The Columbus Metropolitan Freeway Management System (CMFMS) Effectiveness Study:

Part 2 - The After Study

B. Coifman

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16. Abstract

A Freeway Management System (FMS) employs various tools to manage a freeway to increase throughput and reduce delay without additional lanes. The FMS acquires data from the roadway and process these data to identify and respond to problems. If some aspects of the data are unreliable, then the response decisions will likely be faulty.

This study evaluates the performance of the first phase of the Columbus Metropolitan Freeway Management System (CMFMS) along roughly 14 miles (22.5 km) of I-70 and I-71. The system became operational at the end of 2001. The tools developed and the evaluation are intended to both provide a better understanding of the operation of the facility and to help guide future investments in the CMFMS and other FMSs.

The initial objective of this study was to evaluate the performance of the CMFMS. In the course of the evaluation this effort developed calibration tools and performance measures that should also prove useful for ongoing operations. The study specifically develops a suite of performance monitoring tools both to assess the performance of instrumented freeways and the reliability of the surveillance system. It also provides a comprehensive overview of the given traffic monitoring system for practitioners, allowing them to optimize the system. In the course of this work we integrated information from many sources to meet multiple objectives for system management and monitoring. Although presented in the context of the Columbus system, the tools should be generalizable to most freeway surveillance systems.

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THE COLUMBUS METROPOLITAN FREEWAY MANAGEMENT SYSTEM (CMFMS) EFFECTIVENESS STUDY: PART 2 - THE AFTER STUDY

Sponsored by the Ohio Department of Transportation

Associate Professor Benjamin A. Coifman
Department of Civil and Environmental Engineering and Geodetic Science
Department of Electrical and Computer Engineering
The Ohio State University
Hitchcock Hall 470
2070 Neil Ave
Columbus, OH 43210

v: (614) 292-4282
f: (614) 292-3780
e: coifman.1@osu.edu
w: http://www.ceegs.ohio-state.edu/~coifman/

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Research Scientist:
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Graduate Research Assistants:
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  Lixin Liang
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  Chao Wang
  Xin Wang

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  Nathan Denning
  Abdul Kalash
  Mark Lehman.
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INTRODUCTION AND RESEARCH OBJECTIVES

The development and deployment of Intelligent Transportation System (ITS) technologies provide a wide variety of opportunities for local, regional and state agencies to improve the capacity, reliability, and efficiency of their transportation systems. A Freeway Management System (FMS) employs various ITS tools to improve safety, optimize the real capacity of the freeway, and provide a better level of service to motorists without the addition of more traffic lanes [1]. The FMS acquires data from the roadway and process these data to identify and respond to problems, notifying operators and motorists. If some aspects of the data are unreliable, then the response decisions and the information given may well be faulty. Hence, accurate traffic data acquisition is essential for effective traffic surveillance, the backbone of such ITS management applications.

The Ohio Department of Transportation (ODOT), in conjunction with the City of Columbus and the Federal Highway Administration, deployed the first phase of the Columbus Metropolitan Freeway Management System (CMFMS). Figure 1 shows a schematic of the currently deployed system along I-70 and I-71, covering roughly 14 miles (22.5 km) of freeway with detector stations every third of a mile (0.5 km). The system includes dual loop detector stations every mile (1.6 km), spanned by two single loop detector stations in between, ramp meters, 4 changeable message signs (CMS), and an integrated traffic management center (TMC) to coordinate different government agencies and the media. Appendix A shows detailed schematics of the entire system, prepared by Transdyn Controls. The system became operational at the end of 2001. This study evaluates the performance of the first phase to both understand the operation of the facility and to help guide future investments in the CMFMS and other FMSs across the state of Ohio. The second phase build-out is currently under construction and is scheduled to be completed in 2006.

This research originally set out to collect performance data from the CMFMS after deployment and develop tools for a before/after benefit analysis against the before data collected in [2]. The performance measures developed in this first phase of deployment would then be used in the many subsequent planned phases of the CMFMS build-out. When we began collecting the data for this analysis we discovered errors in the basic system data and the scope of the work shifted to addressing this concern. The effort developed calibration tools and performance measures that should also prove useful for ongoing operations. The primary objective of the initial research scope was still met with the added benefit of providing a suite of tools that can be used to ensure optimal system performance.

Data for this evaluation were collected on the mainline and ramps using the CMFMS loop detectors, dedicated probe vehicle runs and Central Ohio Transit Agency (COTA) automatic vehicle location (AVL) system on transit vehicles in the corridor. This study provides quantitative and qualitative results such as: travel times, speed data, traffic volume, and traveler delay. The study develops a suite of performance monitoring tools both to assess the performance of instrumented freeways and the reliability of the surveillance system. It also provides a comprehensive overview of the given traffic monitoring system for practitioners, allowing them to optimize the system. In the course of this work we integrated information from many sources to meet multiple objectives for system management and monitoring.

Measurements From Loop Detectors

As noted previously, there are two types of loop detector stations in the CMFMS, single loop detectors and dual loop detectors, where the name denotes the number of loops in each mainline lane. Both types of stations can measure flow, q, the number of vehicles that pass per unit time, and occupancy, occ, the percentage time that the detector is occupied. Dual loops allow for direct measurement of speed from the traversal time between the two loops of known spacing (generally on the order of 20 ft, or 6 m), while speed can only be estimated at single loops, as presented below.

Before aggregation at the TMC the loop detectors provide transition data to OSU, which is not only valuable to basic research but also allows for more precise data cleaning. To illustrate this point, consider the hypothetical example shown in Figure 2. This example shows the detector response to two passenger cars, one truck, and one detector error in the absence of a vehicle. Unless they are frequent, errors such as the short on-time due to the erroneous actuation go unnoticed in conventional aggregated data but are often easy to identify in the transition data. At the other extreme, many trucks have an effective length that is four times that of the median effective vehicle length. As shown in [3], this variance in length can cause significant errors in conventional speed estimates from single loop detectors, i.e.,

$$mean(speed) = \frac{\hat{L} \cdot q}{occupancy} = \frac{\hat{L}}{mean(on - time)} \tag{1}$$

where $\hat{L}$ is the assumed average vehicle length. But as shown in Figure 2, the long vehicles can extend the mean on-time and thus reduce the estimated speed even though traffic is not actually moving slower. To reduce susceptibility to unusually long vehicles (as well as short detector errors), one can calculate a more robust estimate of speed using the following equation,

$$median(speed) = \frac{\hat{L}}{median(on - time)} \tag{2}$$

In a single loop detector any systemic errors in on-time due to detector sensitivity lead to scaling errors in speed because of an incorrect $\hat{L}$. Likewise, the incorrect loop spacing for a dual loop detector results in scaling error in speed measurements.

The loop data were validated using roughly 325 round-trip, probe vehicle runs through the corridor. Further validation was conducted using COTA AVL data from March 2001-August 2004. Figure 3 shows an example of the COTA AVL data over five consecutive weekdays, the I-71 corridor used in this study runs vertically, roughly through the middle of this figure.

Changing Traffic Patterns

As originally conceived, this study was meant to be a companion to a before study data collection to quantify the impact of the CMFMS. This goal is still retained, but it is limited by two facts, first much of the before data were collected over only two weeks while the after data were collected over three years. Second, and more importantly changing traffic patterns due to the closure and opening major links in the larger highway network impacted measurements or traffic demand during the period of data studied in this research, these events include the following:

Dec 2001	CMFMS "turned on"
March 2002	I-670 closed between I-71 and SR 315 (to date, SR 315 was the western terminus of I-670 and only provided connections to/from the north)
March 2003	Spring and Long St bridges closed for 3 mo, removing the primary northbound on-ramp for downtown travelers and alleviating the bottleneck it caused.
June 2003	South innerbelt resurfacing and restriping south/westbound traffic - knocks out several detector stations.
September 2003	I-670 reopens to SR 315 and now goes further, connecting to I-70 on the west end. The interchange at SR 315 now provides connections to/from the south in addition to the north.
August 2004	Polaris interchange rebuilding begins - knocks out several detector stations

The impacts from several of these events are evident in the analysis below.

Overview

The remainder of this report is divided into three major sections. The first section focuses on evaluating the loop detectors, with particular care given to diagnosing problems at the detectors and calibrating the speed measurements to correct for sensitivity and spacing errors. The second section focuses on system performance measures, looking at how conditions evolve on the instrumented corridor. This section employs average daily travel (ADT) and delay to track the evolution. Care is given to monitoring traffic conditions during the I-670 closure and reopening. Then the ramp metering system performance is evaluated. Next comparisons are made between conditions before and after the CMFMS was turned on. Finally the report closes with conclusions and several appendices

EVALUATING THE LOOP DETECTORS

Loop detectors are the most commonly used vehicle detector for freeway traffic surveillance and they are employed as the primary detection system in the CMFMS. The first step of data processing converts the raw loop transition data into measures and mapping the given loop detector number to the specific location (station and lane) on the freeway. Loop detectors are not always calibrated correctly and may be completely non-operational, so it is necessary to identify non-performing and potentially inaccurate detectors. First, any non-operational loops were identified. It then proved necessary to calibrate the loop detectors in this study, as many of the loops initially provided unreasonable speed measurements. This process began with the dual loop separation measured by ODOT prior to the start up of the CMFMS. Many errors remained in these measurements, as well as the assumed effective length at the single loop detectors due to varying sensitivity from loop to loop. As discussed below, to address these problems, we took the median speed over a day and found the correction factor to make this median equal to the expected value (assumed to be 5 mph, or 8 km/h, over the posted limit for this study). These correction factors were further adjusted after comparing concurrent loop and probe vehicle data and then were subsequently held constant.

It is also important to note that even with the correction factors, the speed measurements from dual loops and estimates at single loops degrade when there are few vehicles in a given sample (typically between 1am and 5am). The problem arises at dual loops due to misdetection errors and at single loops because the true average or median vehicle length of the sample can deviate significantly from the constant $\hat{L}$ calibrated for samples with mostly passenger vehicles, e.g., if the only vehicle that passes in a sample is a long truck. Fortunately, these errors are relatively easy to catch using an occupancy filter, i.e., free flow traffic is characterized by low occupancy. If there are few vehicles in a given sample and they are free flowing the occupancy will be low, typically below 10 percent, even if those vehicles are long vehicles. These samples can be corrected to the assumed free flow speed. On the other hand, congested traffic is characterized by occupancies over 15 or 20 percent (see, e.g., [4]).

The following evaluation tabulates the percentage of operational detectors on monthly and yearly basis as well as the percentage of unmatched pulses in dual loop detectors (the latter error indicating that either one detector is overcounting or the other detector is undercounting in the dual loop detector). Incorrect detector mapping is tracked and loop calibration factors for both single and dual loop detectors are calculated to improve the accuracy of speed measurements. The analysis employs both statistical trends gathered from the detectors and concurrent speeds collected from probe vehicles as they pass over the detectors.

Data Sources

Loop detector data

Data are collected from 45 detector stations on I-70/I-71 in the CMFMS sampled at 240 Hz. These stations include 145 loop detectors on the northbound freeway mainline lanes and 140 loop detectors on the southbound freeway mainline lanes. For all measurements that use information from the paired loops in a dual loop the corresponding pulses from a given vehicle at both loops need to be matched. As explained later, each pulse at the downstream loop is matched to most recent pulse seen at upstream loop. More sophisticated matching can be used, but were not employed in this study as they do not reflect conventional practice.

Probe Vehicle- Travel Time Run Data

The travel time run data are collected from a probe vehicle equipped with a GPS receiver to provide an independent measure of freeway operation. For each tour drivers run a vehicle on two round trips during the morning peak (7AM-9AM) or evening peak (4PM-6PM), Tuesday through Thursday. Travel run data cover almost all of the detector stations on I-70/I-71 from downtown (station 102) to Polaris Parkway (station 33). Drivers are instructed to normally travel in lane 2, the second lane from the left, though they can pass slow vehicles if warranted. The GPS receiver records the location of the vehicle (longitude and latitude), and velocity every second. Figure 4 shows the number of travel time tours by month collected from the probe vehicle. The routing instructions provided to the drivers are shown in Table 1

Since GPS data quality depends on visibility of satellites by a GPS receiver, GPS position errors cannot be avoided. Structures, terrain and even dense foliage can block signal reception or cause multipath interference, resulting in position errors or possibly no position reading at all. Figure 5 shows the GPS position measurements for one round trip, superimposed on an aerial photo of the region. The point highlighted with a star in the figure shows an example of a position error due to an overpass interfering with signal reception. Fortunately, most GPS errors are local in nature, and they do not accumulate from one measurement to the next.

To facilitate comparisons between runs, reducing local noise from measurement errors and passing maneuvers while providing a common reference distance across all runs, each position measurement is projected to the same reference run. For each point on a run, the closest point on the reference run is found. These GPS data are then used throughout our analysis, the first application being loop detector speed validation. For verifying loop speed with GPS velocity, the coordinates associated with the location of loop detector stations are found from a georeferenced, a high resolution aerial photo of I-70/I-71. The coordinates of the detector stations are presented in Appendix B.

A measure of Operational Detectors

There are many errors that can occur at a loop detector or detector station. The most fundamental errors prevent measurements in one or more lanes. A very generous definition of "operational" is used to ensure that no valid data are discarded. Namely, if any data are reported for a given detector during a given day it is labeled "operational" in terms of this test. So some loops labeled as operational may still have fundamental problems. The percentage of detectors not reporting at a detector station is used to track operational detectors, and formalized as follows,

$$\text{Percentage of detectors not reporting} = \left(1 - \frac{\sum_{j=1}^{N} \#\, loops\, reporting}{\#\, loops \times N} \right) \times 100(\%) \qquad (3)$$

Where,

N: Number of days used for the test, set to daily or monthly or yearly values for our study.

loops: Number of detectors at detector station i.

loops reporting: Number of loop detectors at detector station *i* at seen on day *j*.

For example northbound station 23 is a single loop detector station with three lanes, the 31 days in January 2003 has a denominator of 93 lane-days. If hypothetically, one loop was down for 13 of those days only 80 lane-days would have been observed at that station during the month, i.e., the percentage of detectors not reporting would be 14 percent.

Using actual data Figure 6 shows the percentage of detector data not reported in March 2005 by station for the northbound direction. From the plot, it is evident that loop detectors at stations 28 to 34 do not report any data for the entire month. These stations were taken off-line due to the Polaris interchange construction begun in August 2004. Loop station 103 had 68 percent of the expected detector days not report. Closer inspection revealed that the loop station did not report any data for 10 days in March 2005. Moving to a larger time scale, these monthly operational detector station plots can be organized in calendar format to show the loop station status over years, as shown in Figure 7A to 7D. Each figure shows data either from the first six months or last six months of the year over a period of almost four years. Each row in these figures shows data from a single year, each column shows data from the same month over the years, e.g., the fifth row third column of Figure 7A repeats the plot from Figure 6. A quick glance at these yearly plots can reveal how the operational status of the detectors evolves over long periods. Finally, the operational status of detector stations can also be aggregated over an entire year of data, as shown in Figure 8. Each plot shows the operational status of detectors averaged over an entire year for the given direction, e.g., Figure 8C shows that station 21 does not report data for most of year 2004, as expected from the reconstruction work mentioned earlier.

Problems at Loop Detectors

Unmatched Pulses at Dual Loop Detectors

A dual loop detector consists of two single loop detectors spaced a known distance apart. When a vehicle passes over a dual loop detector, the upstream loop detector is activated and then the downstream loop detector. Each actuation results in a pulse being recorded in the data stream. Sometimes, however, one loop may fail to actuate or it may actuate erroneously. As a result, the two loops can be used to validate one another. Each actuation at one loop should be uniquely matched to a single actuation at the other. To quantify the extent of deviation from this expected performance, pulses are matched between the two loops. First, matching each downstream pulses with the most recent upstream pulse, any extra pulses at upstream loop are considered unmatched. Then repeating the process from the upstream loop, matching an upstream pulse with the first downstream pulse to follow, any extra pulses at downstream loop are considered unmatched. The percentage of unmatched pulses provides one measure of the quality of dual loop data and the status of the loop detectors. Figure 9 shows the percentage of unmatched pulses at upstream and downstream loops over the 15 dual loop stations in the CMFMS, for both directions on July 12, 2004 over the entire 24-hr period. The percentage of unmatched pulses is calculated from the number of unmatched pulses at upstream (or downstream) divided by a total number of pulses at the upstream (or downstream) loop. Most of the stations show that fewer than five percent of the pulses go unmatched. Some of these unmatched pulses are due to normal operations such as lane change maneuvers over the detectors and occasional errors that would be expected with any detector. The notable exceptions are stations 10, 16, 102, and 105, all of which exhibit large error rates suggesting chronic problems on this date. In detail, this process is repeated on an individual lane, shown in Figure 10. Both station 105 northbound and station 102 southbound exhibit a large number of unmatched pulses, as explained shortly, these stations were wired incorrectly after the resurfacing and were operating with an incorrect detector mapping.

Incorrect Dual Loop Detector Mapping

Using the relationship between speed and occupancy, dual loop stations with incorrect loop detector mapping can be identified. Generally, speed monotonically decreases with increased occupancy. If the speed-occupancy relationship deviates significantly from this general relationship, the dual loop detector is likely in error, potentially due to an incorrect detector mapping. The time period selected for this test is July 1, 2004 through August 31, 2004. Using all of the aggregated data from these two months, most of the dual loop stations perform as expected, e.g., Figure 11. However, among detectors at all dual loop stations, station 102(NB), station 105(NB), and station 102(SB) present an anomalous relationship of speed and occupancy, as shown in Figure 12. Three lanes at station 102 deviate from the expected monotonic relationship, lane 2 northbound and lanes 1 and 2 southbound. All three lanes at station 105 northbound appear to be anomalous, compared to general relationship of speed-occupancy. Looking at plots of the actual pulses from these two detector stations reveal that the patterns are related to incorrect detector mapping, as shown in Figure 13 (the numeral indicates the lane, -u is the upstream loop, -d is the downstream loop, and RM is a ramp detector). One would expect the downstream time series to lag the upstream by a fraction of a second during free flow conditions. Even with these short time series, at station 102, one can see that the data thought to be northbound lane 2 upstream (NB 2u), lags the data thought to be northbound lane 2 downstream (NB 2d), suggesting that the loops are reversed from the detector mapping. In the southbound direction one can see that the data thought to be SB 1u actually lead the data thought to be SB 2u, while the data thought to be SB 1d actually lead the data thought to be SB 2d. A similar miss-wiring (or configuration error) is evident at station 105 northbound, where the upstream loop in one lane either leads or lags a loop that is assigned to a different lane.

Based on plots of transition pulses in Figure 13 and ADT by lane at the adjacent station (not shown), new detector mapping for these loop stations is suggested in Table 2. These errors have reportedly since been independently confirmed and corrected by ODOT (see appendix H for an addendum to this analysis).

Loop Detector Calibration

Single Loop Detectors

Typically speed at single loops is estimated via Equation 1, while this study uses Equation 2. Both equations yield similar results, with the primary difference being that the latter equation is less susceptible to noise arising from the change in average vehicle length from one sample to the next. In either case, the given detector's sensitivity biases the on-time measurements and scaling errors in speed estimates arise. To illustrate how the sensitivity of a single loop detector changes from detector to detector consider all of the single loop detectors in the CMFMS. Starting with an initial assumption that $\hat{L}$=20 ft (6 m), estimated speeds are collected over a month from a normally off-peak period. Namely, data from 9am to 3pm every day the 5 min estimated speed is recorded using Equation 2 individually for each single loop detector and the median of this superset is shown for the given detector in Figure 14. Applying the median to the large data set removes the impacts of transient events such as incidents. The time period chosen for this experiment is April 1, 2005 through April 30, 2005 except for station 28 through station 34, which were not operational, so these stations were taken from the time period of April 1, 2003 to April 30, 2003.

The impact of detector sensitivity is evident in this figure, consider northbound stations 21 and 23, except for lane 2 at station 23, all of the lanes exhibit a speed below the posted speed limit (65 mph, or 105 km/h). Some stations show that the difference of speed across neighboring lanes is high, e.g., the median speed of lane 2 at station 2 northbound is 30 mph (48 km/h) higher than the other lanes at station 2. While northbound stations 31, 32 and 34 show that the speed in lane 3 is lower than the other lanes, even lower than lane 4, the outside lane. Lanes 2 and 3 at station 18 southbound have a median speed is 30 mph (48 km/h) higher than lane 1. Station 34 southbound indicates that lane 3 is 30 mph (48 km/h) slower than other lanes. Station 110 southbound has a median speed in lane 2 almost twice as large as the other lanes. (Note that in station 110, lane 1 and lane 2 are on I-670, lane 3 and lane 4 are on I-71).

In most cases the discrepancies arise due to variations in detector sensitivity, though some of the lower readings appear to be due to systematic variations in the vehicle fleet (more long vehicles in the particular lane). To correct these speed estimation errors at single loop detectors we calculate a multiplicative correction factor individually for each loop, as follows. First, the daily median speed is taken from speed in off-peak time periods (9a am-3 pm), and this process is repeated for all weekdays in a month. Next, the median of the daily speeds is found, e.g., Figure 14. The correction factor is then defined as the posted speed limit divided by this daily median speed. For example, in this study, the median speed in lane 2 at station 26 northbound is 81mph (130 km/h), so the correction factor is 0.8 (the quotient of 65 mph and 81 mph). Naturally one could use a radar gun or other measurement device to validate the speeds more accurately, which is exactly what we do with the probe vehicle data. To verify the process of generating correction factors is valid, the corrected single loop speeds are compared against the corresponding GPS velocity measurements from the probe vehicle runs. Figure 15 shows a scatter plot of loop speed as the probe vehicle passed versus GPS velocity in lane 2 at station 26 northbound (recall that the GPS probe vehicle runs in lane 2). Without the correction factor the loop speeds exhibit a systematic bias, with almost all estimates being too high (Figure 15A), while this bias is removed after applying the correction factor calculated above (Figure 15B). Figure 16 and Figure 17 show the comparison after the correction factor is applied at all of the single loop detectors passed in the travel time run and the number of observations. After applying the correction factors, most of the single loop detectors report speeds close to the GPS velocity. The largest discrepancies remain at northbound stations 104, 3, 8, 12, 17, 21 and 23 and southbound stations 110, 8, 12, 17, and 21. At stations 8 and 12 for both directions we found a high percentage of the pulses are reported with zero on-time, that is, the detector reportedly turns on and back off in the same sample, which should not be feasible and suggests a chronic error at the detector station. The rest of loop detectors showing the large discrepancy appear to be related to the sensitivity of the loop changing at some point during the four year study period, as will be discussed in detail below.

Ultimately the correction factors simply reflect the fact that given the detector's sensitivity, the true effective vehicle length differs from 20 ft (6 m). Based on the correction factors for single loop detectors, the average effective vehicle length can be estimated, as shown in Figure 18. These estimated average effective vehicle lengths can improve the single loop detector speed estimates.

Dual Loop Detectors

As discussed previously, a dual loop detector provides measured speed from the traversal time between two loops, rather than just the estimated speed available from a single loop detector. As a single loop detector sensitivity results in scaling errors in speed estimation, similar scaling errors occur at a dual loop when the incorrect loop spacing is used. Following the same process used with the single loops, Figure 19 shows the median daily median speed from the midday period, and again, one would expect the results to be close to the posted speed limit. The time period chosen for this experiment is the same as used above for the single loops, either April 2005 or for those stations that were not operational at that time, April 2003.

Most of the dual loop detectors show that median speed in the off-peak time periods are in the range of 60mph to 70mph (97 to 113 km/h), except for stations 4, 10, 102, and 105 northbound and stations 1, 4, 22, 27 and 108 southbound. Like the sensitivity error at single loops, this spacing error at dual loops will have a multiplicative effect. To correct the discrepancy of speed for a dual loop detector, multiplicative correction factors for obtaining the accurate loop separation are once more found by the quotient of the median and expected value, as detailed above. Figure 20 shows loop speed versus GPS velocity in lane 2 at station 26 southbound before and after applying the correction factor, notice how much of the systemic bias is removed. Figure 21 and Figure 22 show the comparison after the correction factor is applied at all of the dual loop detectors passed in the travel time run and the number of observations. The worst performance is exhibited at station 102 both directions and station 105 northbound, many of the dual loop speeds are considerably lower than GPS velocity. These errors are consistent with the incorrect detector mapping discussed above.

Based on the correction factors for dual loop detectors and the original loop spacing provided by ODOT in 2001, the corrected loop spacing can be calculated, as shown in Figure 23. The original spacing was measured when a dual loop detector was installed, while the ODOT spacing reflects the loop spacing estimated by ODOT using radar gun to correct the original spacing. Finally, our spacing is obtained from original spacing multiplied by the calculated correction factor.

Changing Sensitivity of Loop Detectors

As noted in the discussion on single loop detectors above, the correction factors still lead to many large discrepancies between measured and estimated speed because the sensitivity appears to change over time. This section delves deeper into the issue, looking into the stability of the correction factor on a larger time scale. Naturally, if the detector sensitivity changes then the correction factor should follow to keep the speed estimates accurate.

Extending the methodology used to establish the correction factors, this section uses the same time period (9 am-3 pm) and calculates the median speed every weekday. Rather than further processing these daily medians, the value for each day is plotted in a time series at each loop. Figure 24 shows the trend in daily median speed at loop station 17 northbound in this off-peak time period each weekday over four years. The daily median speed in all three lanes for February 2002 through June 2002 is about 20 percent higher than for the rest of the time period. The cause of this shift is unknown, though it is suspected that it arose due to adjustments in the filed. Similar errors were observed at several stations, almost all of which showed a similar piecewise stable trend. Returning to the example, since the correction factor was calculated using data from April, 2005, the loop speed during February 2002 through June 2002 should be overestimated, as illustrated by the cluster of points with loop speed around 90 mph (145 km/h) in Figure 25A. The unexpected trend in median speed makes it necessary to change the correction factor over time. In this case, two different correction factors are required, one during the first half of 2002 and the other applied for the rest of the data. Repeating the comparison of loop speed to GPS velocity, now using the two correction factors, is shown in Figure 25B. In general the correction factor could be calculated periodically to see if the sensitivity of any loop detectors have changed significantly. For example, the correction factor could be updated every week, and correction factor calculated in this week is applied to loop data for next week. One can find the trend in daily median speed at each of the single loop detector stations in Appendix C. Almost all stations exhibit piecewise stable trends, with the largest exception being station 18 southbound, reflecting an error in two lanes that appears to be seasonal.

Figure 26, provides a second example of this phenomena, here the daily median speed at station 23 northbound changes several times over four years. Early on the sensitivity of the loops varies from month to month, presumably due to field adjustments while the CMFMS was still starting up, stabilizing approximately May 2002. The daily median speed in lane 2 dramatically increased starting from July 2004, and daily median speed in lane 1 decreased after October 2004. Once more, since the correction factor for lane 2 is calculated using data from April 2005 (high median speed), loop speed before July 2005 adjusted with this correction factor is expected to be low, as shown in Figure 16. Once more these problems can be solved by applying different corrections factor over time. Closer investigation of the data in lane 2 suggests that it is operating in pulse mode after July 2004, with all individual vehicle on-times being identical.

A third example illustrates other findings evident in the daily median speed trends could be used to find incorrect detector mappings. Figure 27 shows the daily median speed trends at station 104 northbound, after the station was down for several months, in October 2003 speed in lane 1 decreased while speed in lane 2 increased. The daily median speed in lane 1 after October 2003 is similar to median speed at lane 2 before October 2003. To check the possibility that these two lanes were switched, two sample days are taken from before and after the outage, namely March 10, 2003 and June 22, 2004. There are no ramps between northbound station 104 and station 103 and they are about 1/3 of a mile (0.5 km) apart. So within a given lane, one would expect to see similar trends in traffic volume at the two stations. Looking first before the outage, using 5 min volumes over the 24 hr day, in Figure 28A we see that indeed this supposition holds. Likewise, the cumulative distribution (CDF) of individual vehicle on-times should be similar within the same lane between the two stations and the figure shows indeed this is the case. After the outage, however, as shown in Figure 28B, both suppositions fail. Now lane 2 at station 104 is similar to lane 1 at station 103 in both the volume and on-time distributions (likewise, lane 1 at the former is now similar to lane 2 at the latter). We speculate that there is a mapping error at station 104 after October 2003 for the following reasons. Provided traffic was free flowing throughout the day, the measured on-times should be proportional to the unobserved vehicle lengths. At station 103, both before and after, lane 1 had few long on-times while lane 2 had 10-15 percent of on-times that would correspond to long vehicles, and one would expect to see few trucks in lane 1.

System Performance Measures

Many performance measures were developed in the course of this research, although many of these measures are simply refinements on earlier techniques, there were several small but significant advances. The first performance measure is the summary plots, showing directional conditions along the entire corridor over time and space. The next performance measure is estimated travel time and delay. Then we measure average daily travel (ADT) and hours of delay. With these latter metrics, the most significant contribution were filters to allow one to clearly view trends over several years of data, extracting value from archived data.

Summary Plots

The basic summary plot shows directional conditions in the form of speed along the entire corridor over time and space. It is essentially a matrix indexed by location and time containing the speeds for that sample. In this study we used 5 min samples with synchronized start time at every station. Links are taken to begin and end at the midpoint between two detector stations though one could easily use station to station, or even simply index by station number rather than distance. Finally, we use a continuous gradient from dark to light (dark red to bright green in the color version of the plots), ranging between 0 mph and 65 mph (105 km/h), though one could discretize the space to only a few speed bins. Figure 29 shows the summary plot for one day of northbound traffic (direction of travel is from bottom to top). The vertical axis is distance along the roadway, as indicated on the left, with a second axis on the right showing the station number. As indicated on the figure, queuing is evident at four different instances and three different locations in the plot (all recurring bottlenecks in this case).

Daily summary plots can be organized in calendar format to show the traffic state over the entire month. Figure 30 shows an example of such a presentation. The first seven columns show Sunday through Saturday, respectively. If the month starts on a day other than Sunday, the extra cells are populated with data from the end of the preceding month, similarly if the month ends before Saturday, the remaining cells are populated with the corresponding data from the following month. The final column shows the weekday average for that row and the last row shows the column average for that day of the week. This monthly plot includes the data from Figure 29 (fourth row third column, highlighted with a dashed circle). A quick glance at this plot can reveal the queuing due to incidents and recurring bottlenecks alike.

The summary plots also show the operational status of the detectors, if no data were received for a given station at a given time, the cell is left black (in the color version of the plots such missing data are shown in white), indicating a failure somewhere in the surveillance system. Several small outages are apparent throughout the month. Three brief system-wide outages are apparent in this month, as manifest as the vertical white lines in the third and fifth rows. Then, in the fifth row, seventh column, one can see two horizontal black lines, indicating that two detector stations were down the entire day. Summary plots for the entire study period can be found in Appendix D. Note that for the southbound direction, travel is also shown progressing from bottom to top, so the distance axis on the left hand side of the plot and corresponding station labels on the right hand side are in reverse order from the northbound plots.

The monthly data can be summarized to get the average weekday conditions and the average weekend conditions over the month. Taking the difference between the daily conditions and the respective monthly average yields the summary difference plot, e.g., Figure 31 shows the summary difference plot corresponding to Figure 29. The summary difference plot shows how conditions differ from "normal," highlighting non-recurring events, neutral gray is average, darker denotes slower than average speed and lighter is faster (in the color versions of the plots white is average and red/green intensity is proportional to the amount below/above average speed for that time and location). Note that one could also use the average of the last N days, or the last N specific day of the week to generate the summary difference plot. Like the summary plot, the summary difference plot can easily be presented for the entire month in the calendar format, e.g., Figure 32. Each cell in Figure 32 corresponds to the same cell in Figure 30. Summary difference plots for the entire study period can be found in Appendix E.

Of course the average monthly summary plots are useful in their own right, highlighting periods of recurring congestion. Taken over time, they also reflect evolving traffic patterns, e.g., average monthly summary plots can be organized in calendar format to show the evolution of recurring traffic conditions over extended time periods. Figure 33 and Figure 34 show examples of such a presentation. In each figure, the twelve columns show January through December, respectively, while the five rows correspond to year 2001 through 2005. Among other features, these plots present changes in the pattern of recurring congestion arising from the I-670 closure and subsequent reopening. The months surrounded a dashed line represent the period during the I-670 closure. In the northbound direction the period that I-670 was closed exhibits a shift in the recurring congestion, with delay moving upstream, i.e., towards the bottom of the plots. The decreased traffic from I-670 eastbound to I-71 northbound alleviated congestion at the 11th Ave lane drop (station 4), while traffic conditions between station 102 and station 105 became more congested than when I-670 was open. This result will be discussed in greater detail below. Note that the incorrect detector mapping for station 102 and station 105 were not corrected in these plots and caused low speed for some months, i.e., station 102 has the problem from August 2003 to February 2005, and station 105 has from August 2003 to September 2004.

For the southbound direction, during the I-670 closure the congestion is observed near station 1 for morning and evening peaks. Note that as with the northbound summary plots, the direction of travel is from bottom to top, so the mile markers and station numbers are presented in reverse order from the northbound plots. After the reopening I-670, the southbound evening peak congestion is alleviated, and morning peak congestion is reduced for several months. The incorrect detector mapping is also observed at station 102 from August 2003, continuing until February 2005.

Just as the daily summary difference plots highlighted differences from the average day, monthly summary difference plots can be generated to show the changing of traffic pattern due to major events on the freeway from month-to-month or year-to-year. Choosing the latter, the monthly summary difference plots represent the difference of traffic condition between the present year and the previous year in the same month. Compared to daily summary difference plots that highlight non-recurring congestion, the monthly summary difference plots present yearly variation of recurring traffic conditions, and are calculated as follows:

$$Monthly\ average\ diff\ speed_{(i,j)} = Monthly\ average\ speed_{(i,j)} - Monthly\ average\ speed_{(i-1,j)}$$

where,

i = current year,

i-1= previous year,

j = current month

Like the summary plot, the summary difference plot can be organized in a calendar format, as shown in Figure 35 and Figure 36. Once more the twelve columns show January through December, respectively and the five rows correspond to year 2001 through 2005. Note that although data were collected from December 2001, monthly summary difference plots can only be generated starting December 2002 since this month is the first time that data from the previous year are available. As with the monthly summary plots, the monthly summary difference plots surrounded by a dashed line correspond to the I-670 closure. In the northbound direction, after I-670 reopened, conditions downstream of the I-71/I-670 junction became more congested, i.e., station 1 to station 5. For the southbound direction, the location around I-71/I-670 junction was more congested during I-670 closure, and congestion was alleviated after I-670 reopened.

Travel Time and Delay

This research considered several measures and estimates of delay. The simplest approach sums successive link distances divided by the current speed at the loops to estimate the travel time on the extended segment. With the individual vehicle measurements provided by the CMFMS it is actually possible to estimate vehicle trajectories over an extended link from local data at a detector station [5]. In fact with the individual vehicle actuations it is even possible to reidentify vehicles and measure the true travel time between loop detector stations [6, 7]. For this research effort, it was decided that the individual vehicle actuations would not be used directly, since these data are uncommon from most traffic monitoring systems.

Constraining the research to conventional aggregated data from the detectors, the simplest estimate discussed above does not capture conditions experienced by any one traveler, it is a cross-section capturing instantaneous conditions. Without more sophisticated forecasting, it is the best one can do for real time systems. But for this project it was decided that for all historical travel times we would better approximate conditions experienced by travelers. Specifically, we use the speed matrix and link spacing underlying the summary plot, e.g., Figure 29, assume that conditions remain constant on a given link for the entire 5 min sample and distance spanned by the link, then estimate vehicle trajectories assuming that vehicles traveled at these prevailing conditions. So trajectories change slope at the boundaries of the cells, either at the end of a link or at the end of a 5 min sample. From the trajectories one can estimate travel time directly, taking the difference in the times that a trajectory pass the chosen start and end points. Figure 37 shows one such estimated trajectory against a measured trajectory from the probe vehicle data. This procedure was validated by comparing the estimated travel times to the measured travel times for over 100 probe vehicle tours, with each tour broken into several segments, ranging from 2 miles to 10 miles (3-16 km), see the scatter plots of Figure 38-39. The travel times were also compared against the COTA AVL data, e.g., Figure 40 shows 598 independent measurements over five consecutive weekdays. Some errors remain in these latter plots because it is difficult to distinguish between COTA vehicles on ramps and overpasses and those still on the main line, and the AVL system sometimes introduces a delay to the time stamp so the reported position does not always correspond to the reporting time.

This travel time estimation can be applied to a specific start time and location, as was done in the preceding validation. Or they can be applied every five minutes through the entire day at a given start location. These data can then be presented in a time series for that day. Statistics over several days can also be calculated, e.g., Figure 41 shows the mean and median travel times as a function of start time for two different links over an entire month. One can easily produce the min and max, or other percentiles over N days, or the N preceding specific day of the week. Such statistics can yield easy to report measures of reliability, e.g., the 95th percentile travel time. Such measures are origin and destination specific, while an operator may be interested in many origins or many destinations. So one can also plot the data in the form of equi-travel time contours. Figure 42B shows lines of equi-travel times from mile 0, as extracted from the speed data in the summary plot shown in Figure 42A. Traffic flows from bottom to top and most of the congestion in this figure is due to queuing upstream of a recurring bottleneck at mile 2.5 (4 km). A queue behind an incident is visible starting around noon at mile 3 (4.8 km) and lasts about an hour. This extraction can be generalized, averaging across several days (median day, mean day, 95th percentile, etc.), and the presentation tailored for the particular application.

Of course a travel time estimate allows an agency to estimate delay. In our study, we define delay to be travel below 55 mph (89 km/h). For a given five minute sample and link, we take the delay to be:

$$\text{total vehicle delay} = \text{flow} \cdot \max\left(\frac{\text{link distance}}{\text{speed}} - \frac{\text{link distance}}{\text{55mph}}, 0\right) \tag{4}$$

resulting in a delay matrix of the same size as the speed summary matrix. One can then sum across rows (delay at a link over a day), columns (delay across the corridor at an instant) or any other region of the matrix, e.g., Figure 43. In this case, the delay due to the incident within the instrumented area is 287 veh-hrs and a total of 971 veh-hrs of delay were measured on this day. The average weekday in this month had 390 veh-hrs of delay.

Performance Measurement and Monitoring

Many metrics are well suited to time series presentation (speed, flow, occupancy, travel time, delay, etc.), e.g., Figure 41. Other measures are well suited to averaging over time and space (vehicle miles traveled- VMT, delay, amount of time delay is present, etc.), e.g., Figures 29 and 42, or deviations from typical conditions, e.g., Figure 31. For some of the metrics it makes sense to aggregate by day in addition to other time periods (VMT, delay, amount of time delay is present, and average daily travel- ADT). When examining time series of these daily values over an extended period, it quickly becomes difficult to pull out meaningful trends in the presence of typical daily variability (e.g., incidents or holidays). To overcome this problem we take the median of the weekday values for each week. One could easily use min, max or another statistic; restrict the analysis to a specific day of the week, or so forth. This process of taking the median weekday allows one to review several years of data on a single plot and still extract useful information (henceforth referred to as the weekly median).

Average Daily Travel (ADT) and Delay

Several performance measures were considered in this work. Ultimately, Average Daily Travel (ADT) was chosen to measure throughput and vehicle delay (as defined above) was chosen to measure congestion. For example, Figures 44-47 show the weekly median ADT and delay at 8 directional stations for three years (vertical delineations show each month, abbreviated by the first letter on the plots). In all of these figures the chevron on the map to the right of the plots shows the direction and approximate location of the given detector station. Of course if a detector goes down in one or more lanes, the measures will no longer be valid. The measures from the affected station are presented during these periods because they may still hold meaning, however, they are shown with a different line style (a darker color for this report) to allow a user to easily identify such periods when one or more lanes are down in the given direction at the station. If the mean of bad detectors during a given week is greater than zero (Equation 3), the detector status is displayed as some loops not reporting on the plots. In each of the plots the vertical axis shows weekly median ADT (10,000 vehicles per day) or weekly median delay (vehicle-hours per day). Appendix F shows the evolution of weekly median ADT and delay for all of the directional stations in the CMFMS. The reader is cautioned that the vertical scale differs between loop detector stations, so one should be careful when comparing the ADT and Delay over stations.

Monitoring Traffic Conditions During the I-670 Closure and Reopening

The impacts of many of the major events enumerated earlier are evident in Figures 44-47. For example, I-670 offered an alternative route for traffic on the southern portion of the instrumented corridor and the plots indicate the period of the I-670 closure. Construction on I-670 began in March 2002 and ended in September 2003. Both ADT and delay increased significantly on the parallel portion of the I-71 corridor, e.g., Figure 44 for northbound traffic. Prior to the closure, northbound traffic from I-70 or I-71 could not take I-670 and were restricted by bottleneck around station 109 (the lower half of Figure 44). Thus, we see ADT drops from before closure to after the closure in Figure 44. The impact of the closure on ADT is much smaller north of the junction of the two routs, e.g., Figure 45. However, the increased flow from I-670 after reopening resulted in a higher ADT at these stations and has caused a bottleneck on I-71 within a mile (1.6 km) of the junction to become active (compare the delay at the two locations in Figure 45, that straddle the bottleneck). For southbound traffic, Figure 46 suggests that after reopening I-670 delay was alleviated around the I-71/I-670 junction, but increased slightly at the southern end of the corridor. The plots also show that after I-670 reopened, southbound I-71 ADT increased slightly north of the junction with I-670 and dropped south of the junction.

Evaluation of the Ramp Metering System

Ramp metering is one of the most frequently used methods of urban freeway control to reduce mainline congestion. Ramp metering limits access to the freeway mainline so as to avoid or reduce congestion and improve efficiency of the freeway itself. The ramp meter is a set of traffic signals located on a freeway entrance ramp, usually located about halfway down the ramp. It functions exactly like a normal traffic light, cycling between red and green. This section evaluates the ramp meter system on I-71 using a probe vehicle equipped with GPS. The details of the traffic responsive ramp metering algorithms deployed in the CMFMS are proprietary to the contractor that deployed them, however, according to the ODOT engineers operating the system, the contractor has stated that the algorithms generally use conditions at the mainline loop detector station immediately downstream of the given ramp.

Probe Vehicle- Ramp Run Data

Just over half of the probe vehicle tours were the so-called travel time runs described earlier. The remaining tours followed a different route to collect data about the operation of the ramp meters. As with the travel time runs, these ramp run data are collected from a probe vehicle equipped with a GPS receiver to provide an independent measure of freeway operation. For each tour drivers run a vehicle on three round trips during the morning peak (7AM-9AM) or evening peak (4PM-6PM), Tuesday through Thursday. The ramp run is shorter than the travel time run since the ramp meters are only present in the southern half of the corridor. The data span from downtown (station 102) to Cooke Road (station 14). Drivers are instructed to normally travel in the outside lane, though they can pass slow vehicles if warranted, and to exit the freeway at many specific locations so that they can re-enter the freeway through as many ramp meters on a given pass as possible (spanning between Long St and Cooke Rd). Each run passes through a total of four ramp meters northbound and six ramp meters southbound, the study area for the ramp run data is shown in Figure 48. The GPS receiver records the location of the vehicle (longitude and latitude), and velocity every second. Figure 49 shows the number of ramp tours by month collected from the probe vehicle. The routing instructions provided to the drivers are shown in Table 3. Figure 50 shows the data from one round trip superimposed on an aerial photograph, illustrating the path of a probe vehicle collecting ramp run data. Once more, to facilitate comparisons between runs, reducing local noise from measurement errors and passing maneuvers while providing a common reference distance across all runs, each position measurement is projected to a common reference run.

As originally proposed, the ramp runs were to be compared to the metering status recorded by the CMFMS. Midway through this study it became apparent that recording the metering status from the ODOT system would take more effort than originally anticipated. As discussed below, this task was eventually accomplished, but not until the last few months of the study. When the delay in obtaining the CMFMS status became apparent, the probe vehicle drivers were instructed to record the status of all visible ramp meters as they passed them. The reports were then verified by checking the probe vehicle velocity upstream of ramp meters, looking for the presence or absence of stops on the ramp (indicating the meters were on or off, respectively).

The Status of Ramp Meters Using Ramp Run Data

Most of the ramp meter stations in the CMFMS are traffic responsive, with the metering rate set automatically depending on the mainline traffic conditions. If the mainline is congested, then the ramp meter should be on. Hence, if the mainline travel time experienced by the probe vehicle is larger than measured under normal free flow conditions, one would expect the travel time on the ramp section should also be increased. Figure 51 shows velocity verse distance from four selected runs through the meters at Long St. The analysis area is limited to the start of an on-ramp to the start of the following off-ramp, divided into three sections: on the ramp upstream of the meter, between the meter and end of ramp, and mainline between on and off ramp. Probe vehicles exhibit two patterns of velocity in upstream of a ramp meter, either the vehicle stops several times or the driver gradually increases velocity as they pass the ramp meter. Using the drivers' reports, generally the former corresponds to the meter beings on while the latter to the meter being off. It is intuitive to expect that a vehicle reduces speed and stops due to ramp meter operation. Meanwhile, the mainline condition is divided into two cases: congestion and free flow. The mean velocity of the probe vehicle over the mainline section is used to determine the presence or absence mainline congestion. If the mean velocity is less than 45 mph (72 km/h), the mainline is taken to be congested, otherwise it is taken to be free flowing. So in aggregate four different combinations are possible:

1) Meter off, Mainline free flow,

2) Meter on, Mainline free flow,

3) Meter off, Mainline congested,

4) Meter on, Mainline congested,

as illustrated in Figure 51. Both *Meter off, Mainline free flow* and *Meter on, Mainline congested* would be expected from normal ramp meter operation. *Meter on, Mainline free flow* could indicate a problem with the metering algorithm or it may simply show that the meters are successful in restricting flow enough to keep the mainline from becoming congested. In any event, *Meter off, Mainline congested* clearly indicates a fault in traffic responsive metering.

Figure 52 Tabulates the status of ramp metering and the corresponding mainline traffic conditions at Long St. for all of the ramp runs. Figure 52A shows a scatter plot of travel time upstream of the meter versus the mainline travel time. Note that mainline travel time includes all travel from the meter to the next off-ramp. Each point on the plot is coded with one of four symbols to denote which of the four conditions observed on the given run. But this scatter plot lacks a temporal component. Using the same data, Figure 52B shows the status of the ramp meter and mainline traffic condition as a function of the time of day. Ramp run data are collected in morning (AM) and evening peak times (PM). The top plot shows that on all AM runs the meter was off and mainline free flow while the lower plot shows that this state is also dominant in the PM, though the other three states are also observed. The only time of day pattern evident is that the *Meter on, Mainline free flow* state was only observed after 17:00, though this result may be due to the small number of observation. Next, to see if the condition changed from month to month or year to year, Figure 52C-D show the number of times each state was observed on a given date (the horizontal axis spans two years). Here we see that most occurrences of *Meter off, Mainline congested* happened in the first year of observation. The analysis was repeated using speed data from the mainline loop detectors immediately downstream of the ramp rather than the probe vehicle travel time, and then again using the mainline loop detectors immediately upstream of the ramp. The results using both conditions from the mainline loop speeds are similar to those presented using the probe vehicle travel time, and thus are not shown.

The analysis is repeated at the other ramp meters in the ramp tour (including the mainline speed analysis), the plots using the probe vehicle mainline travel times are included in Appendix G. Summarizing the results, Tables 4-6 show the percentage of observations in each of the four conditions.

Of the ten ramps in the ramp run tour, the Long St. meter is unique in the fact that it is the only ramp serving traffic entering directly from downtown. At the time the CMFMS was turned on there were concerns that this meter would result in congestion on the arterials feeding the ramp. To test this possibility, the ramp meter tour was laid out to provide over half a mile (0.8 km) of travel on Long St. upstream of the ramp. Only one or two percent of the days exhibited queuing upstream of the ramp due to the meter. Consulting the operators in the CMFMS, they stated that they manually override the traffic responsive metering at the Long St. ramp.

The Status of Ramp Meters Using Ramp Detector Data

Each ramp meter station has several detectors on the on-ramp for use by the traffic responsive metering algorithms, but they also provide an insight into the traffic condition on the ramp section and the status of ramp metering. There are a total of 17 ramp meter stations in Phase I of the CMFMS. Table 7 and Figure 53 show the location of the ramp metering stations. Each ramp metering station has three loop detectors embedded in the on-ramp, i.e., queue, demand, pass, at the entrance, upstream of meter and downstream of meter, respectively. Many of the stations also have a fourth loop on an adjacent off-ramp, i.e., exit. The data recorded by these sensors include volume and occupancy, aggregated every 20 seconds. Each ramp station also provides the metering rate every 20 seconds in veh/min while a metering rate of zero indicates that the ramp meter is off.

Figure 54 shows a time series of the metering rate over an entire 24-hr period on April 19, 2005 at ramp metering station 7. According to the data the meter turned on unexpectedly for several minutes early in the morning, this event will be discussed in detail below. The meter also turned on for an extended period during the evening peak. Since the status of a traffic responsive ramp meter depends on the mainline traffic conditions, we consider the metering rate in conjunction with traffic measurements at the mainline detector station immediately downstream of the ramp. In this case mainline loop detector station 4 is located immediately downstream of ramp metering station 7. One would expect the ramp meter to turn on when the mainline becomes congested or is at risk of doing so. Figure 55 shows the occupancy and speed at loop station 4, with different markers to indicate whether the meter at ramp station 7 on or off. Note that the mainline occupancy and speed are averaged across all lanes. The left column shows 5 min occupancy and 5 min speed for the entire 24hrs at mainline loop detector station 4, blue points represent measurements when meter is off, and red stars represent measurements when the meter is on. For clarity, the middle column repeats the data restricted to the samples when the meter is off and the right column repeats the data restricted to the samples when the meter is on. A few samples exhibit congested conditions in the middle column, i.e., high occupancy and low speed measurements, around 17hr while the meter is off. These points may be due to the difference of the aggregation periods, i.e., the ramp meter data is aggregated into 20 sec samples while the mainline is aggregated into 5 min samples. During the early morning metering event, however, the mainline traffic condition is clearly freely flow throughout.

Figure 56 extends the analysis to all 17 ramp metering stations on April 19, 2005. Several ramp metering stations show that the meter turns on in the early morning, e.g., ramp station 2, 5, 7, 11, 12, 13, 14, and 16. The range of reported metering rates is between 10 veh/min and 20 veh/min at most stations. However, ramp station 5 reports a metering rate over 90 veh/min (5400 veh/hr), well over the capacity of a freeway lane. For this study, it is assumed that it is not reasonable to have a metering rate over 30 veh/min, corresponding to a maximum ramp flow 1800 veh/hour.

