.1 to 10.0	217
10.1 to 15.0	189
15.1 to 20.0	51
> 20.0	7

10-meter Air Temp. and 10-meter Dewpoint Diff. (Ta-Td) [°F]

Interval	Hours
-1.0 to 1.0	5
1.1 to 5.0	86
5.1 to 10.0	142
10.1 to 15.0	154
15.1 to 20.0	109
> 20.0	76

Table 3
Browns Ferry Nuclear Plant ΔT Anomaly
1986-1987

Air Parcel Transport Distances

46-meter WD Range (degrees)	Hours with ΔT Anomaly*	Overwater Distance (kilometers)	Overland Distance (meters)
000	0	NA**	>2500***
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.			
100	0	NA**	>2500
110	0	7.4	>2500
120	20	14.6	396
130	35	12.6	305
140	84	7.3	244
150	145	4.9	213
160	169	3.9	213
170	210	3.3	213
180	203	3.0	213
190	141	2.4	213
200	81	2.4	244
210	38	2.6	244
220	19	2.4	274
230	7	3.3	305
240	0	3.1	427
250	0	3.4	487
260	0	3.1	671
270	0	2.4	853
280	0	2.8	853
290	0	4.4	1585
300	0	13.9	1890
310	0	9.8	>2500
320	0	NA**	>2500
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350	0	NA**	>2500

* Sum of hours with ΔT anomaly for the two 10-degree sectors centered on wind direction.

** No significant overwater transport within 16 kilometers of the plant.

*** Meteorological tower is more than 2500 meters from the shoreline