Figure 57 shows metering rate by date versus time of day at meter station 5. The figure shows March 28, 2005 (0328) to May 5, 2005 (0505). Each row shows the data from one date and the magnitude of the metering rate is distinguished with green, blue or red as follows:

Blank: meter off

Light gray: 0 veh/min< metering rate ≤ 15 veh/min

Medium gray: 15 veh/min< metering rate ≤ 30 veh/min

Dark gray: metering rate >30 veh/min

The meter turns on most weekdays between 16hr and 18hr in response to the evening peak. It also turns on a few times for non-recurring events, e.g., around noon on 0423. An unreasonably high metering rate is observed near midnight on weekdays, as was seen in Figure 56. This late night operation is presumed to be an error of the system. Also worth noting, the time of occurrence for the late night operation shifts an hour later after the start of Daylight Savings Time, i.e., the source of the error does not adjust for Daylight Savings. Figure 58 shows the shows metering rate by date versus time of day at all 17 metering stations. Seven stations exhibit the late night operation on weekdays, i.e., stations 2, 5, 7, 11, 12, 13, and 14, while one station exhibits this operation every day of the week, i.e., station 16. In all cases the error shifts an hour ahead with the start of Daylight Savings, but in five cases it eventually shifts back, i.e., stations 7, 11, 12, 13, and 14. The date of the recovery is different at each station, suggesting something changed in the field rather than at the traffic management center. At last report ODOT was investigating the source of the systemic late night operation.

Nine stations appear to respond to recurring congestion, with metering starting around the same time on most weekdays. All of the stations except 1 and 6 appear to respond to non-recurring congestion at some point during the study period. Stations 1 and 3 appear to have fixed time metering, as confirmed by ODOT. According to the data, however, the fixed time metering did not adjust for Daylight Savings, with the start and end times shifting an hour later in April. This problem appears to be corrected in the most recent data, although care should be taken in the future to make sure that the system correctly adjusts for Daylight Savings Time.

Before and After the CMFMS

In early 2001 Wilbur Smith Associates conducted a study of conditions on I-71 [2]. The report includes peak hour travel times between 5th Ave and Morse Rd, collected from a floating car over a two week period. The study collected roughly 20 runs in each direction during the morning peak period and again during the peak period. Figures 59 and 60 compare these data from before the CMFMS was turned on against the over 350 round trips collected in this study after the CMFMS was turned on (see Table 8 for the number of runs used in this comparison). The present study covers a much longer stretch of I-71, and the data have been divided into groups corresponding to before the I-670 closure, during the I-670 closer and after I-670 reopens. In Figure 59, the northbound speeds during all three of the after periods in the AM peak are all above the before study by 2-5 mph (3-8 km/h). This direction is away from the dominant AM flow, i.e., away from the central business district (CBD), the direction of travel is from left to right in this figure. In the PM peak, when northbound traffic becomes the dominant flow, the results are more ambiguous. The data reported in the body of the before study do not agree with the data reported in the appendix of the before study. As a result, both curves are shown on the PM plot. Unfortunately, for many links the two sets of before data completely span all three of the after data sets. In either case, the results between 5th Ave and 17th Ave are surprising, with the before speeds exceeding all three of the after speeds. Recall that there is a lane drop at 11th Ave resulting in a bottleneck and queued traffic upstream. This pattern is evident in both of the after data sets while I-670 is open, speeds slowly increase as one approaches the bottleneck. During the I-670 closure the demand is limited far upstream of this location and the bottleneck is rarely active. So the I-670 closure should exhibit the highest speeds across all of the data sets, yet it still falls below both of the before data sets. This unexpected discrepancy may be due to the relatively small size of the before sample, collected over only two weeks. It may also be due to differing criteria, e.g., our drivers were instructed to travel in lane 2, second from the median while it is unclear which lane the before data came from. If one compares I-670 open (collected during the first few months that the CMFMS was in operation) against the I-670 reopened, one sees a slight decline in speeds on the roadway over time. The demand on the facility has exhibited a slow steady climb over time. There is little opportunity to control conditions in the northbound direction. Most of the PM demand comes from the CBD during the peak period and one would have to meter Long St. and other CBD ramps at low rates to prevent the bottleneck at 11th Ave from becoming active.

Figure 60 shows similar results are evident in the southbound direction, though in this figure traffic moves from right to left. In the AM when this direction experiences the dominant flow, the before study data fall about 10 mph (16 km/h) higher than the after data. Once more there is a discrepancy between the body and appendix of the before study, so both curves are shown on the AM plot. Again it is believed that the discrepancy between the before and after data is due at least in part to the vehicles traveling in different lanes in the two studies. In any event, looking at the three sets of after data, almost all links show that conditions improve on I-71 between I-670 open and I-670 reopened even though demand has slowly increased. It is believed this outcome arises from the fact that most of the controls on I-71 can influence the southbound traffic. Finally, the PM southbound peak travel is similar between the before study and after study, with the only differences being on the first and last links (most likely due to the before vehicles entering or exiting the freeway, respectively).

The before study also presents traffic volume data from ODOT on I-71 between 5th Ave and I-270. For the links that have this before data, these reference volumes are shown on the weekly median ADT plots in Appendix F. Relative to this before sample, almost all links exhibit a higher demand after the CMFMS was turned on.

Closing and Conclusions

This research examined the performance of the first phase of the CMFMS. We first examined the performance of the detectors to validate that they are operating correctly, this calibration task is necessary for any traffic monitoring system. Many of the tools developed in this work are applicable to other traffic monitoring systems. For example, we were able to correct for loop sensitivity errors at single loop detectors and spacing errors at dual loop detectors. Careful evaluation of the data also revealed a few detector mapping errors.

The work then shifted attention to the operation of the CMFMS as a whole. We developed many different ways to graphically mine historical data from the system. One of the fundamental tools is our so-called summary plot, showing the evolution of speed over time and space. This plot shows queues growing and shrinking in response both to recurring and non-recurring congestion. It also shows many system failures that prevent data measurement at one or more stations. Taking the difference between a specific day and some average of several days can highlight non-recurring events. In either case, once comfortable with these plots, one can easily review conditions from an entire month on a single sheet of paper. Related to the summary plots and the underlying speed data, the research also examined several measures to capture travel time conditions experienced by travelers. After validation, once one can measure travel time it is a simple task to measure and quantify delay. Naturally, care must be taken to ensure that any speeding vehicles or detector errors do not result in negative delay. This delay and ADT were used to evaluate the system at each detector station. Ordinarily one would expect to see variation from day to day as well as a difference between weekday and weekend conditions. This variability makes it difficult to interpret a plot of time series data more than a few weeks long. To address this problem, we used the conceptually simple weekly median filter to clearly show conditions from each week over three years. Once more, care must be taken to differentiate between changes due to detectors being down and changes due to travel patterns, as was done in the body of this work. These measures clearly reflected the impact of I-670 closing for rebuilding and then reopening over a year later. Next, attention shifted to the operation of the ramp meters. Several problems were identified, the largest being the presence of mainline congestion while the adjacent meter remains off. Finally, comparisons were made between travel speeds and volumes before and after the CMFMS was turned on.

Lessons Learned

Many valuable lessons were learned in the course of this research, briefly reviewing several of them,

- This work developed a methodology for evaluating phase I of the CMFMS that can immediately be transferred to phase II or other FMSs.

- Considerable information can be extracted from the data stream on the health and performance of the system. Several problems were diagnosed from the data that were concurrently found or verified through extensive field visits, e.g., the detector mapping problems, while other problems were only identified with the data, e.g., detector sensitivity and spacing correction factors. These correction factors should be applied immediately to improve the performance of the system.

- Other problems became evident in our supplemental data collection, e.g., the ramp meters being off even though the main line was congested. So some system fine-tuning is necessary.

- Many of the diagnostics were feasible only because of the fine temporal resolution of the data. Although most current off-line applications do not utilize such high resolution data, given the steady decrease in data storage costs it would be wise to collect and archive the data at the highest resolution possible (e.g., we can store an entire year of event data for under $1,000). Without such archival activities, future applications will similarly be limited to lower resolution data.

- Finally, we believe that it would be of benefit for ODOT to develop the skills either in house or collaboratively with other agencies to conduct these evaluations on a continuing basis, and in the process, develop even more powerful diagnostic tools.

References

[1] Ontario Ministry of Transportation, Freeway Traffic Management Systems web page http://www.mto.gov.on.ca/english/traveller/compass/systems/, accessed on December 1, 2005.

[2] Wilbur Smith Associates, *Framework for Benefit Evaluation of Columbus Metropolitan Freeway Management System, Final Report*, 2001.

[3] Coifman, B., Dhoorjaty, S., Lee, Z. "Estimating Median Velocity Instead of Mean Velocity at Single Loop Detectors", *Transportation Research: Part C*, vol 11, no 3-4, 2003, pp 211-222.

[4] Jain, M., Coifman, B., "Improved Speed Estimates from Freeway Traffic Detectors" *ASCE Journal of Transportation Engineering*, Vol 131, No 7, 2005, pp483-495.

[5] Coifman, B. "Estimating Travel Times and Vehicle Trajectories on Freeways Using Dual Loop Detectors", *Transportation Research: Part A*, vol 36, no 4, 2002, pp. 351-364.

[6] Coifman, B., Cassidy, M. "Vehicle Reidentification and Travel Time Measurement on Congested Freeways", Transportation Research: Part A, vol 36, no 10, 2002, pp. 899-917.

[7] Coifman, B. "Identifying the Onset of Congestion Rapidly with Existing Traffic Detectors", Transportation Research: Part A, vol 37, no 3, 2003, pp. 277-291.

Table 1 Travel Time Run Driving Directions for each tour:

1. Exit the Center for Automotive Research (CAR, OSU campus), go to Kenny, Get on 315 at Lane Ave interchange
2. 315 south - Stay in left hand lane
3. 71 north - Stay one lane over from leftmost lane (please try to be consistent from one run to the next as to where you change lanes)
4. Polaris Exit - Turn around
5. 71 south - Stay one lane over from leftmost lane
6. At 70/71/315 split, head south on 71 and turn around at first exit, Greenlawn Ave (if legal, otherwise continue to Frank Rd and turn there).
7. Return on I71 and do a second loop to Polaris, repeating steps 3-5.
8. 315 north - Stay in left hand lane
9. CAR - Exit 315 at Lane Ave, take quickest route to CAR
10. You may pass slow moving vehicles as necessary, but try to move with the traffic in lane 2.
11. To the extent possible, note the state of all observed meters and the time you pass (it is fine if you miss a few, just make sure it is clear which ones were "off" and which ones were missed in your report).
12. On your southbound trips, note the time or other message displayed on the CMS by the fairgrounds (again to the extent possible).
13. Please also note the weather conditions or anything else that might impact traffic.

Table 2 New detector mapping based on a plot of pulses, the contents of each cell reflect the lane assignment in use at the time of data collection.

Station / Lane	St 102(NB)		St 102(SB)		St 105(NB)	
	U/S	D/S	U/S	D/S	U/S	D/S
Lane 1	u/s 1	d/s 1	u/s 1	u/s 2	u/s 2	d/s 1
Lane 2	d/s 2	u/s 2	d/s 1	d/s 2	u/s 1	d/s 2
Lane 3	u/s 3	d/s 3	u/s 3	d/s 3	u/s 3	u/s 4
Lane 4	-	-	-	-	d/s 4	d/s 3

Table 3, Ramp Meter Run Driving Directions for each tour:

1. Starting at Center for Automotive Research (CAR, OSU campus), on Kinnear Road, take Kinnear to Kenny, take a right on Kenny to Lane. Take a right on Lane and enter 315 South (on the right).
2. Take 315 South to 70 East.
3. Take 70 East to 71 North. On 71 North get off at the Broad Street exit.
4. Take a left on Broad Street. Take a right on 4th St.. Take 4th St. to Long St.
5. Take a right on Long Street to 71 North. Enter 71 going north.
6. Make a mental note of the status of the ramp meter (on/off) and write it down when you come to a stop, repeat for all other meters.
7. Now on 71 going north exit at 11th Avenue. Reenter at 11th Avenue going north.
8. Exit and reenter at the 17th Avenue and Hudson Avenue exits.
9. Continue north on 71 to Cooke Road (skip Weber and N. Broadway when going north). At Cooke Road exit and turn left to reenter 71 going south.
10. Exit and reenter 71 going south at N. Broadway, Weber, Hudson, 17th and 5th (skip 11th when going south).
11. After reentering 71 South at 5th Avenue continue to Broad St., exit and reenter 71.
12. Exit freeway immediately at Main St, go straight across Main to Rich St., head west to 4th St., turn right to Long St.
13. Take a right on Long Street and take Long to the 71 North entrance.
14. Repeat this run through the exits and entrances (steps 6-12) two more times. Upon reaching Broad St. southbound for the third time, continue south on 71. Take the 70 West split to 315 North. Exit at Lane Avenue.
15. Take a left on Lane and travel Lane to Kenny. Take a left on Kenny and travel Kenny to Kinnear. Take a left on Kinnear and return to the CAR.

Table 4, Percentage of observation in each of condition

Direction	Section	Meter on, ML Cong.	Meter off, ML FF	Meter off, ML Cong.	Meter on, ML FF
NB	Long St	18%	76%	4%	3%
	11th Ave	2%	91%	7%	0%
	17th Ave	1%	90%	7%	2%
	Hudson St	1%	84%	15%	1%
SB	Cook Rd	3%	88%	7%	2%
	E. North Broadway	10%	88%	1%	1%
	Weber Rd	4%	93%	3%	0%
	Hudson St	5%	87%	5%	3%
	17th Ave	0%	88%	12%	0%
	5th Ave	0%	92%	8%	0%

Table 5, Percentage of observation in each of condition during morning peak

Direction	Section	Meter on, ML Cong.	Meter off, ML FF	Meter off, ML Cong.	Meter on, ML FF
NB	Long St	0%	100%	0%	0%
	11th Ave	0%	99%	1%	0%
	17th Ave	0%	99%	1%	0%
	Hudson St	0%	99%	1%	0%
SB	Cook Rd	10%	69%	17%	4%
	E. North Broadway	30%	68%	2%	0%
	Weber Rd	12%	80%	7%	1%
	Hudson St	11%	68%	13%	8%
	17th Ave	0%	80%	20%	0%
	5th Ave	0%	96%	4%	0%

Table 6, Percentage of observation in each of condition during evening peak

Direction	Section	Meter on, ML Cong.	Meter off, ML FF	Meter off, ML Cong.	Meter on, ML FF
NB	Long St	28%	62%	6%	4%
	11th Ave	3%	86%	11%	0%
	17th Ave	2%	85%	10%	3%
	Hudson St	1%	76%	22%	2%
SB	Cook Rd	0%	98%	1%	1%
	E. North Broadway	0%	99%	1%	1%
	Weber Rd	0%	99%	1%	0%
	Hudson St	2%	96%	2%	0%
	17th Ave	1%	92%	7%	0%
	5th Ave	0%	90%	10%	0%

Table 7, Locations and ramp detector stations

Ramp station #	Location	Ramp station #	Location	Ramp station #	Location
1	Mound St (WB)	7	5th St (NB)	13	Weber Rd (SB)
2	3rd St (WB)	8	11th Ave (NB)	14	E.N.Broad St (SB)
3	Main St (SB)	9	17th Ave (SB)	15	Cook Rd (SB)
4	Broad St (NB)	10	17th Ave (NB)	16	Morse Rd (SB)
5	Long St (NB)	11	Hudson St (SB)	17	Sinclair Rd (SB)
6	5th St (SB)	12	Hudson St (NB)	-	-

Table 8, Sample size by category for travel time comparison:

Event on I-270	Northbound		Southbound	
	AM	PM	AM	PM
I-670 open	9	13	9	13
I-670 closed	51	66	51	66
I-670 reopen	114	112	114	112
Sum of data	174	191	174	191

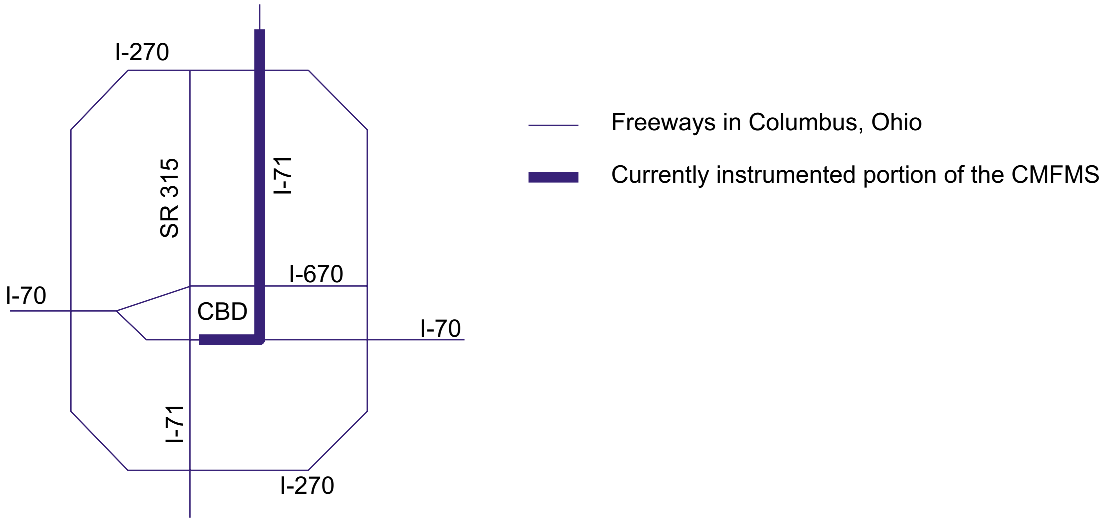


Figure 1, Map of the freeway system in Columbus, OH showing the 14 miles of instrumented facility stretching north from the central business district (CBD)

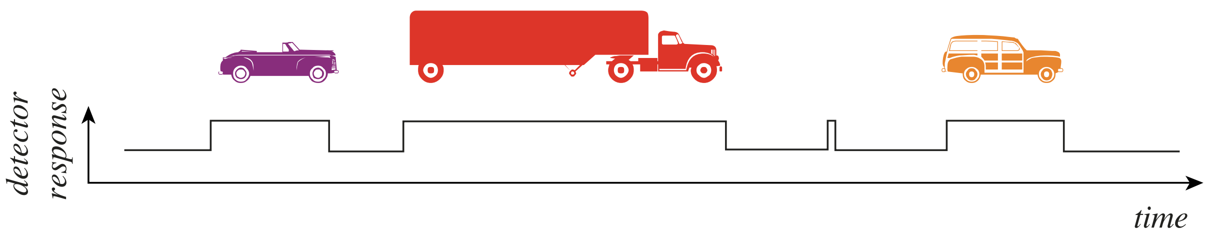


Figure 2, A hypothetical example showing the detector response to three successive vehicles and one erroneous-detection.

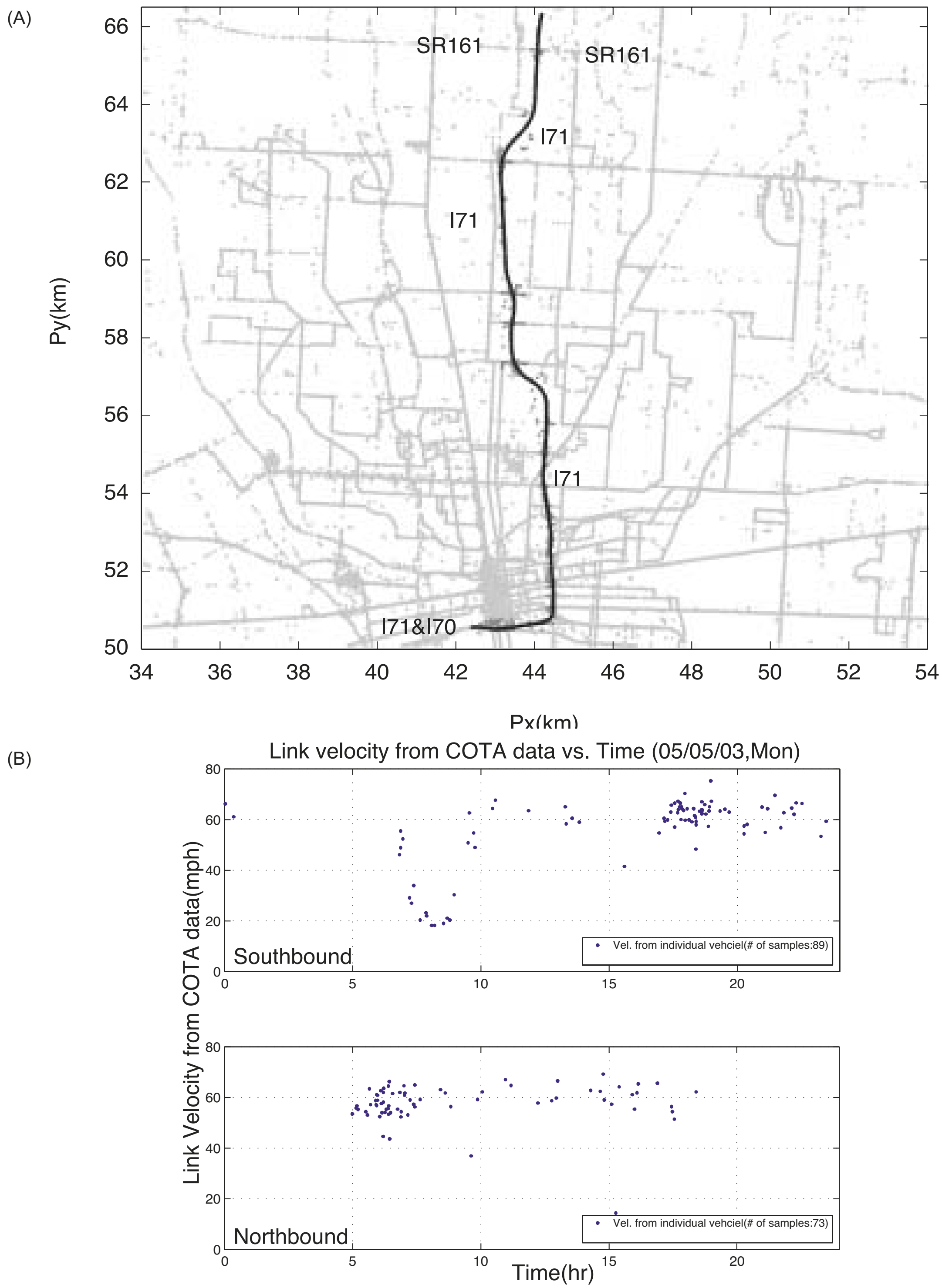


Figure 3, (A) Five days of COTA AVL data, roughly centered on the I-71 corridor running vertically through this plot. (B) Time series link velocity recorded by COTA vehicles on the I-71 corridor in one day.

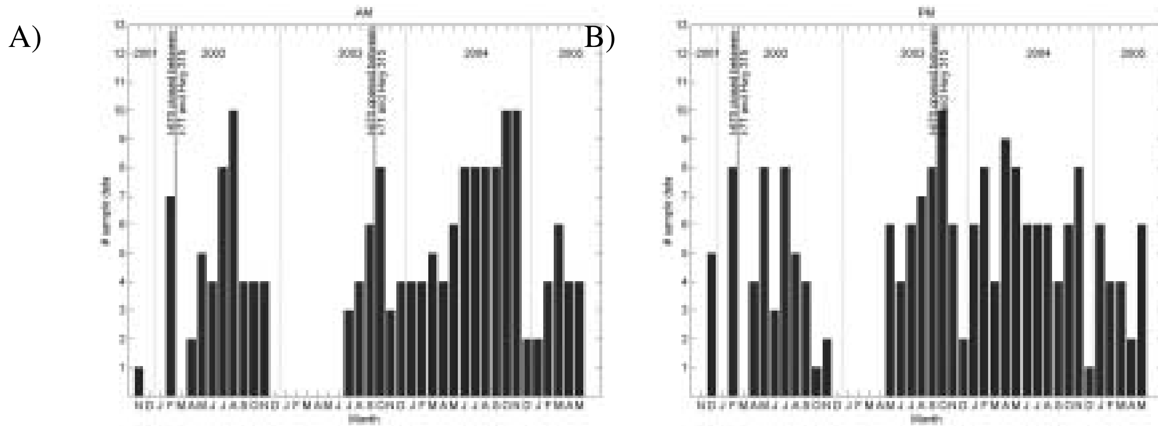


Figure 4, The number of travel time tours by month (A) AM (7hr to 9hr), (B) PM (16hr to 18hr). Each entry corresponds to two round trips, i.e., two travel measurements.

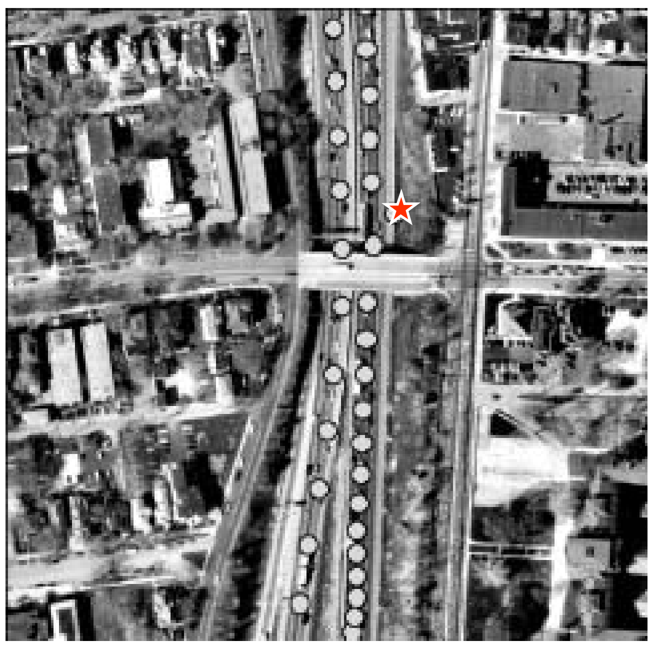


Figure 5, GPS position error from travel run data, highlighted with a star.

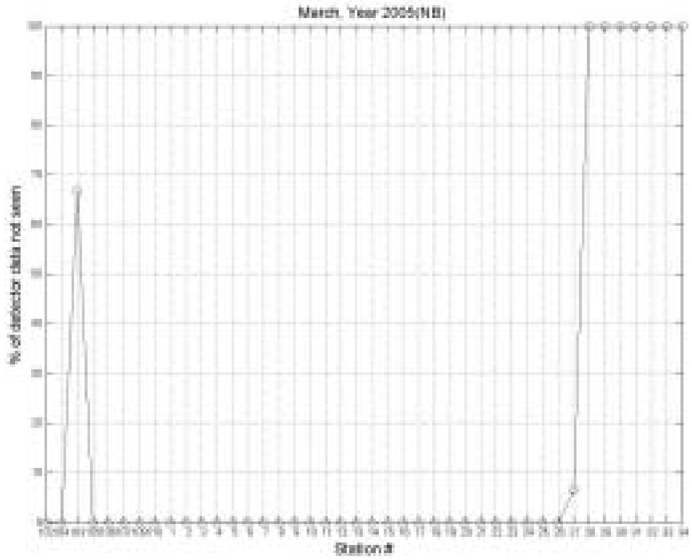


Figure 6, The operational status of the detectors in August 2003 in the northbound direction. The percentage of detectors not reporting is shown on the vertical axis, and the station number is shown on the horizontal axis.

Figure 7A, Monthly operational detectors in calendar format (Northbound, January to June)

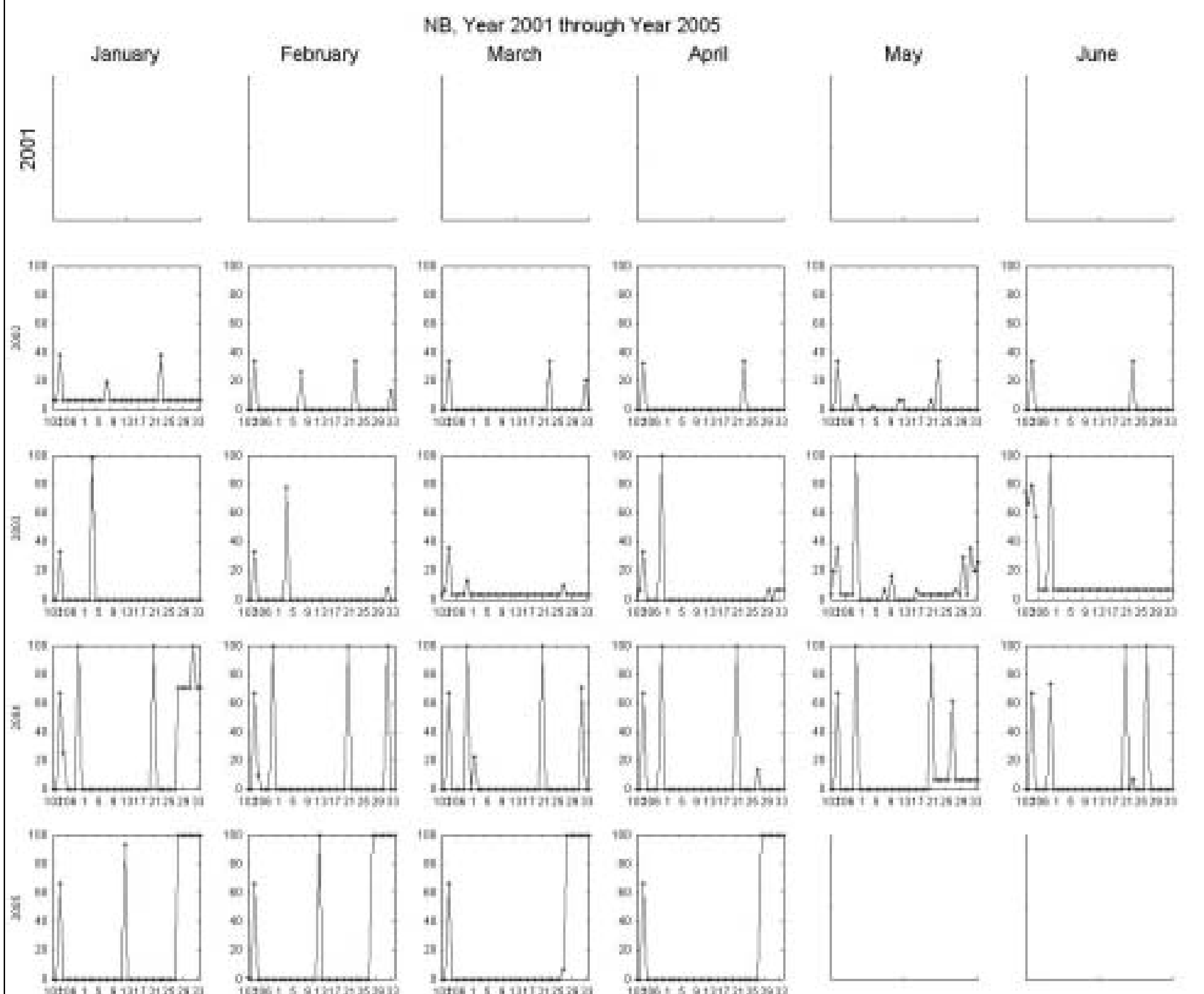


Figure 7B, Monthly operational detectors in calendar format (Northbound, July to December)

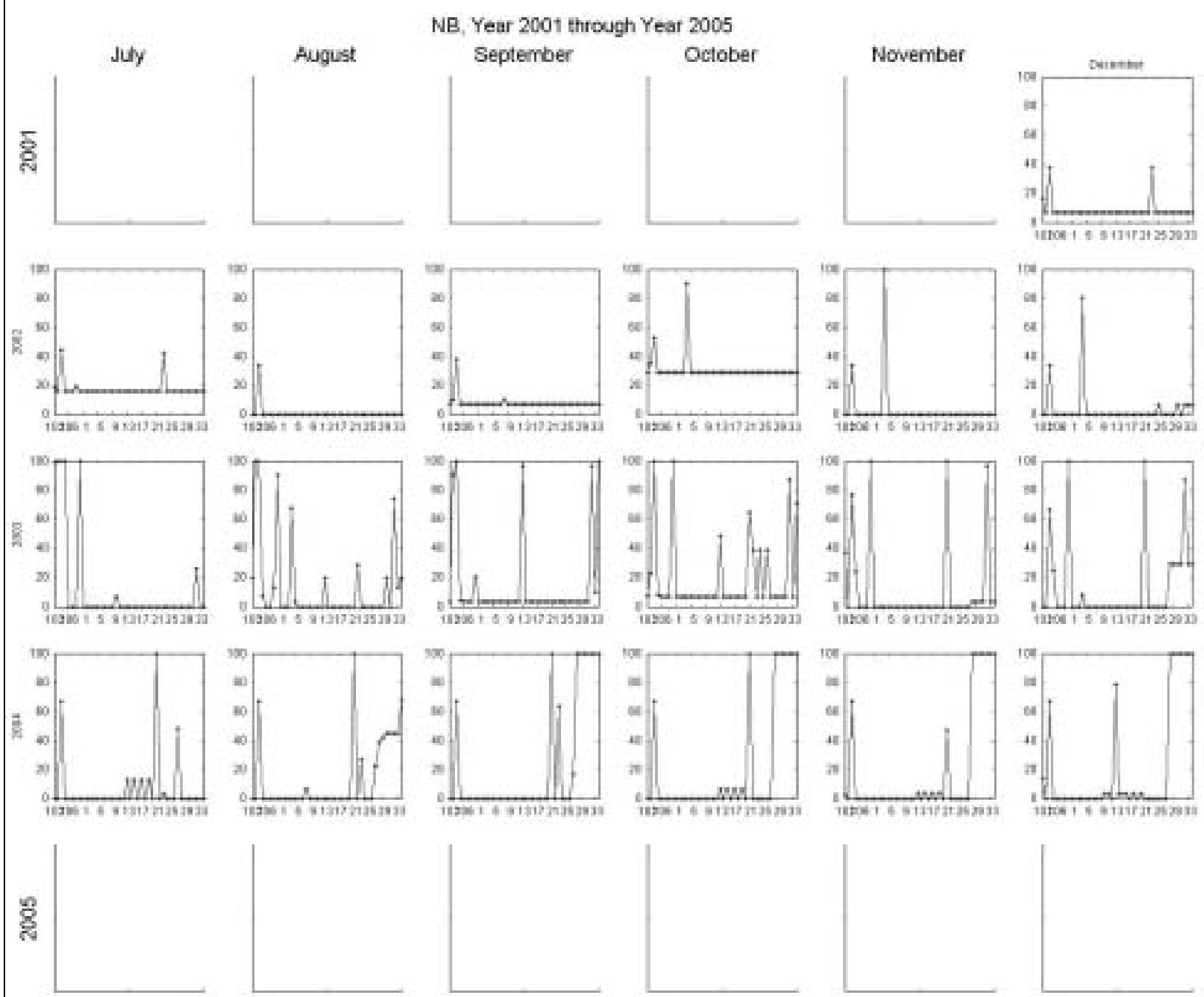


Figure 7C, Monthly operational detectors in calendar format (Southbound, January to June)

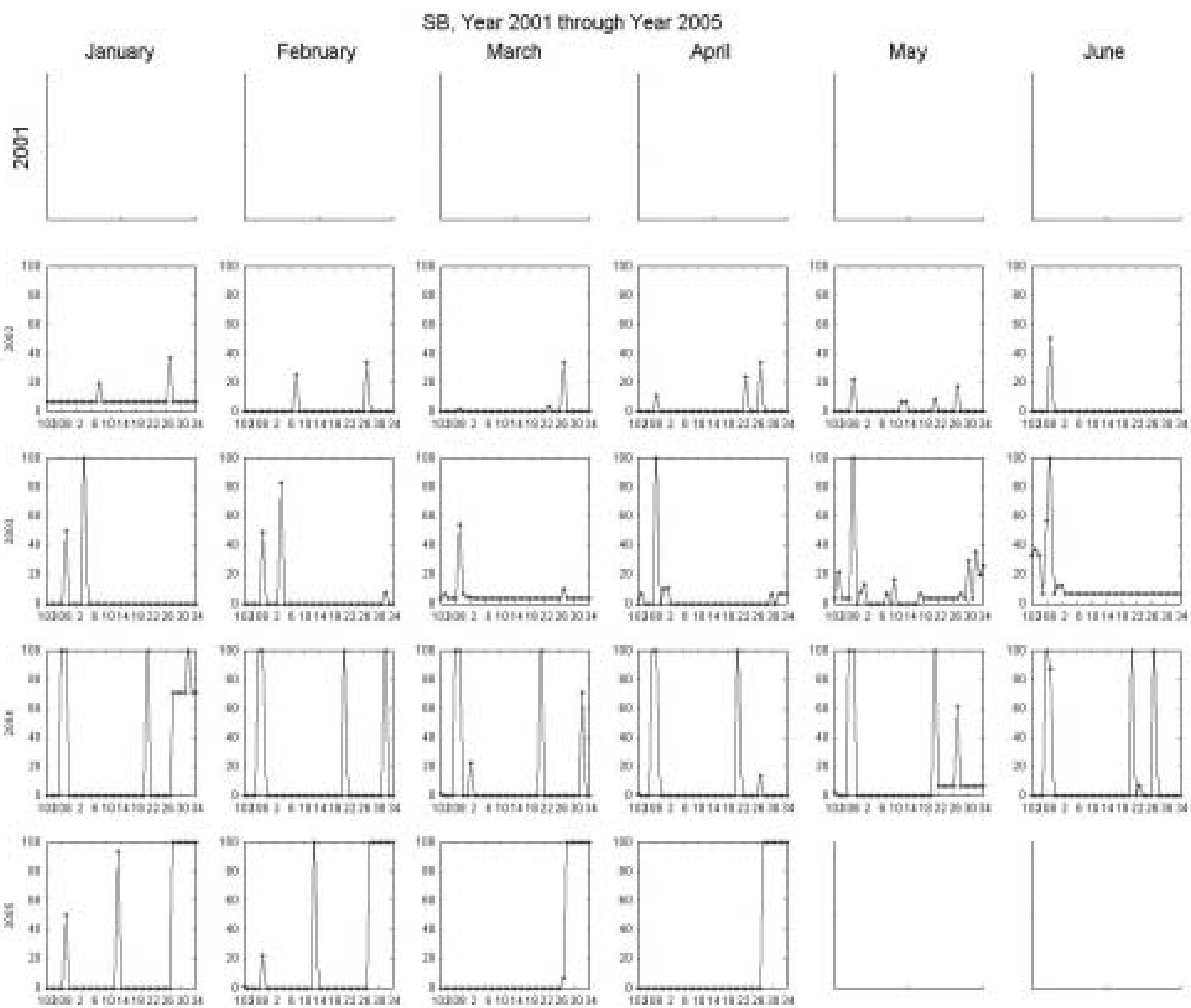
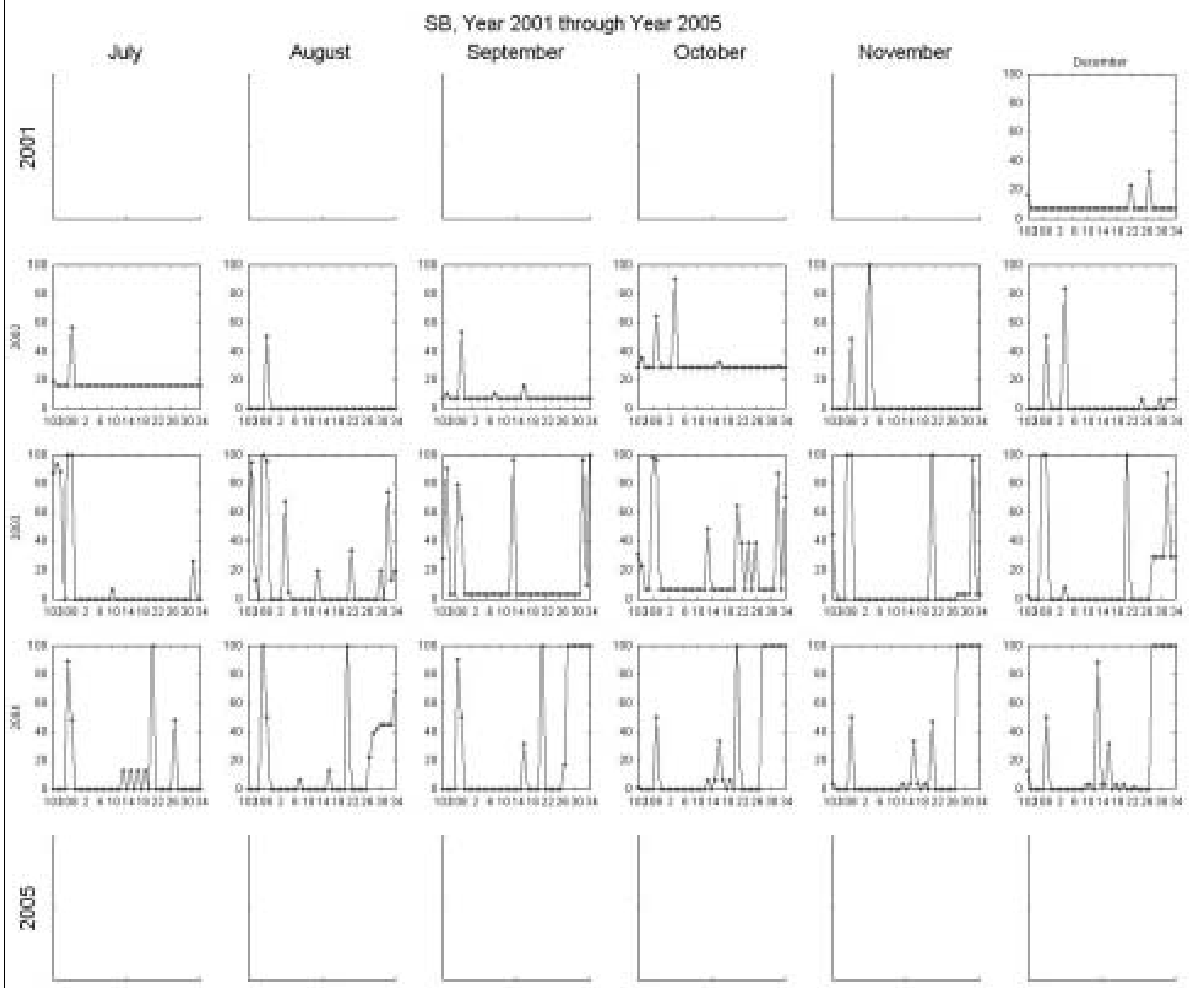


Figure 7D, Monthly operational detectors in calendar format (Southbound, July to



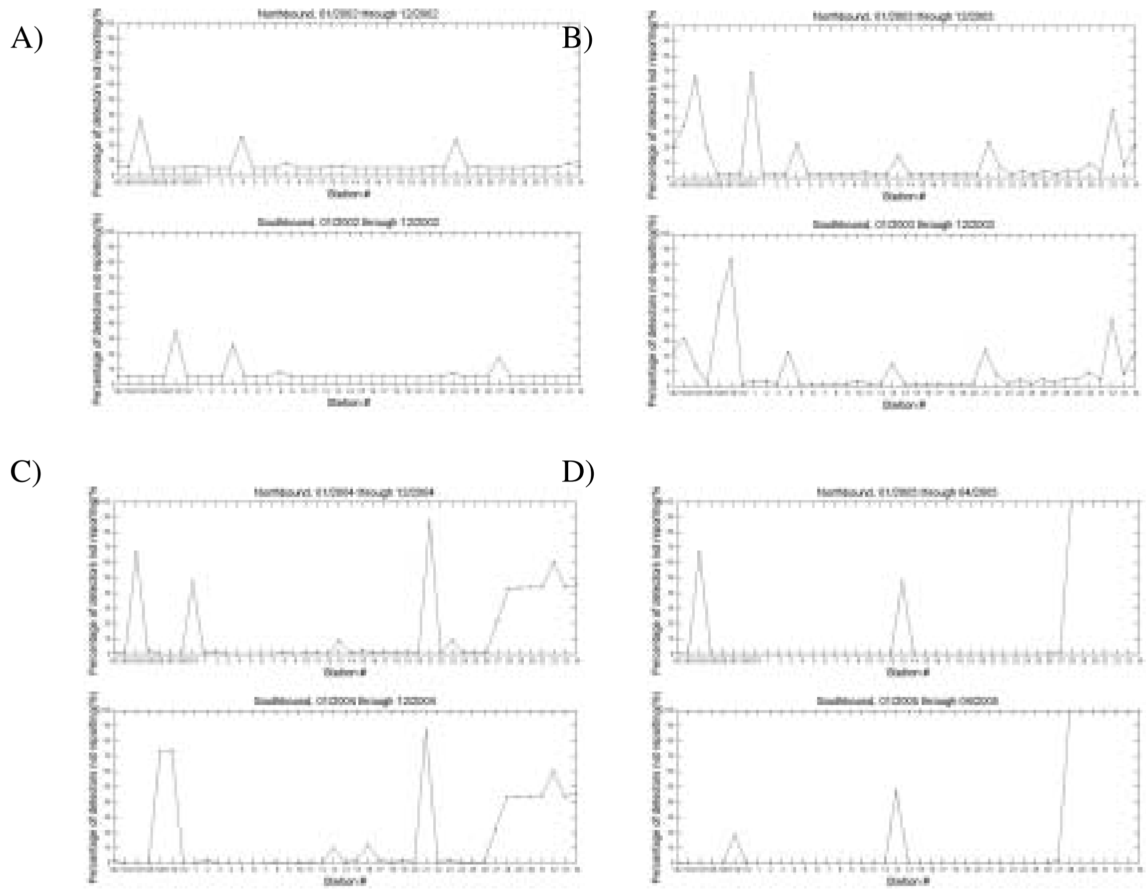


Figure 8, Yearly operational detectors over all stations. In each pair of plots the top plot shows northbound, and bottom shows southbound for each year plot. Note results for year 2005 only include the first four months.

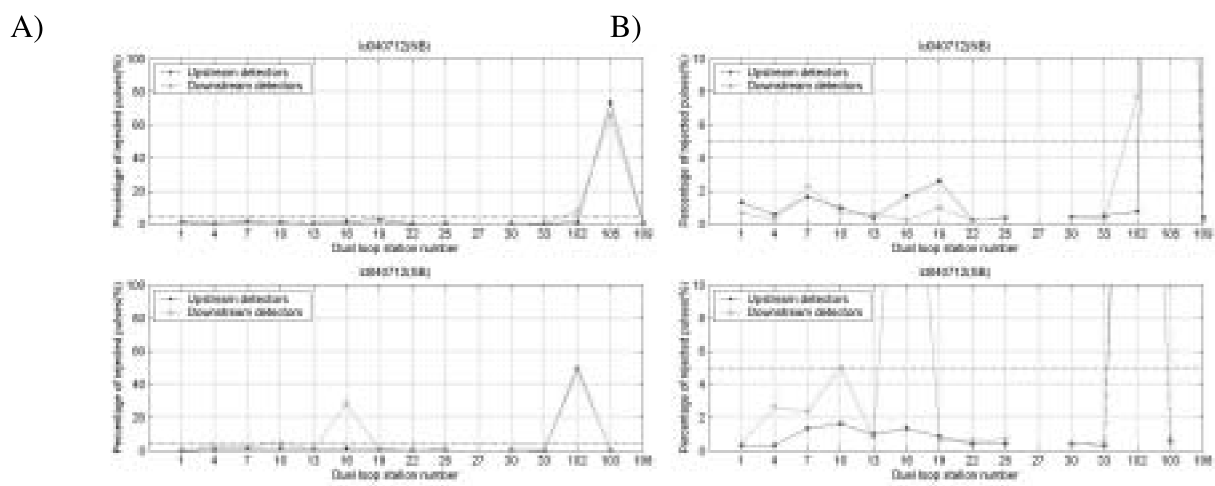


Figure 9, Total percentage of unmatched pulses at each loop at the 15 dual loop stations. Top plots show northbound, bottom show southbound. The left column shows the results on the large vertical scales while the right column zooms in on the same plots.

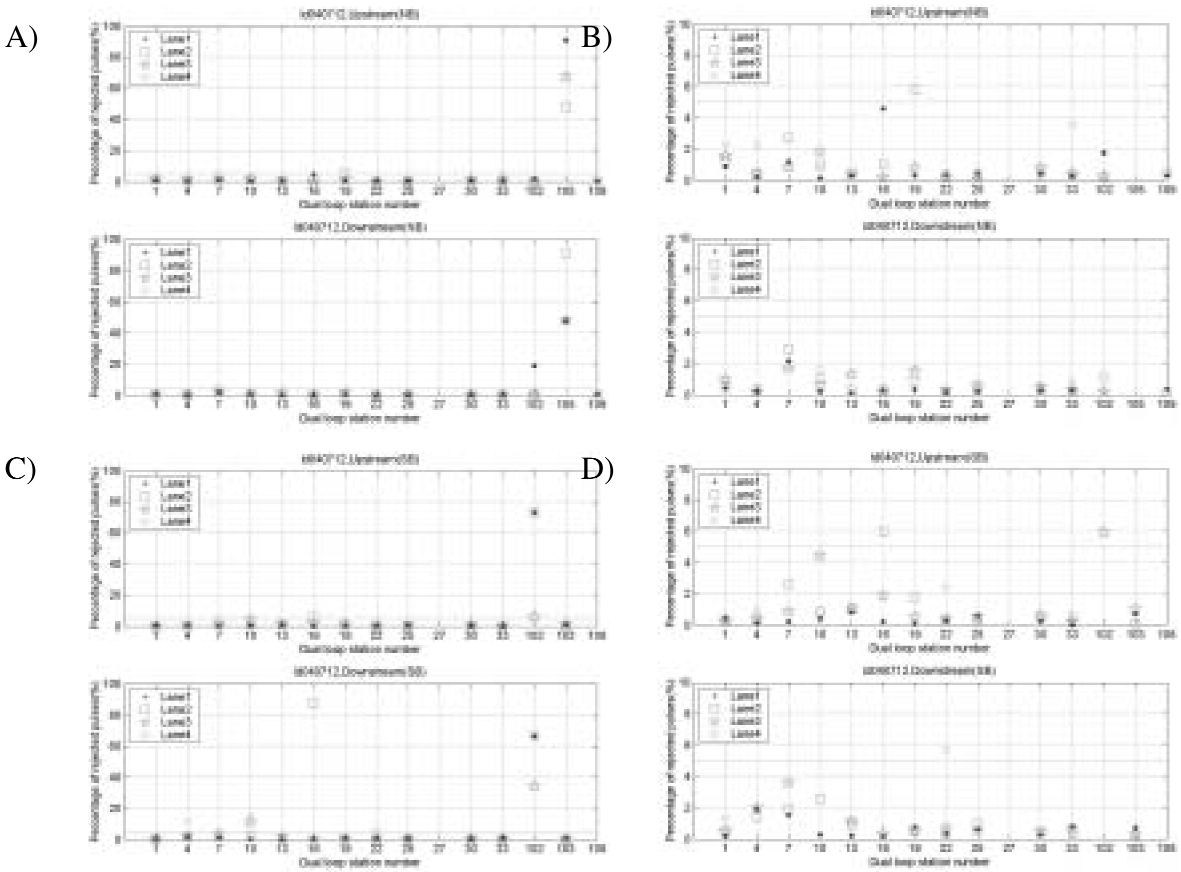


Figure 10, Total percentage of unmatched pulses in each loop for both directions, respectively. In each pair of plots the top plots show upstream loop detectors, bottom shows downstream loop detector for each direction. The left column shows the results on a large scale while the right column shows details of the same data.

A) B)

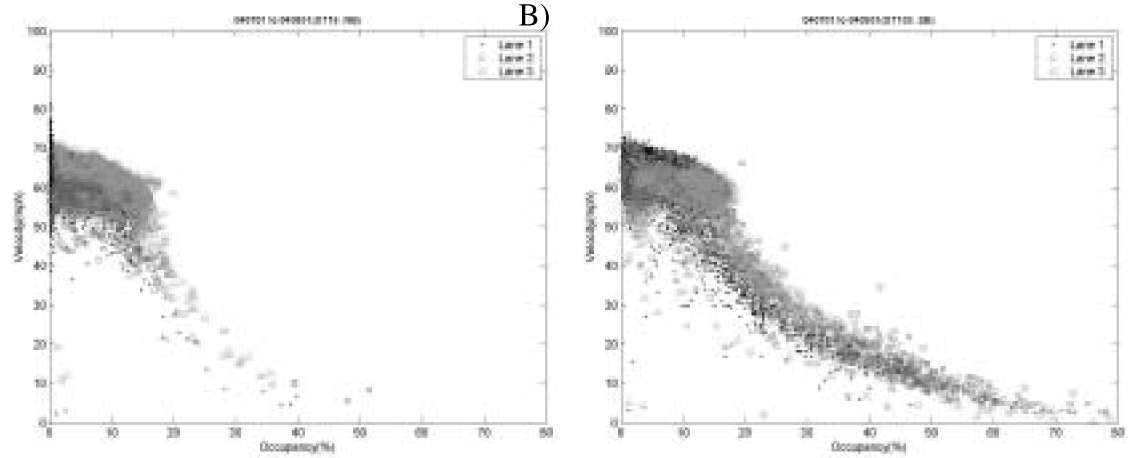


Figure 11, Examples of the expected relationship between speed and occupancy A) Station 16 northbound, B) Station 103 southbound.

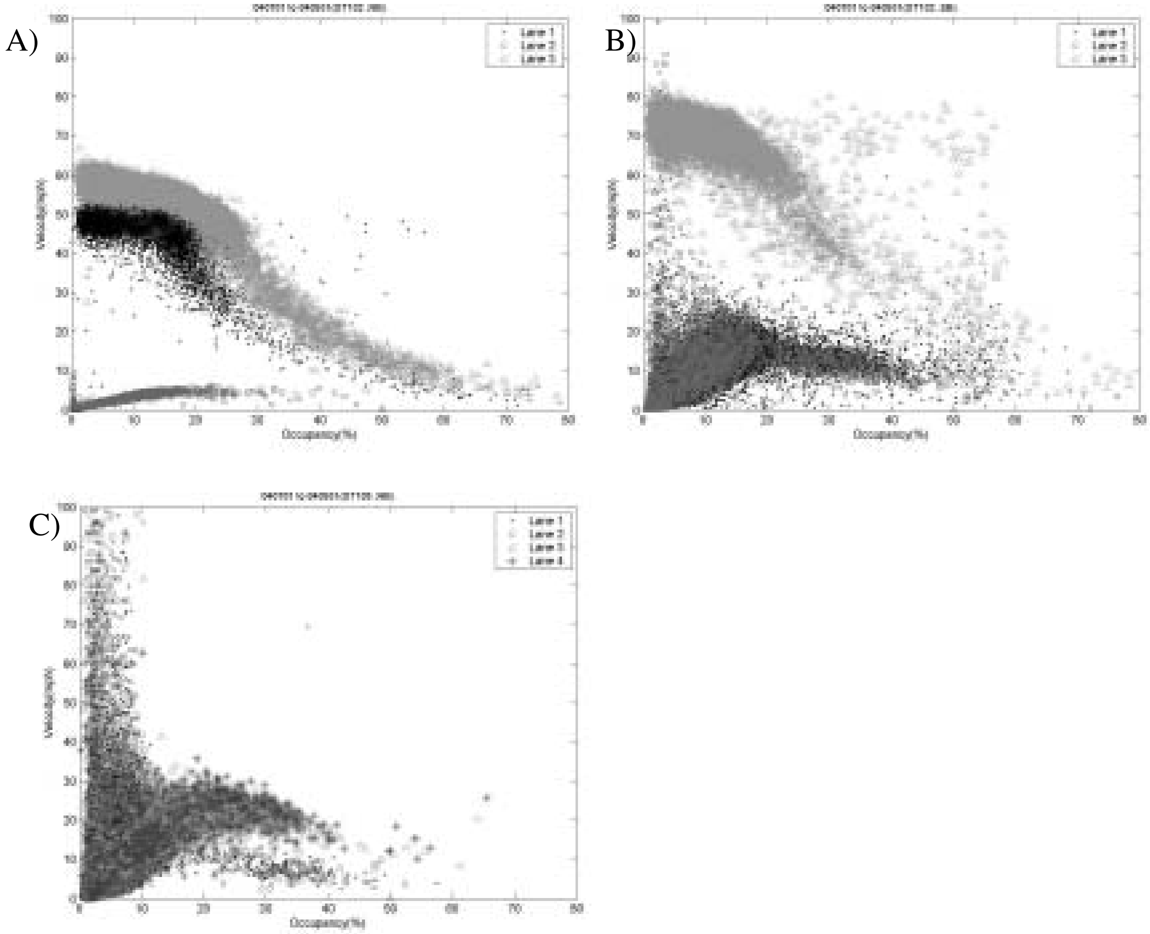


Figure 12, Anomalous relationship of speed and occupancy A) Station 102 northbound, B) Station 102 southbound, C) Station 105 northbound.

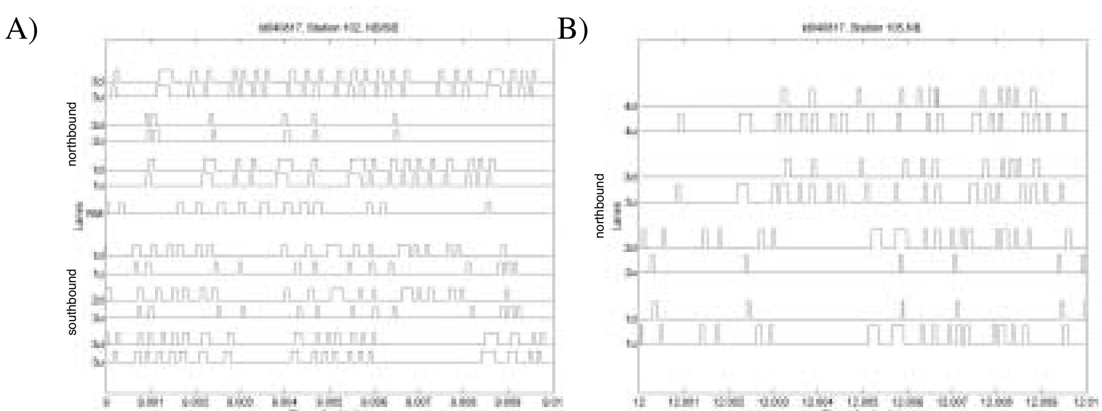


Figure 13, Plots of transition pulses for a short time period A) Station 102 for both directions, B) Station 105 northbound

A) B)

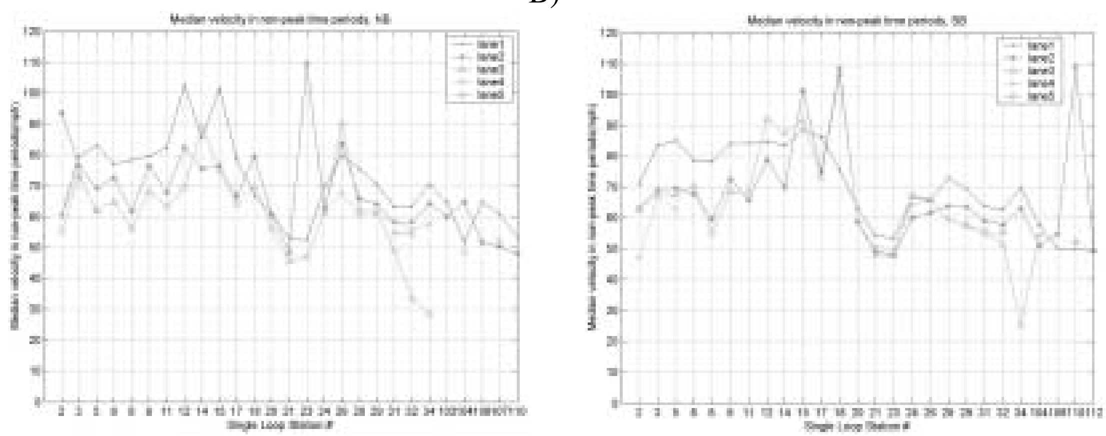


Figure 14, Median speeds in non-peak time periods at single loop detectors A) Northbound direction, B) Southbound direction.

A) B)

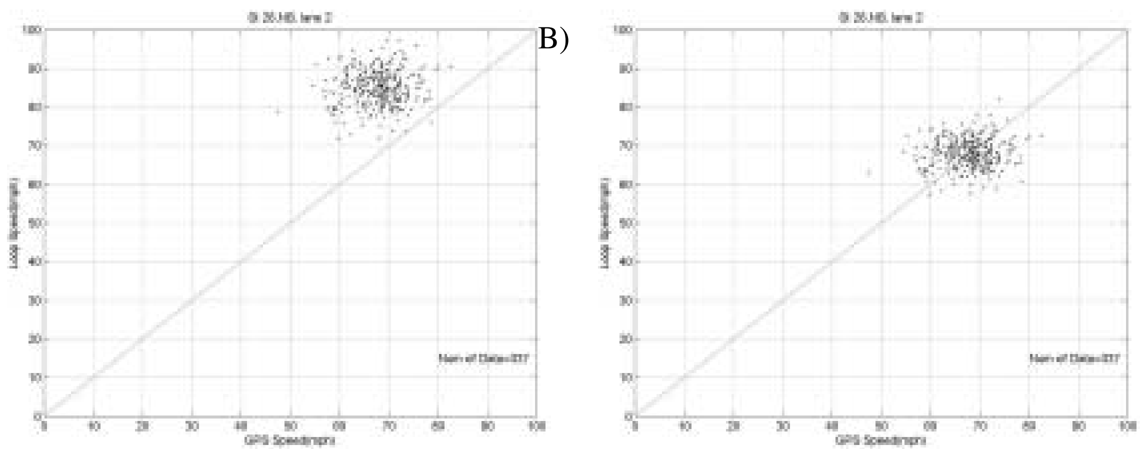


Figure 15, Comparison between loop speed and GPS velocity at station 26, lane 2. The left column shows that loop speed is higher than GPS velocity, i.e., loop speed overestimated. The right column shows the difference of loop speed and GPS speed is within 10mph, and unbiased after applying the correction factor.

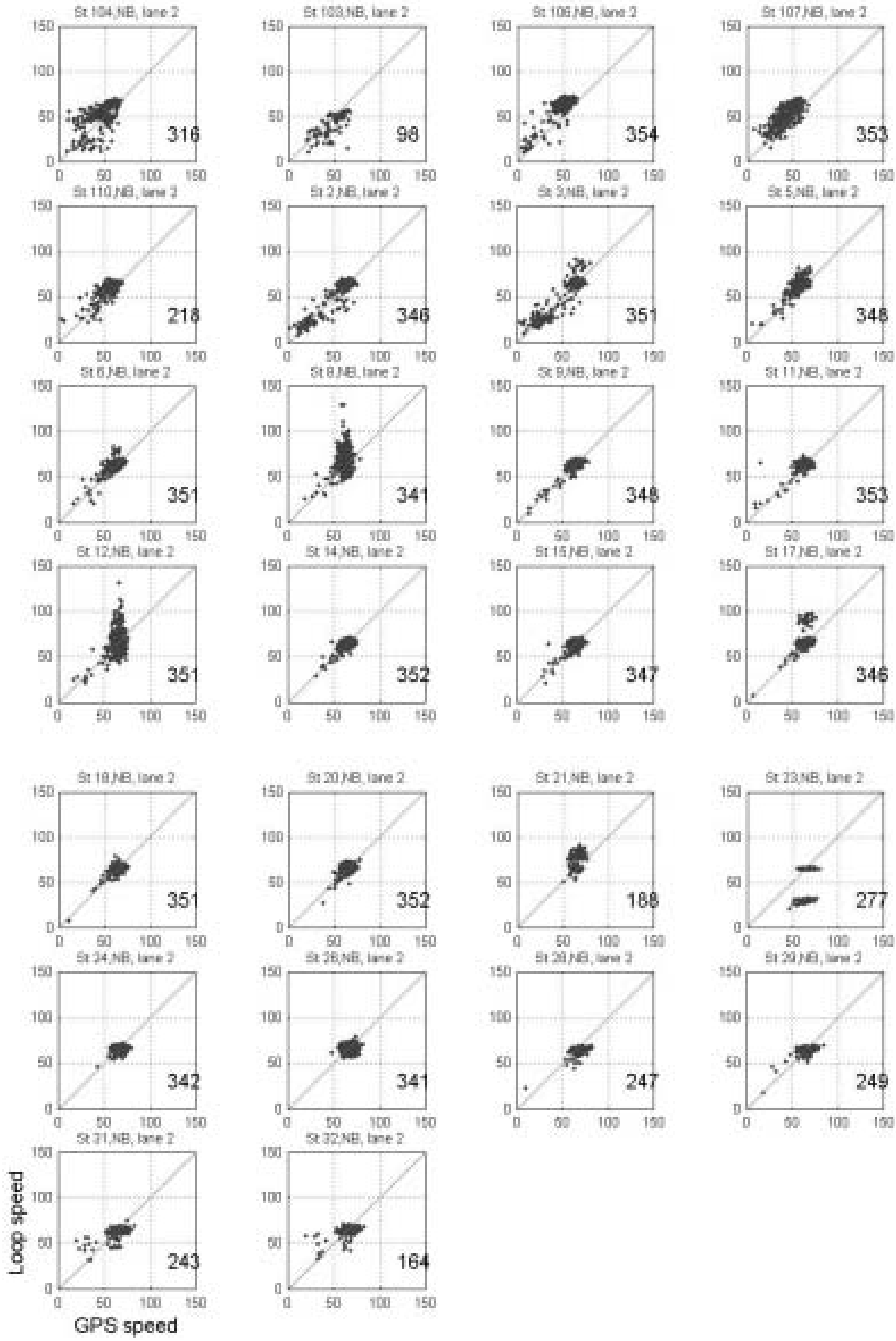


Figure 16, Comparison between single loop speed measurements incorporating correction factors and concurrent probe vehicle velocity measurements for northbound single loops.

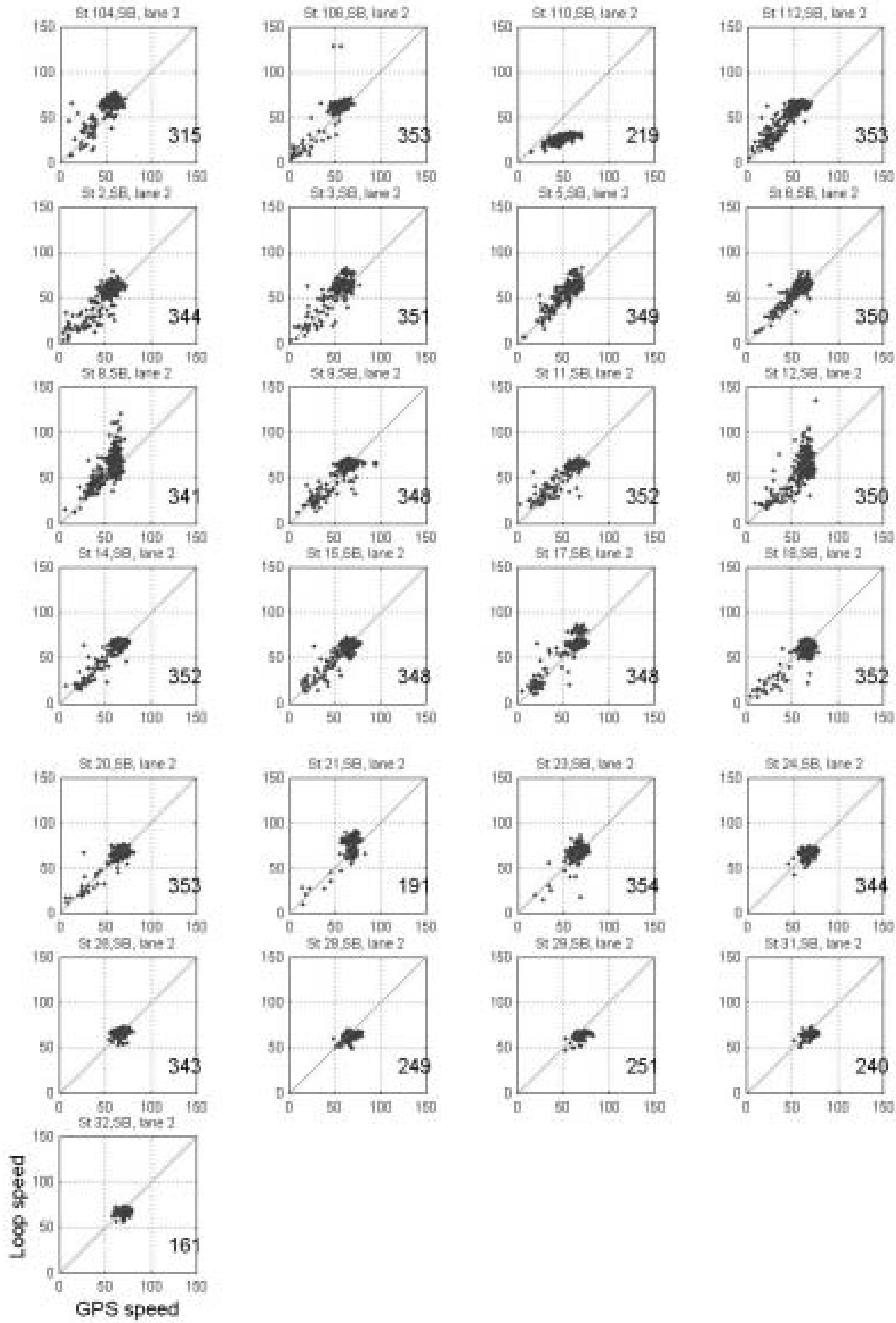


Figure 17, Comparison between single loop speed measurements incorporating correction factors and concurrent probe vehicle velocity measurements for southbound single loops.

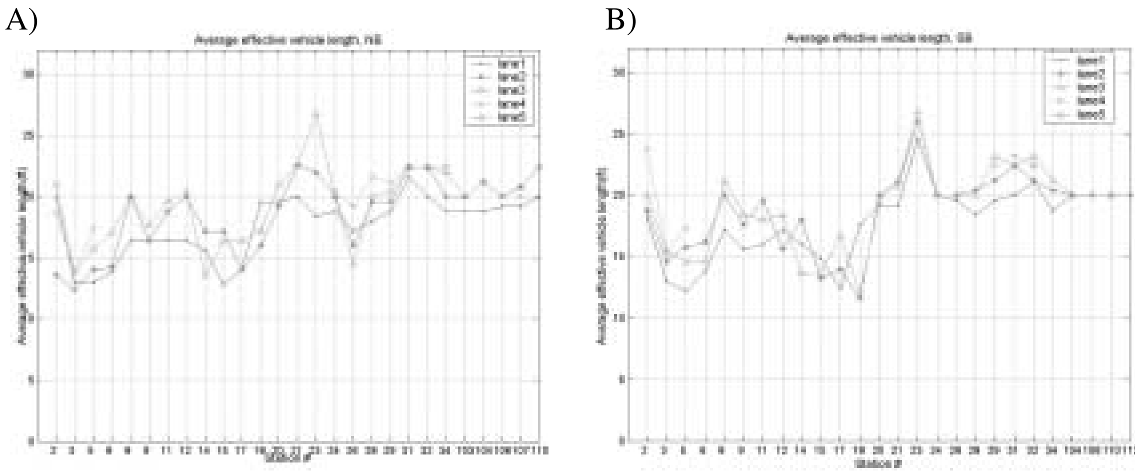


Figure 18, Average effective vehicle length at single loop detectors A) Northbound, B) Southbound.

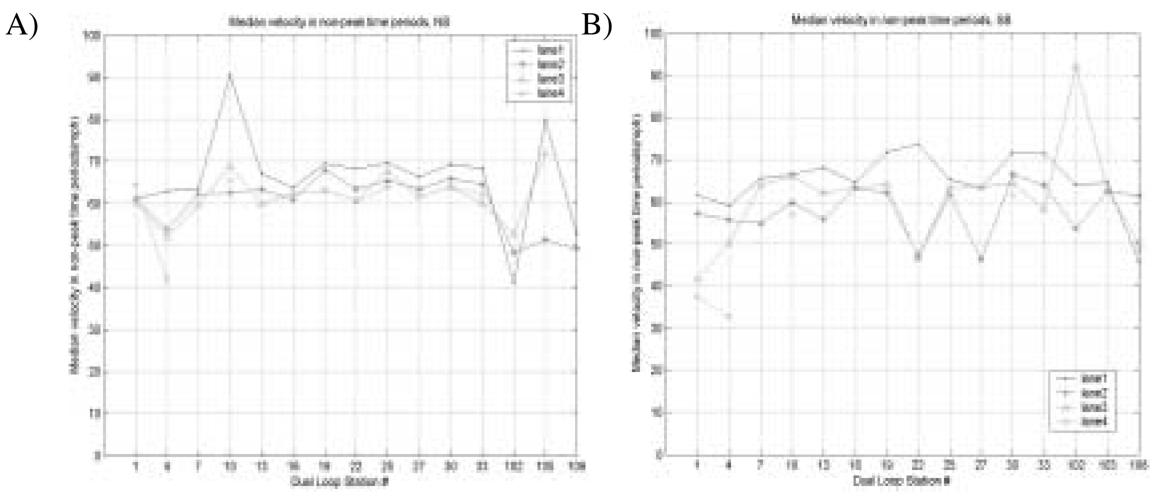


Figure 19, Median velocities in off-peak time periods at dual loop detectors

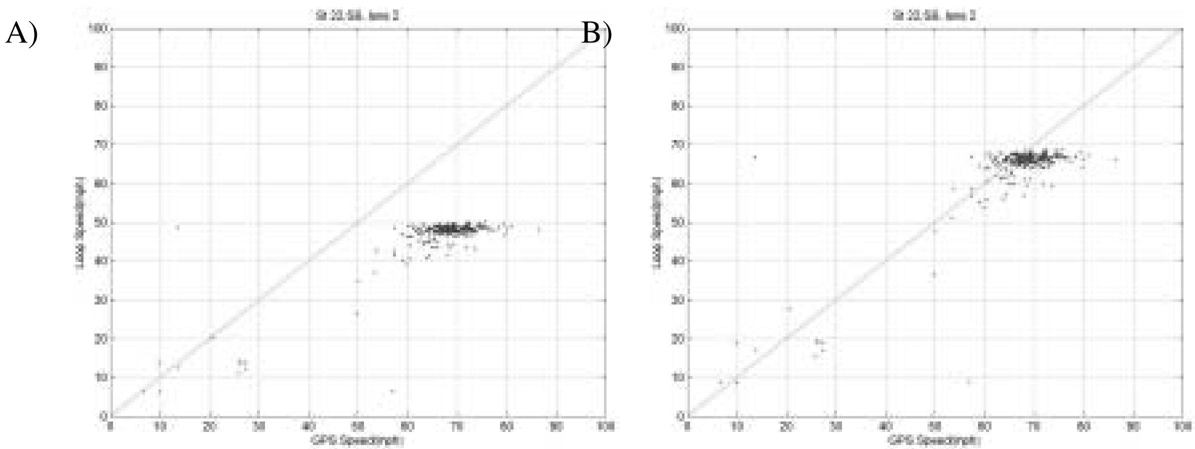


Figure 20, Comparison between loop speed and GPS velocity at station 22, lane 2. The left column shows that loop speed is lower than GPS velocity without the correction factor. The right column shows the difference of loop speed and GPS speed is within 10mph, applying the correction factor.

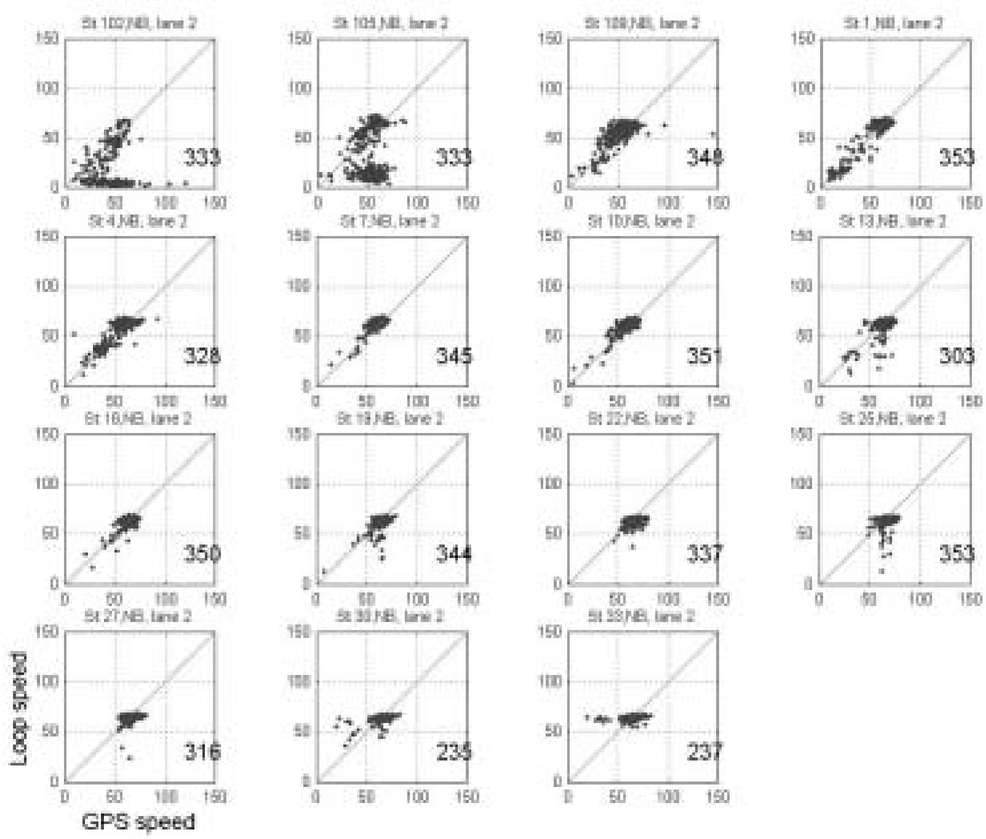


Figure 21, Comparison between dual loop speed measurements incorporating correction factors and concurrent probe vehicle velocity measurements for northbound dual loops.

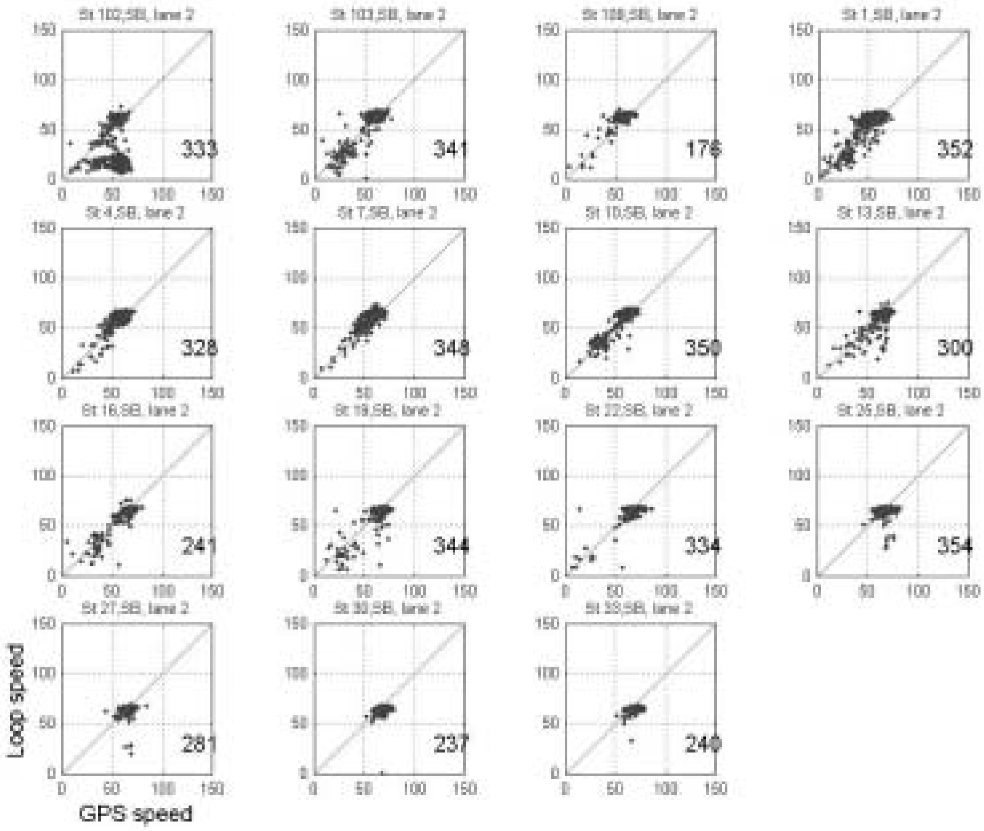
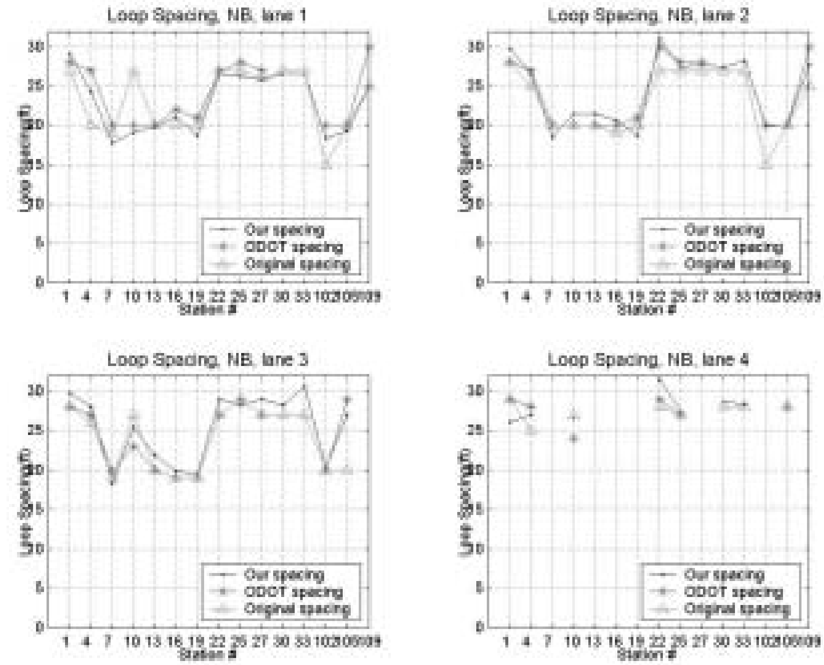


Figure 22, Comparison between dual loop speed measurements incorporating correction factors and concurrent probe vehicle velocity measurements for southbound dual loops.

A)



B)

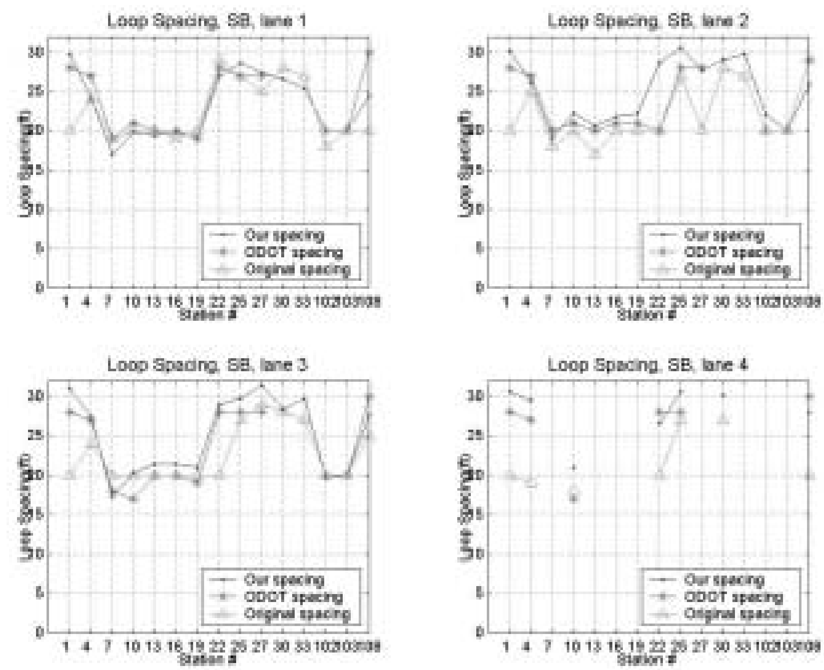


Figure 23, Loop separation for dual loop detectors A) northbound, B) southbound

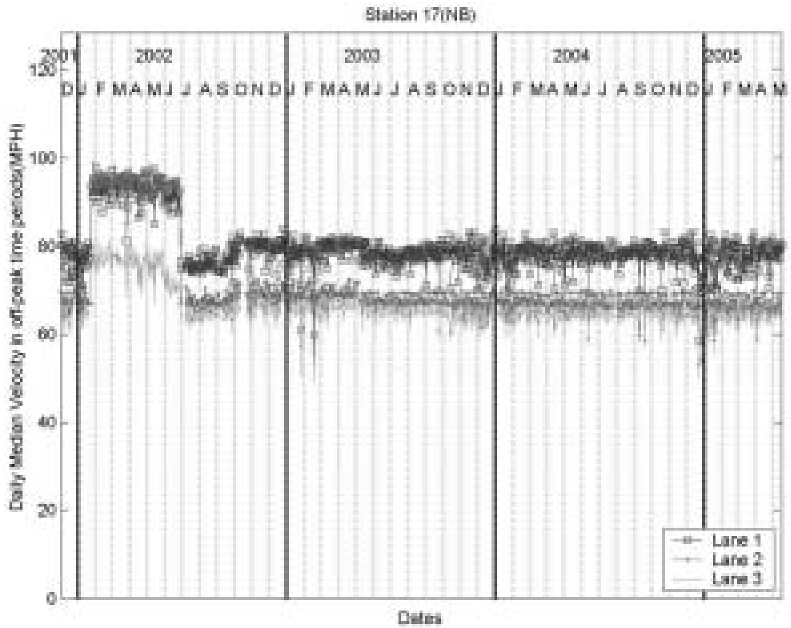


Figure 24, Daily median speed trends at loop station 23 northbound over four years

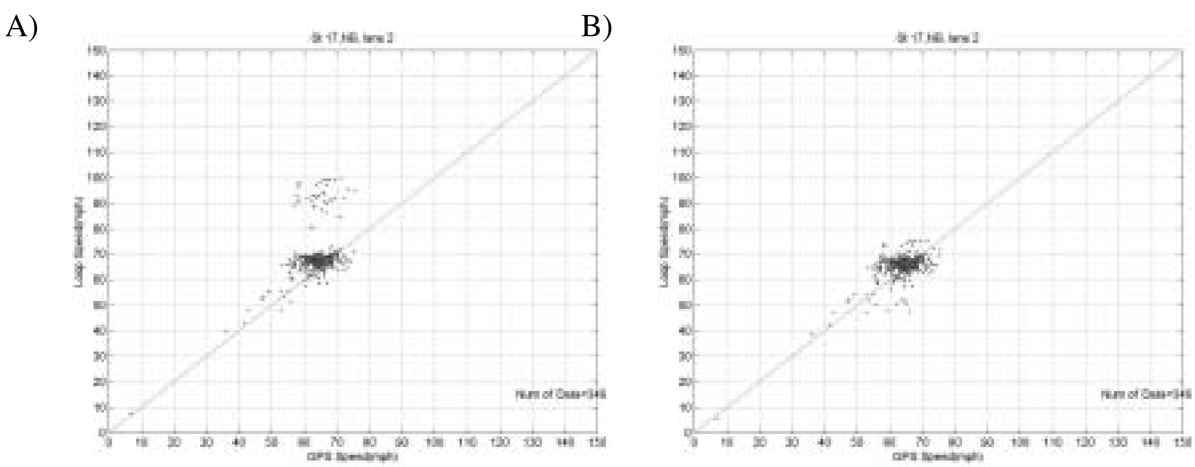


Figure 25, Comparison of Loop speed and GPS velocity, A) after applying a single correction factor, B) after applying two correction factors

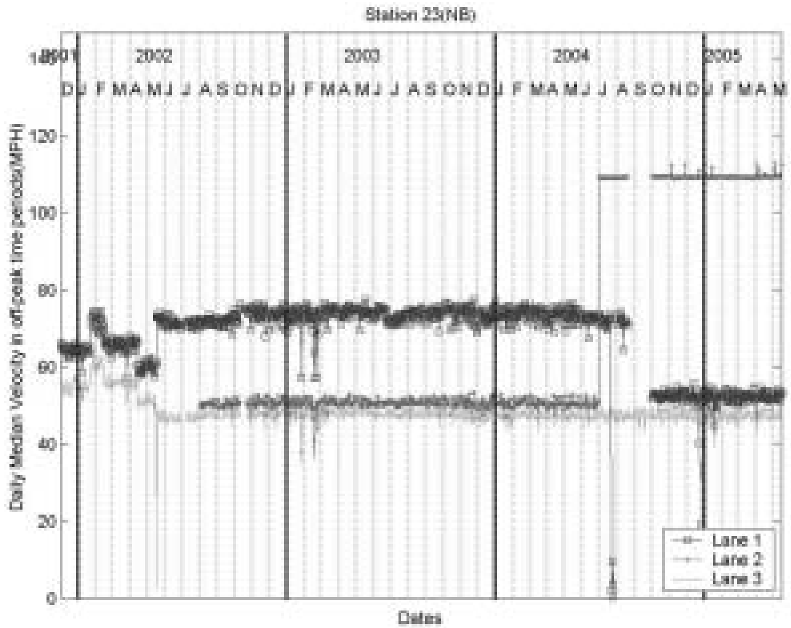


Figure 26, Daily median speed trend at loop station 23 northbound

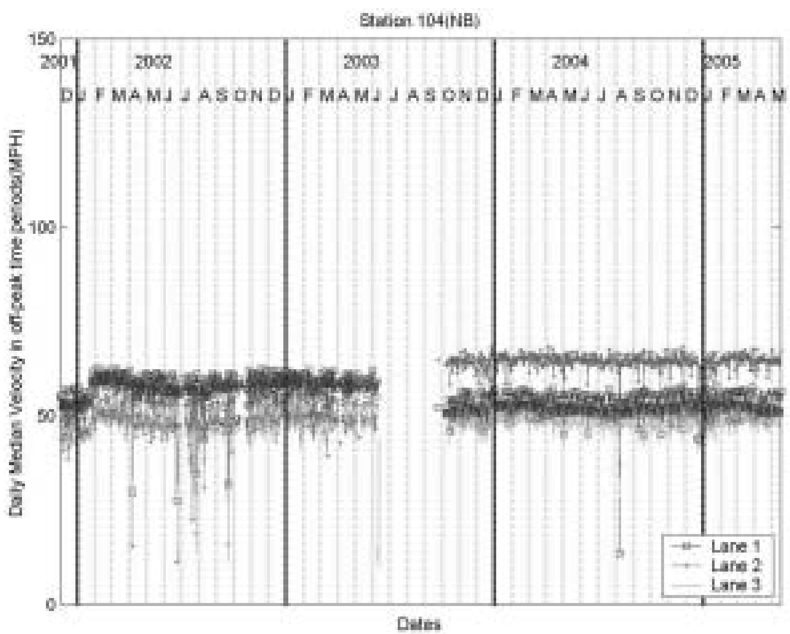
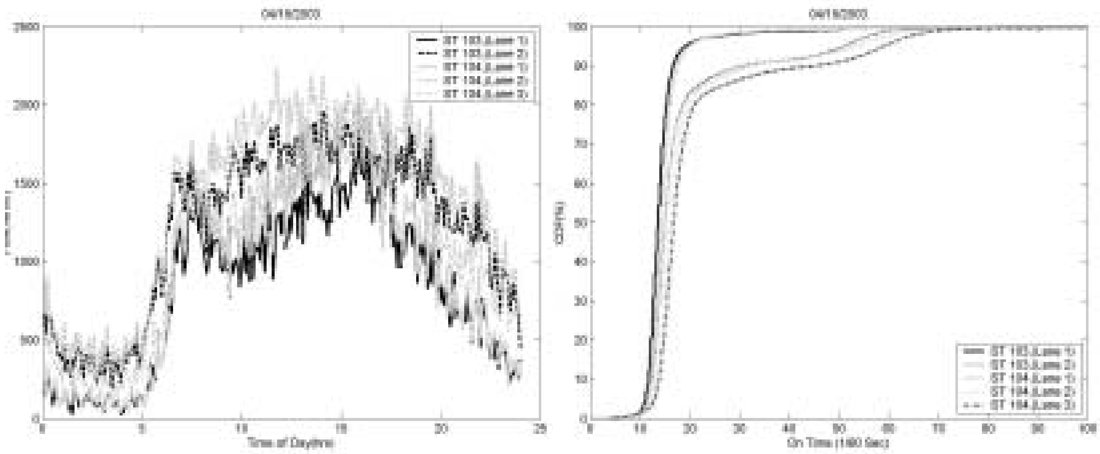


Figure 27, Daily median speed trends at loop station 104 northbound

A)



B)

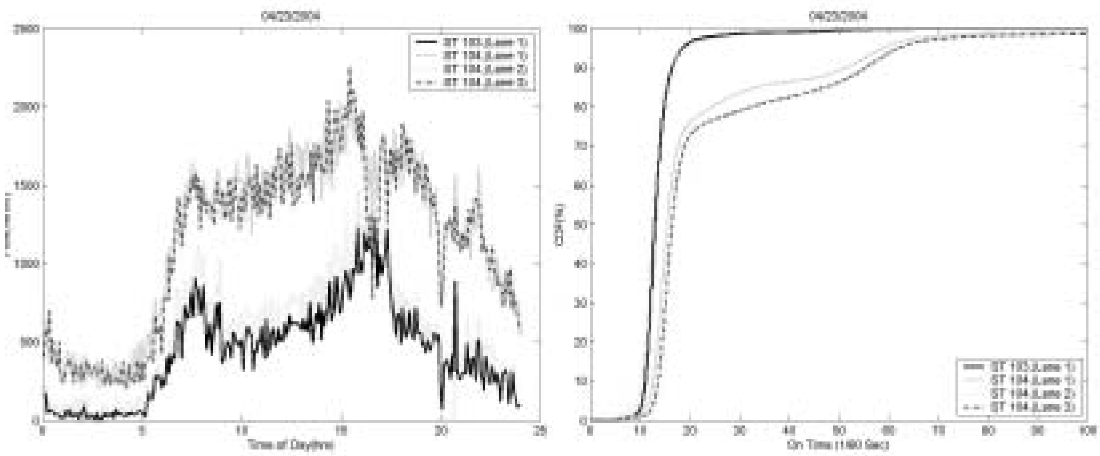


Figure 28, The left column shows the flow at station 103 and station 104 northbound. The right column shows CDF of on-times for the entire 24hr day at both loop stations. The row corresponds to results for 04/18/2003 and 04/23/2004. Note that lane 3 at station 103 does not function on 04/18/2003, and lane 2 and lane 3 at station 103 do not function on 04/23/2004.

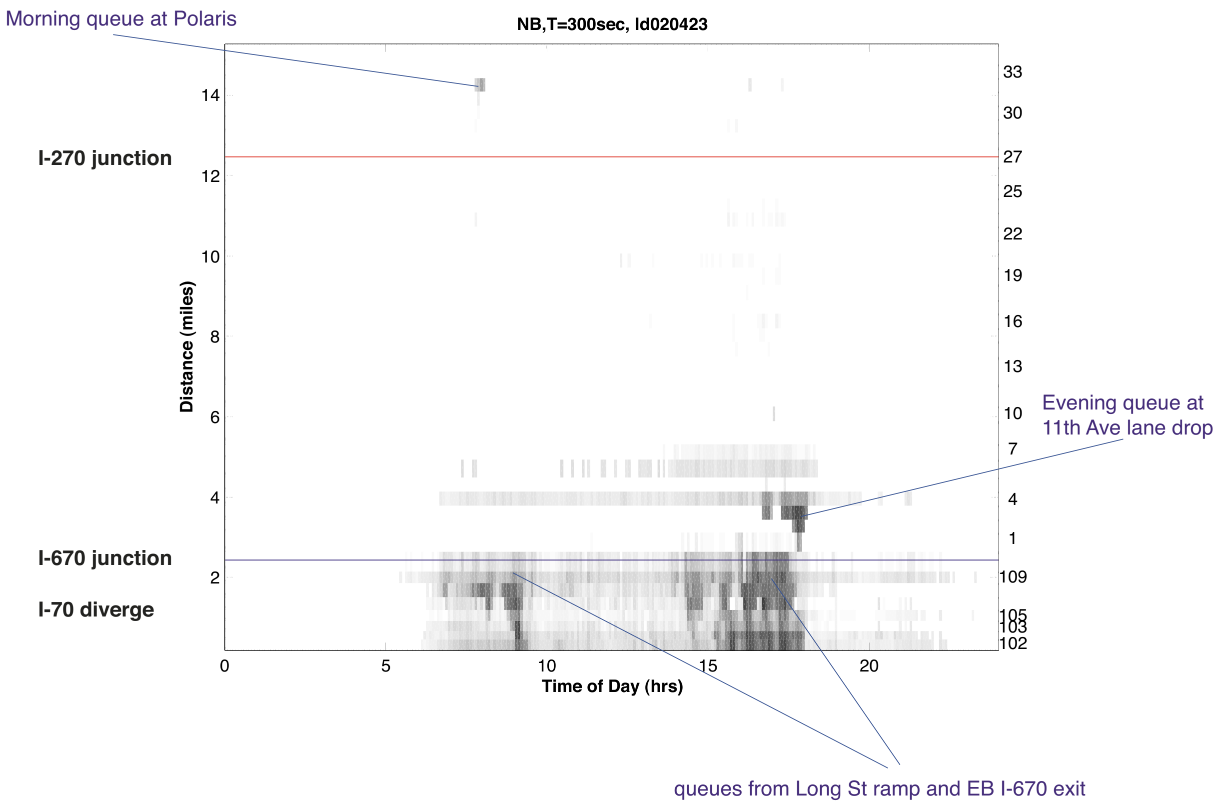


Figure 29, A sample summary plot showing the evolution of traffic conditions over the entire corridor over 24 hrs.

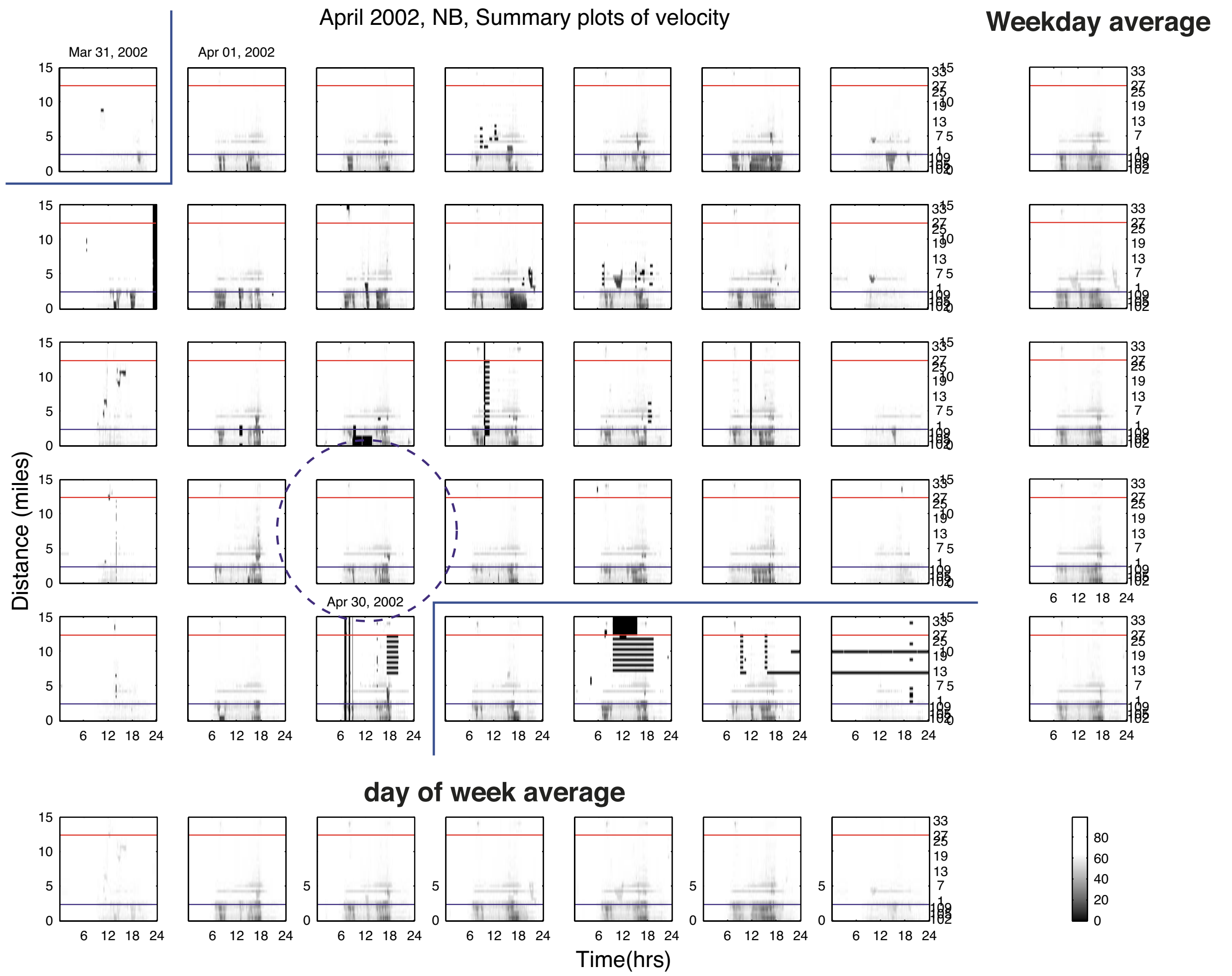


Figure 30, A sample monthly summary plot showing the evolution of traffic conditions over the entire corridor over 30 days.

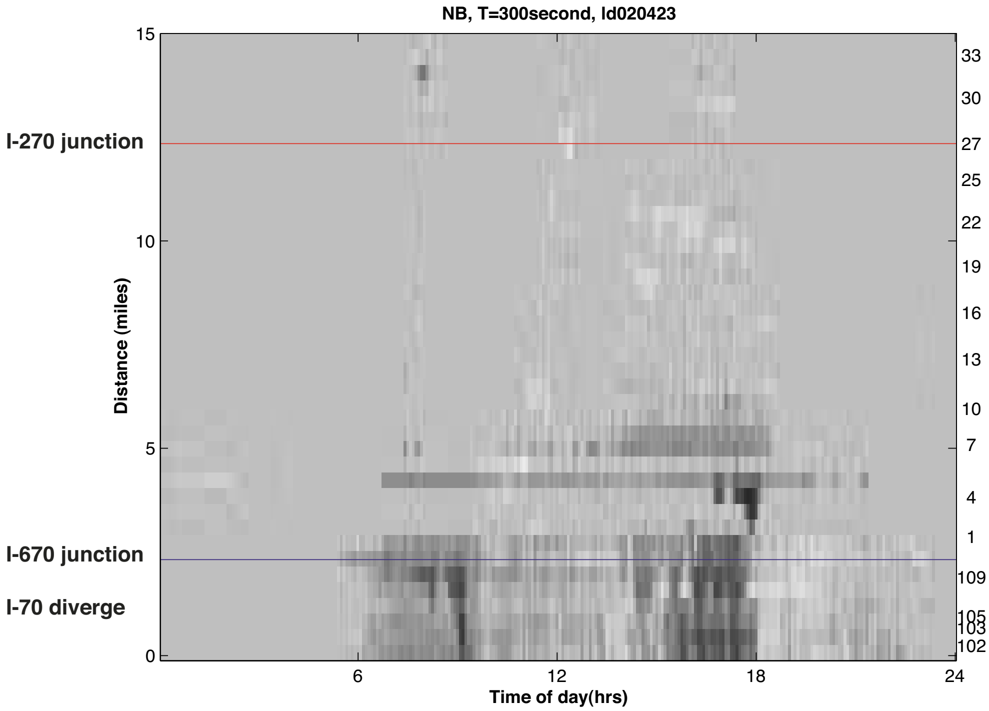


Figure 31, A sample summary difference plot showing the evolution of traffic conditions over the entire corridor over 24 hrs.

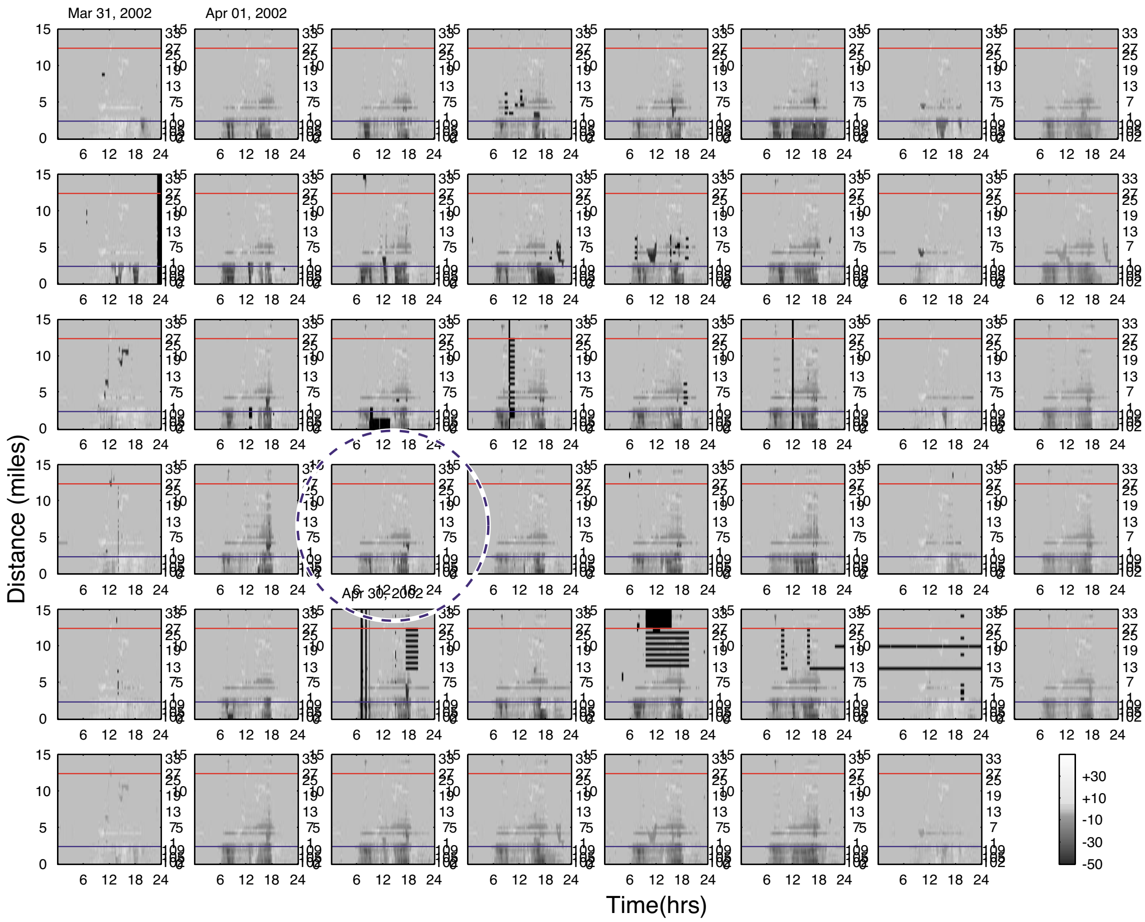


Figure 32, A sample monthly summary difference plot showing the evolution of traffic conditions over the entire corridor over 30 days.

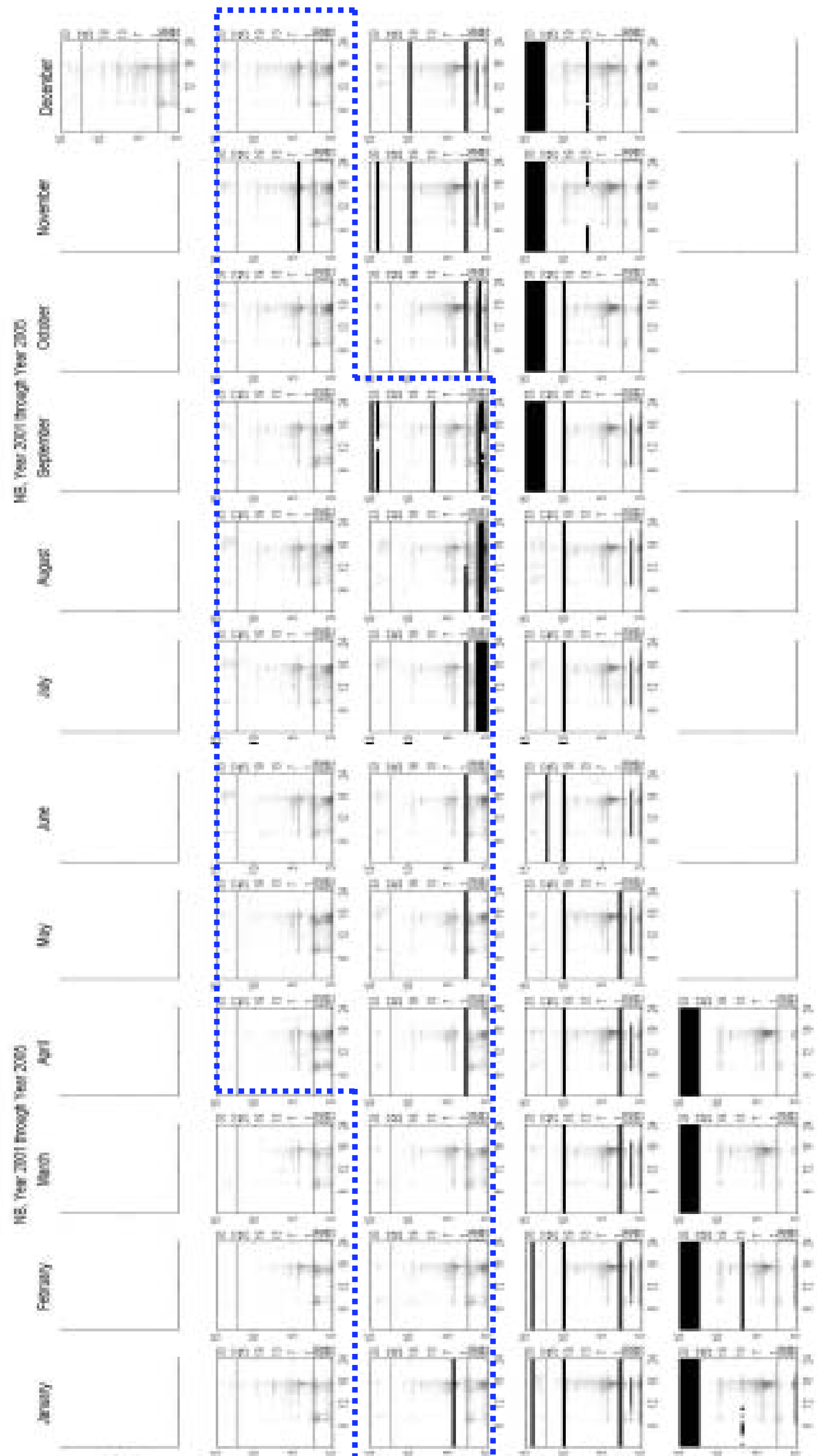


Figure 33, Monthly average summary plot for northbound direction

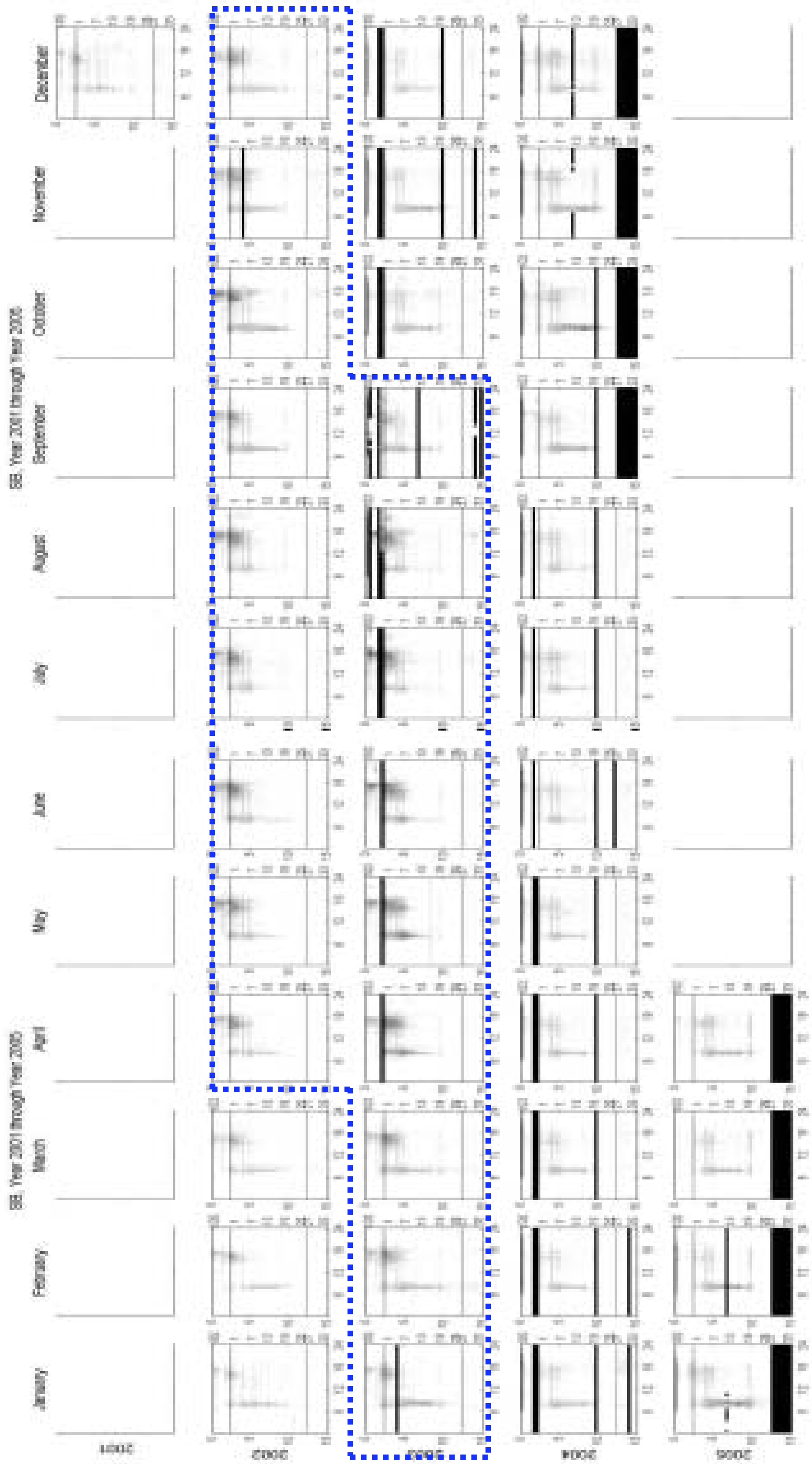


Figure 34, Monthly average summary plot for southbound direction

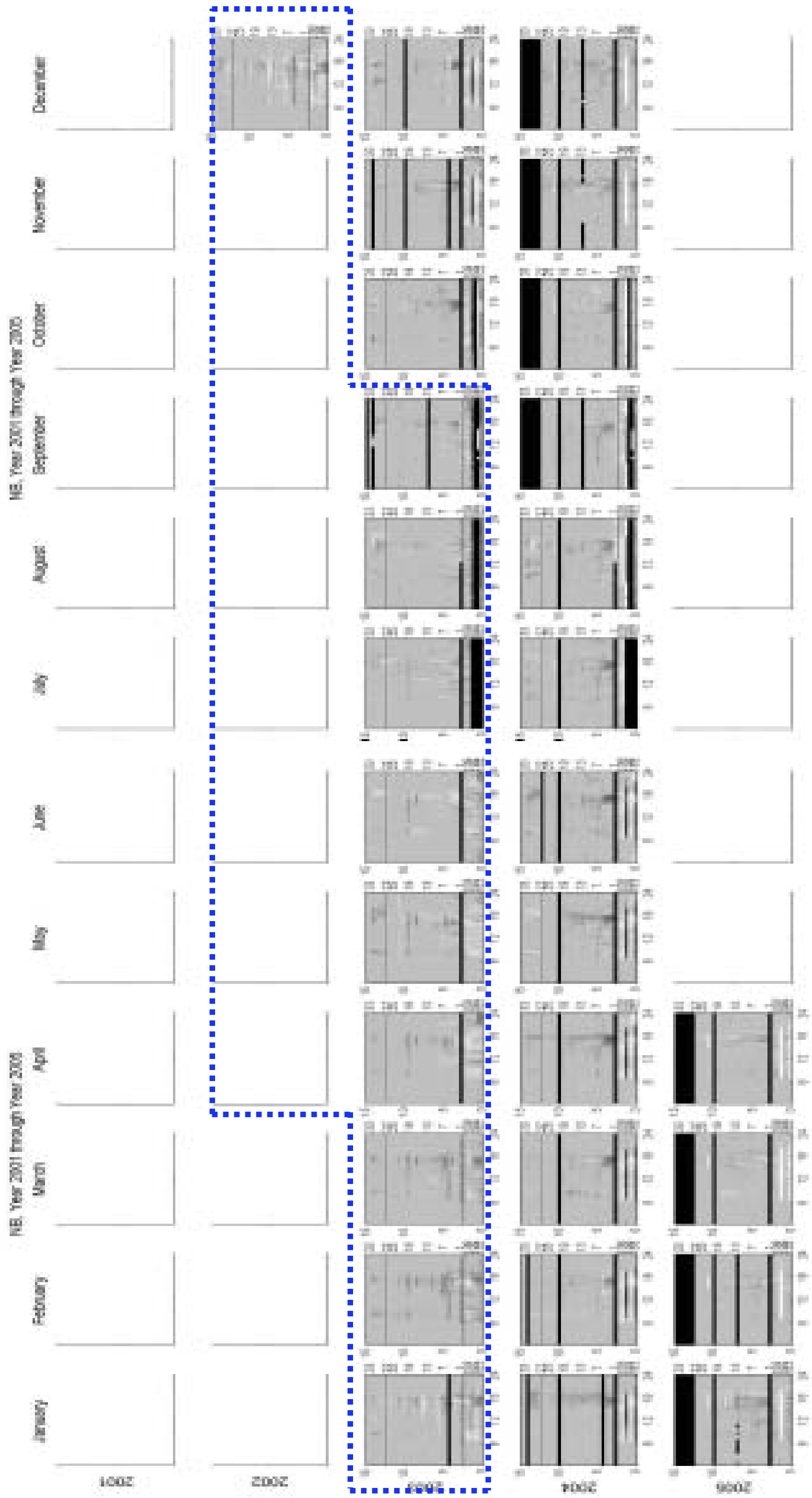


Figure 35, Monthly average summary difference plot for northbound direction

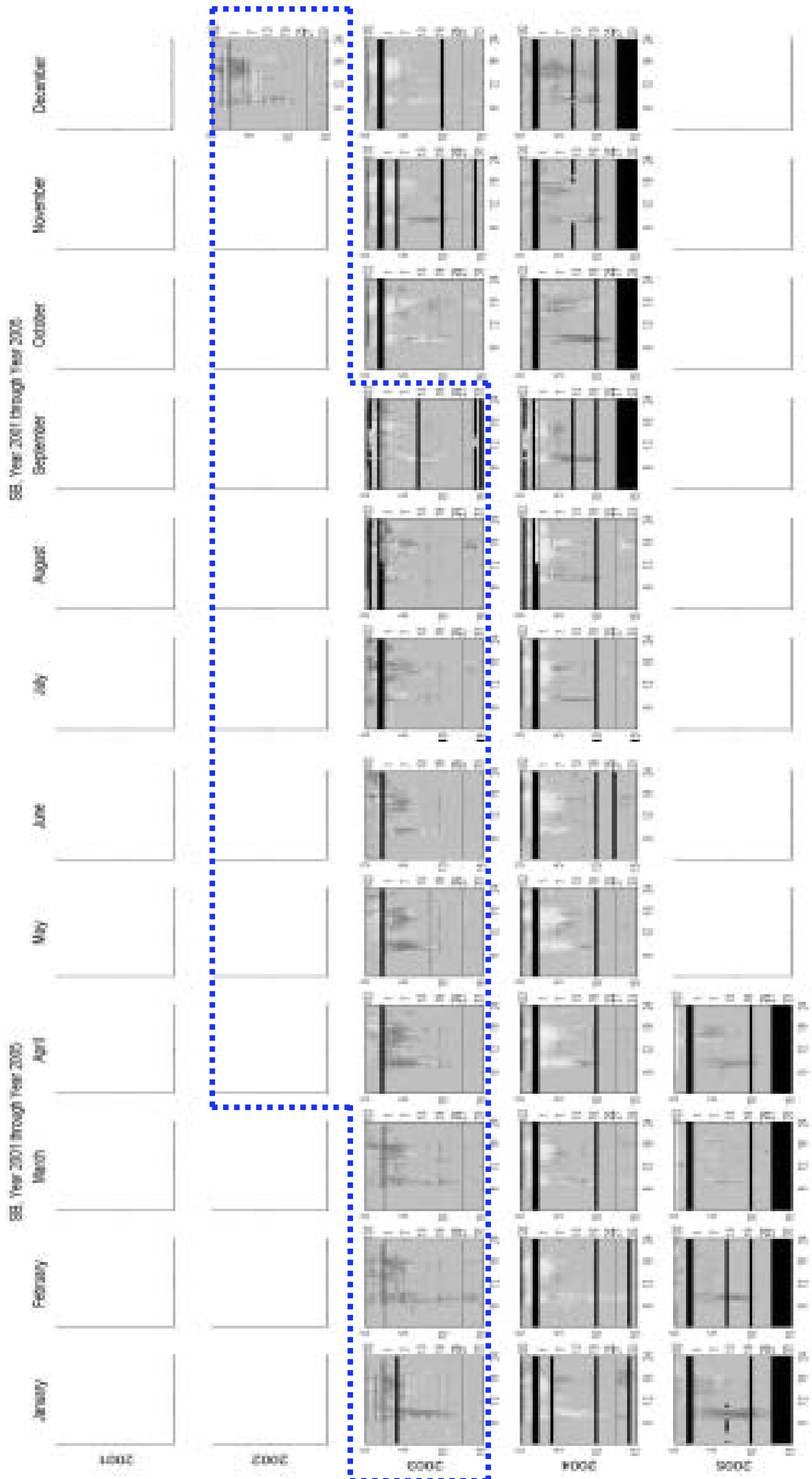


Figure 36, Monthly average summary difference plot for southbound direction

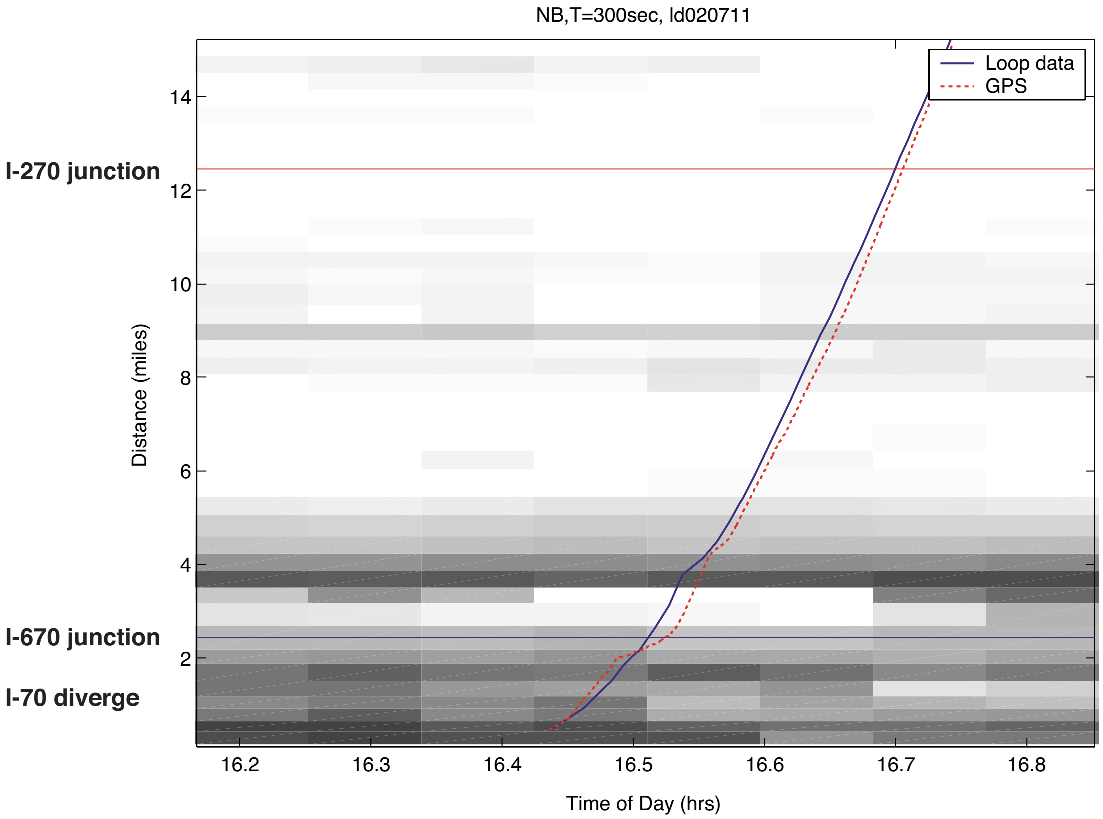


Figure 37, Estimate trajectories then find time between two locations to estimate travel time. Each cell of the velocity summary plot is 5 min by the length of the link. Vehicles are assumed to traverse each cell at the constant cell speed, changing only at cell boundaries.

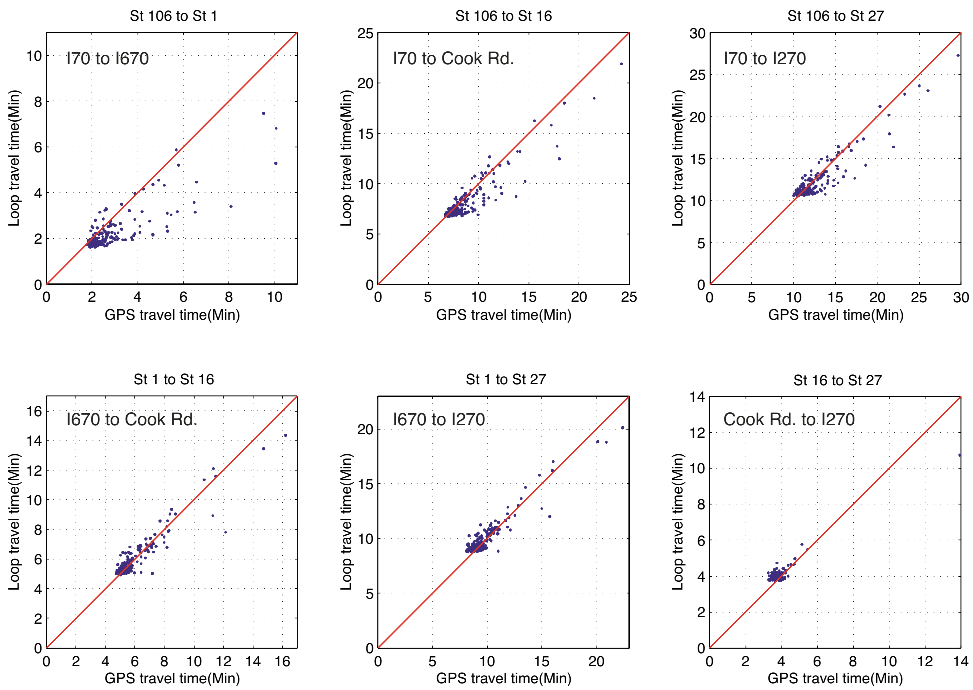


Figure 38, Comparisons between loop estimated travel times and probe vehicle measured travel times, northbound.

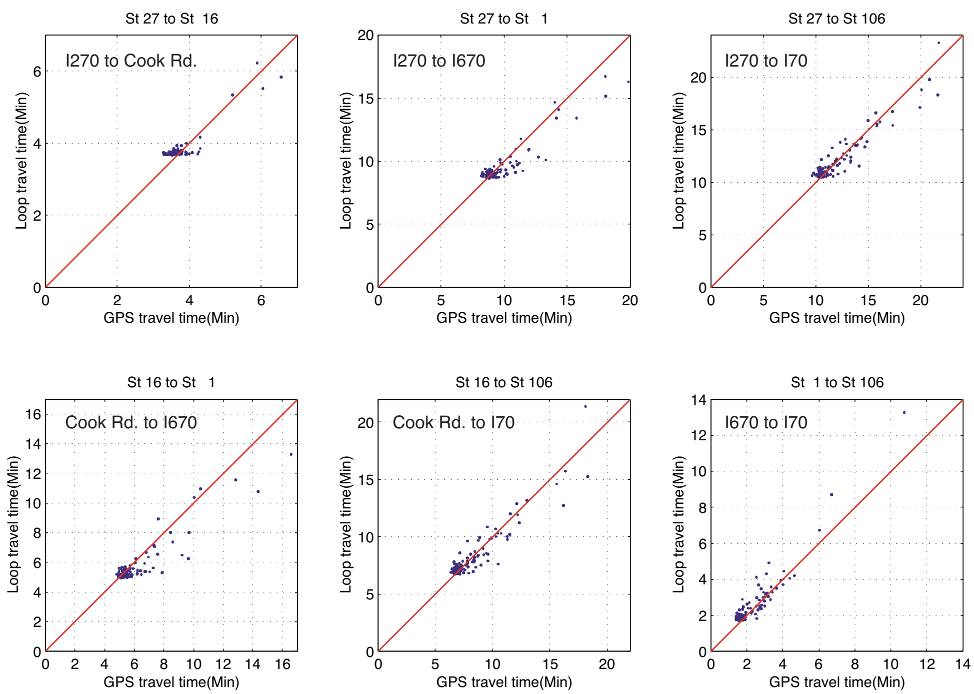


Figure 39, Comparisons between loop estimated travel times and probe vehicle measured travel times, southbound.

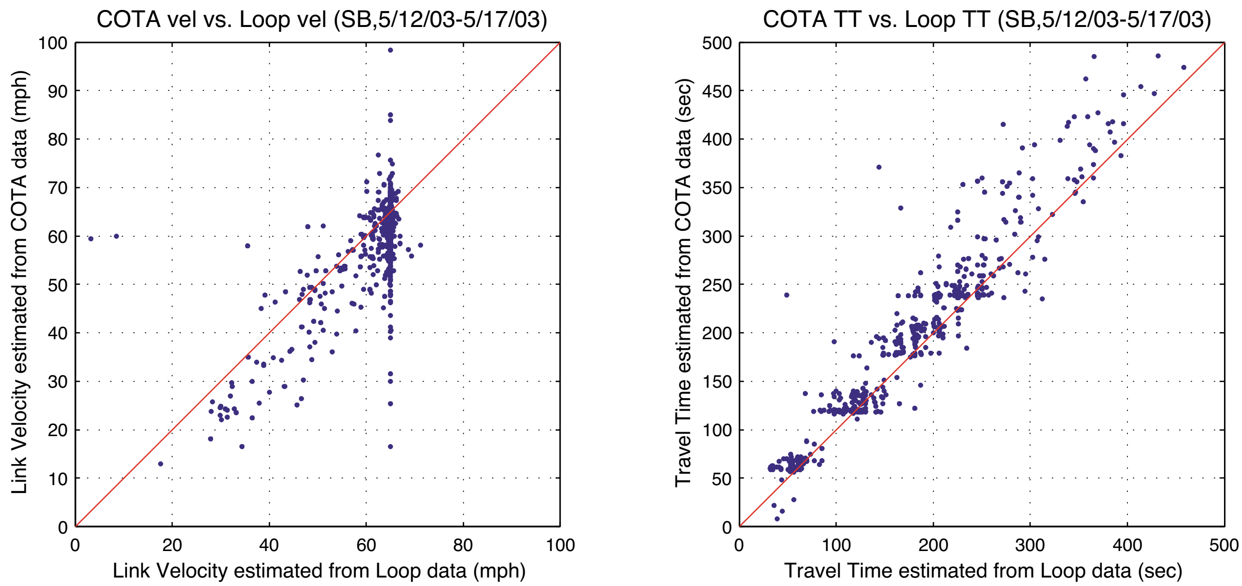


Figure 40, Comparisons between loop estimated travel times and COTA AVL measured travel times, southbound.

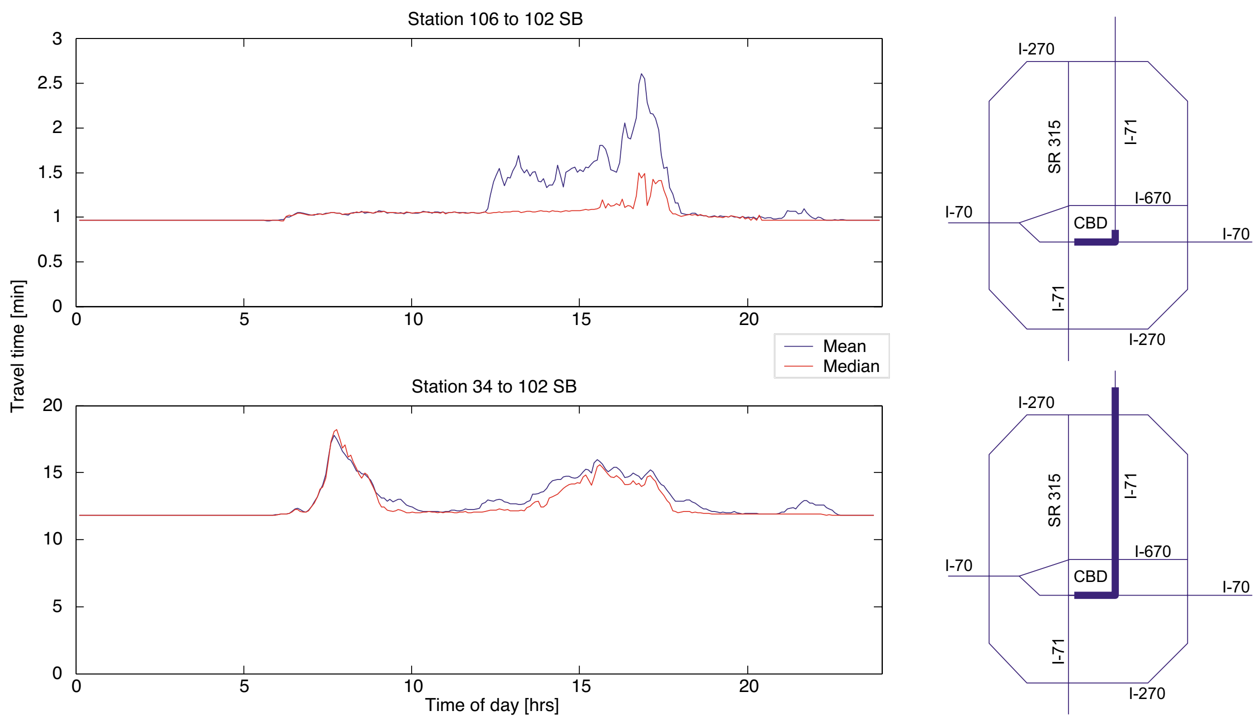


Figure 41, Mean and median travel times as a function of start time for two different southbound links (shown on the right) over an entire month.

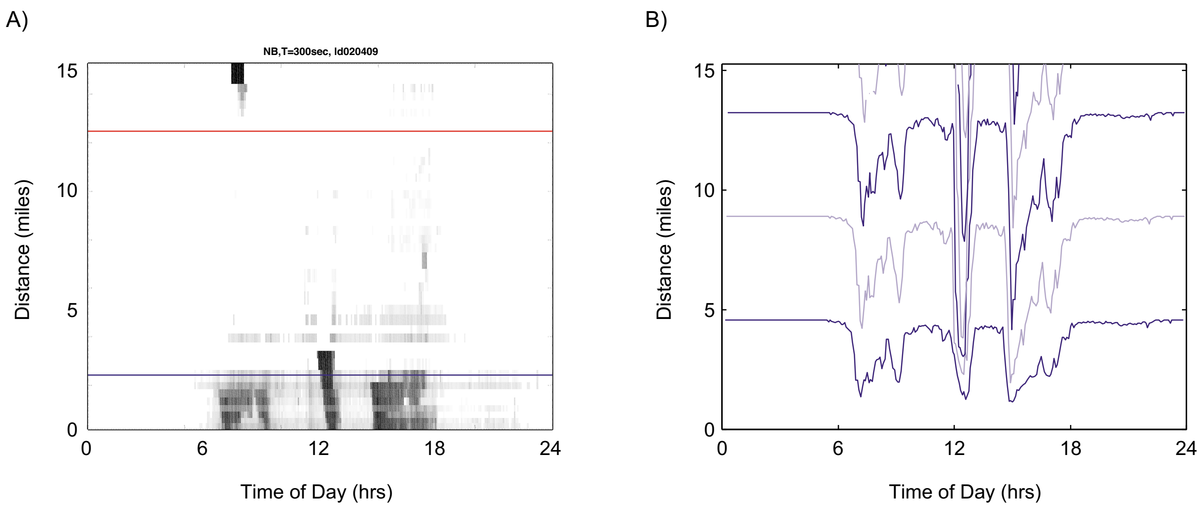


Figure 42, (A) Speed summary plot along the instrumented section of I-71 on a sample day. (B) Corresponding curves of equi-travel time from mile zero shown at 5 min intervals.

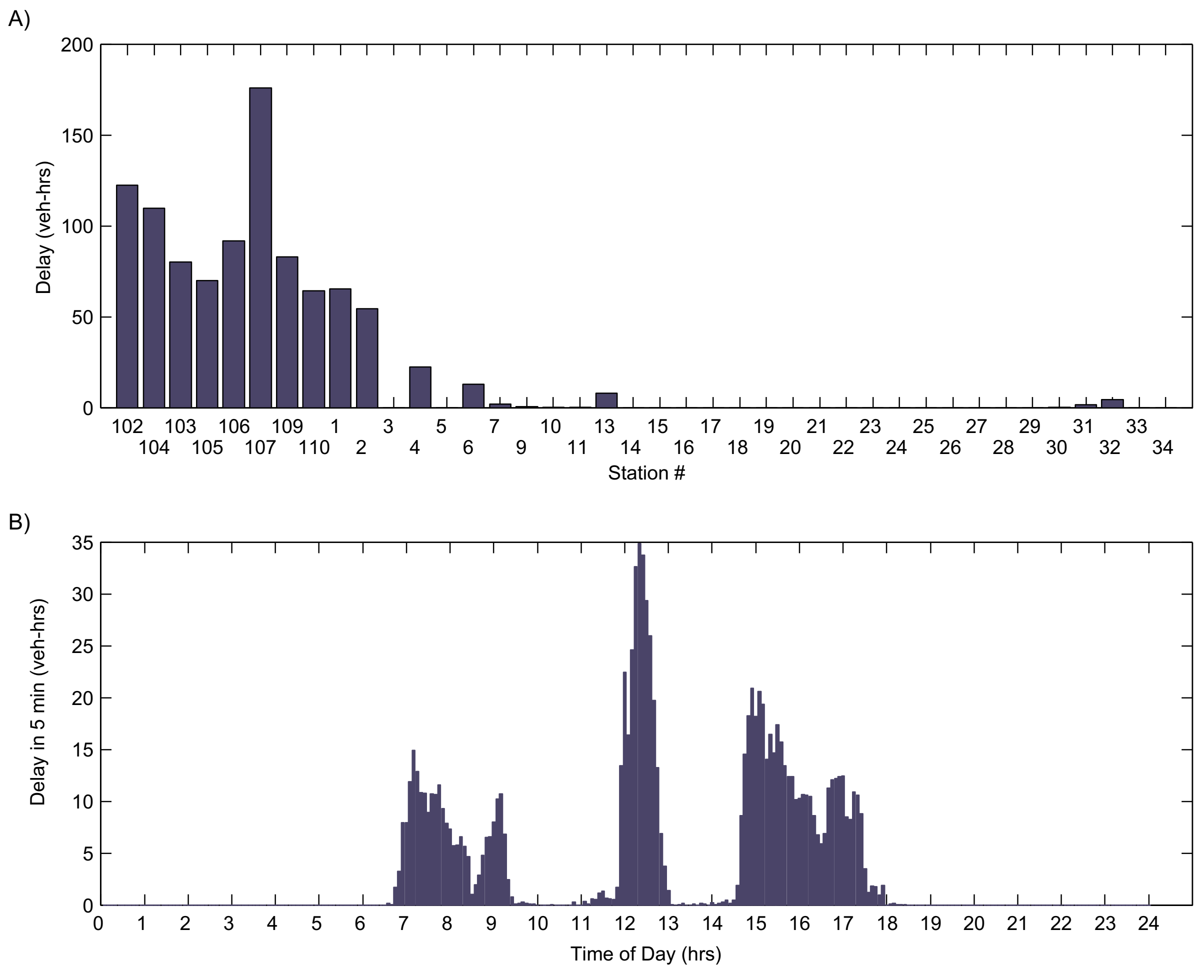


Figure 43, The total delay corresponding to Figure 41A is 971 veh-hrs, (A) shown by detector station sorted by increasing distance (from Figure 26), (B) shown by time of day, note the peak around noon due to an incident.

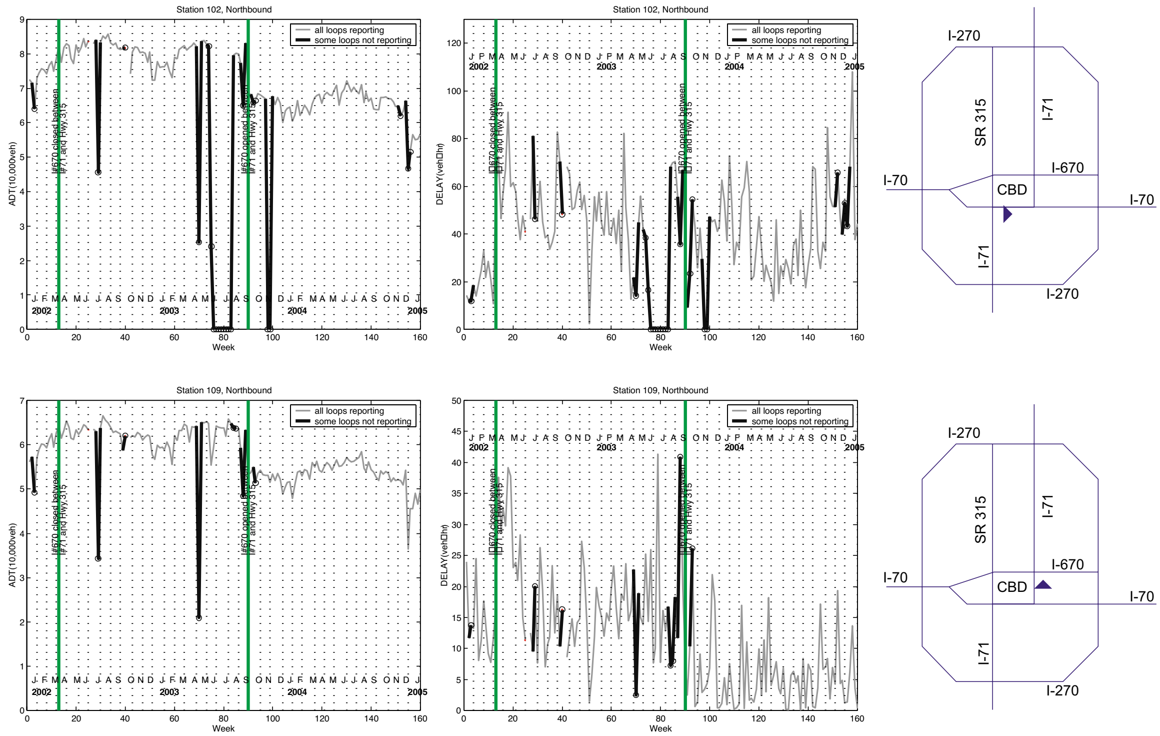


Figure 44, Northbound weekly median daily ADT and delay for the two detector stations shown on the right over three years.

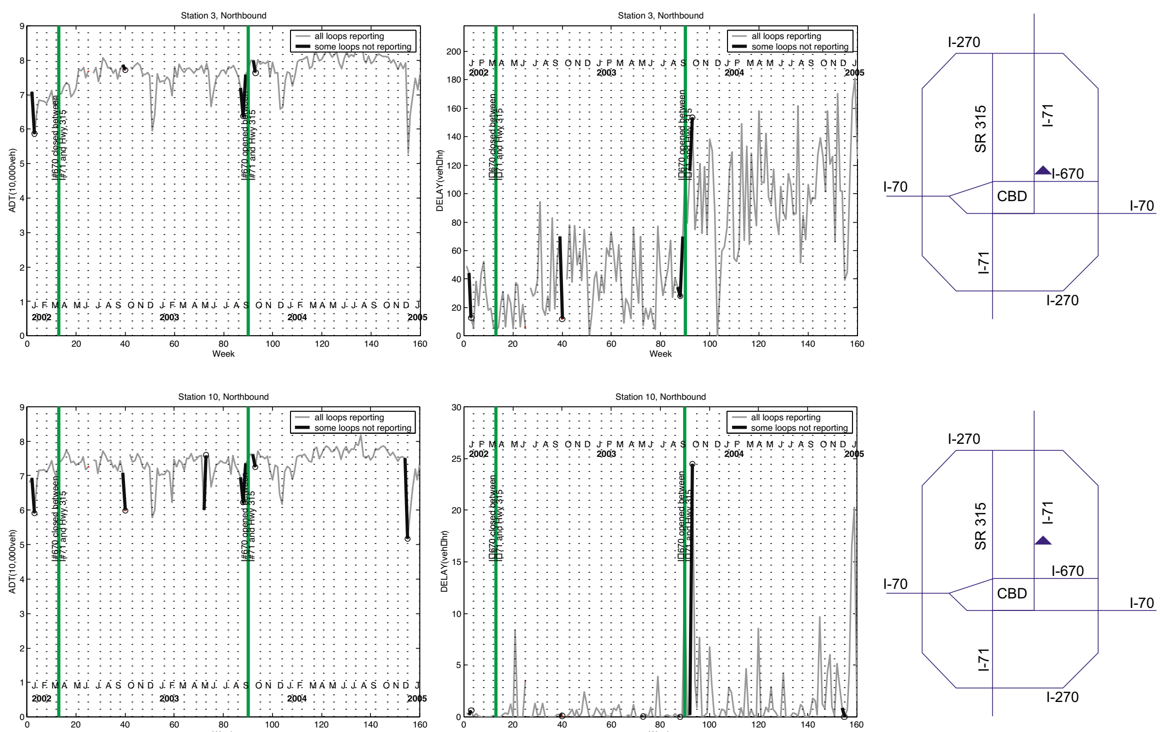


Figure 45, Northbound weekly median daily ADT and delay for the two detector stations shown on the right over three years.

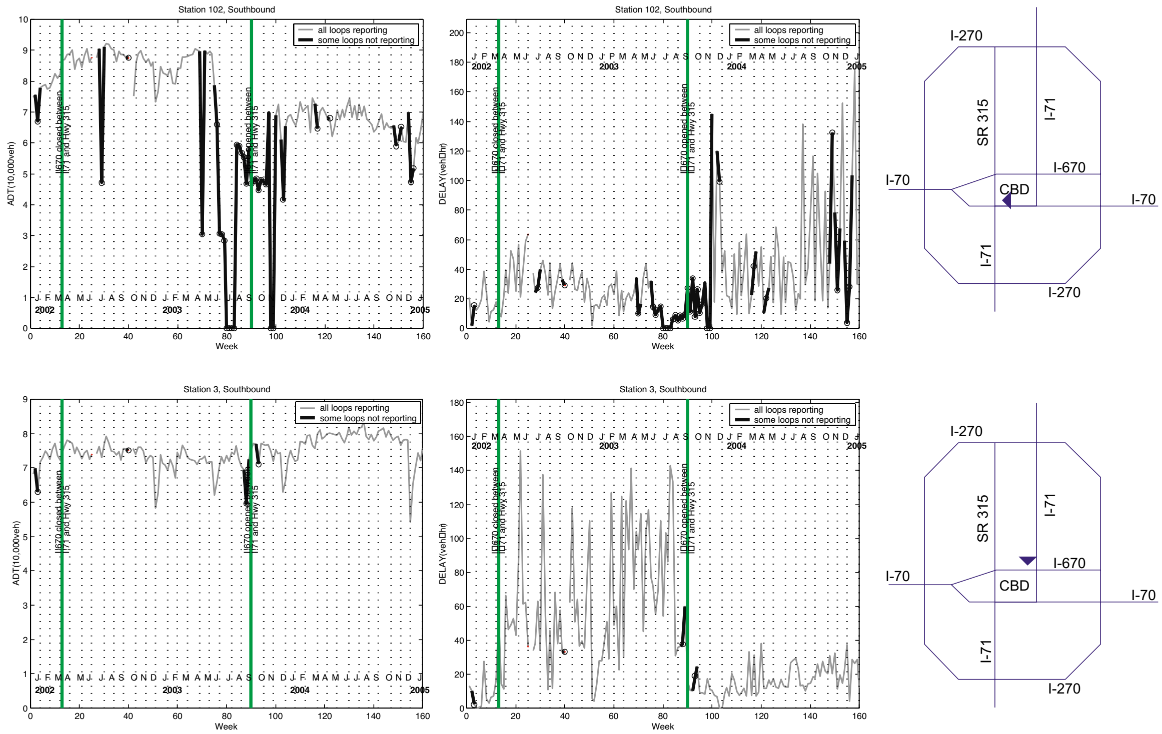


Figure 46, Southbound weekly median daily ADT and delay for the two detector stations shown on the right over three years.

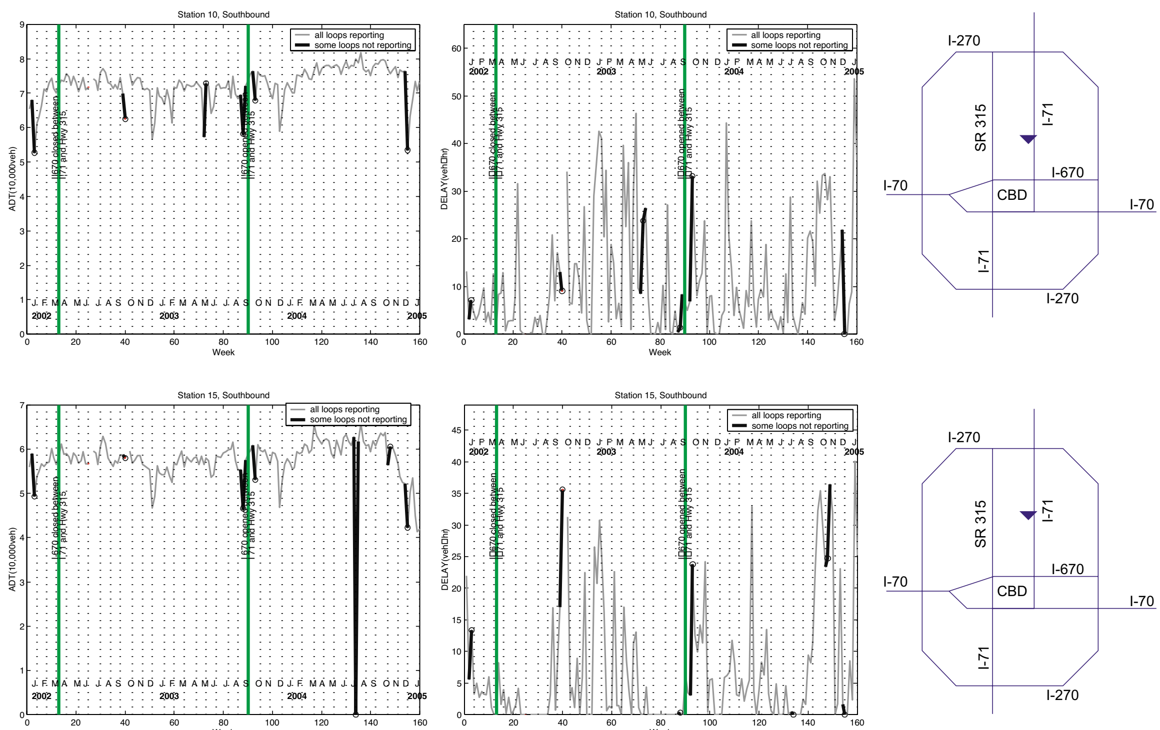


Figure 47, Southbound weekly median daily ADT and delay for the two detector stations shown on the right over three years.

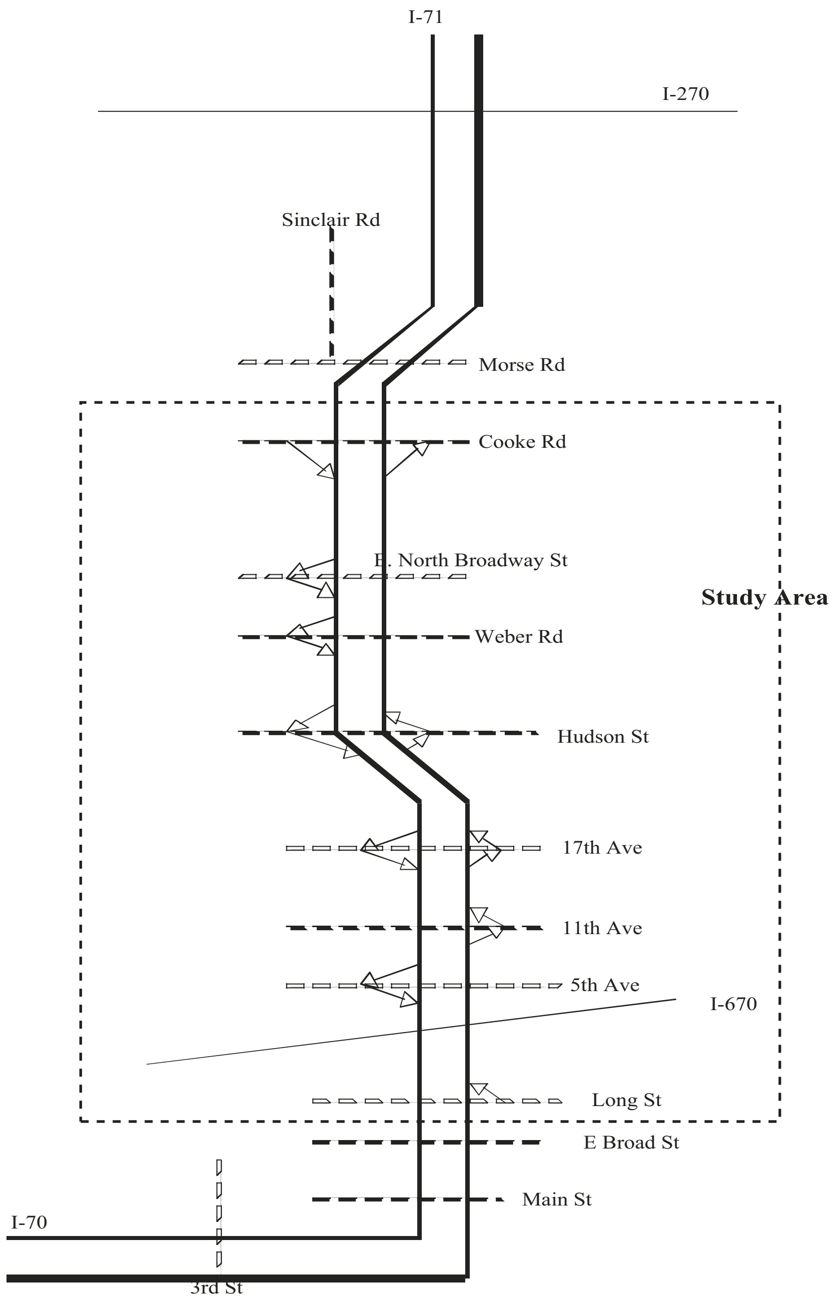


Figure 48, A schematic of the study area collecting ramp run data

A) B)

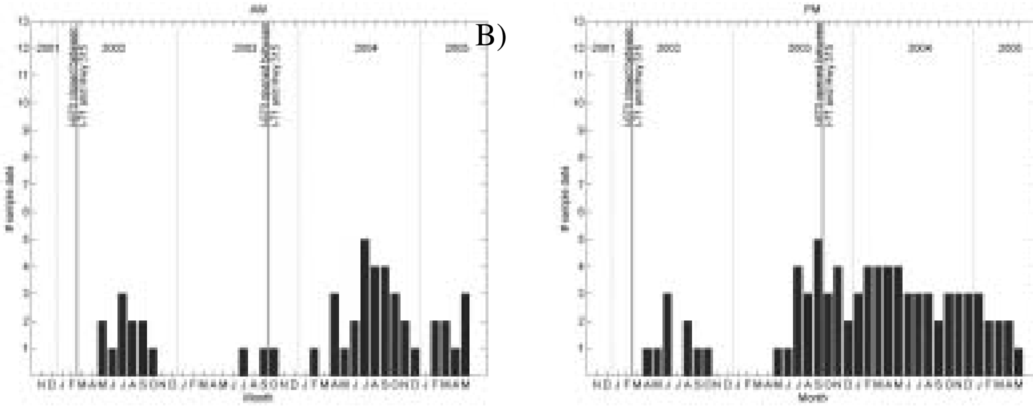


Figure 49, The number of ramp tours by month (A) AM (7hr to 9hr), (B) PM (16hr to 18hr). Each entry corresponds to three round trips.

A) B)

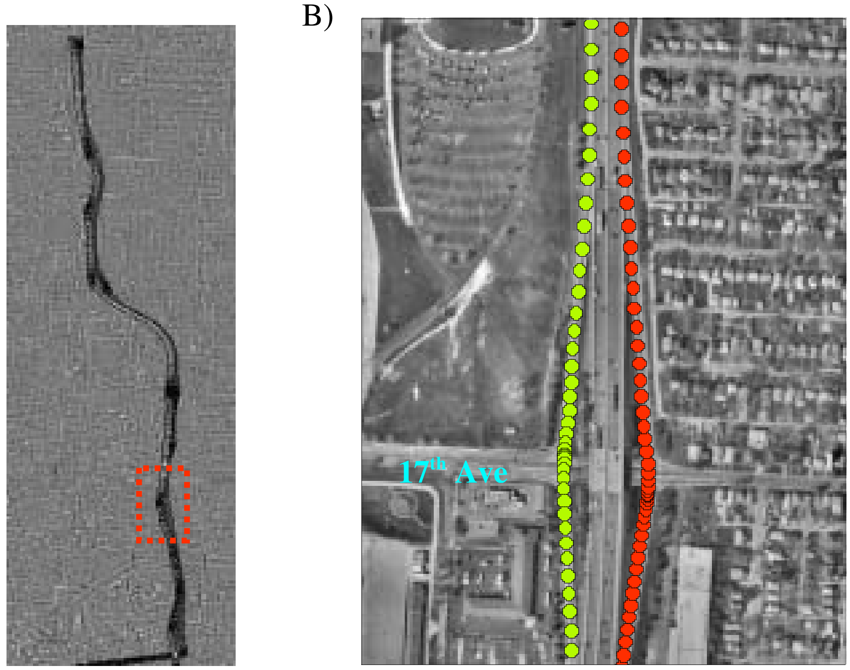


Figure 50, Path of a probe vehicle on I-71. The right column shows the trajectories on ramp section in 17th Ave for both directions

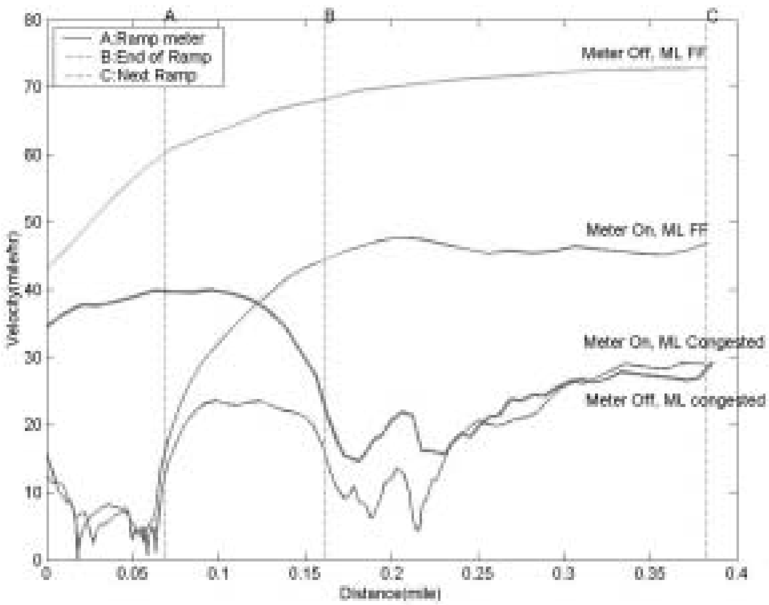


Figure 51, Velocity versus Distance provided by probe vehicles in study area

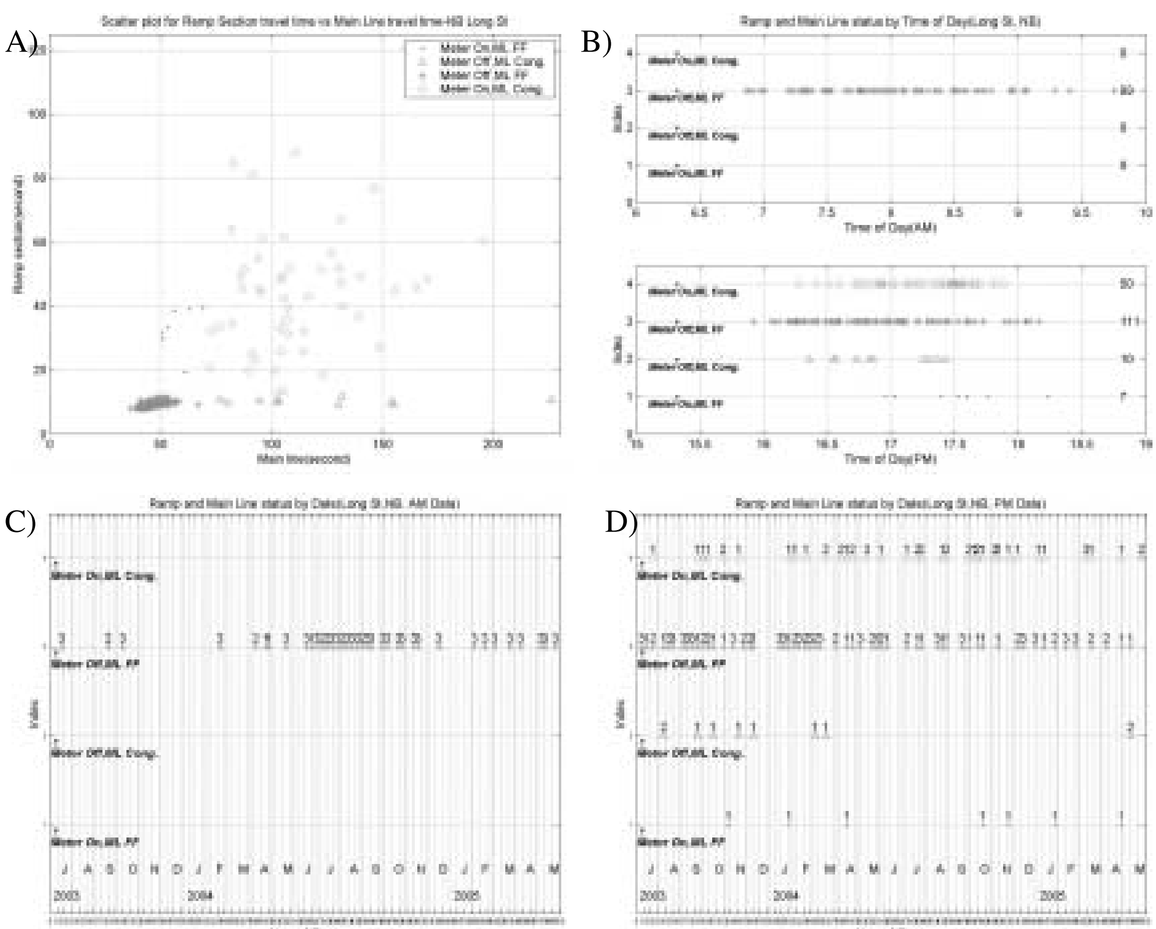


Figure 52, Ramp meter status and mainline condition at Long St northbound

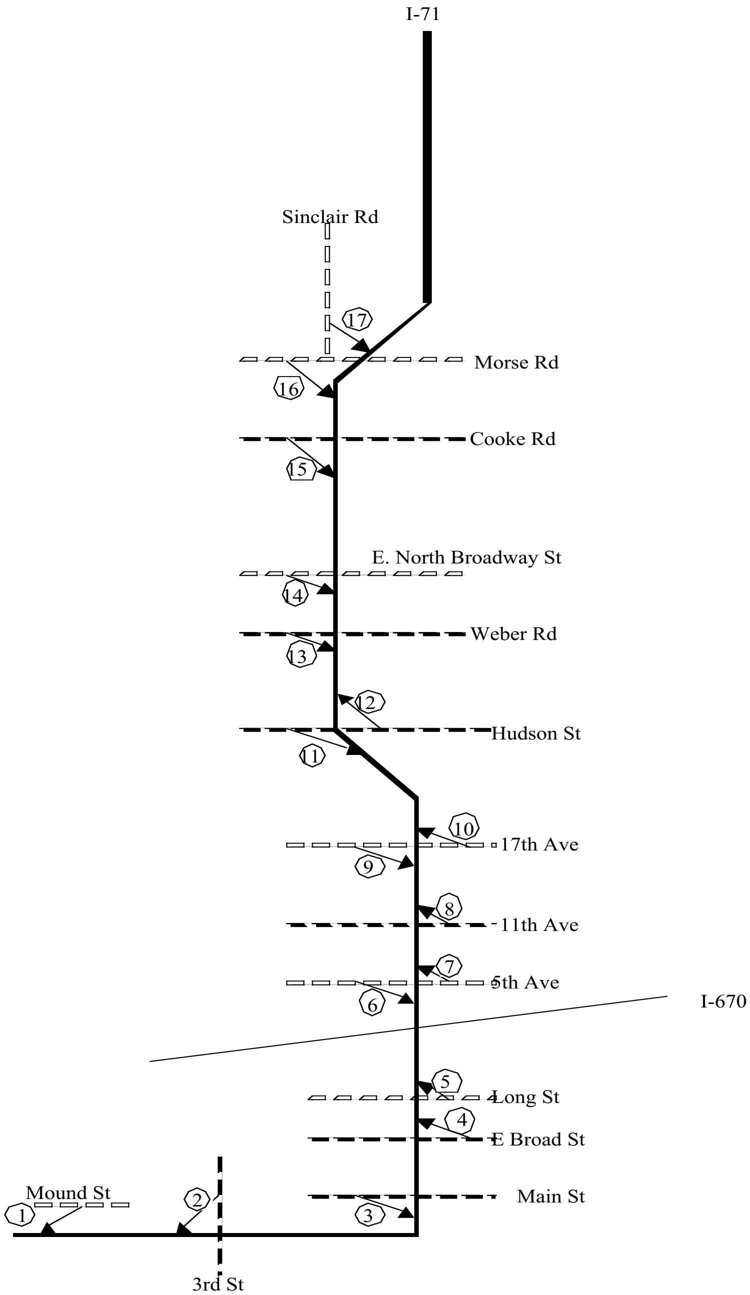


Figure 53, A schematic of the ramp detector stations

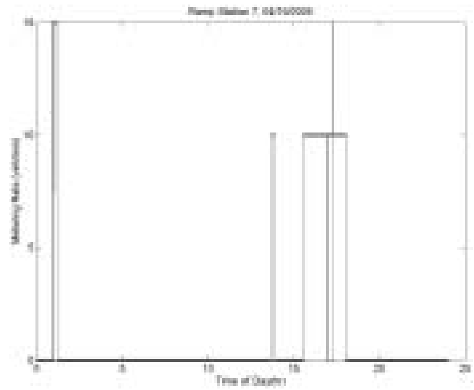


Figure 54, Metering rate over an entire 24-hr period at station 7

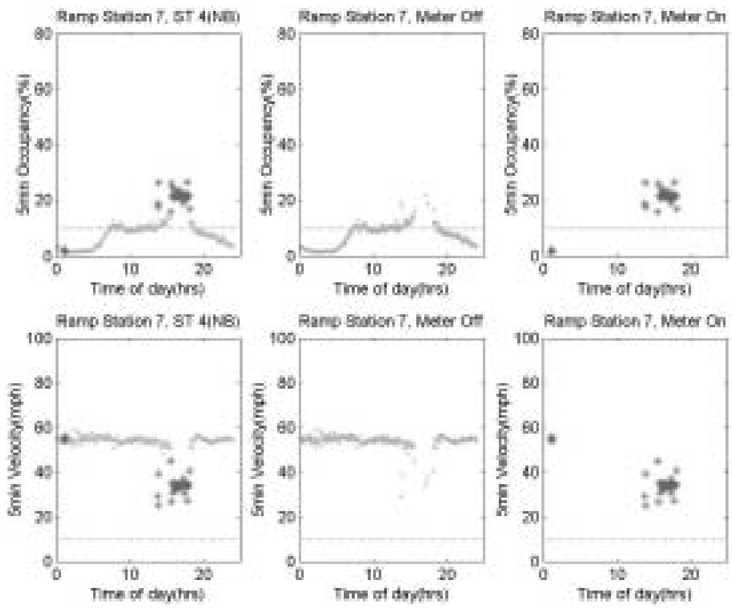


Figure 55, Occupancy and speed at mainline loop station 4, located on downstream of ramp station 7

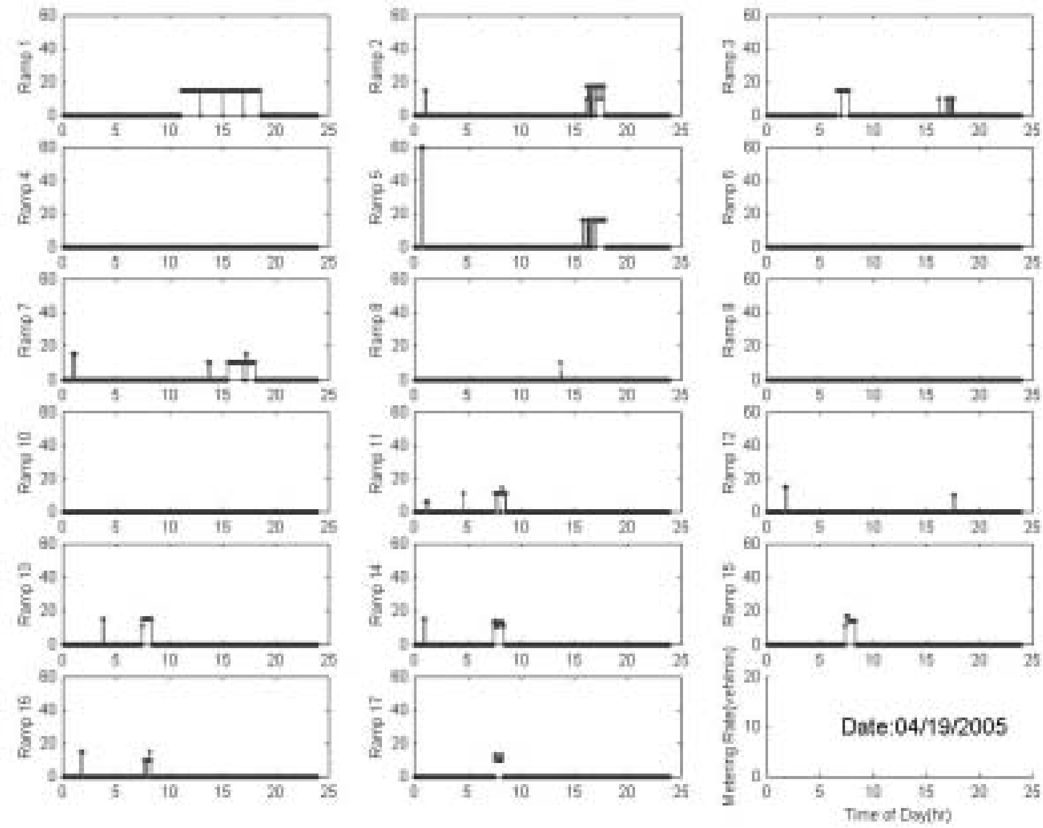


Figure 56, Metering rate over the entire 24hrs for 17 ramp stations, respectively

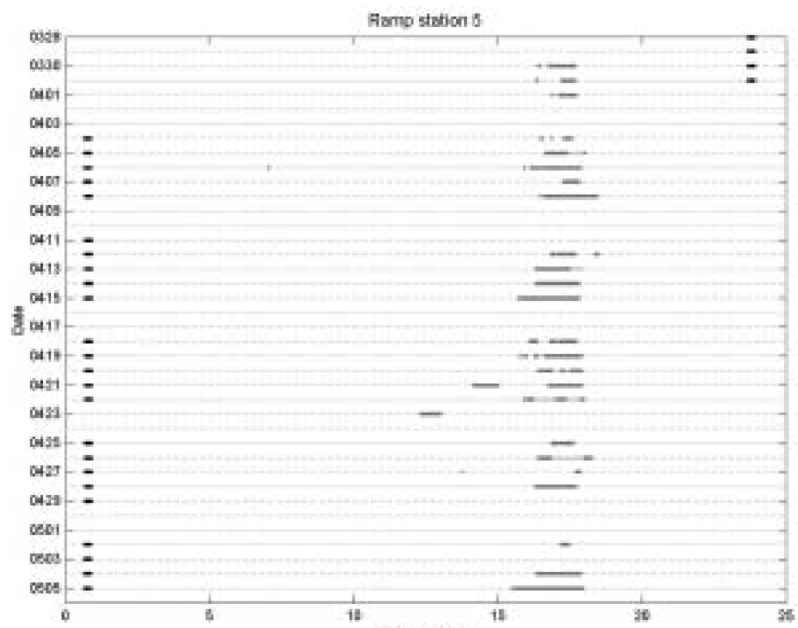


Figure 57, Metering rate by date versus time of day at ramp station 5

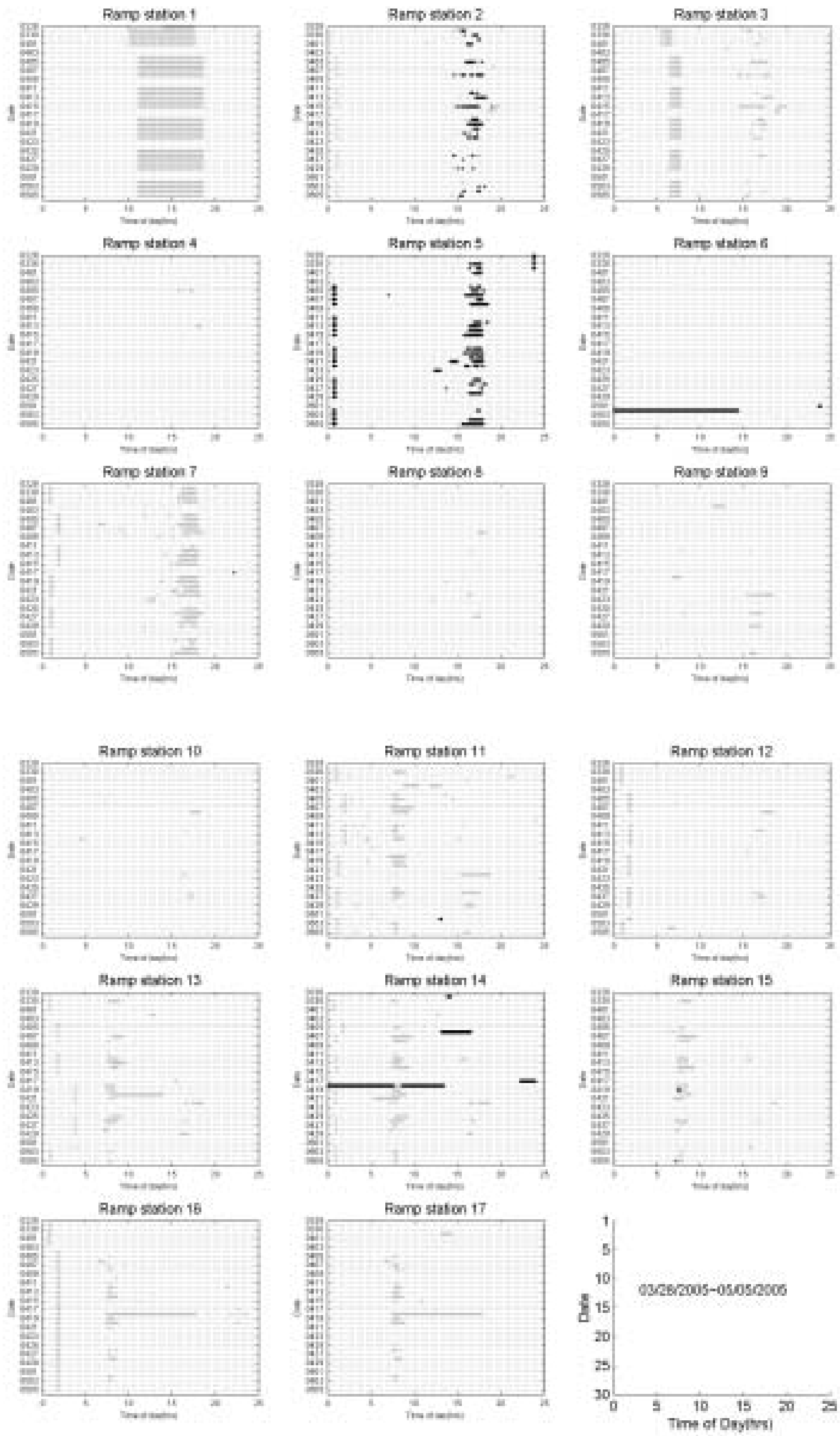


Figure 58, Metering rate by date versus time of day, over 39 sample days

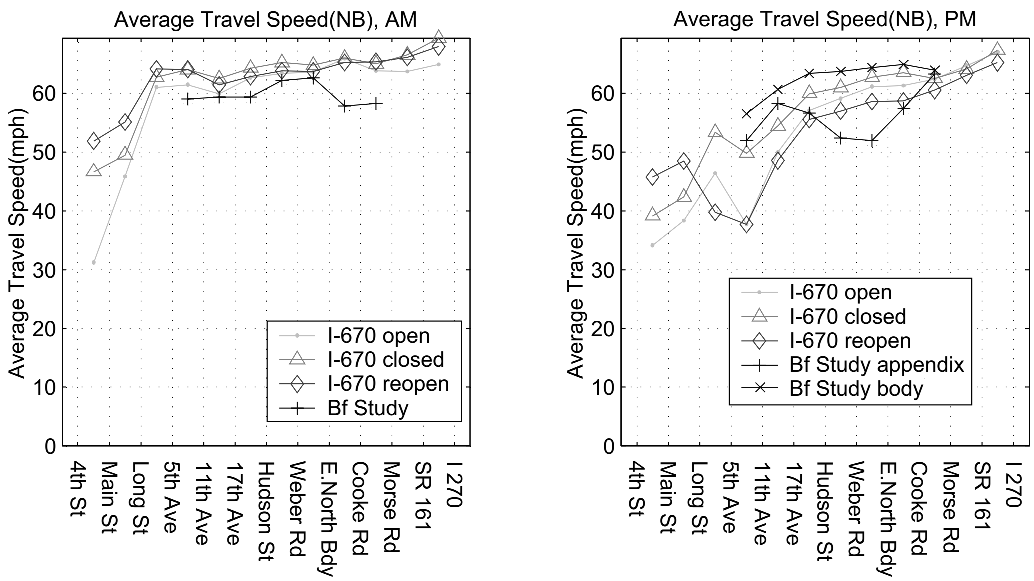


Figure 59, Northbound travel time on I-71 before and after the start of CMFMS operations

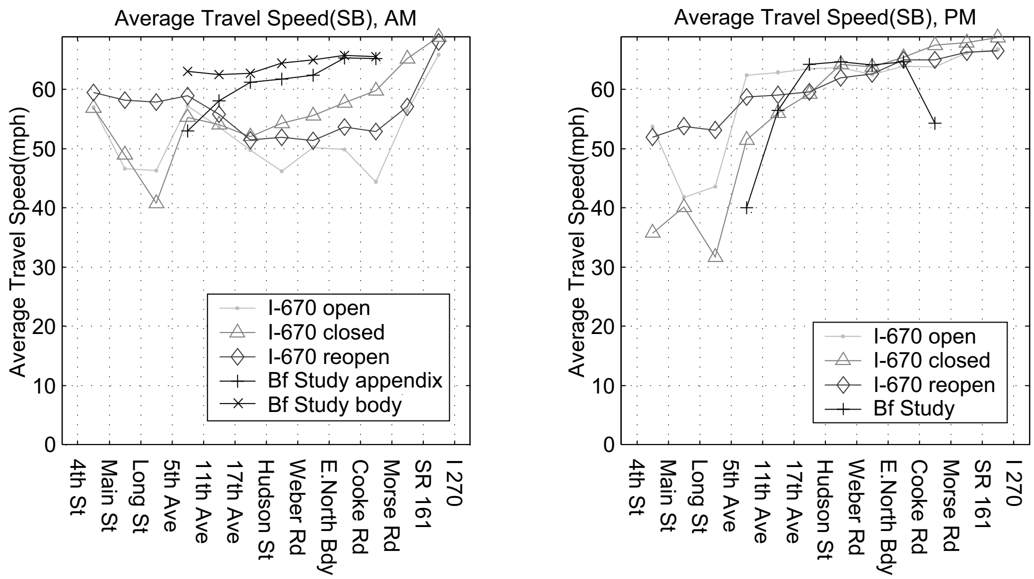


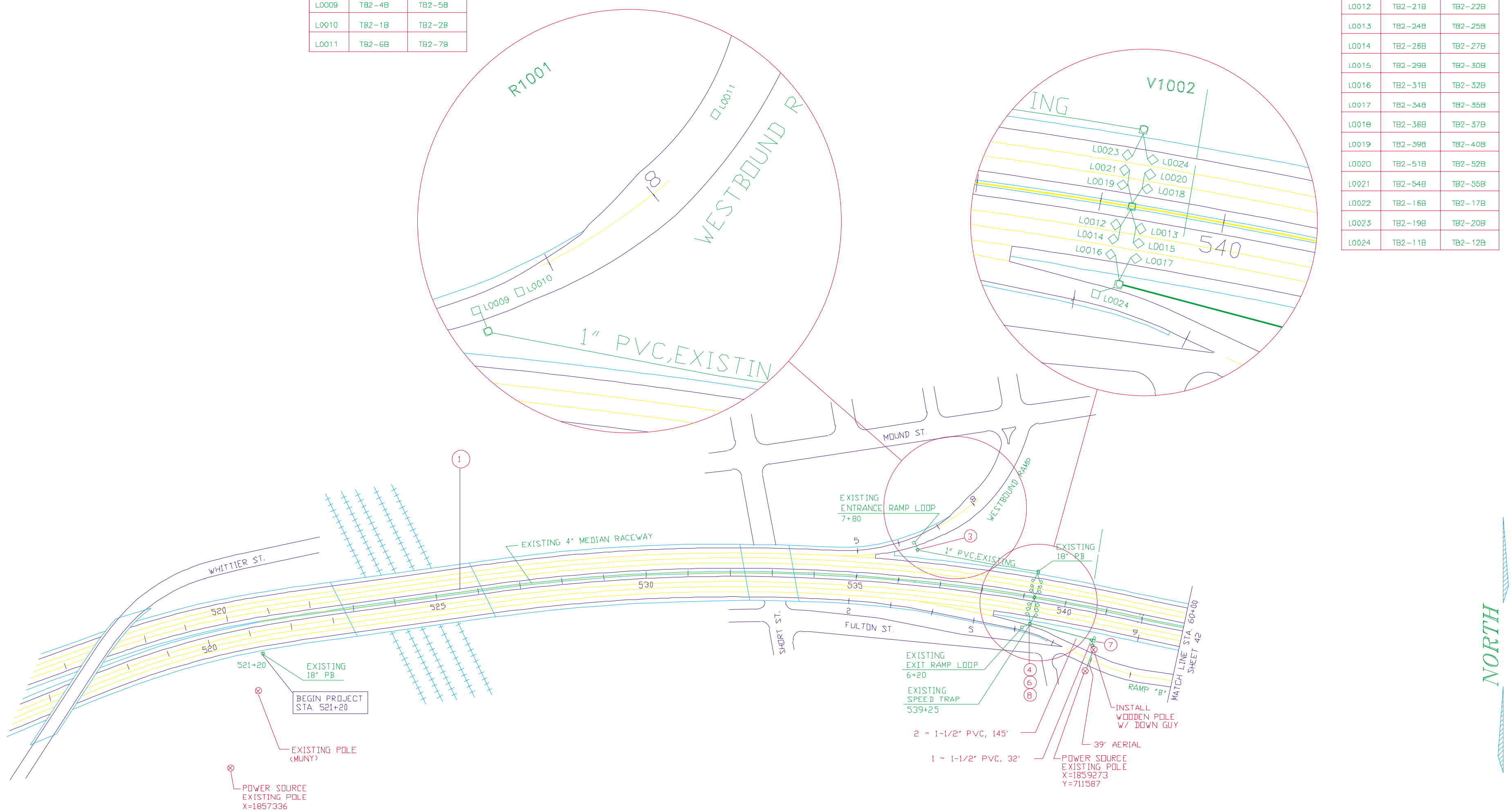
Figure 60, Northbound travel time on I-71 before and after the start of CMFMS operations

APPENDIX A: I-71 SCHEMATICS

ODOT has authorized the use and inclusion of the schematics presented in this appendix. ODOT claims ownership of these diagrams and that they have a written statement from Transdyn Controls to this effect.

STATION 7+80 R1001		
LOOP	T1	T2
L0009	TB2-4B	TB2-5B
L0010	TB2-1B	TB2-2B
L0011	TB2-6B	TB2-7B

STATION 540+75 V1002		
LOOP	T1	T2
L0012	TB2-21B	TB2-22B
L0013	TB2-24B	TB2-25B
L0014	TB2-26B	TB2-27B
L0015	TB2-29B	TB2-30B
L0016	TB2-31B	TB2-32B
L0017	TB2-34B	TB2-35B
L0018	TB2-36B	TB2-37B
L0019	TB2-39B	TB2-40B
L0020	TB2-51B	TB2-52B
L0021	TB2-54B	TB2-55B
L0022	TB2-16B	TB2-17B
L0023	TB2-19B	TB2-20B
L0024	TB2-11B	TB2-12B



NOTE:

DESIGNED BY	R. EUSEY
DRAWN BY	R. EUSEY
CHECKED BY	C. WILLIAMS
DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION	BY	APP.
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Pleasanton, California

STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

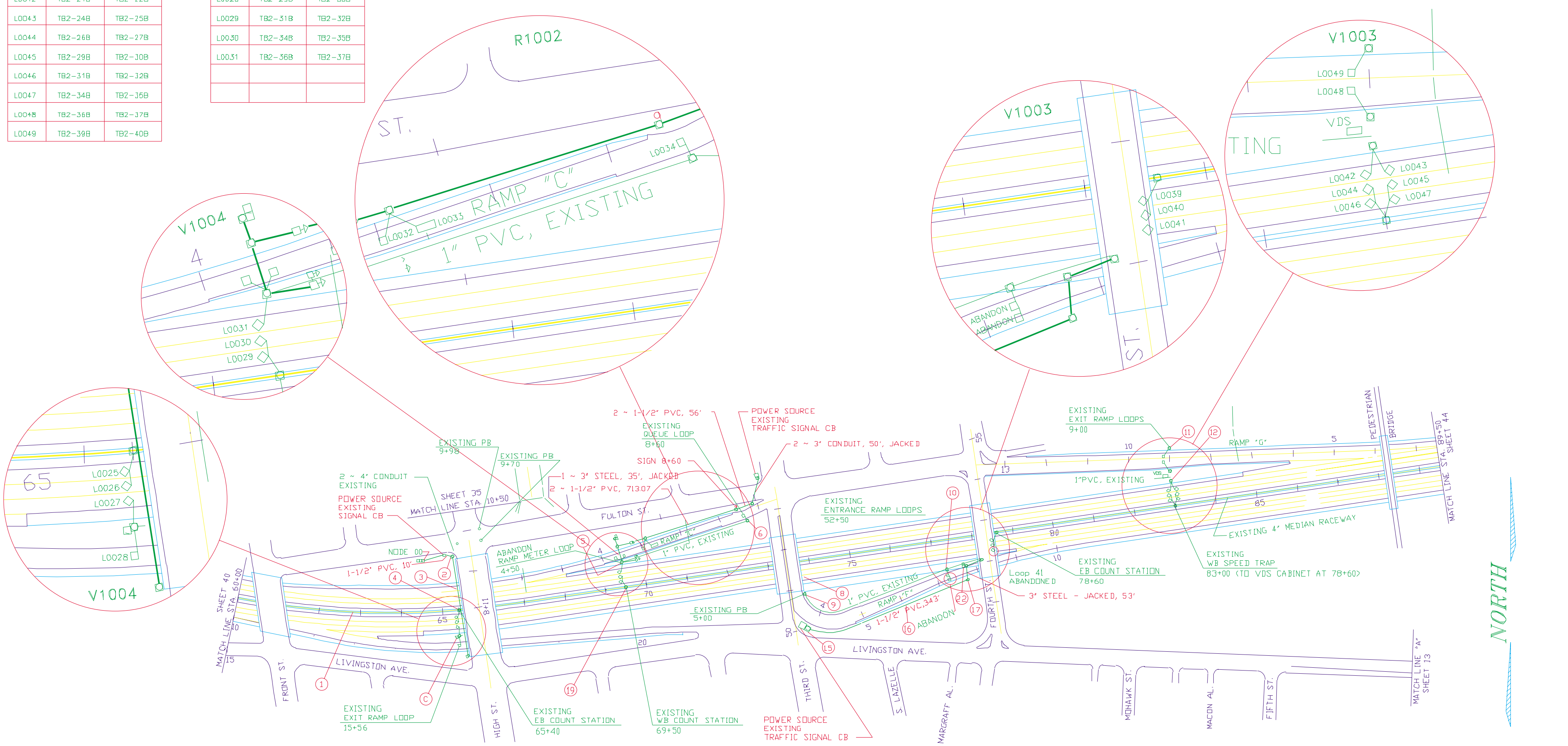
VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE	JOB NO. 3004	
CAD FILE NO. 3004-500101	SHT. 1	OF 1
DRAWING NO. 3004-5001-01	REV. 1	

STATION 78+60 V1003		
LOOP	T1	T2
L0039	TB2-51B	TB2-52B
L0040	TB2-54B	TB2-55B
L0042	TB2-21B	TB2-22B
L0043	TB2-24B	TB2-25B
L0044	TB2-26B	TB2-27B
L0045	TB2-29B	TB2-30B
L0046	TB2-31B	TB2-32B
L0047	TB2-34B	TB2-35B
L0048	TB2-36B	TB2-37B
L0049	TB2-39B	TB2-40B

STATION 65+40 V1004		
LOOP	T1	T2
L0025	TB2-21B	TB2-22B
L0026	TB2-24B	TB2-25B
L0027	TB2-26B	TB2-27B
L0028	TB2-29B	TB2-30B
L0029	TB2-31B	TB2-32B
L0030	TB2-34B	TB2-35B
L0031	TB2-36B	TB2-37B

STATION 8+60 R1002		
LOOP	T1	T2
L0032	TB2-4B	TB2-6B
L0033	TB2-1B	TB2-2B
L0034	TB2-6B	TB2-7B



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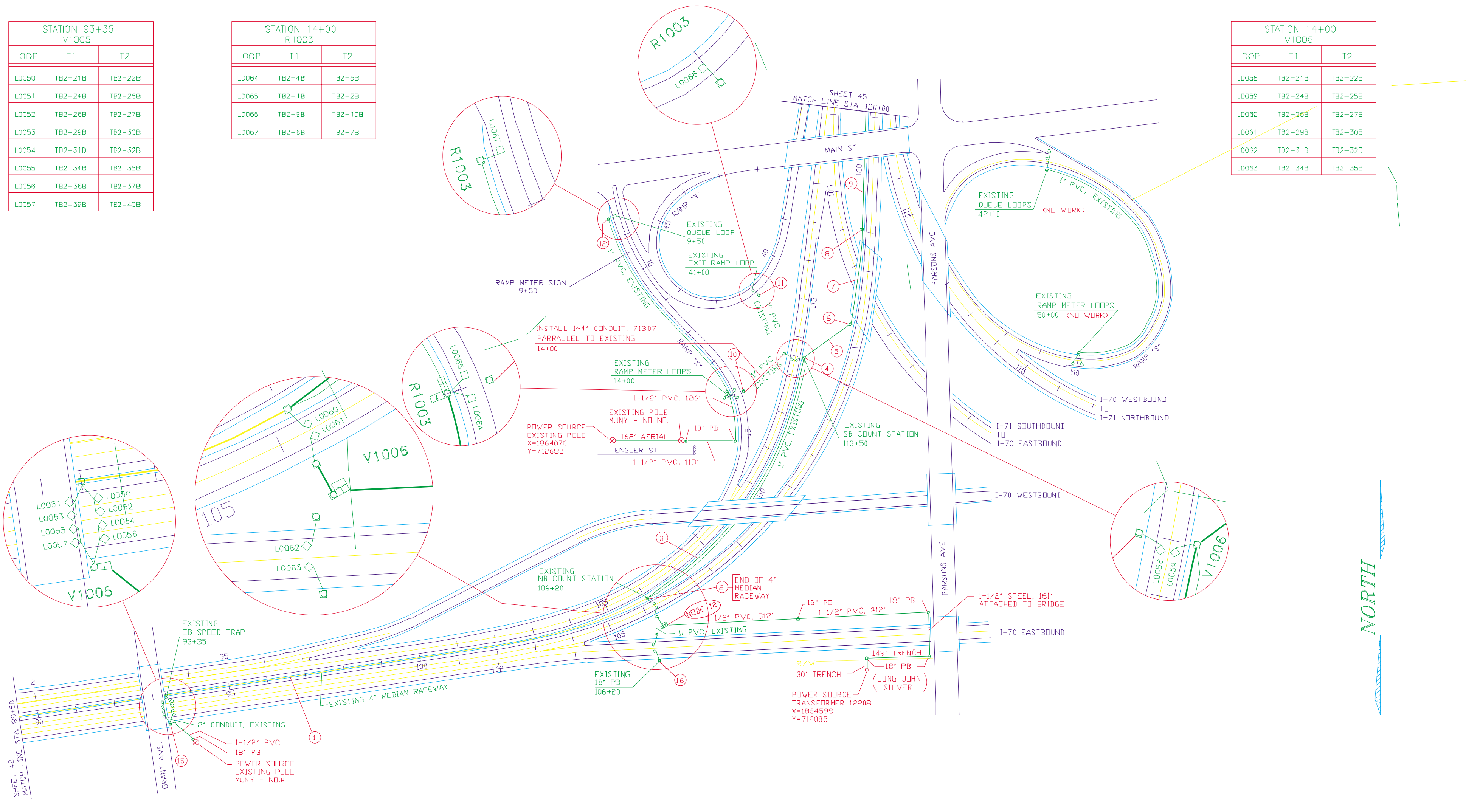
CAD FILE NO. 3004-500201
SHT. 1 OF 1
DRAWING NO. 3004-5002-01
REV. 1

STATION 93+35 V1005		
LOOP	T1	T2
L0050	TB2-21B	TB2-22B
L0051	TB2-24B	TB2-25B
L0052	TB2-26B	TB2-27B
L0053	TB2-29B	TB2-30B
L0054	TB2-31B	TB2-32B
L0055	TB2-34B	TB2-35B
L0056	TB2-36B	TB2-37B
L0057	TB2-39B	TB2-40B

STATION 14+00 R1003		
LOOP	T1	T2
L0064	TB2-4B	TB2-5B
L0065	TB2-1B	TB2-2B
L0066	TB2-9B	TB2-10B
L0067	TB2-6B	TB2-7B

STATION 14+00 V1006		
LOOP	T1	T2
L0058	TB2-21B	TB2-22B
L0059	TB2-24B	TB2-25B
L0060	TB2-26B	TB2-27B
L0061	TB2-29B	TB2-30B
L0062	TB2-31B	TB2-32B
L0063	TB2-34B	TB2-35B



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CHECKED BY	C. WILLIAMS
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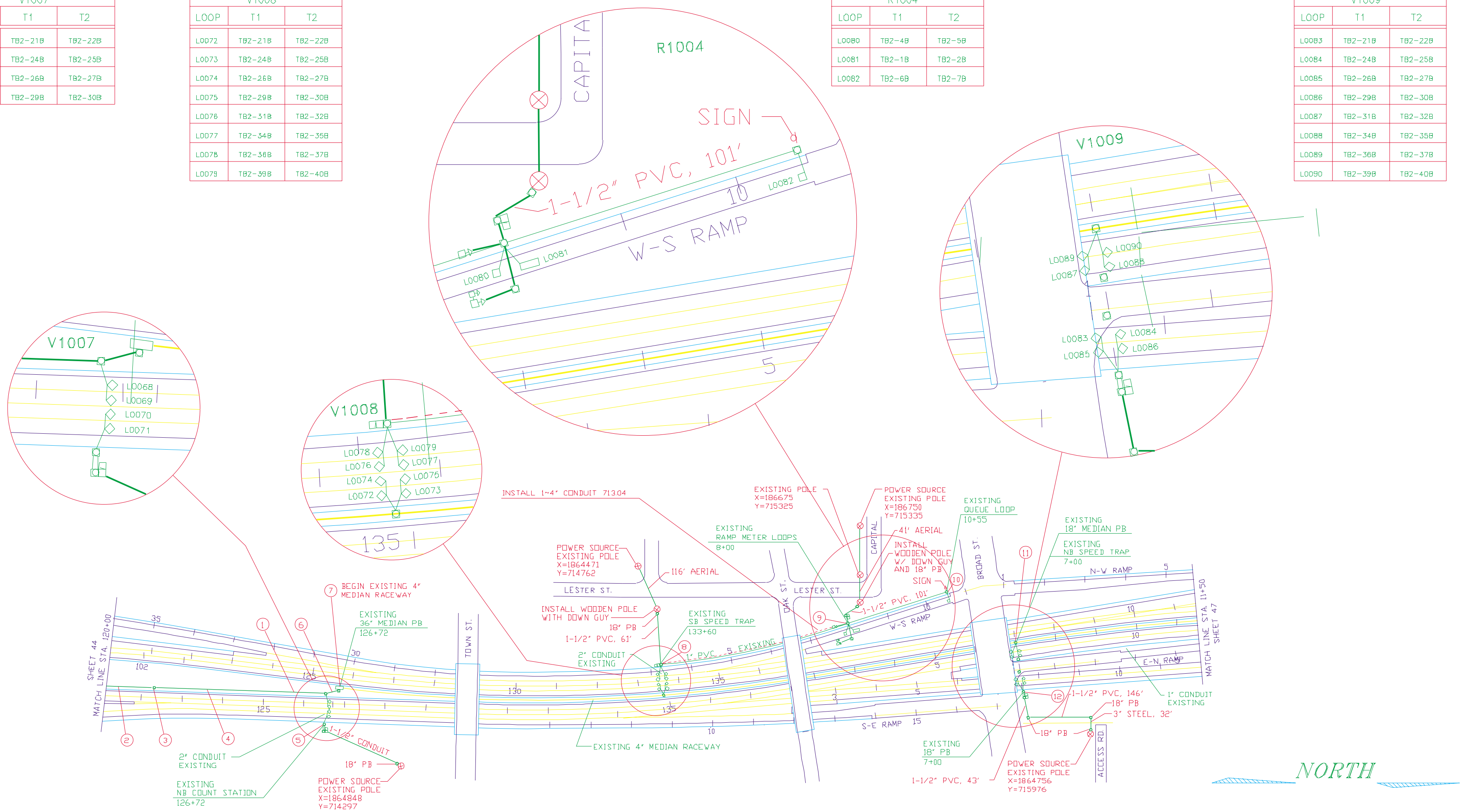
CAD FILE NO. 3004-500301	SHT. 1	OF 1	
DRAWING NO. 3004-5003-01			REV. 1

STATION 126+72 V1007		
LOOP	T1	T2
L0068	TB2-21B	TB2-22B
L0069	TB2-24B	TB2-25B
L0070	TB2-26B	TB2-27B
L0071	TB2-29B	TB2-30B

STATION 133+60 V1008		
LOOP	T1	T2
L0072	TB2-21B	TB2-22B
L0073	TB2-24B	TB2-25B
L0074	TB2-26B	TB2-27B
L0075	TB2-29B	TB2-30B
L0076	TB2-31B	TB2-32B
L0077	TB2-34B	TB2-35B
L0078	TB2-36B	TB2-37B
L0079	TB2-39B	TB2-40B

STATION 8+00 R1004		
LOOP	T1	T2
L0080	TB2-4B	TB2-5B
L0081	TB2-1B	TB2-2B
L0082	TB2-6B	TB2-7B

STATION 7+00 V1009		
LOOP	T1	T2
L0083	TB2-21B	TB2-22B
L0084	TB2-24B	TB2-25B
L0085	TB2-26B	TB2-27B
L0086	TB2-29B	TB2-30B
L0087	TB2-31B	TB2-32B
L0088	TB2-34B	TB2-35B
L0089	TB2-36B	TB2-37B
L0090	TB2-39B	TB2-40B



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DESIGNED BY	R. EUSCY
DRAWN BY	R. EUSCY
CHECKED BY	C. WILLIAMS
DATE: 03-04-99	UPDATE: 09-03-02

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0	04-27-99	ISSUED FOR CONSTRUCTION	/S/	R.E.	PI
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Pleasanton, California

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CITY OF COLUMBUS MFMS

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TERMINATION DETAILS

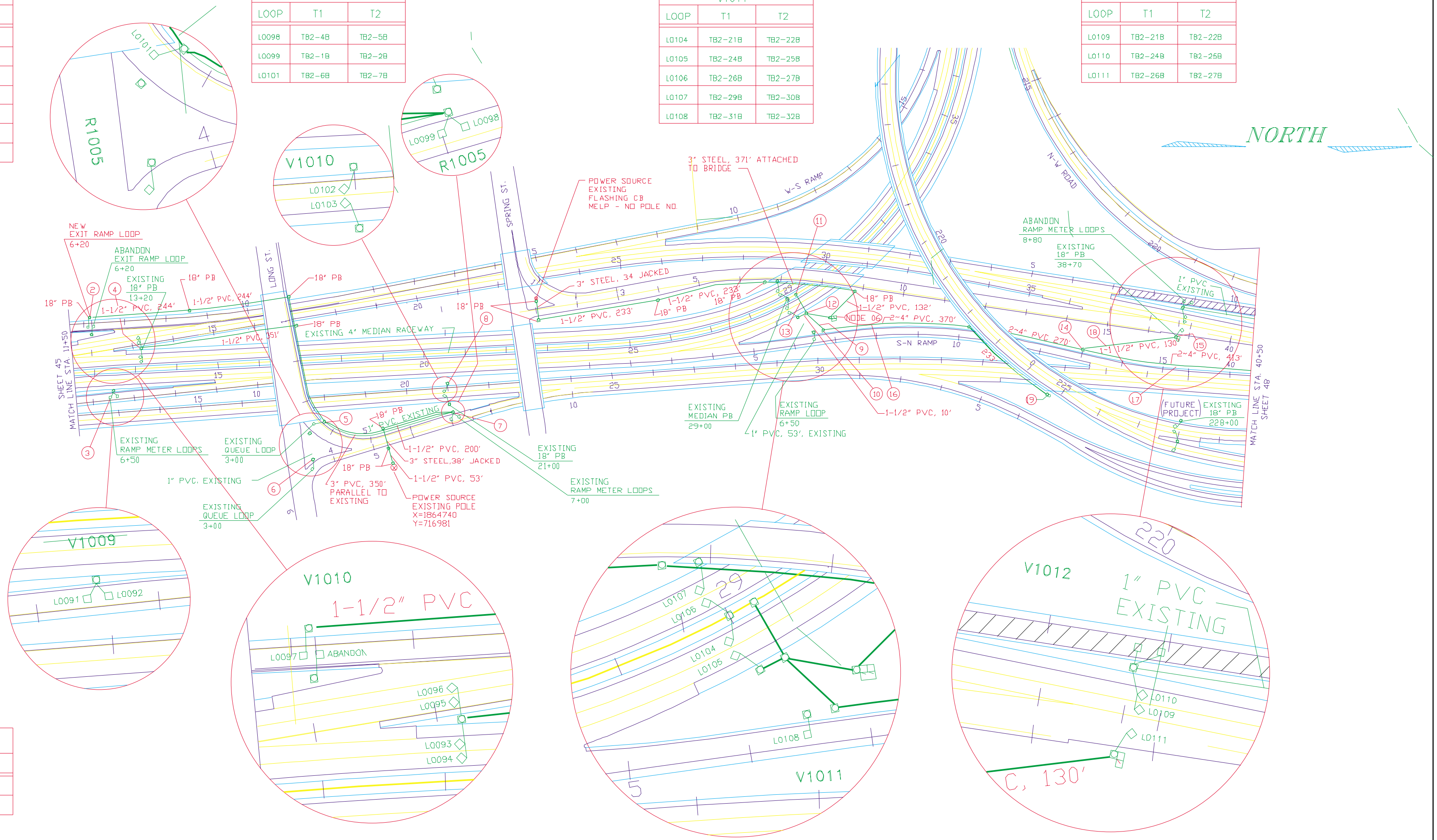
SCALE: NONE		JOB NO. 3004	
CAD FILE NO. 3004-500401		SHT. 1	OF 1
DRAWING NO. 3004-5004-01		REV. 1	

STATION 121+00 V1010		
LOOP	T1	T2
L0093	TB2-26B	TB2-27B
L0094	TB2-29B	TB2-30B
L0095	TB2-31B	TB2-32B
L0096	TB2-34B	TB2-35B
L0097	TB2-36B	TB2-37B
L0102	TB2-21B	TB2-22B
L0103	TB2-24B	TB2-25B

STATION 7+00 R1005		
LOOP	T1	T2
L0098	TB2-4B	TB2-5B
L0099	TB2-1B	TB2-2B
L0101	TB2-6B	TB2-7B

STATION 6+95 V1011		
LOOP	T1	T2
L0104	TB2-21B	TB2-22B
L0105	TB2-24B	TB2-25B
L0106	TB2-26B	TB2-27B
L0107	TB2-29B	TB2-30B
L0108	TB2-31B	TB2-32B

STATION 38+70 V1012		
LOOP	T1	T2
L0109	TB2-21B	TB2-22B
L0110	TB2-24B	TB2-25B
L0111	TB2-26B	TB2-27B



1	08-30-02	FIELD AS-BUILT	MC	
0	04-27-99	ISSUED FOR CONSTRUCTION	/S/ R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL	/S/ R.E.	C.W.
REV.	DATE	DESCRIPTION	BY	APP.

NOTE:

DESIGNED BY R. EUSEY
DRAWN BY R. EUSEY
CHECKED BY C. WILLIAMS
DATE: 03-04-99 UPDATE: 09-03-02

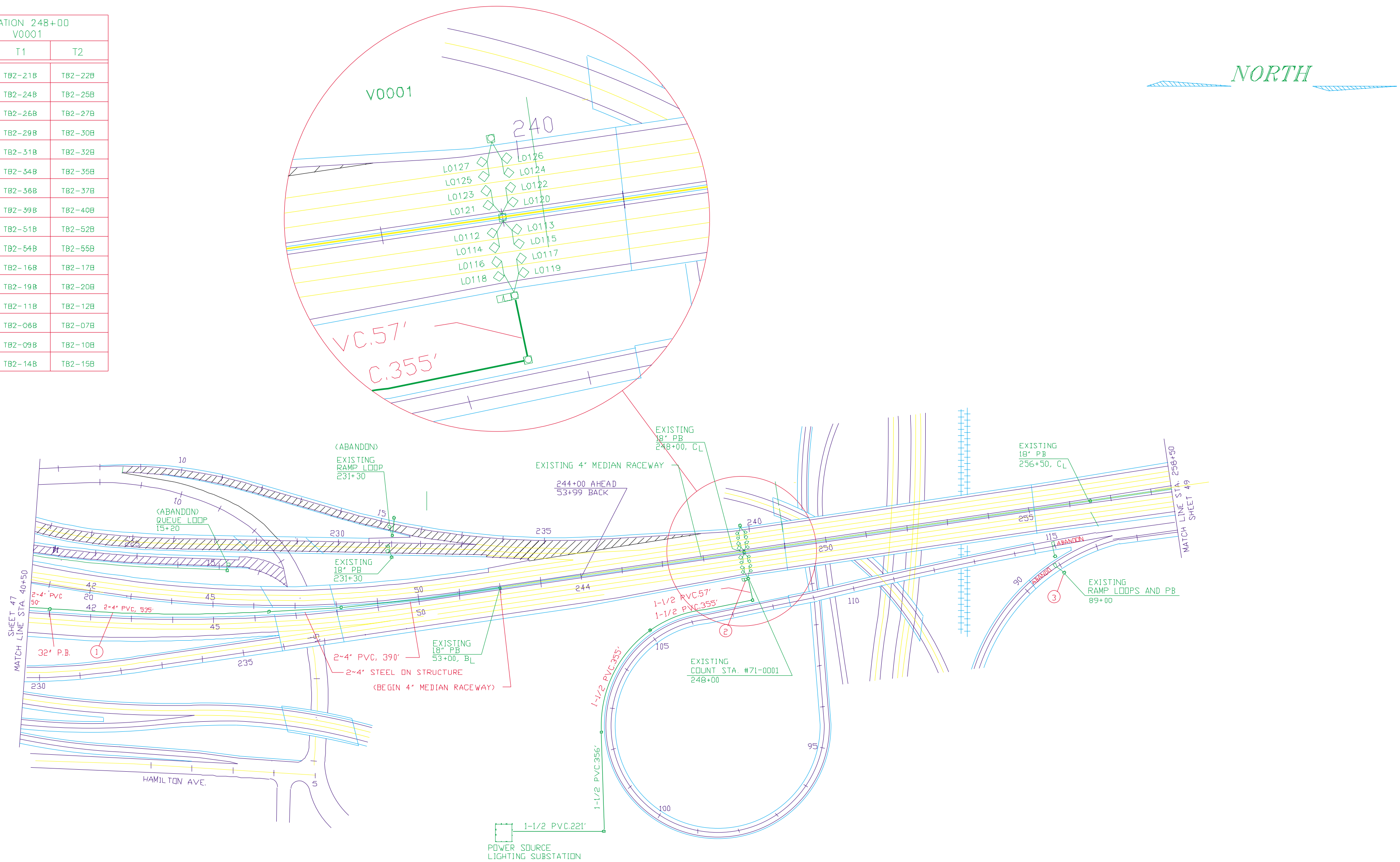
TRANSDYN CONTROLS
Pleasanton, California

STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE
JOB NO. 3004
CAD FILE NO. 3004-500501
SHT. 1 OF 1
DRAWING NO. 3004-5005-01
REV. 1

STATION 248+00 V0001		
LOOP	T1	T2
L0112	TB2-21B	TB2-22B
L0113	TB2-24B	TB2-25B
L0114	TB2-26B	TB2-27B
L0115	TB2-29B	TB2-30B
L0116	TB2-31B	TB2-32B
L0117	TB2-34B	TB2-35B
L0118	TB2-36B	TB2-37B
L0119	TB2-39B	TB2-40B
L0120	TB2-51B	TB2-52B
L0121	TB2-54B	TB2-55B
L0122	TB2-16B	TB2-17B
L0123	TB2-19B	TB2-20B
L0124	TB2-11B	TB2-12B
L0125	TB2-06B	TB2-07B
L0126	TB2-09B	TB2-10B
L0127	TB2-14B	TB2-15B



NOTE:

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CHECKED BY C. WILLIAMS
DATE: 03-04-99 UPDATE: 09-03-02

REV.	DATE	DESCRIPTION		BY	APP.
1	08-30-02	FIELD AS-BUILT		MC	
0	04-27-99	ISSUED FOR CONSTRUCTION	/S/	R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL	/S/	R.E.	C.W.

TRANSDYN CONTROLS
Pleasanton, California

STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

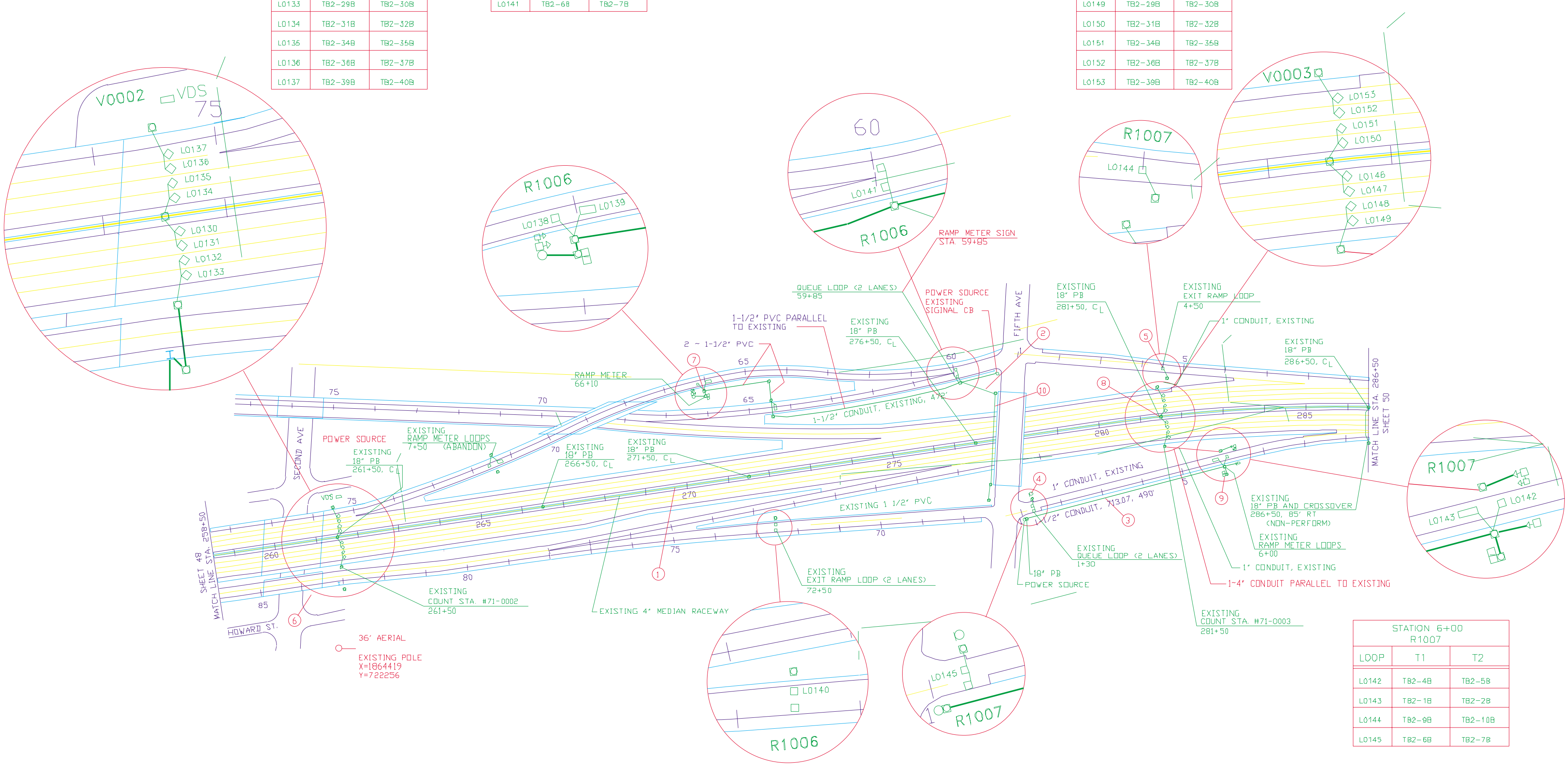
SCALE: NONE
JOB NO. 3004
CAD FILE NO. 3004-500601
SHT. 1 OF 1
DRAWING NO. 3004-5006-01
REV. 1

STATION 261+50 V0002		
LOOP	T1	T2
L0130	TB2-21B	TB2-22B
L0131	TB2-24B	TB2-25B
L0132	TB2-26B	TB2-27B
L0133	TB2-29B	TB2-30B
L0134	TB2-31B	TB2-32B
L0135	TB2-34B	TB2-35B
L0136	TB2-36B	TB2-37B
L0137	TB2-39B	TB2-40B

STATION 66+10 R1006		
LOOP	T1	T2
L0138	TB2-4B	TB2-5B
L0139	TB2-1B	TB2-2B
L0140	TB2-9B	TB2-10B
L0141	TB2-6B	TB2-7B

STATION 281+50 V0003		
LOOP	T1	T2
L0146	TB2-21B	TB2-22B
L0147	TB2-24B	TB2-25B
L0148	TB2-26B	TB2-27B
L0149	TB2-29B	TB2-30B
L0150	TB2-31B	TB2-32B
L0151	TB2-34B	TB2-35B
L0152	TB2-36B	TB2-37B
L0153	TB2-39B	TB2-40B

NORTH



STATION 6+00 R1007		
LOOP	T1	T2
L0142	TB2-4B	TB2-5B
L0143	TB2-1B	TB2-2B
L0144	TB2-9B	TB2-10B
L0145	TB2-6B	TB2-7B

NOTE:

DESIGNED BY: R. EUSEY
DRAWN BY: R. EUSEY
CHECKED BY: C. WILLIAMS
DATE: 03-04-99 UPDATE: 09-05-02

REV.	DATE	DESCRIPTION	BY	APP.
1	08-26-02	FIELD AS-BUILT	MC	
0	04-27-99	ISSUED FOR CONSTRUCTION	/S/ R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL	/S/ R.E.	C.W.

TRANSDYN CONTROLS
Pleasanton, California

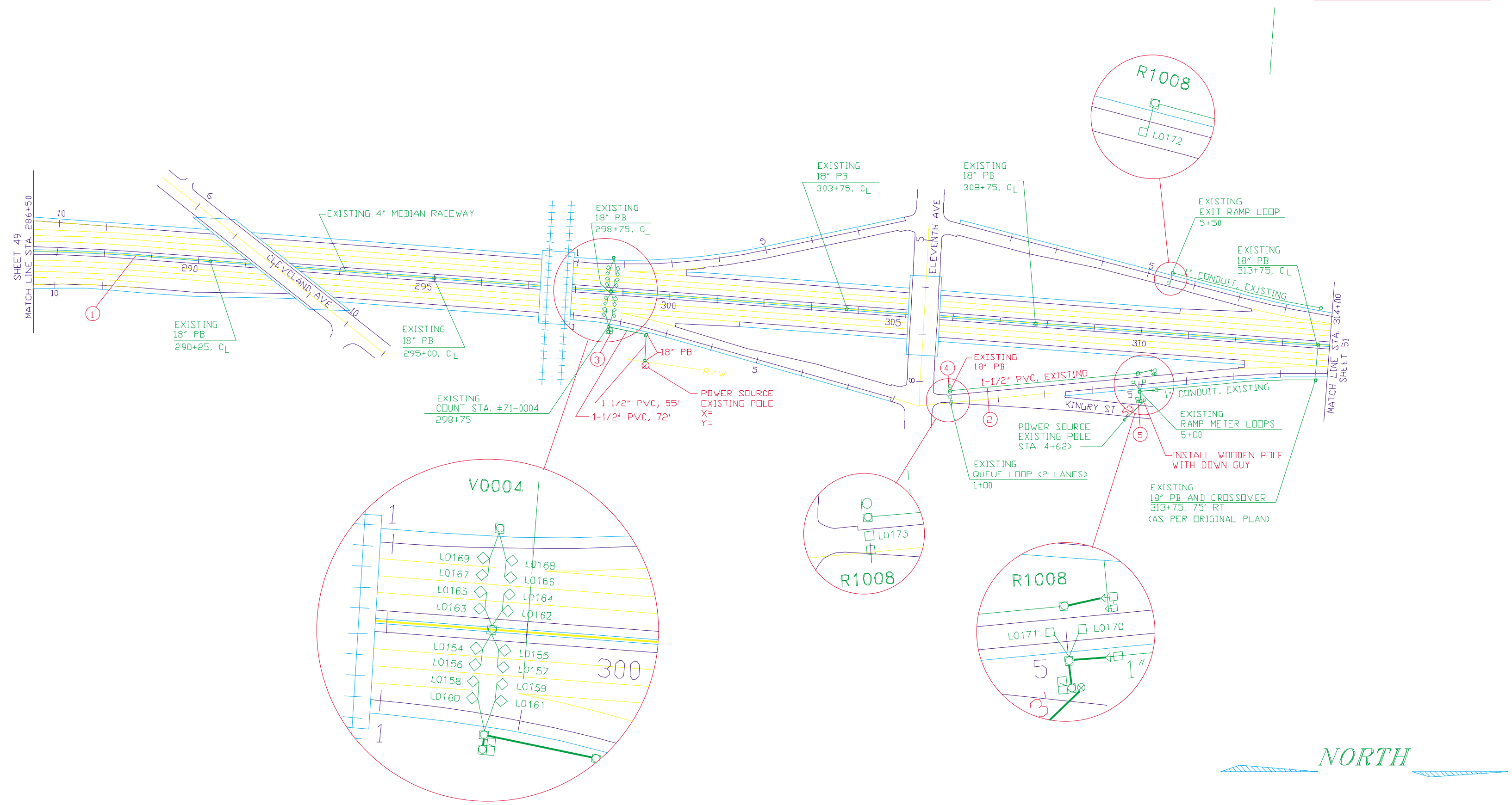
STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE
JOB NO. 3004
CAD FILE NO. 3004-500701
SHT. 1 OF 1
DRAWING NO. 3004-5007-01
REV. 1

STATION 298+75 V0004		
LOOP	T1	T2
L0154	TB2-21B	TB2-22B
L0155	TB2-24B	TB2-25B
L0156	TB2-26B	TB2-27B
L0157	TB2-29B	TB2-30B
L0158	TB2-31B	TB2-32B
L0159	TB2-34B	TB2-35B
L0160	TB2-36B	TB2-37B
L0161	TB2-39B	TB2-40B
L0162	TB2-51B	TB2-52B
L0163	TB2-54B	TB2-55B
L0164	TB2-16B	TB2-17B
L0165	TB2-19B	TB2-20B
L0166	TB2-11B	TB2-12B
L0167	TB2-06B	TB2-07B
L0168	TB2-09B	TB2-10B
L0169	TB2-14B	TB2-15B

STATION 5+00 R1008		
LOOP	T1	T2
L0170	TB2-4B	TB2-5B
L0171	TB2-1B	TB2-2B
L0172	TB2-9B	TB2-10B
L0173	TB2-6B	TB2-7B



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CHECKED BY	C. WILLIAMS
DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION	BY	APP
1	08-30-02	FIELD AS-BUILT	MC	
0	04-27-99	ISSUED FOR CONSTRUCTION /S/	R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL /S/	R.E.	C.W.

TRANSDYN CONTROLS
Pleasanton, California

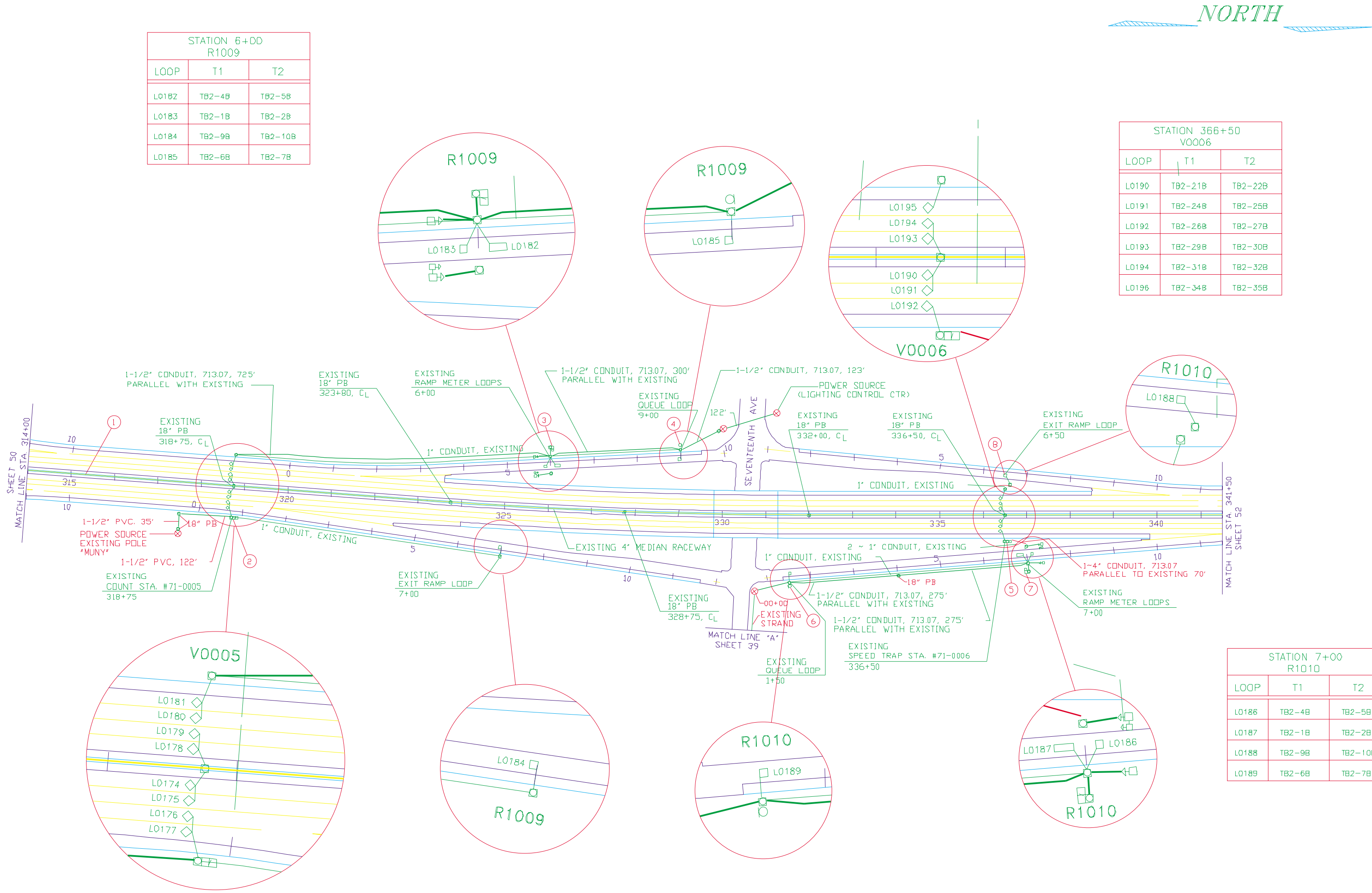
STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE	JOB NO. 3004	
CAD FILE NO. 3004-500801	SHT. 1	OF 1
DRAWING NO. 3004-5008-01	REV. 1	

STATION 6+00 R1009		
LOOP	T1	T2
L0182	TB2-4B	TB2-5B
L0183	TB2-1B	TB2-2B
L0184	TB2-9B	TB2-10B
L0185	TB2-6B	TB2-7B

STATION 366+50 V0006		
LOOP	T1	T2
L0190	TB2-21B	TB2-22B
L0191	TB2-24B	TB2-25B
L0192	TB2-26B	TB2-27B
L0193	TB2-29B	TB2-30B
L0194	TB2-31B	TB2-32B
L0196	TB2-34B	TB2-35B



STATION 318+75 V0005		
LOOP	T1	T2
L0174	TB2-21B	TB2-22B
L0175	TB2-24B	TB2-25B
L0176	TB2-26B	TB2-27B
L0177	TB2-29B	TB2-30B
L0178	TB2-31B	TB2-32B
L0179	TB2-34B	TB2-35B
L0180	TB2-36B	TB2-37B
L0181	TB2-39B	TB2-40B

STATION 7+00 R1010		
LOOP	T1	T2
L0186	TB2-4B	TB2-5B
L0187	TB2-1B	TB2-2B
L0188	TB2-9B	TB2-10B
L0189	TB2-6B	TB2-7B

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DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION	BY	APP
1	08-30-02	FIELD AS-BUILT	MC	
0	04-27-99	ISSUED FOR CONSTRUCTION	/S/ R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL	/S/ R.E.	C.W.

TRANSDYN CONTROLS
Pleasanton, California

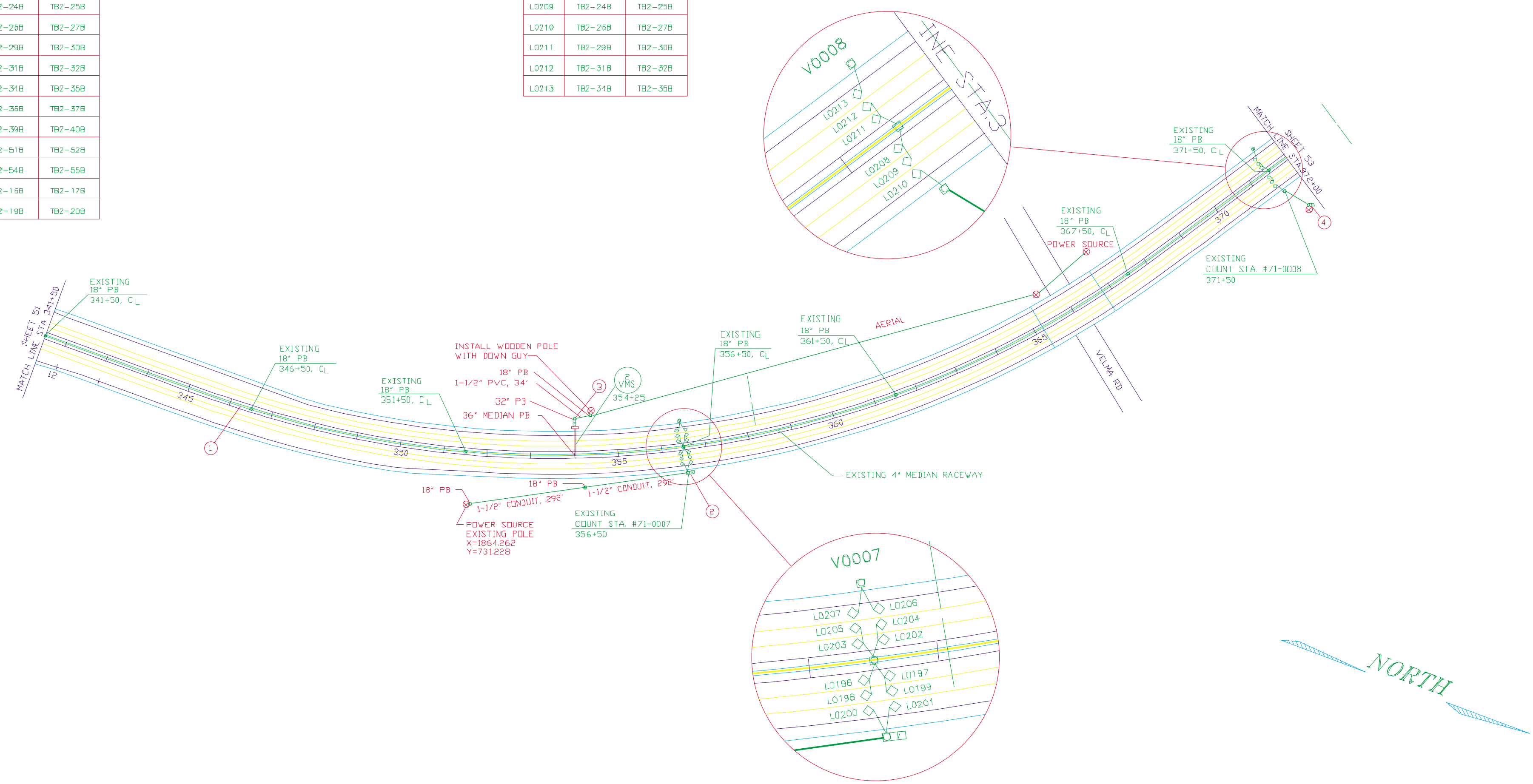
STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE	JOB NO. 3004
CAD FILE NO. 3004-500901	SHT. 1 OF 1
DRAWING NO. 3004-5009-01	REV. 1

STATION 360+50 V0007		
LOOP	T1	T2
L0196	TB2-21B	TB2-22B
L0197	TB2-24B	TB2-25B
L0198	TB2-26B	TB2-27B
L0199	TB2-29B	TB2-30B
L0200	TB2-31B	TB2-32B
L0201	TB2-34B	TB2-35B
L0202	TB2-36B	TB2-37B
L0203	TB2-39B	TB2-40B
L0204	TB2-51B	TB2-52B
L0205	TB2-54B	TB2-55B
L0206	TB2-16B	TB2-17B
L0207	TB2-19B	TB2-20B

STATION 371+50 V0008		
LOOP	T1	T2
L0208	TB2-21B	TB2-22B
L0209	TB2-24B	TB2-25B
L0210	TB2-26B	TB2-27B
L0211	TB2-29B	TB2-30B
L0212	TB2-31B	TB2-32B
L0213	TB2-34B	TB2-35B



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DRAWN BY	R. EUSEY
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REV.	DATE	DESCRIPTION		BY	APP.
1	08-30-02	FIELD AS-BUILT		MC	
0	04-27-99	ISSUED FOR CONSTRUCTION	/S/	R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL	/S/	R.E.	C.W.

TRANSDYN CONTROLS
Pleasanton, California

STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

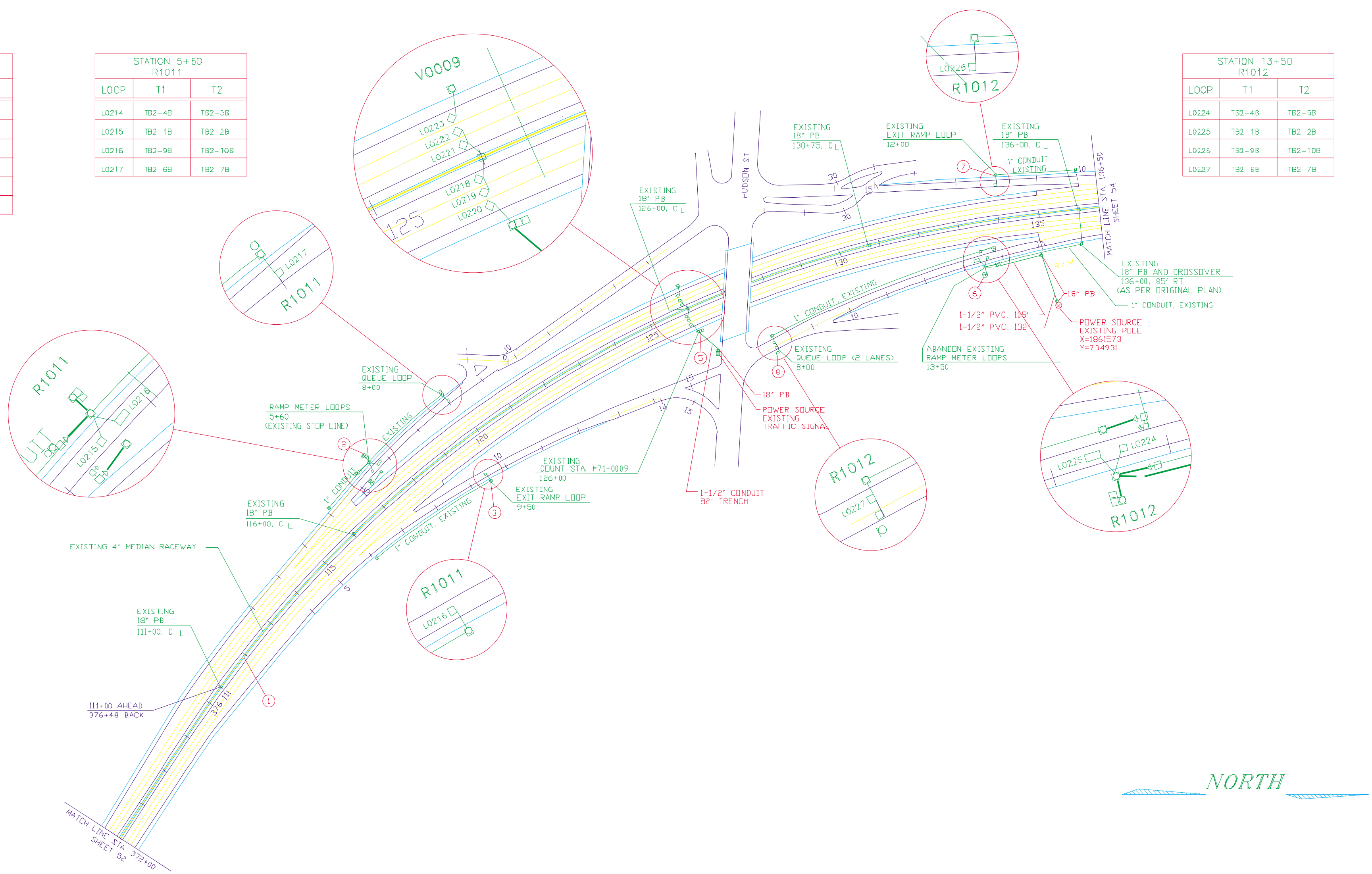
VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE	JOB NO. 3004
CAD FILE NO. 3004-501001	SHT. 1 OF 1
DRAWING NO. 3004-5010-01	REV. 1

STATION 126+00 V0009		
LOOP	T1	T2
L0218	TB2-21B	TB2-22B
L0219	TB2-24B	TB2-25B
L0220	TB2-26B	TB2-27B
L0221	TB2-29B	TB2-30B
L0222	TB2-31B	TB2-32B
L0223	TB2-34B	TB2-35B

STATION 5+60 R1011		
LOOP	T1	T2
L0214	TB2-4B	TB2-5B
L0215	TB2-1B	TB2-2B
L0216	TB2-9B	TB2-10B
L0217	TB2-6B	TB2-7B

STATION 13+50 R1012		
LOOP	T1	T2
L0224	TB2-4B	TB2-5B
L0225	TB2-1B	TB2-2B
L0226	TB2-9B	TB2-10B
L0227	TB2-6B	TB2-7B



NOTE:

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CHECKED BY	C. WILLIAMS
DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION	BY	APP
1	08-30-02	FIELD AS-BUILT	MC	
0	04-27-99	ISSUED FOR CONSTRUCTION /S/	R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL /S/	R.E.	C.W.

TRANSDYN CONTROLS
Pleasanton, California

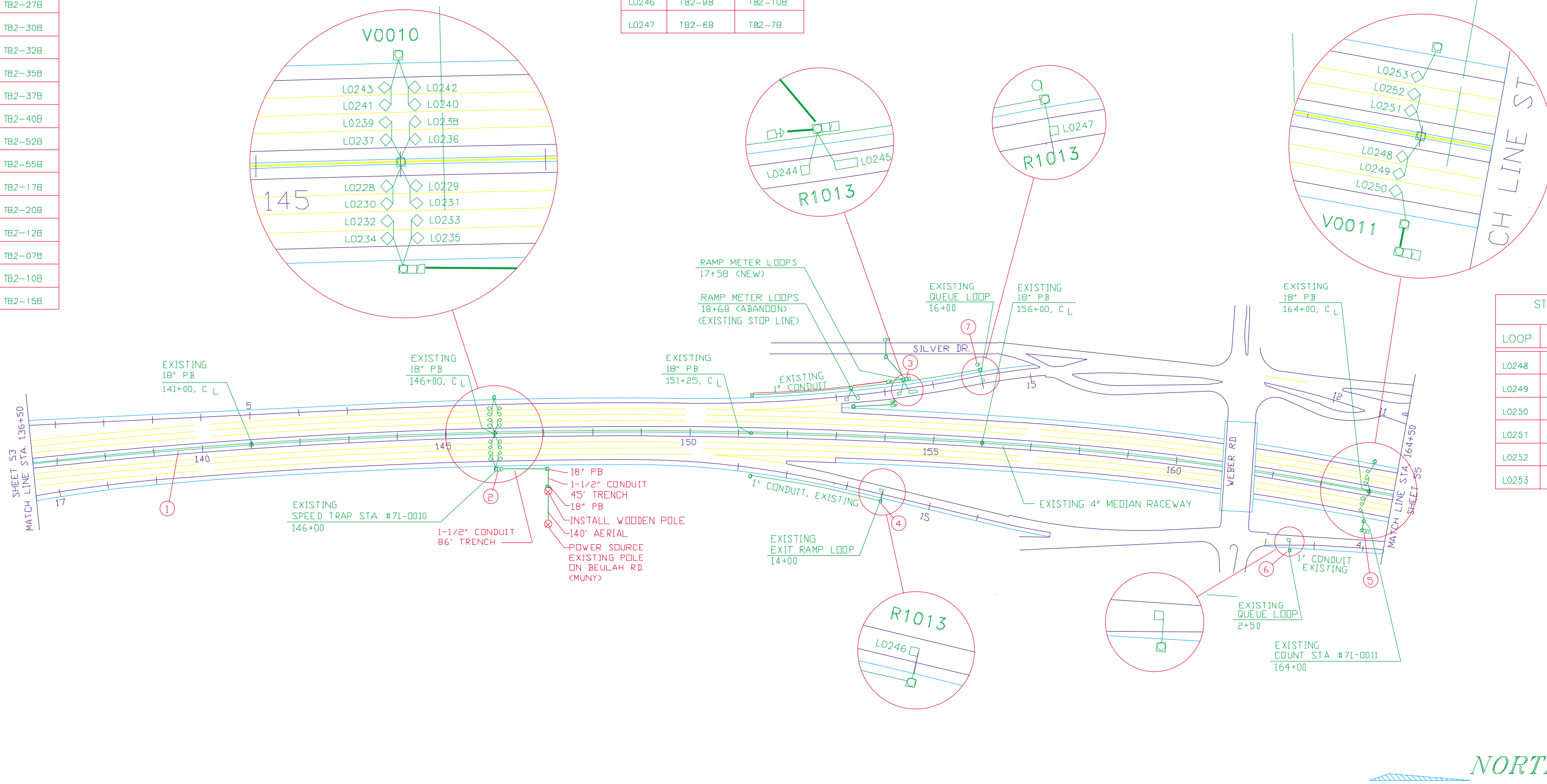
STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE		JOB NO. 3004	
CAD FILE NO. 3004-5001101		SHT. 1	OF 1
DRAWING NO. 3004-5011-01		REV. 1	

STATION 146+00 V0010		
LOOP	T1	T2
L0228	TB2-21B	TB2-22B
L0229	TB2-24B	TB2-25B
L0230	TB2-26B	TB2-27B
L0231	TB2-29B	TB2-30B
L0232	TB2-31B	TB2-32B
L0233	TB2-34B	TB2-35B
L0234	TB2-36B	TB2-37B
L0235	TB2-39B	TB2-40B
L0236	TB2-51B	TB2-52B
L0237	TB2-54B	TB2-55B
L0238	TB2-16B	TB2-17B
L0239	TB2-19B	TB2-20B
L0240	TB2-11B	TB2-12B
L0241	TB2-06B	TB2-07B
L0242	TB2-09B	TB2-10B
L0243	TB2-14B	TB2-15B

STATION 17+58 R1013		
LOOP	T1	T2
L0244	TB2-4B	TB2-5B
L0245	TB2-1B	TB2-2B
L0246	TB2-9B	TB2-10B
L0247	TB2-6B	TB2-7B



STATION 164+00 V0011		
LOOP	T1	T2
L0248	TB2-21B	TB2-22B
L0249	TB2-24B	TB2-25B
L0250	TB2-26B	TB2-27B
L0251	TB2-29B	TB2-30B
L0252	TB2-31B	TB2-32B
L0253	TB2-34B	TB2-35B

NOTE:

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DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION		BY	APP.
1	08-30-02	FIELD AS-BUILT		MC	
0	04-27-99	ISSUED FOR CONSTRUCTION	/S/	R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL	/S/	R.E.	C.W.

TRANSDYN CONTROLS
Pleasanton, California

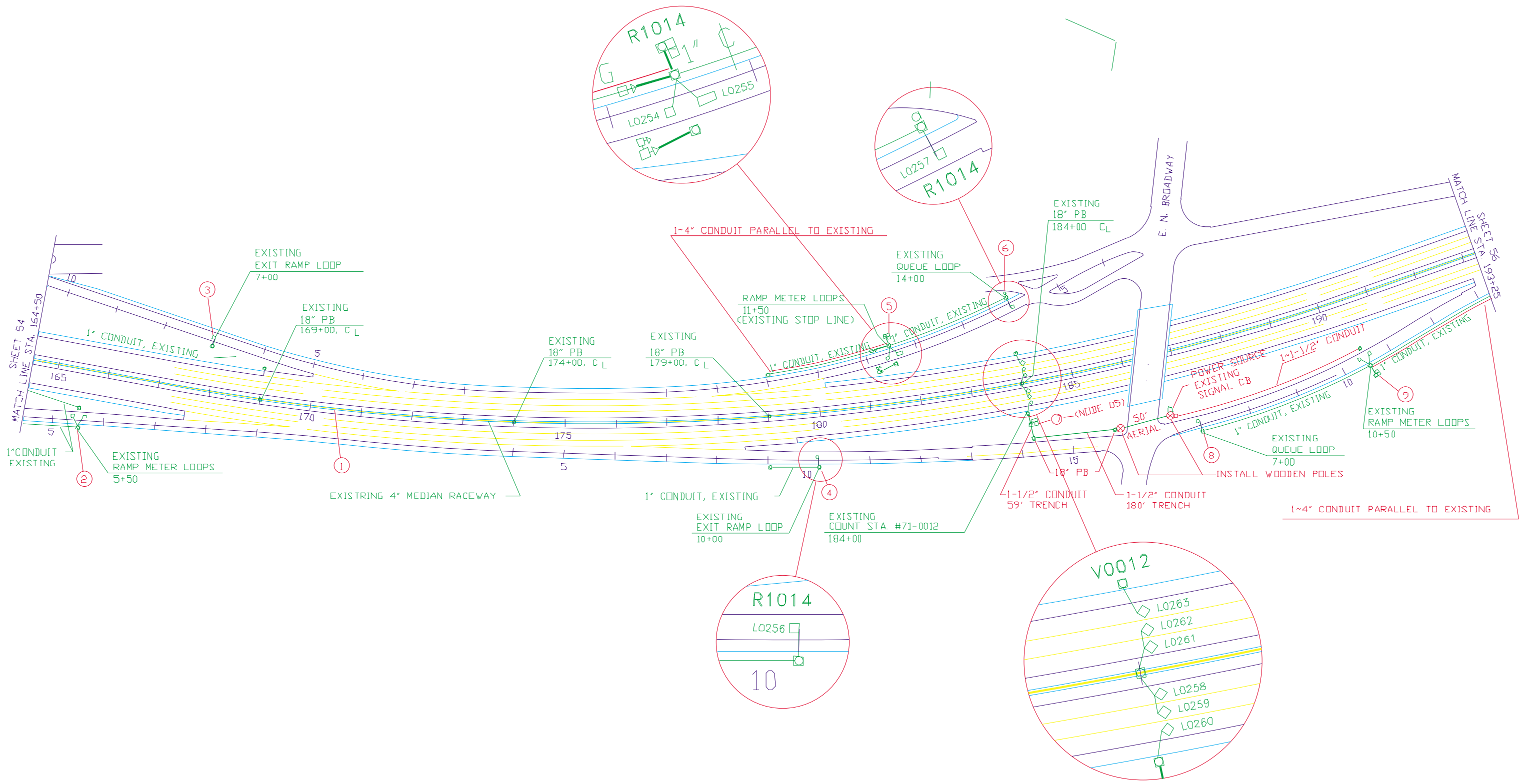
STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE	JOB NO. 3004	
CAD FILE NO. 3004-5001201	SHT. 1	OF 1
DRAWING NO. 3004-5012-01	REV. 1	

STATION 11+50 R1014		
LOOP	T1	T2
L0254	TB2-4B	TB2-5B
L0255	TB2-1B	TB2-2B
L0256	TB2-9B	TB2-10B
L0257	TB2-6B	TB2-7B

STATION 184+00 V0012		
LOOP	T1	T2
L0258	TB2-21B	TB2-22B
L0259	TB2-24B	TB2-25B
L0260	TB2-26B	TB2-27B
L0261	TB2-29B	TB2-30B
L0262	TB2-31B	TB2-32B
L0263	TB2-34B	TB2-35B



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DRAWN BY	R. EUSEY
CHECKED BY	C. WILLIAMS
DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION		BY	APP.
1	08-28-02	FIELD AS-BUILT		MC	
0	04-27-99	ISSUED FOR CONSTRUCTION	/S/	R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL	/S/	R.E.	C.W.

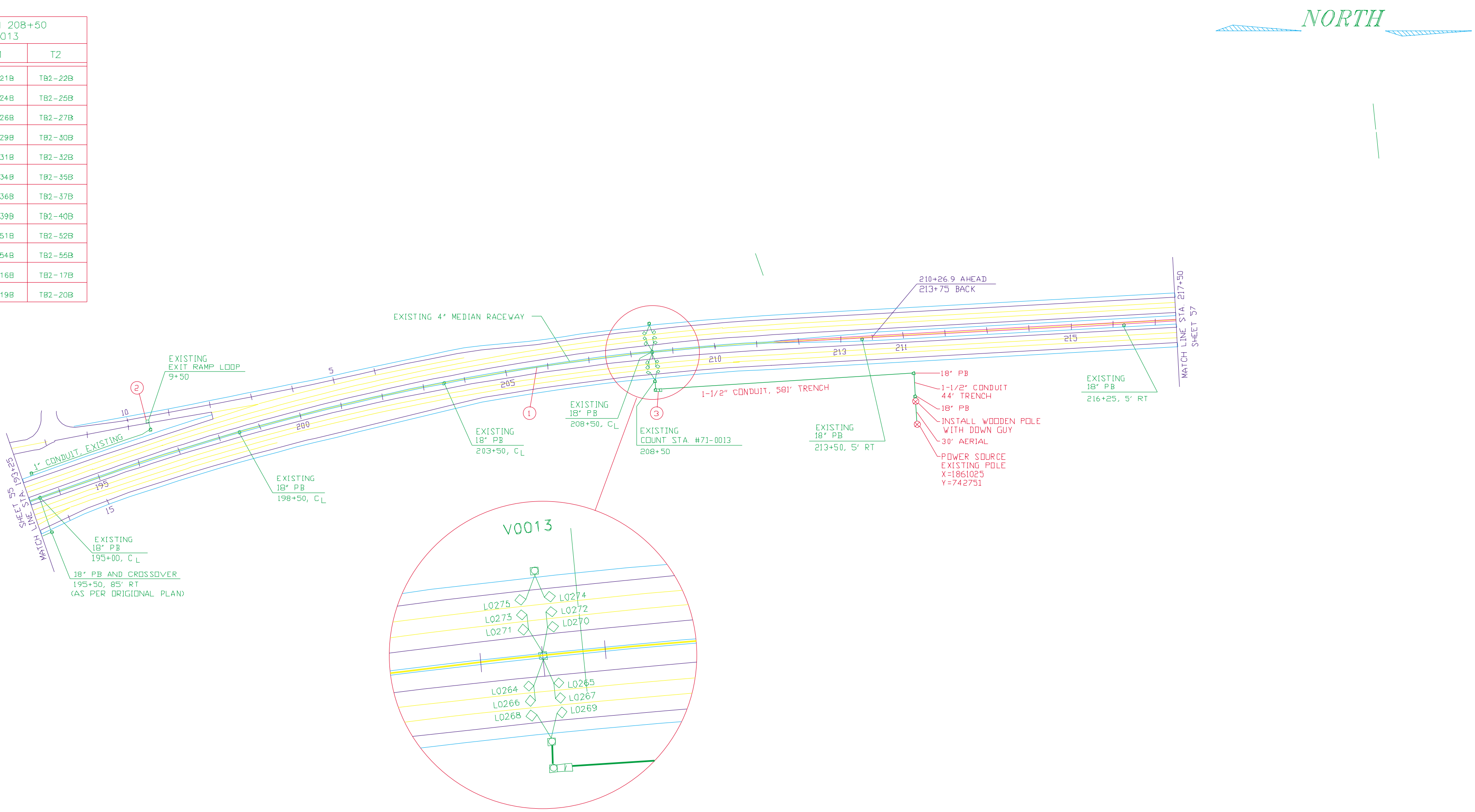
TRANSDYN CONTROLS
Pleasanton, California

STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE
JOB NO. 3004
CAD FILE NO. 3004-5001301
SHT. 1 OF 1
DRAWING NO. 3004-5013-01
REV. 1

STATION 208+50 V0013		
LOOP	T1	T2
L0264	TB2-21B	TB2-22B
L0265	TB2-24B	TB2-25B
L0266	TB2-26B	TB2-27B
L0267	TB2-29B	TB2-30B
L0268	TB2-31B	TB2-32B
L0269	TB2-34B	TB2-35B
L0270	TB2-36B	TB2-37B
L0271	TB2-39B	TB2-40B
L0272	TB2-51B	TB2-52B
L0273	TB2-54B	TB2-55B
L0274	TB2-16B	TB2-17B
L0275	TB2-19B	TB2-20B



NOTE:

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DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION		BY	APP.
1	08-30-02	FIELD AS-BUILT		MC	
0	04-27-99	ISSUED FOR CONSTRUCTION	/S/	R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL	/S/	R.E.	C.W.

TRANSDYN CONTROLS
Pleasanton, California

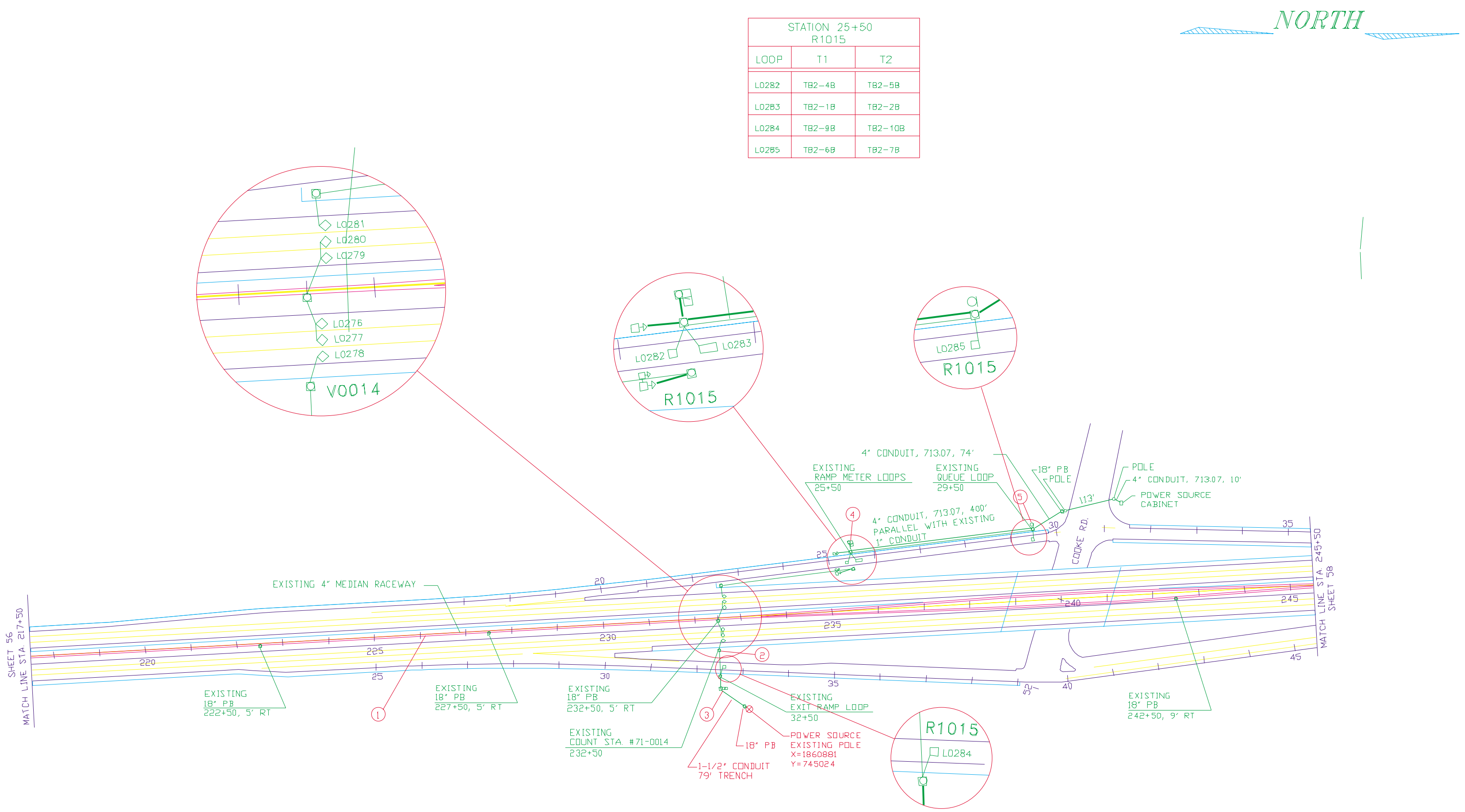
STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE	JOB NO. 3004
CAD FILE NO. 3004-5001401	SHT. 1 OF 1
DRAWING NO. 3004-5014-01	REV. 1

STATION 232+50 V0014		
LOOP	T1	T2
L0276	TB2-21B	TB2-22B
L0277	TB2-24B	TB2-25B
L0278	TB2-26B	TB2-27B
L0279	TB2-29B	TB2-30B
L0280	TB2-31B	TB2-32B
L0281	TB2-34B	TB2-35B

STATION 25+50 R1015		
LOOP	T1	T2
L0282	TB2-4B	TB2-5B
L0283	TB2-1B	TB2-2B
L0284	TB2-9B	TB2-10B
L0285	TB2-6B	TB2-7B



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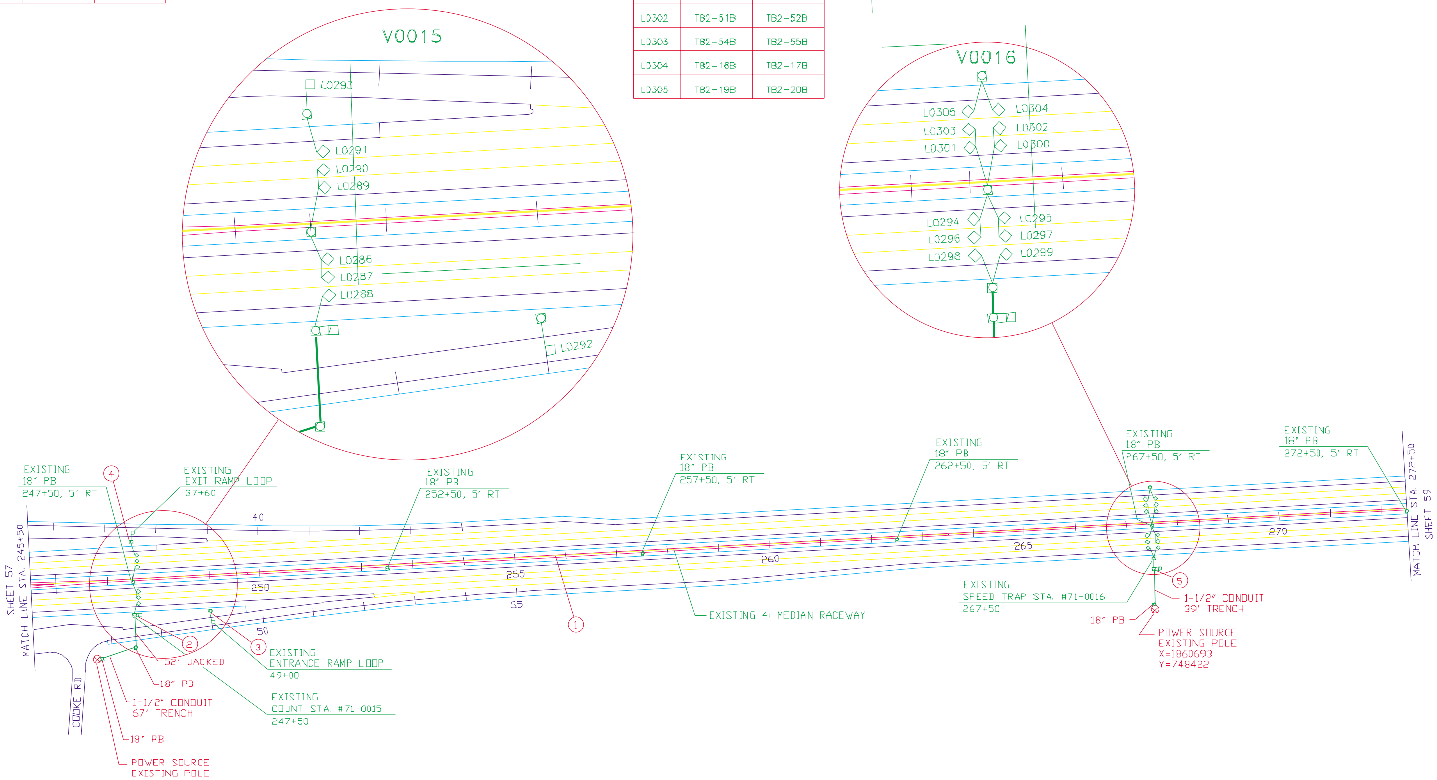
VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE		JOB NO. 3004	
CAD FILE NO. 3004-5001501		SHT. 1	OF 1
DRAWING NO. 3004-5015-01		REV. 1	

STATION 247+50 V0015		
LOOP	T1	T2
L0286	TB2-21B	TB2-22B
L0287	TB2-24B	TB2-25B
L0288	TB2-26B	TB2-27B
L0289	TB2-29B	TB2-30B
L0290	TB2-31B	TB2-32B
L0291	TB2-34B	TB2-35B
L0292	TB2-36B	TB2-37B
L0293	TB2-39B	TB2-40B

STATION 267+50 V0016		
LOOP	T1	T2
L0294	TB2-21B	TB2-22B
L0295	TB2-24B	TB2-25B
L0296	TB2-26B	TB2-27B
L0297	TB2-29B	TB2-30B
L0298	TB2-31B	TB2-32B
L0299	TB2-34B	TB2-35B
L0300	TB2-36B	TB2-37B
L0301	TB2-39B	TB2-40B
L0302	TB2-51B	TB2-52B
L0303	TB2-54B	TB2-55B
L0304	TB2-16B	TB2-17B
L0305	TB2-19B	TB2-20B

NORTH



NOTE:

DESIGNED BY	R. EUSEY
DRAWN BY	R. EUSEY
CHECKED BY	C. WILLIAMS
DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION		BY	APP
1	08-30-02	FIELD AS-BUILT		MC	
0	04-27-99	ISSUED FOR CONSTRUCTION	/S/	R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL	/S/	R.E.	C.W.

TRANSDYN CONTROLS
Pleasanton, California

STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

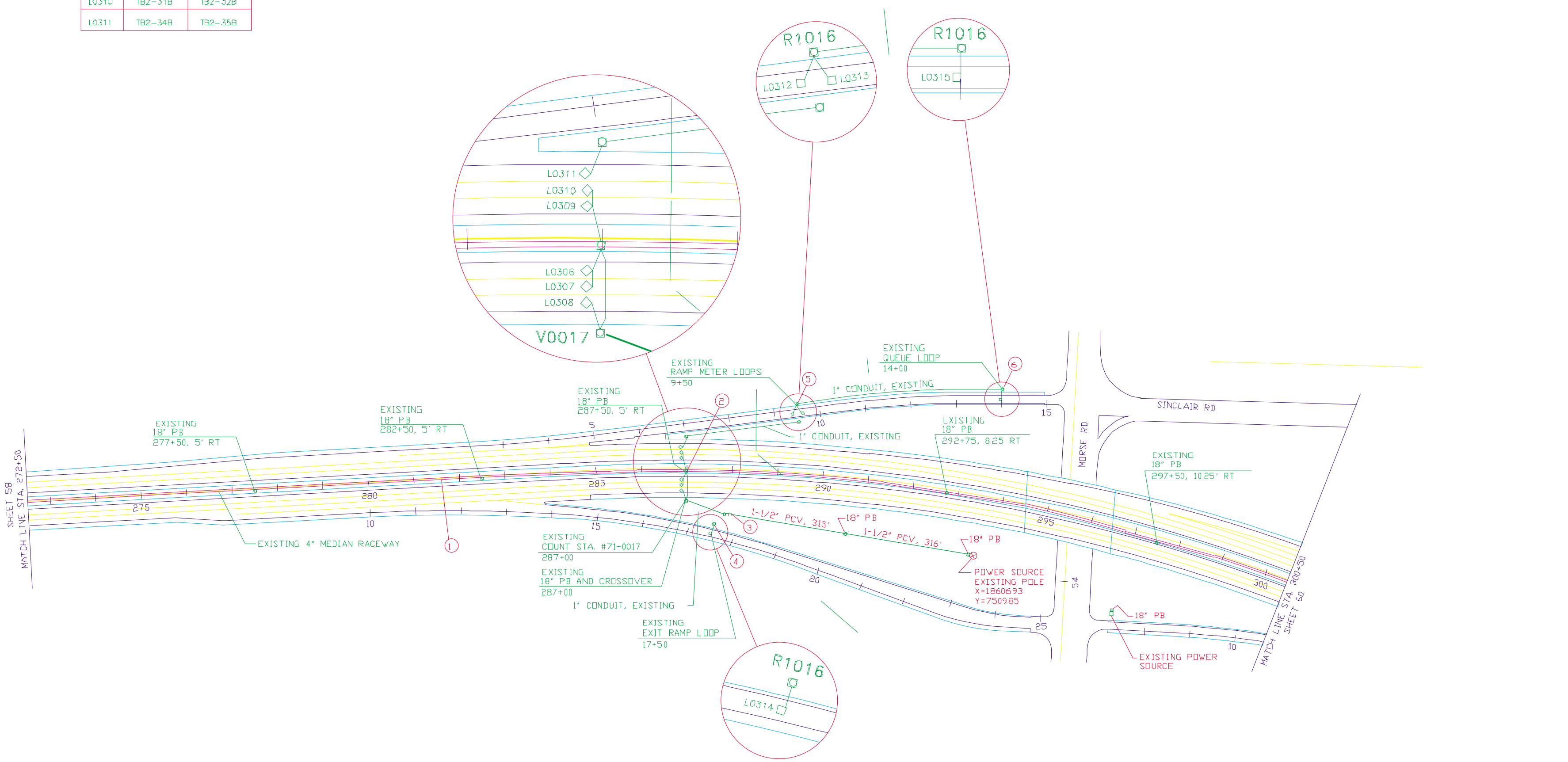
VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE	JOB NO. 3004	
CAD FILE NO. 3004-5001601	SHT. 1	OF 1
DRAWING NO. 3004-5016-01		REV. 1

STATION 287+00 V0017		
LOOP	T1	T2
L0306	TB2-21B	TB2-22B
L0307	TB2-24B	TB2-25B
L0308	TB2-26B	TB2-27B
L0309	TB2-29B	TB2-30B
L0310	TB2-31B	TB2-32B
L0311	TB2-34B	TB2-36B

STATION 9+50 R1016		
LOOP	T1	T2
L0312	TB2-4B	TB2-5B
L0313	TB2-1B	TB2-2B
L0314	TB2-9B	TB2-10B
L0315	TB2-6B	TB2-7B

NORTH



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DESIGNED BY	R. KUSEY
DRAWN BY	R. KUSEY
CHECKED BY	C. WILLIAMS
DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION	BY	APP.
1	08-30-02	FIELD AS-BUILT	MC	
0	04-27-99	ISSUED FOR CONSTRUCTION	/S/ R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL	/S/ R.E.	C.W.

TRANSDYN CONTROLS

Pleasanton, California

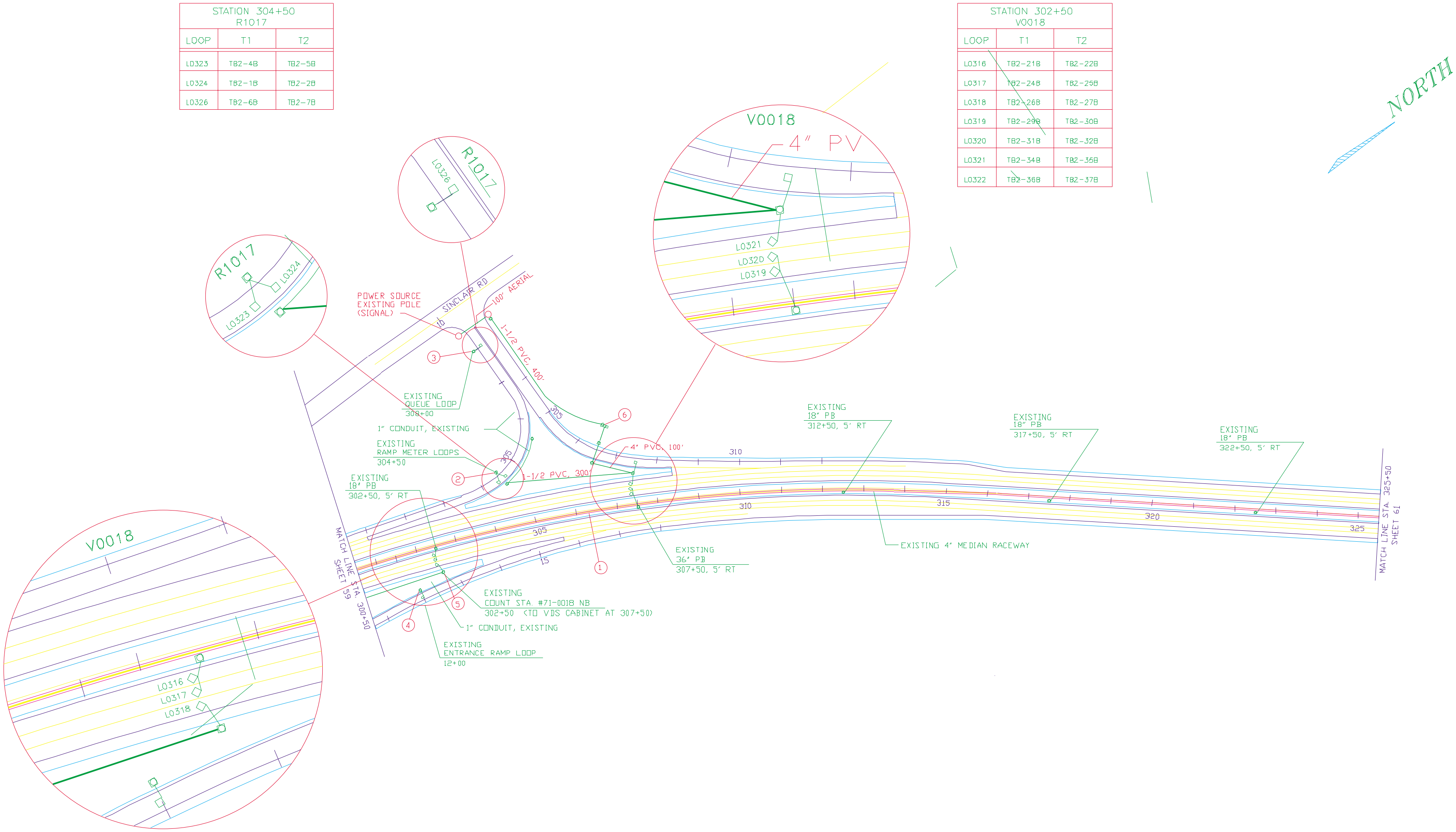
STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE
JOB NO. 3004
CAD FILE NO. 3004-5001701
SHT. 1 OF 1
DRAWING NO. 3004-5017-01
REV. 1

STATION 304+50 R1017		
LOOP	T1	T2
L0323	TB2-4B	TB2-5B
L0324	TB2-1B	TB2-2B
L0326	TB2-6B	TB2-7B

STATION 302+50 V0018		
LOOP	T1	T2
L0316	TB2-21B	TB2-22B
L0317	TB2-24B	TB2-25B
L0318	TB2-26B	TB2-27B
L0319	TB2-29B	TB2-30B
L0320	TB2-31B	TB2-32B
L0321	TB2-34B	TB2-35B
L0322	TB2-36B	TB2-37B



NOTE:

DESIGNED BY	R. EUSEY
DRAWN BY	R. EUSEY
CHECKED BY	C. WILLIAMS
DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION		BY	APP.
1	08-30-02	FIELD AS-BUILT		MC	
0	04-27-99	ISSUED FOR CONSTRUCTION	/S/	R.E.	PI
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TRANSDYN CONTROLS
Pleasanton, California

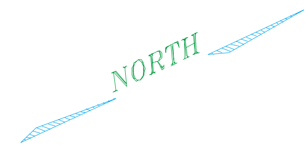
STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

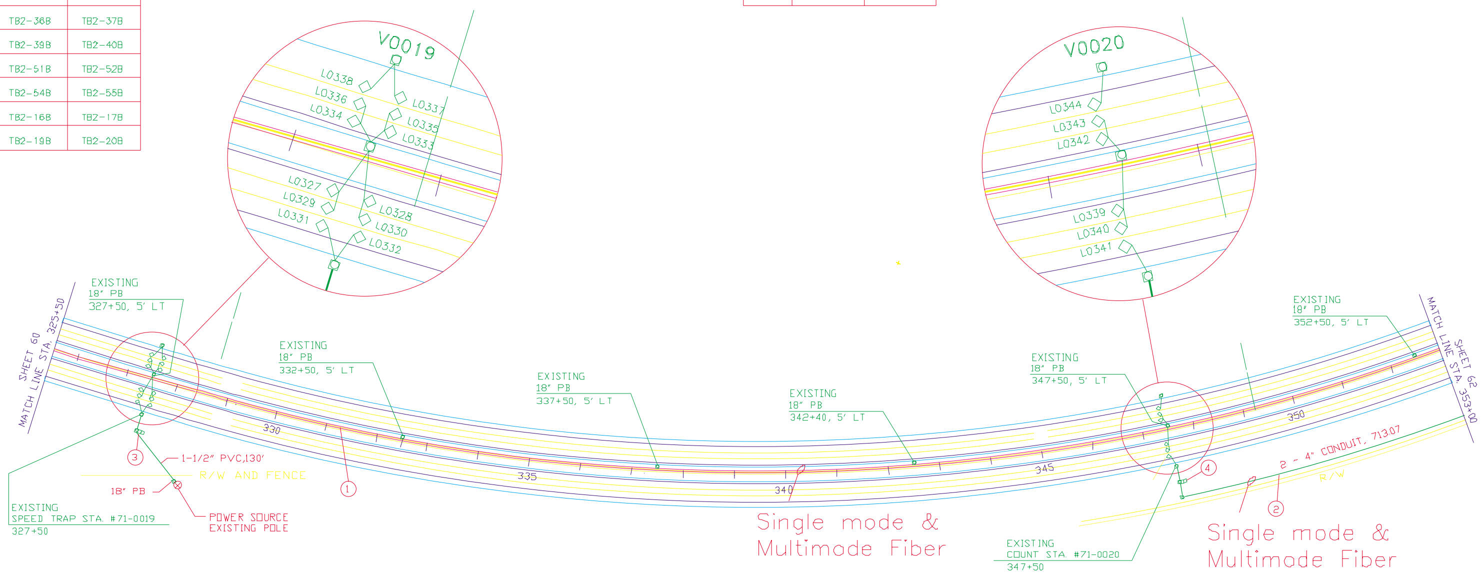
VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE	JOB NO. 3004
CAD FILE NO. 3004-5001801	SHT. 1 OF 1
DRAWING NO. 3004-5018-01	REV. 1

STATION 327+50 V0019		
LOOP	T1	T2
L0327	TB2-21B	TB2-22B
L0328	TB2-24B	TB2-25B
L0329	TB2-26B	TB2-27B
L0330	TB2-29B	TB2-30B
L0331	TB2-31B	TB2-32B
L0332	TB2-34B	TB2-35B
L0333	TB2-36B	TB2-37B
L0334	TB2-39B	TB2-40B
L0335	TB2-51B	TB2-52B
L0336	TB2-54B	TB2-55B
L0337	TB2-16B	TB2-17B
L0338	TB2-19B	TB2-20B

STATION 347+50 V0020		
LOOP	T1	T2
L0339	TB2-21B	TB2-22B
L0340	TB2-24B	TB2-25B
L0341	TB2-26B	TB2-27B
L0342	TB2-29B	TB2-30B
L0343	TB2-31B	TB2-32B
L0344	TB2-34B	TB2-35B





NOTE:

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DATE: 03-04-99 UPDATE: 09-03-02

REV.	DATE	DESCRIPTION	BY	APP.
1	08-30-02	FIELD AS-BUILT	MC	
0	04-27-99	ISSUED FOR CONSTRUCTION /S/	R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL /S/	R.E.	C.W.

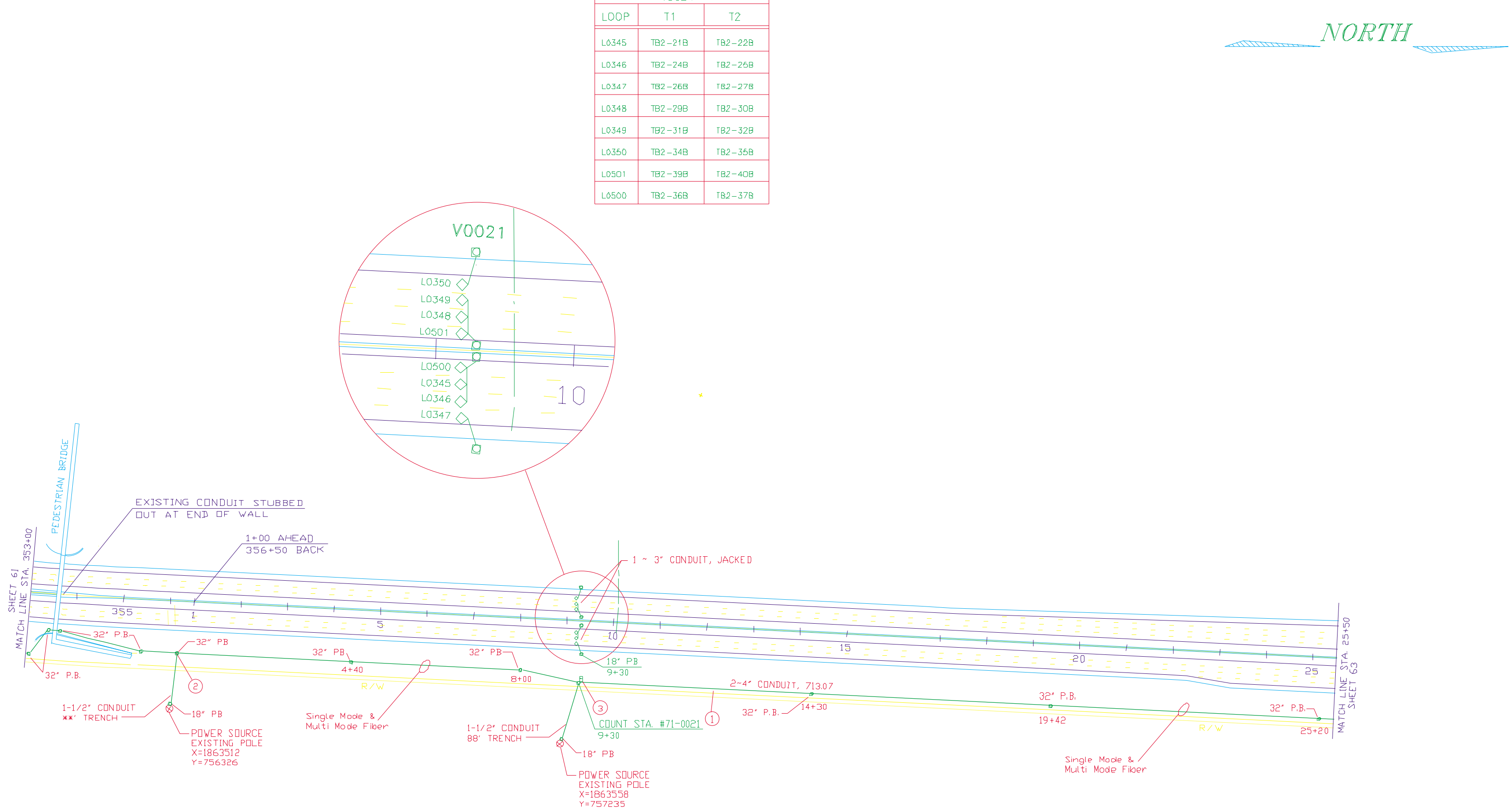
TRANSDYN CONTROLS
Pleasanton, California

STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE
JOB NO. 3004
CAD FILE NO. 3004-5001901
SHT. 1 OF 1
DRAWING NO. 3004-5019-01
REV. 1

STATION 9+30 V0021		
LOOP	T1	T2
L0345	TB2-21B	TB2-22B
L0346	TB2-24B	TB2-25B
L0347	TB2-26B	TB2-27B
L0348	TB2-29B	TB2-30B
L0349	TB2-31B	TB2-32B
L0350	TB2-34B	TB2-35B
L0501	TB2-39B	TB2-40B
L0500	TB2-36B	TB2-37B



NOTE:

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DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION		BY	APP.
1	08-29-02	FIELD AS-BUILT		MC	
0	04-27-99	ISSUED FOR CONSTRUCTION	/S/	R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL	/S/	R.E.	C.W.

TRANSDYN CONTROLS
Pleasanton, California

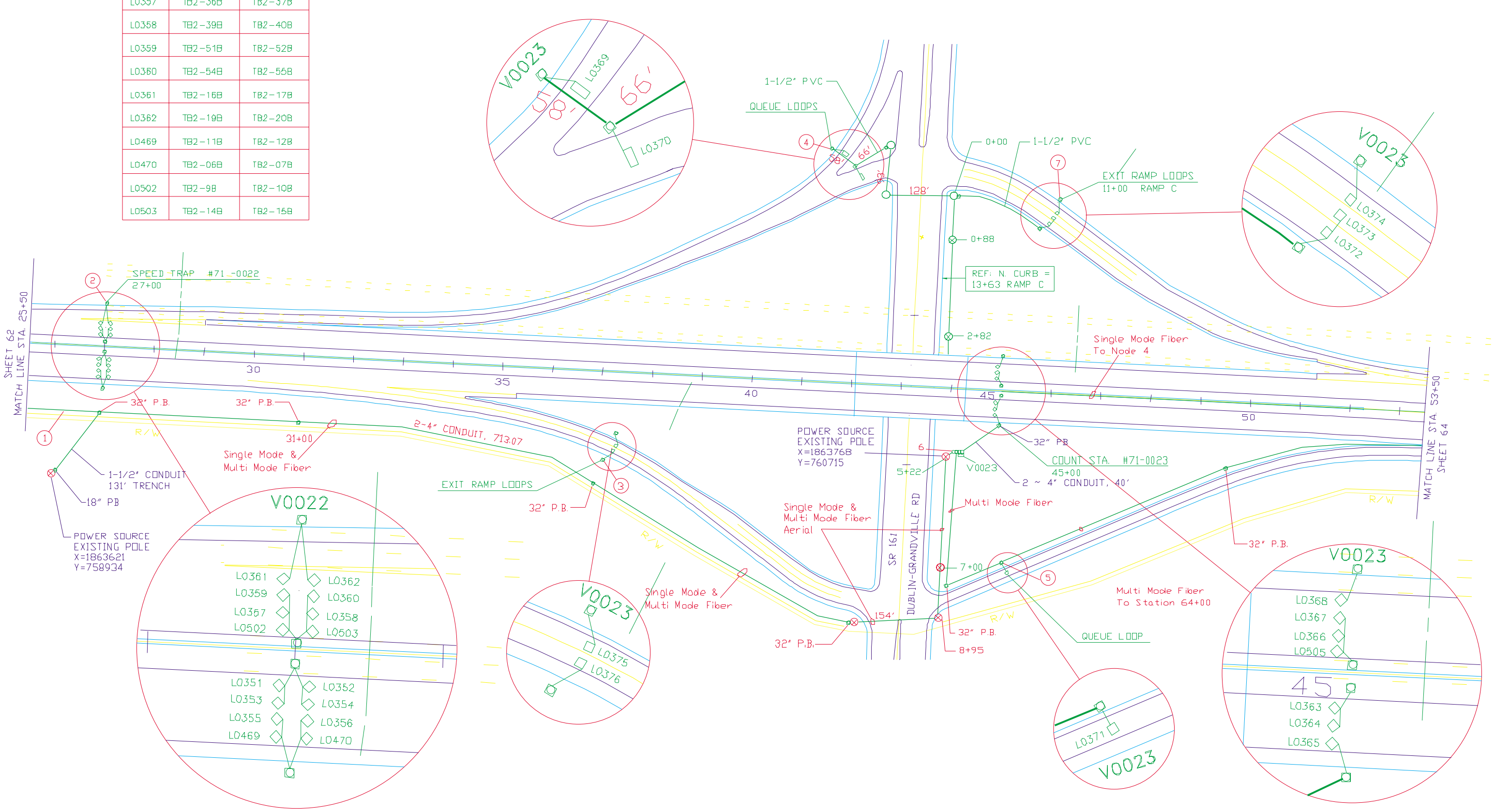
STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE	JOB NO. 3004	
CAD FILE NO. 3004-5002001	SHT. 1	OF 1
DRAWING NO. 3004-5020-01		REV. 1

STATION 27+00 V0022		
LOOP	T1	T2
L0351	TB2-21B	TB2-22B
L0352	TB2-24B	TB2-25B
L0353	TB2-26B	TB2-27B
L0354	TB2-29B	TB2-30B
L0355	TB2-31B	TB2-32B
L0356	TB2-34B	TB2-36B
L0357	TB2-36B	TB2-37B
L0358	TB2-39B	TB2-40B
L0359	TB2-51B	TB2-52B
L0360	TB2-54B	TB2-55B
L0361	TB2-16B	TB2-17B
L0362	TB2-19B	TB2-20B
L0469	TB2-11B	TB2-12B
L0470	TB2-06B	TB2-07B
L0502	TB2-9B	TB2-10B
L0503	TB2-14B	TB2-15B

NORTH



STATION 45+00 V0023		
LOOP	T1	T2
L0363	1B2-21B	1B2-22B
L0364	1B2-24B	1B2-25B
L0365	1B2-26B	1B2-27B
L0366	1B2-29B	1B2-30B
L0367	1B2-31B	1B2-32B
L0368	1B2-34B	1B2-35B
L0369	1B2-36B	1B2-37B
L0370	1B2-39B	1B2-40B
L0371	1B2-51B	1B2-52B
L0372	1B2-54B	1B2-55B
L0373	1B2-16B	1B2-17B
L0374	1B2-19B	1B2-20B
L0375	1B2-11B	1B2-12B
L0376	1B2-06B	1B2-07B
L0505	1B2-14B	1B2-15B

NOTE:

DESIGNED BY	R. EUSEY
DRAWN BY	R. EUSEY
CHECKED BY	C. WILLIAMS
DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION	BY	APP.
1	08-29-02	FIELD AS-BUILT	MC	
0	04-27-99	ISSUED FOR CONSTRUCTION /S/	R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL /S/	R.E.	C.W.

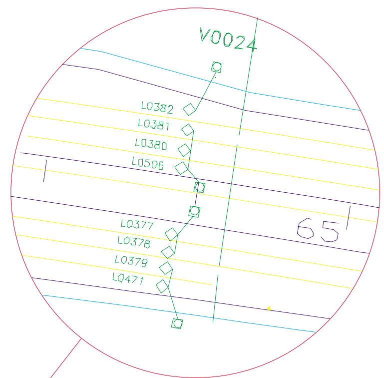
TRANSDYN CONTROLS
Pleasanton, California

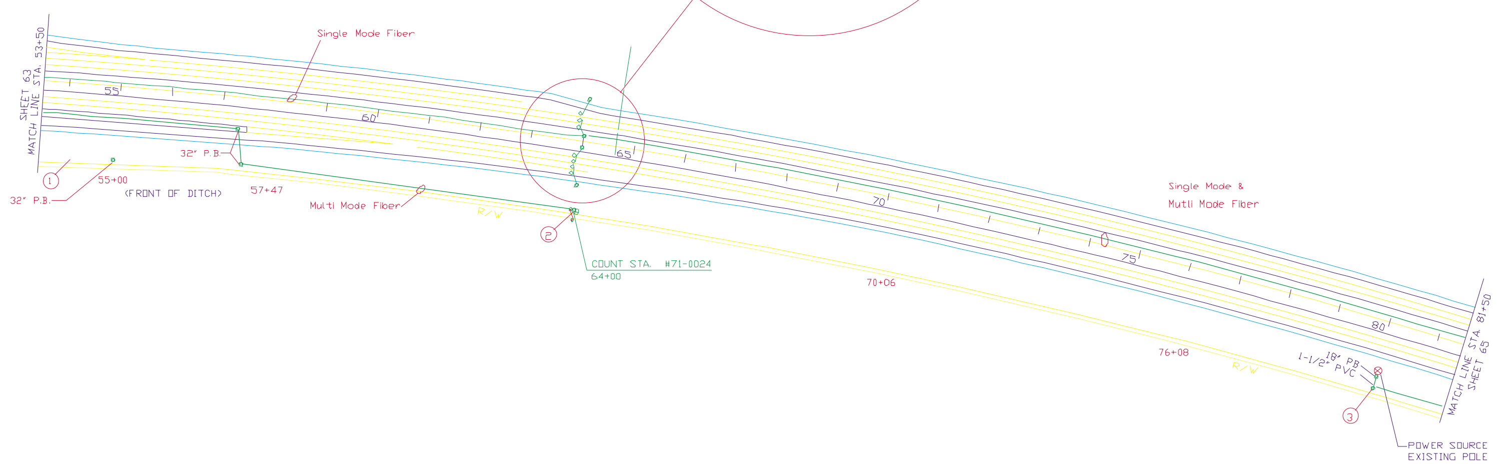
STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE	JOB NO. 3004
CAD FILE NO. 3004-502101	SHT. 1 OF 1
DRAWING NO. 3004-5021-01	REV. 1

STATION 64+00 V0024		
LOOP	T1	T2
L0377	TB2-21B	TB2-22B
L0378	TB2-24B	TB2-25B
L0379	TB2-26B	TB2-27B
L0380	TB2-29B	TB2-30B
L0381	TB2-31B	TB2-32B
L0382	TB2-34B	TB2-35B
L0471	TB2-36B	TB2-37B
L0506	TB2-39B	TB2-40B





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DESIGNED BY	R. EUSEY
DRAWN BY	R. EUSEY
CHECKED BY	S. WILLIAMS
DATE: 03-04-99	UPDATE: 09-03-02

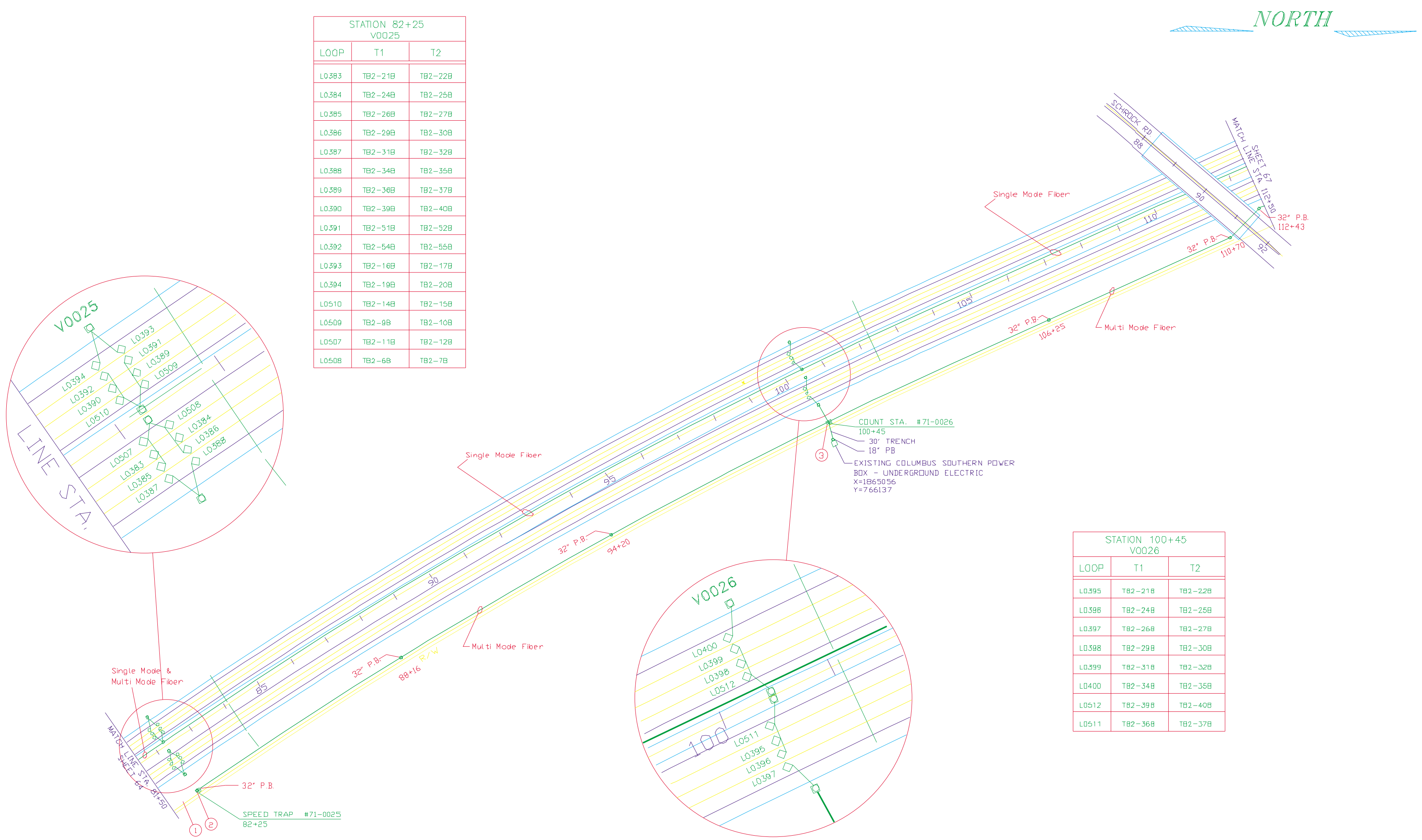
REV.	DATE	DESCRIPTION	BY	APP.
1	08-28-02	FIELD AS-BUILT	MC	
D	04-27-99	ISSUED FOR CONSTRUCTION /S/	R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL /S/	R.E.	C.W.

TRANSDYN CONTROLS
Pleasanton, California

STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE		JOB NO. 3004	
CAD FILE NO. 3004-502201		SHT. 1	OF 1
DRAWING NO. 3004-5022-01			REV. 1



STATION 82+25 V0025		
LOOP	T1	T2
L0383	TB2-21B	TB2-22B
L0384	TB2-24B	TB2-25B
L0385	TB2-26B	TB2-27B
L0386	TB2-29B	TB2-30B
L0387	TB2-31B	TB2-32B
L0388	TB2-34B	TB2-35B
L0389	TB2-36B	TB2-37B
L0390	TB2-39B	TB2-40B
L0391	TB2-51B	TB2-52B
L0392	TB2-54B	TB2-55B
L0393	TB2-16B	TB2-17B
L0394	TB2-19B	TB2-20B
L0510	TB2-14B	TB2-15B
L0509	TB2-9B	TB2-10B
L0507	TB2-11B	TB2-12B
L0508	TB2-6B	TB2-7B

STATION 100+45 V0026		
LOOP	T1	T2
L0395	TB2-21B	TB2-22B
L0396	TB2-24B	TB2-25B
L0397	TB2-26B	TB2-27B
L0398	TB2-29B	TB2-30B
L0399	TB2-31B	TB2-32B
L0400	TB2-34B	TB2-35B
L0512	TB2-39B	TB2-40B
L0511	TB2-36B	TB2-37B

NOTE:

DESIGNED BY	R. EUSEY
DRAWN BY	R. EUSEY
CHECKED BY	C. WILLIAMS
DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION		BY	APP.
1	08-28-02	FIELD AS-BUILT		MC	
0	04-27-99	ISSUED FOR CONSTRUCTION	/S/	R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL	/S/	R.E.	C.W.

TRANSDYN CONTROLS
Pleasanton, California

STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE		JOB NO. 3004	
CAD FILE NO. 3004-502301		SHT. 1	OF 1
DRAWING NO. 3004-5023-01			REV. 1

STATION 127+45 V0027		
LOOP	T1	T2
L0401	TB2-21B	TB2-22B
L0402	TB2-24B	TB2-25B
L0403	TB2-26B	TB2-27B
L0404	TB2-29B	TB2-30B
L0405	TB2-31B	TB2-32B
L0406	TB2-34B	TB2-35B
L0407	TB2-36B	TB2-37B
L0408	TB2-39B	TB2-40B
L0409	TB2-51B	TB2-52B
L0410	TB2-54B	TB2-55B
L0475	TB2-16B	TB2-17B
L0476	TB2-19B	TB2-20B
L0477	TB2-11B	TB2-12B
L0516	TB2-4B	TB2-5B
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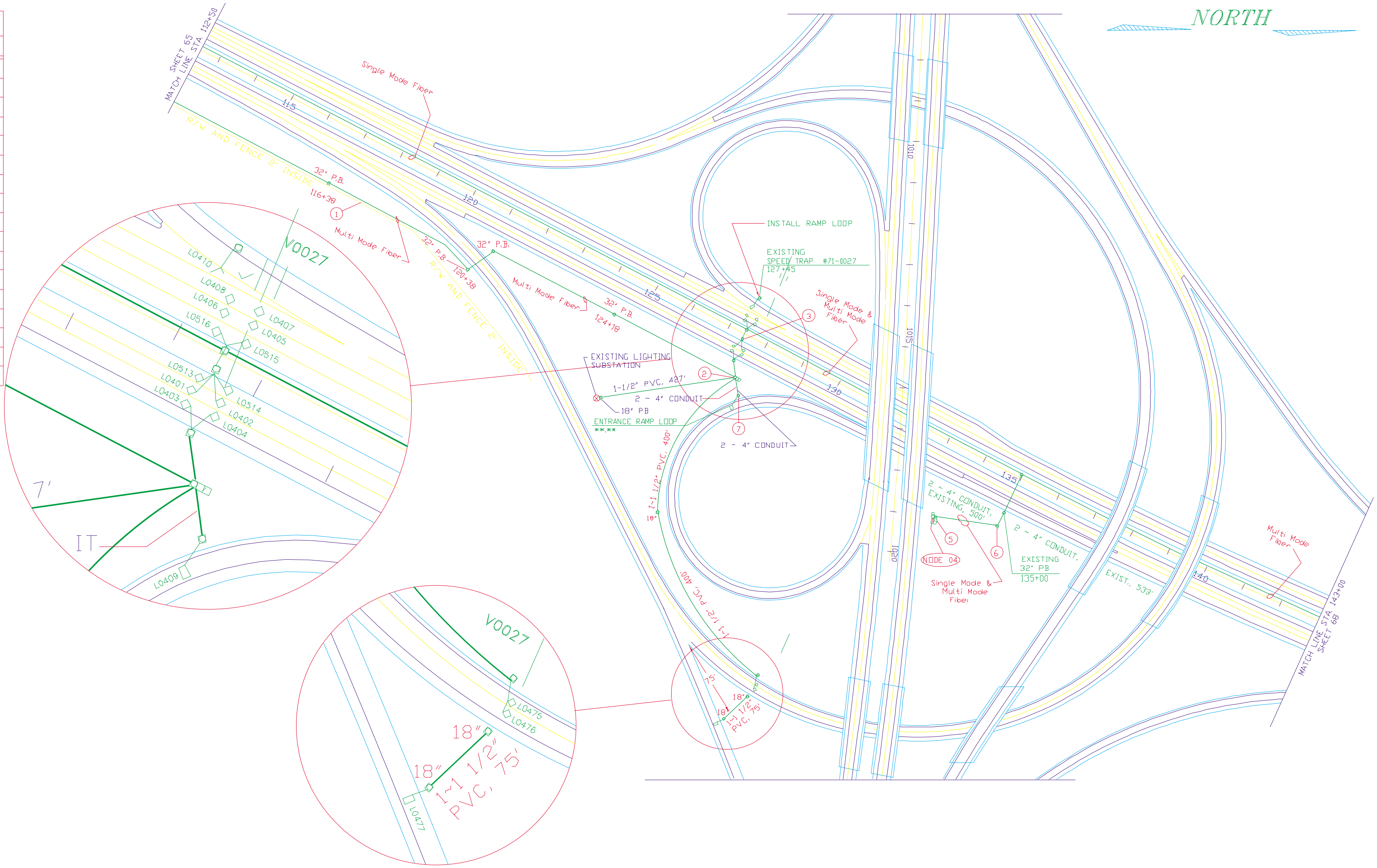
L0514	TB2-9B	TB2-10B



NOTE:

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DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION	BY	APP.
1	08-30-02	FIELD AS-BUILT	MC	
0	04-27-99	ISSUED FOR CONSTRUCTION	/S/ R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL	/S/ R.E.	C.W.

TRANSDYN CONTROLS
Pleasanton, California

STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE | JOB NO. 3004
CAD FILE NO. 3004-502401 | SHT. 1 OF 1
DRAWING NO. 3004-5024-01 | REV. 1

STATION 151+00 V0028		
LOOP	T1	T2
L0411	TB2-21B	TB2-22B
L0412	TB2-24B	TB2-25B
L0413	TB2-26B	TB2-27B
L0414	TB2-29B	TB2-30B
L0415	TB2-31B	TB2-32B
L0416	TB2-34B	TB2-35B
L0417	TB2-36B	TB2-37B
L0519	TB2-39B	TB2-40B
L0520	TB2-51B	TB2-52B

STATION 167+75 V0029		
LOOP	T1	T2
L0418	TB2-21B	TB2-22B
L0419	TB2-24B	TB2-25B
L0420	TB2-26B	TB2-27B
L0421	TB2-29B	TB2-30B
L0422	TB2-31B	TB2-32B
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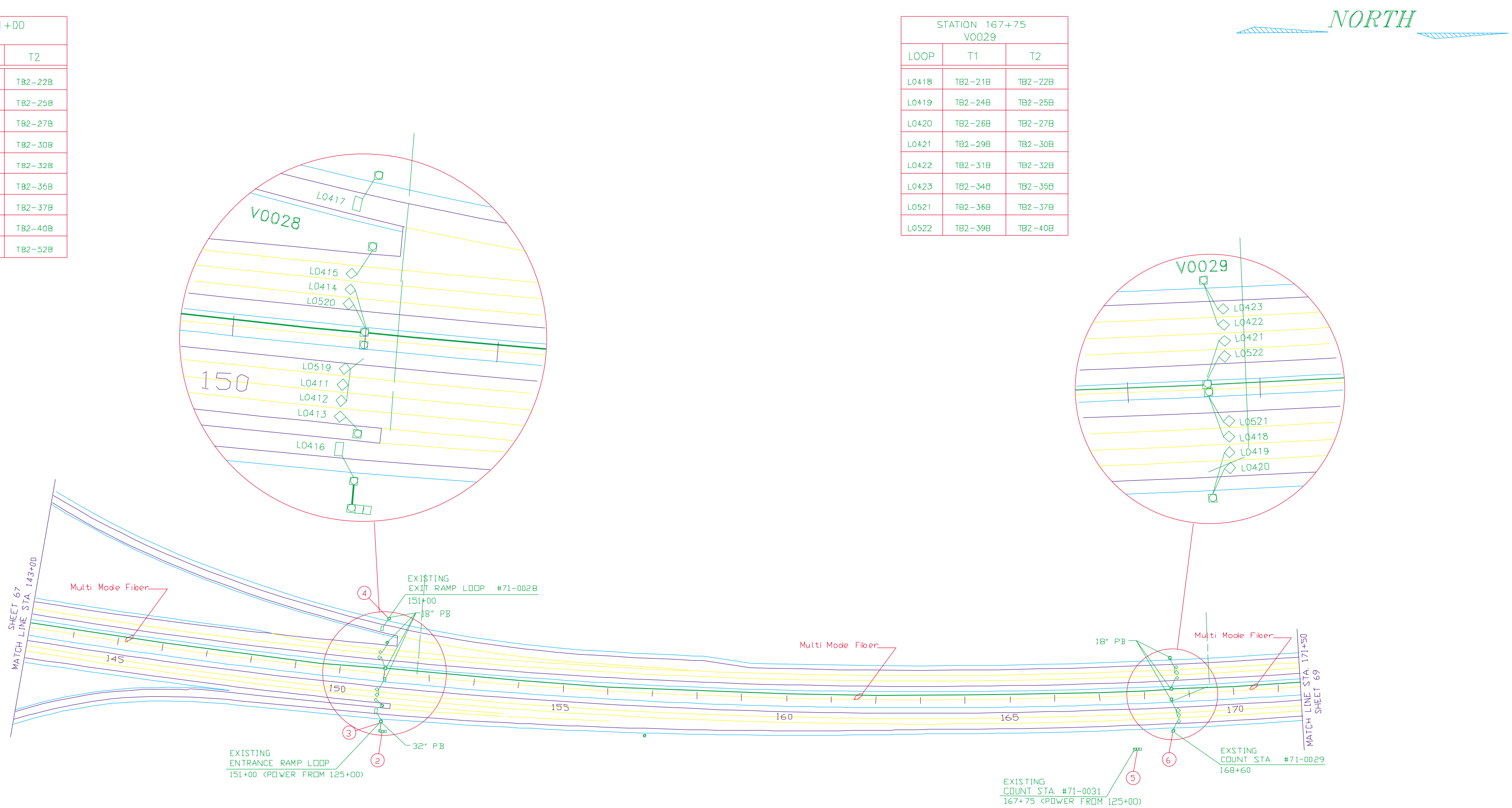
L0522	TB2-39B	TB2-40B



NOTE:

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CHECKED BY	C. WILLIAMS
DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION	BY	APP.
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TRANSDYN CONTROLS

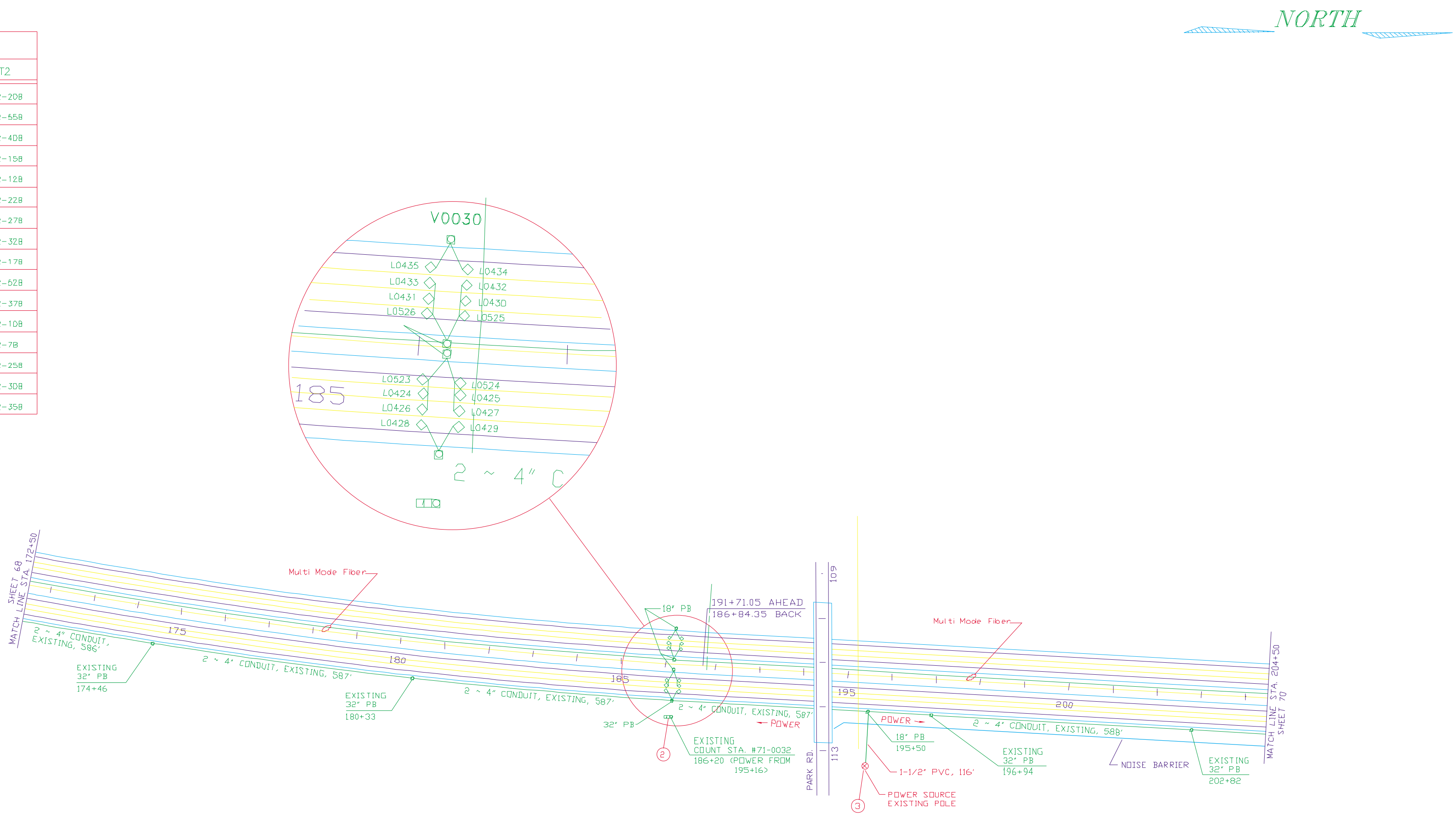
Pleasanton, California

STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE	JOB NO. 3004		
CAD FILE NO. 3004-502501	SHT. 1	OF 1	
DRAWING NO. 3004-5025-01		REV. 1	

STATION 186+20 VD030		
LOOP	T1	T2
L0435	TB2-19B	TB2-20B
L0433	TB2-54B	TB2-55B
L0431	TB2-39B	TB2-40B
L0526	TB2-14B	TB2-15B
L0523	TB2-11B	TB2-12B
L0424	TB2-21B	TB2-22B
L0426	TB2-26B	TB2-27B
L0428	TB2-31B	TB2-32B
L0434	TB2-16B	TB2-17B
L0432	TB2-51B	TB2-52B
L0430	TB2-36B	TB2-37B
L0525	TB2-9B	TB2-10B
L0524	TB2-6B	TB2-7B
L0425	TB2-24B	TB2-25B
L0427	TB2-29B	TB2-30B
L0429	TB2-34B	TB2-35B



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DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION		BY	APP.
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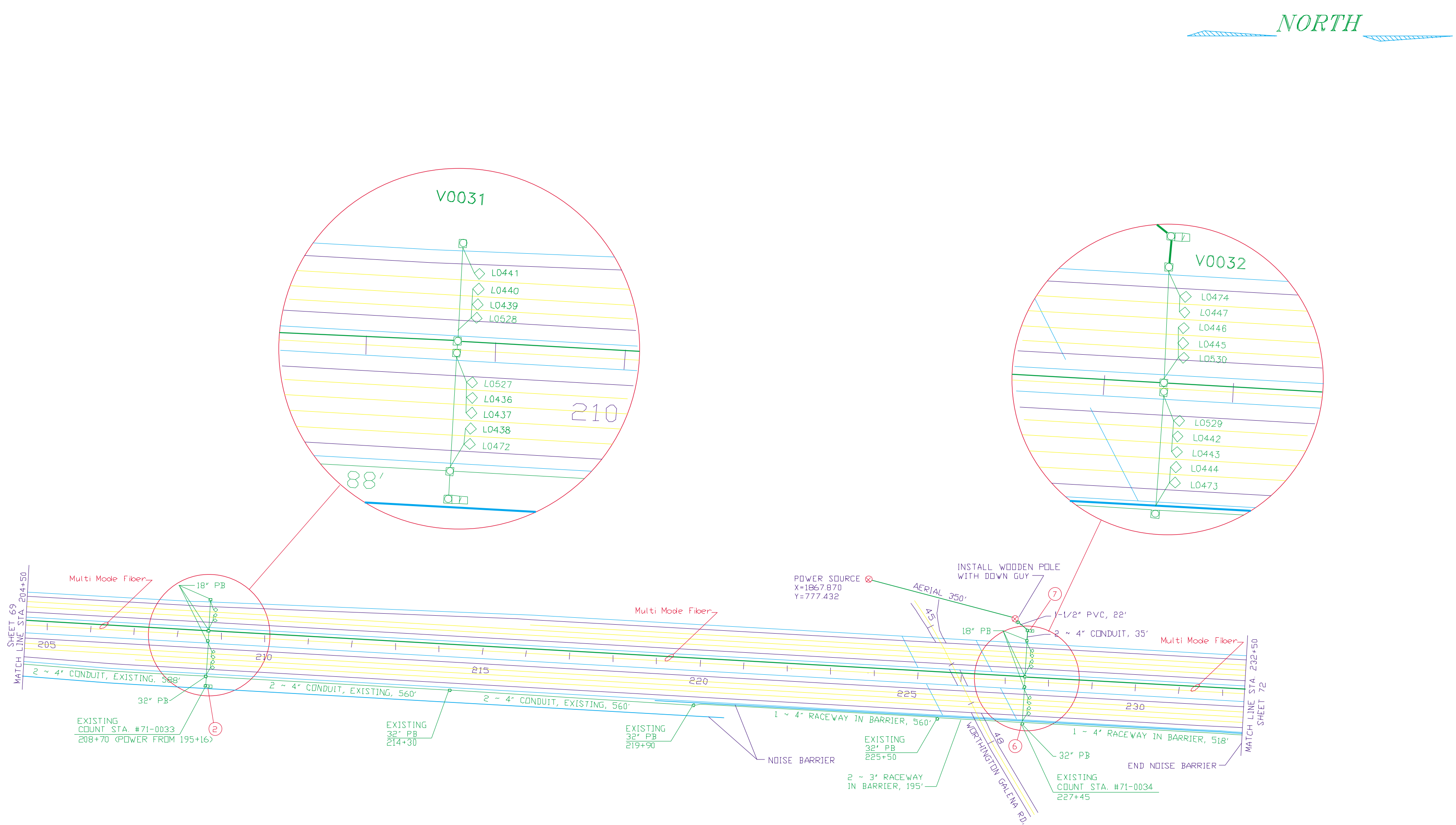
0	04-27-99	ISSUED FOR CONSTRUCTION	/S/	R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL	/S/	R.E.	C.W.

TRANSDYN CONTROLS
Pleasanton, California

STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

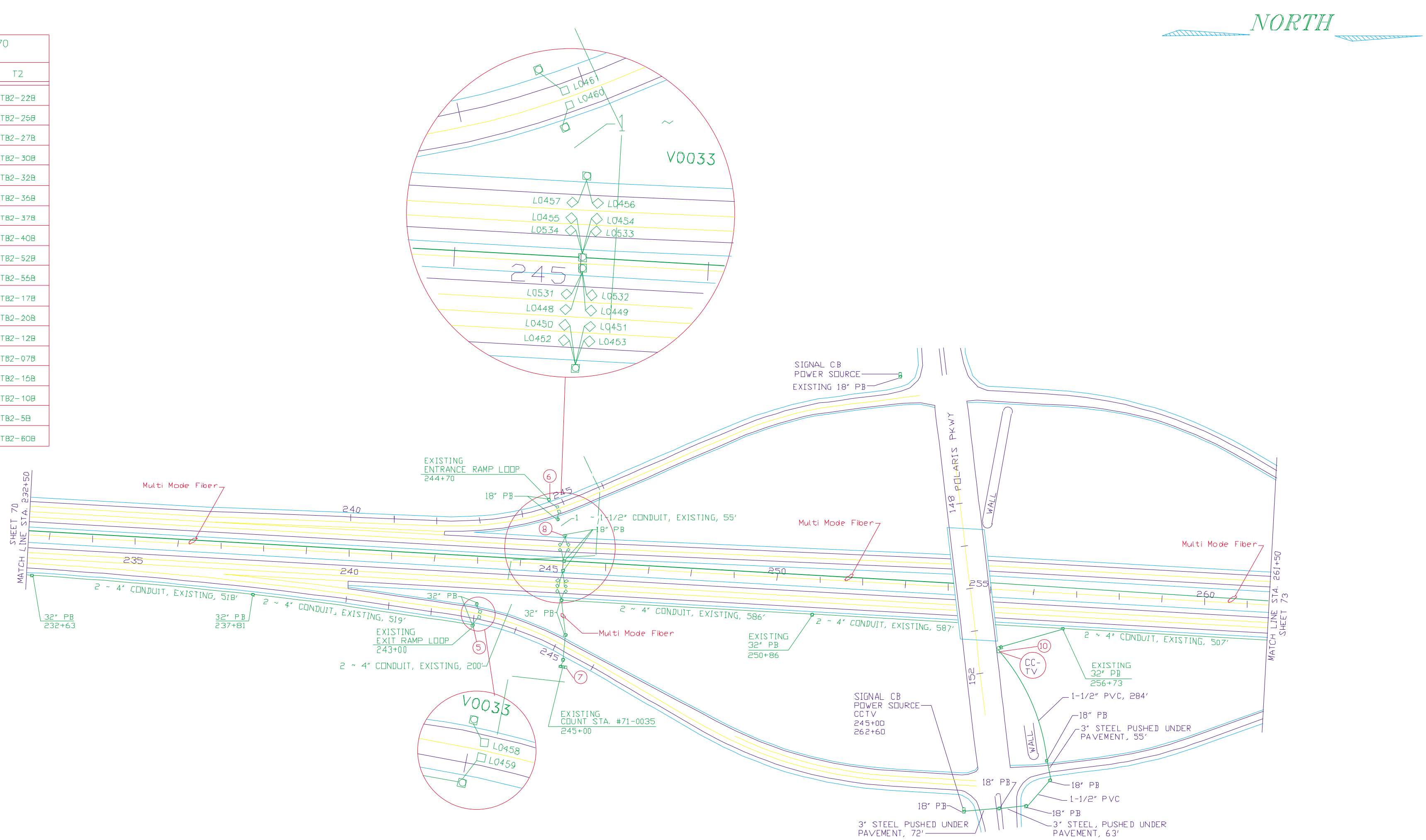
VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE	JOB NO. 3004
CAD FILE NO. 3004-502601	SHT. 1 OF 1
DRAWING NO. 3004-5026-01	REV. 1



NORTH
V0031
L0441
L0440
L0439
L0528
L0527
L0436
L0437
L0438
L0472
210
88'
V0032
L0474
L0447
L0446
L0445
L0530
L0529
L0442
L0443
L0444
L0473
MATCH LINE STA 204+50
SHEET 69
Multi Mode Fiber
18" PB
205
210
2 ~ 4" CONDUIT, EXISTING, 528'
32" PB
EXISTING
COUNT STA. #71-0033
208+70 (POWER FROM 195+16)
2
2 ~ 4" CONDUIT, EXISTING, 560'
EXISTING
32" PB
214+30
215
2 ~ 4" CONDUIT, EXISTING, 560'
EXISTING
32" PB
219+90
Multi Mode Fiber
220
NOISE BARRIER
POWER SOURCE
X=1867.870
Y=777.432
AERIAL 350'
45
INSTALL WOODEN POLE
WITH DOWN GUY
7
1-1/2" PVC, 22'
18" PB
2 ~ 4" CONDUIT, 35'
1 ~ 4" RACEWAY IN BARRIER, 560'
225
EXISTING
32" PB
225+50
2 ~ 3" RACEWAY
IN BARRIER, 195'
WORTHINGTON GALENA RD.
48
6
32" PB
EXISTING
COUNT STA. #71-0034
227+45
230
Multi Mode Fiber
1 ~ 4" RACEWAY IN BARRIER, 518'
END NOISE BARRIER
MATCH LINE STA 232+50
SHEET 72

STATION 244+70 V0033		
LOOP	T1	T2
L0448	TB2-21B	TB2-22B
L0449	TB2-24B	TB2-25B
L0450	TB2-26B	TB2-27B
L0451	TB2-29B	TB2-30B
L0452	TB2-31B	TB2-32B
L0453	TB2-34B	TB2-35B
L0454	TB2-36B	TB2-37B
L0455	TB2-39B	TB2-40B
L0456	TB2-51B	TB2-52B
L0457	TB2-54B	TB2-55B
L0458	TB2-16B	TB2-17B
L0459	TB2-19B	TB2-20B
L0460	TB2-11B	TB2-12B
L0461	TB2-06B	TB2-07B
L0532	TB2-14B	TB2-15B
L0531	TB2-9B	TB2-10B
L0533	TB2-4B	TB2-5B
L0534	TB2-59B	TB2-60B



NOTE:

DESIGNED BY	R. EUSEY
DRAWN BY	R. EUSEY
CHECKED BY	C. WILLIAMS
DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION		BY	APP.
1	08-28-02	FIELD AS-BUILT		MC	
0	04-27-99	ISSUED FOR CONSTRUCTION	/S/	R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL	/S/	R.E.	C.W.

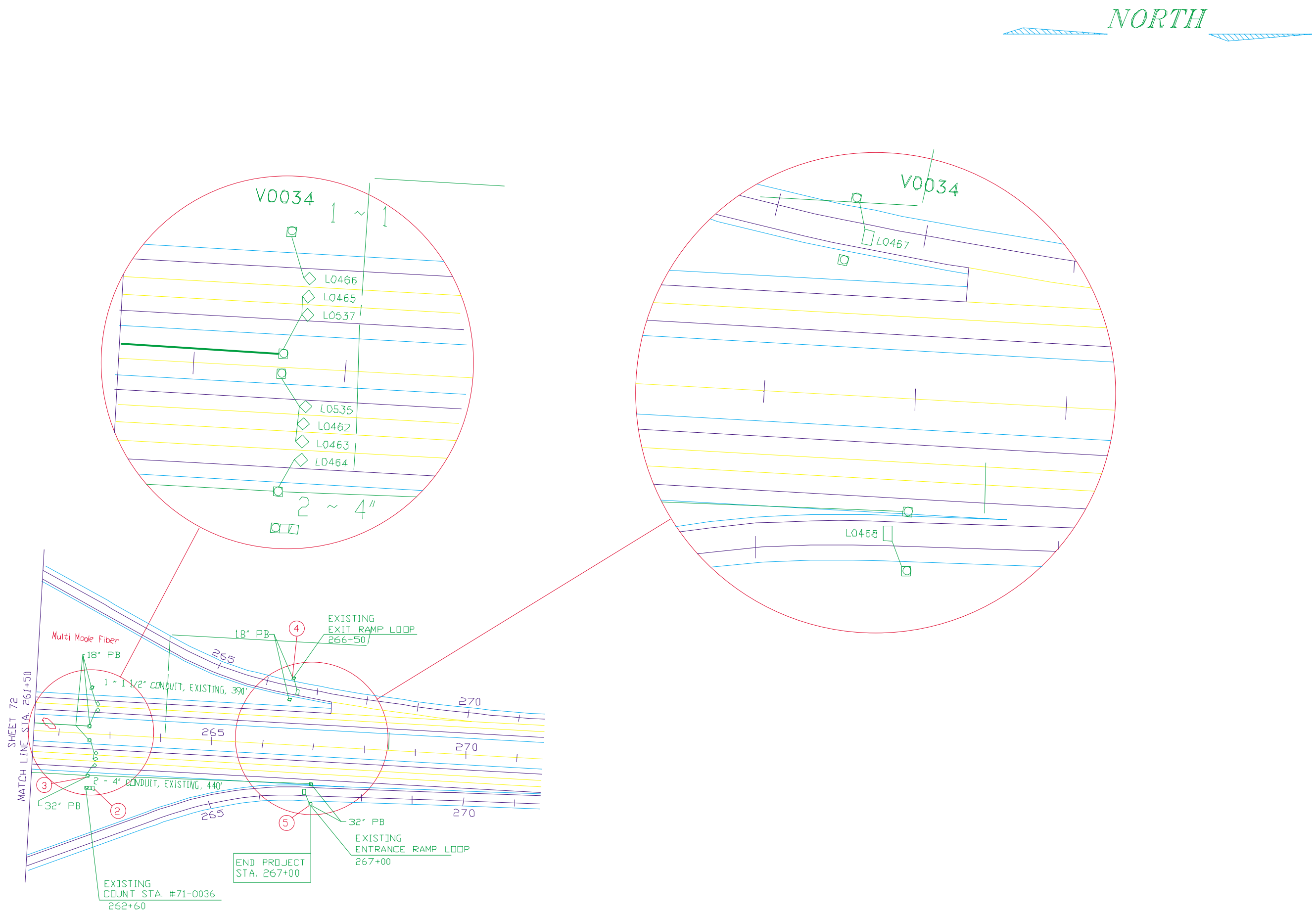
TRANSDYN CONTROLS
Pleasanton, California

STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE
JOB NO. 3004
CAD FILE NO. 3004-502801
SHT. 1 OF 1
DRAWING NO. 3004-5028-01
REV. 1

STATION 262+60 V0034		
LOOP	T1	T2
L0462	TB2-21B	TB2-22B
L0463	TB2-24B	TB2-25B
L0464	TB2-26B	TB2-27B
L0465	TB2-29B	TB2-30B
L0466	TB2-31B	TB2-32B
L0467	TB2-34B	TB2-35B
L0468	TB2-36B	TB2-37B
L0535	TB2-39B	TB2-40B
L0537	TB2-54B	TB2-55B



NOTE:

DESIGNED BY	R. EUSEY
DRAWN BY	R. EUSEY
CHECKED BY	C. WILLIAMS
DATE: 03-04-99	UPDATE: 09-03-02

REV.	DATE	DESCRIPTION	BY	APP.
1	08-30-02	FIELD AS-BUILT	MC	
0	04-27-99	ISSUED FOR CONSTRUCTION /S/	R.E.	PI
A	04-20-99	ISSUED FOR APPROVAL /S/	R.E.	C.W.

TRANSDYN CONTROLS
Pleasanton, California

STATE OF OHIO, D.O.T.
CITY OF COLUMBUS MFMS

VDS/RMS LOOP
TERMINATION DETAILS

SCALE: NONE	JOB NO. 3004
CAD FILE NO. 3004-502901	SHT. 1 OF 1
DRAWING NO. 3004-5029-01	REV. 1

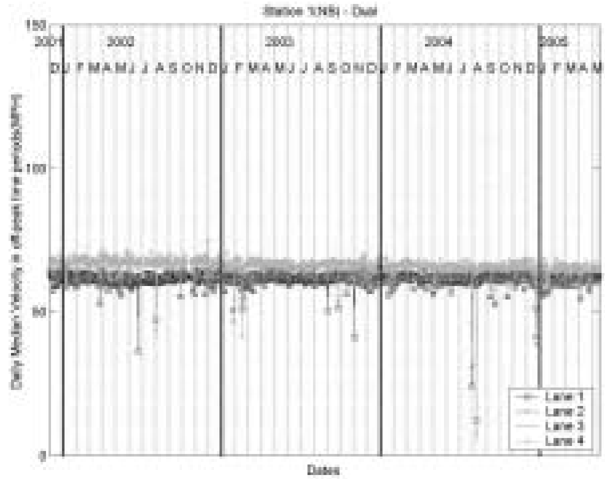
APPENDIX B: COORDINATES OF THE DETECTOR STATIONS

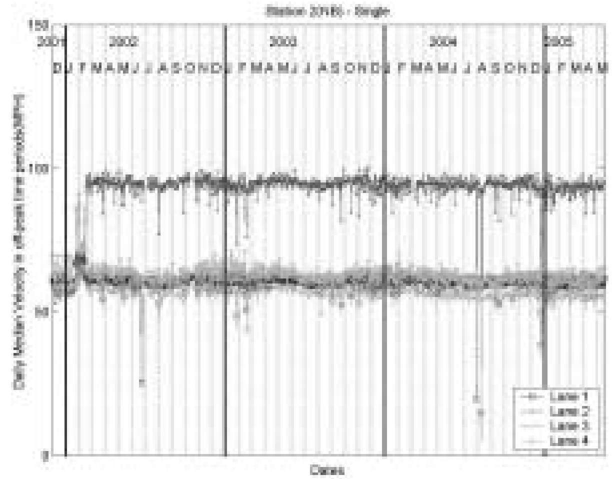
Coordinates of loop detector stations

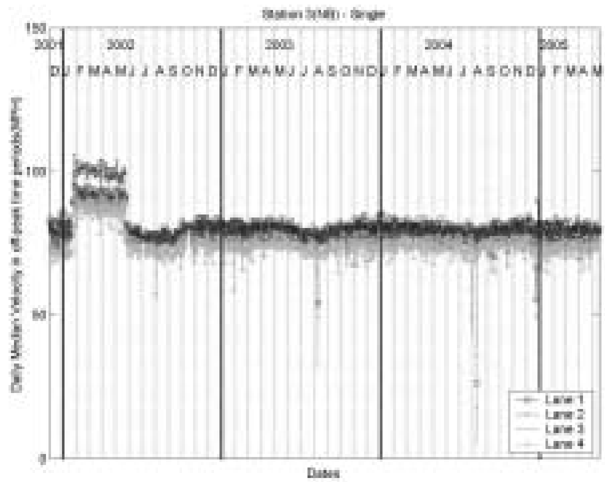
Station	North		South	
	Longitude	Latitude	Longitude	Latitude
102	-83.002714	39.953253	-83.002714	39.953414
104	-82.999106	39.952925	-82.997639	39.953225
103	-82.994350	39.953461	-82.992600	39.953817
105	-82.989081	39.954036	-	-
106	-82.984194	39.954994	-82.983372	39.956447
107	-82.982475	39.959786	-	-
108	-	-	-82.982725	39.961619
109	-82.982747	39.964494	-	-
110	-82.983117	39.968125	-82.983433	39.965706
111	-82.983564	39.970469	-	-
112	-	-	-82.983697	39.973125
1	-82.983708	39.978275	-82.983872	39.978247
2	-82.984425	39.981958	-82.984603	39.981933
3	-82.985411	39.987308	-82.985608	39.987292
4	-82.985200	39.992067	-82.985375	39.992069
5	-82.984631	39.997644	-82.984856	39.997653
6	-82.984433	40.002411	-82.984597	40.002386
7	-82.985322	40.007686	-82.985469	40.007628
8	-82.988797	40.010469	-82.988931	40.010381
9	-82.993983	40.014656	-82.994153	40.014611
10	-82.995031	40.019922	-82.995242	40.019906
11	-82.994614	40.024769	-82.994786	40.024806
12	-82.994453	40.030442	-82.994617	40.030417
13	-82.996508	40.036394	-82.996711	40.036369
14	-82.997136	40.044325	-82.997353	40.044311
15	-82.997406	40.048311	-82.997639	40.048306
16	-82.997831	40.054164	-82.998072	40.054164
17	-82.998189	40.059119	-82.998425	40.059119
18	-82.996931	40.063547	-82.996358	40.064739
19	-82.992008	40.068425	-82.992161	40.068539
20	-82.988119	40.074297	-82.988331	40.074294
21	-82.987736	40.078722	-82.987972	40.078722
22	-82.987403	40.083419	-82.987683	40.083447
23	-82.987125	40.087975	-82.987394	40.087978
24	-82.986528	40.093206	-82.986839	40.093242
25	-82.985072	40.098092	-82.985375	40.098153
26	-82.982669	40.102717	-82.982972	40.102850
27	-82.978092	40.109519	-82.978364	40.109617
28	-82.974653	40.115147	-82.974964	40.115231
29	-82.972617	40.121108	-82.972931	40.121108
30	-82.972061	40.125072	-82.972406	40.125072
31	-82.971794	40.128811	-82.972122	40.128811
32	-82.971322	40.134850	-82.971697	40.134850
33	-82.971022	40.139392	-82.971333	40.139392

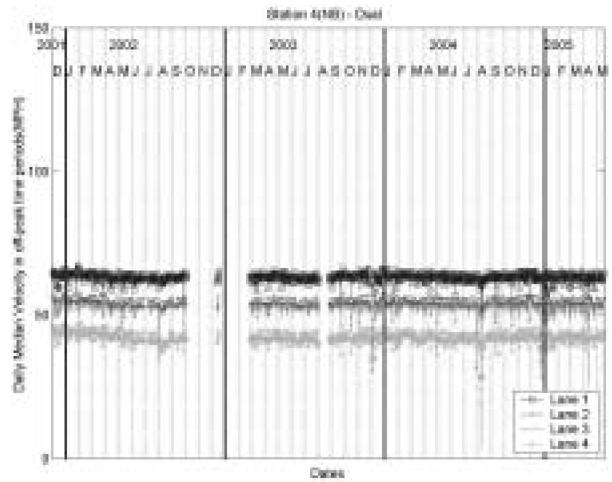
APPENDIX C: DAILY TRENDS IN DETECTOR SPEEDS

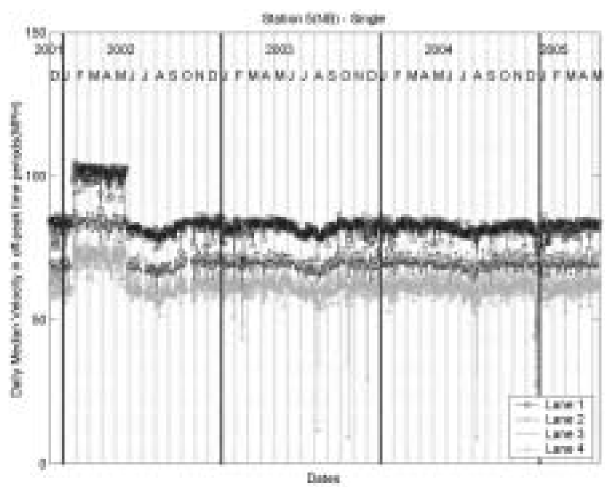
NORTHBOUND

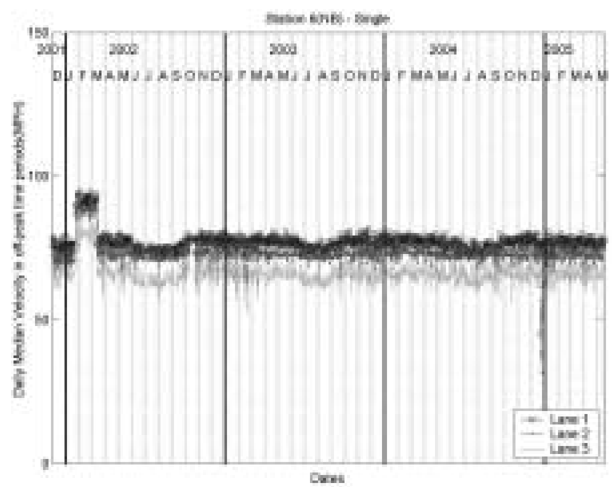

Station 1(NB) - Dual
2001
2002
2003
2004
2005
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

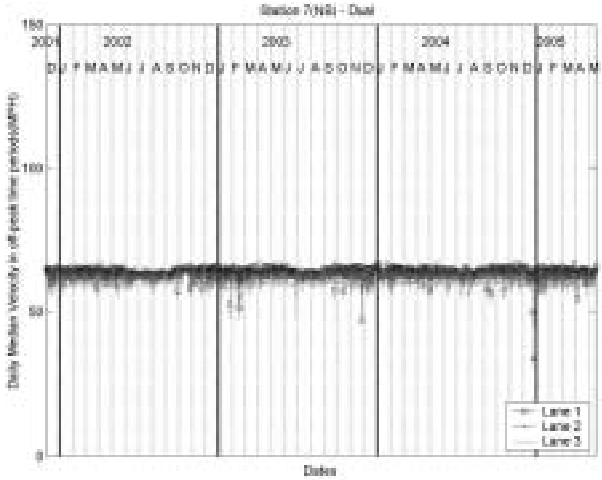

Station 2(NB) - Single
2001
2002
2003
2004
2005
Dates
Lane 1
Lane 2
Lane 3
Lane 4

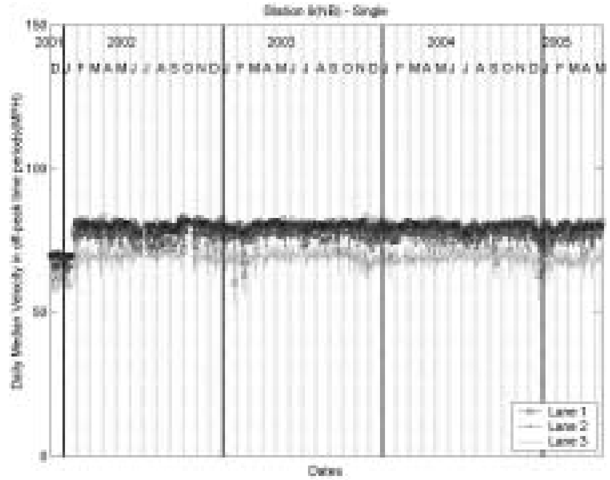

Station 3(NB) - Single
2001
2002
2003
2004
2005
Dates
Lane 1
Lane 2
Lane 3
Lane 4

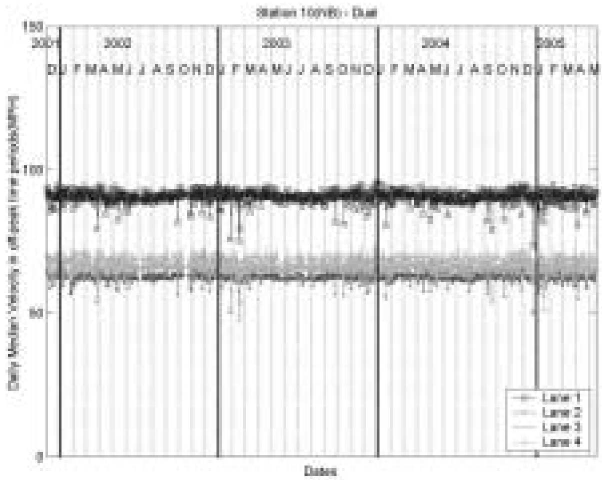

Station 4(NB) - Dual
2001
2002
2003
2004
2005
Dates
Lane 1
Lane 2
Lane 3
Lane 4

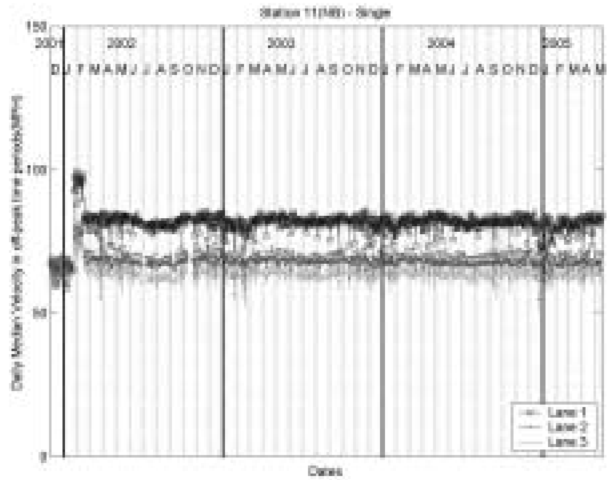

Station 5(NB) - Single
2001
2002
2003
2004
2005
Dates
Lane 1
Lane 2
Lane 3
Lane 4

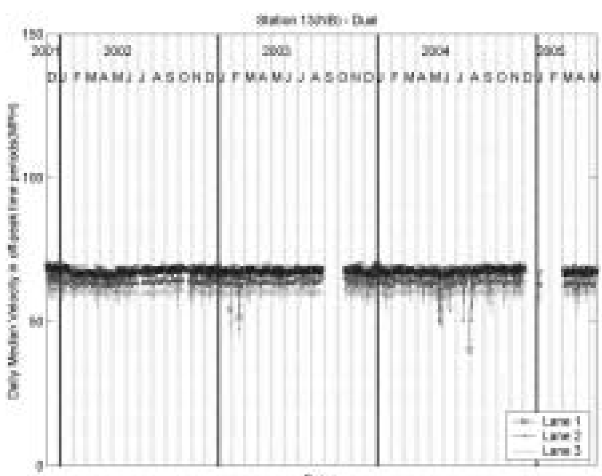

Station 6(NB) - Single
2001
2002
2003
2004
2005
Dates
Lane 1
Lane 2
Lane 3

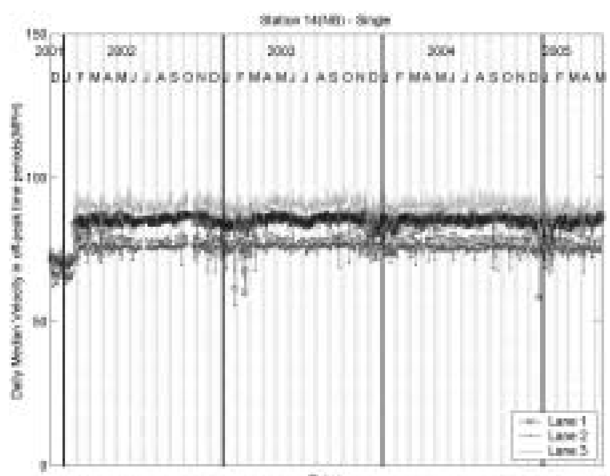

Station 7(NB) - Dual
Lane 1
Lane 2
Lane 3
Dates

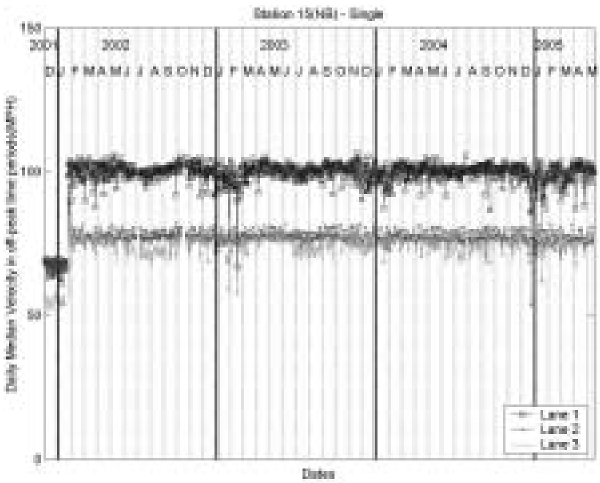

Station 8(NB) - Single
Lane 1
Lane 2
Lane 3
Dates

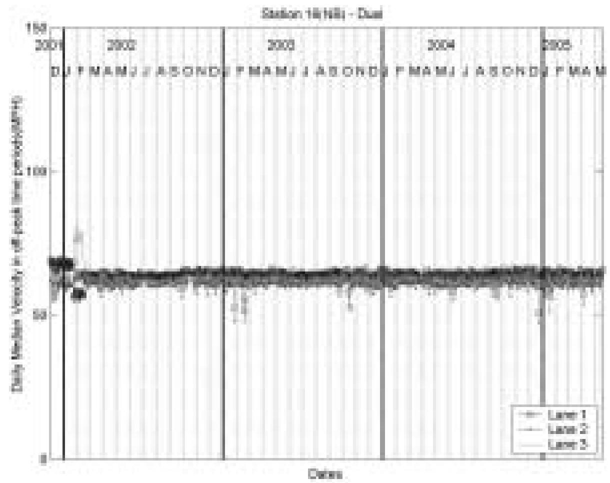

Station 10(NB) - Dual
Lane 1
Lane 2
Lane 3
Lane 4
Dates

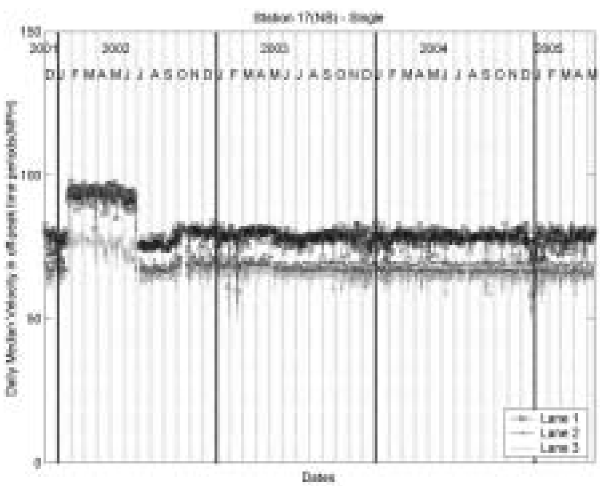

Station 11(NB) - Single
Lane 1
Lane 2
Lane 3
Dates

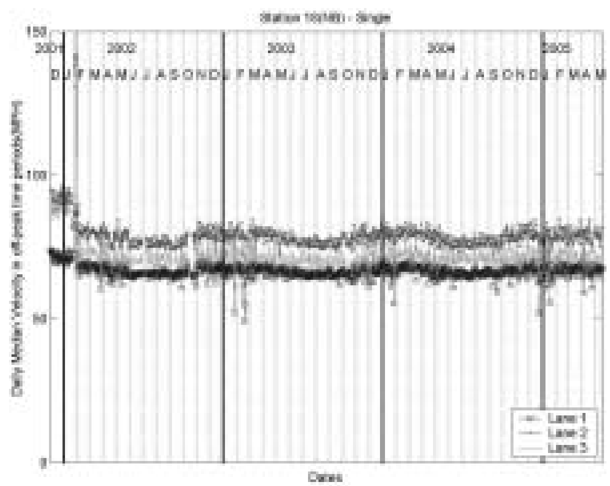

Station 13(NB) - Dual
Lane 1
Lane 2
Lane 3
Dates

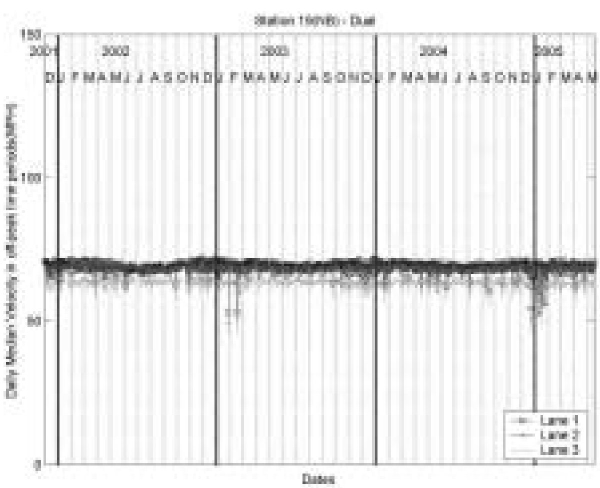

Station 14(NB) - Single
Lane 1
Lane 2
Lane 3
Dates

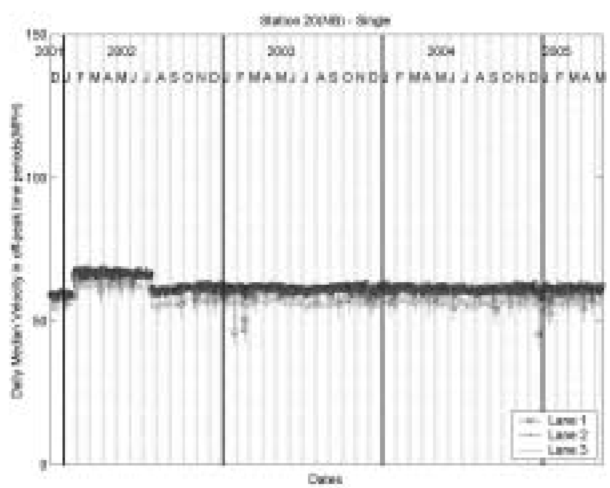

Station 15(NB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

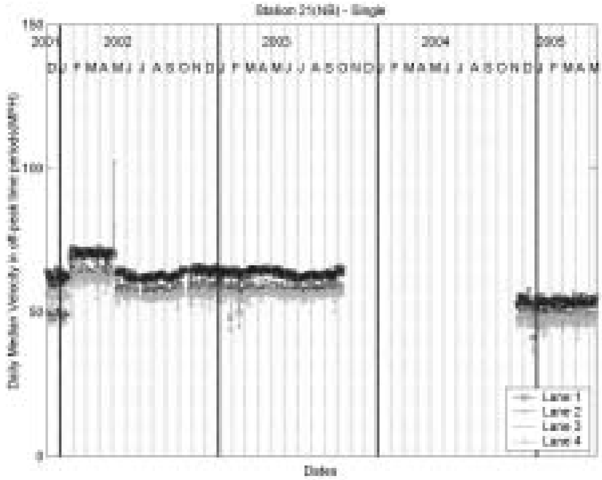

Station 16(NB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

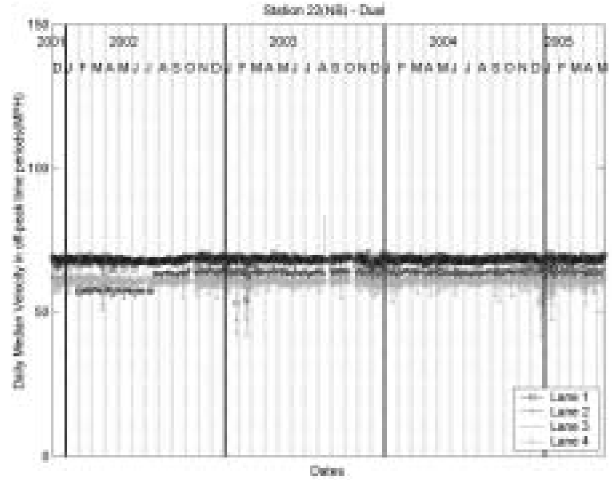

Station 17(NB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

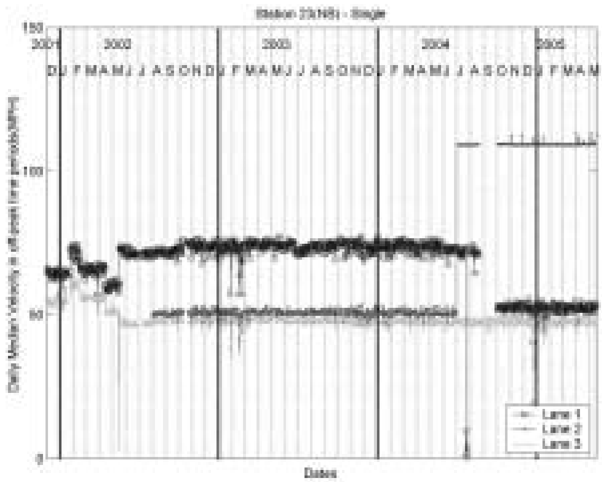

Station 18(NB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

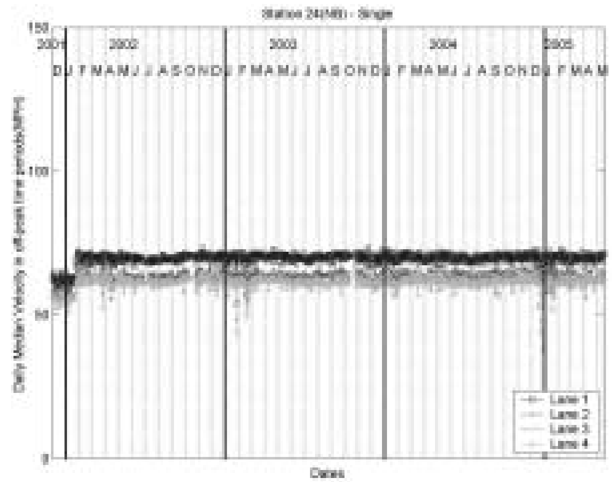

Station 19(NB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

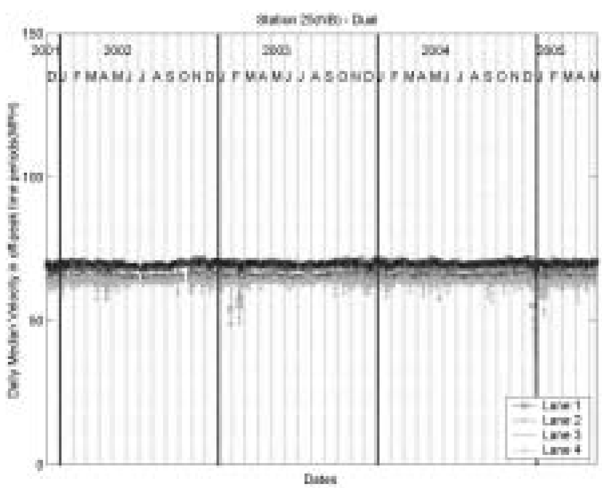

Station 20(NB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

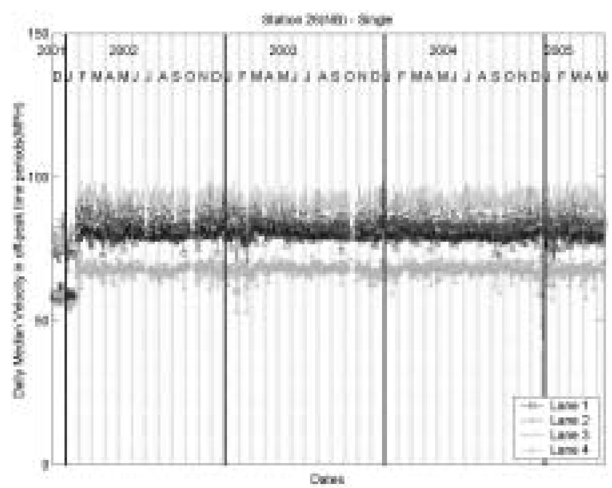

Station 21(NB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

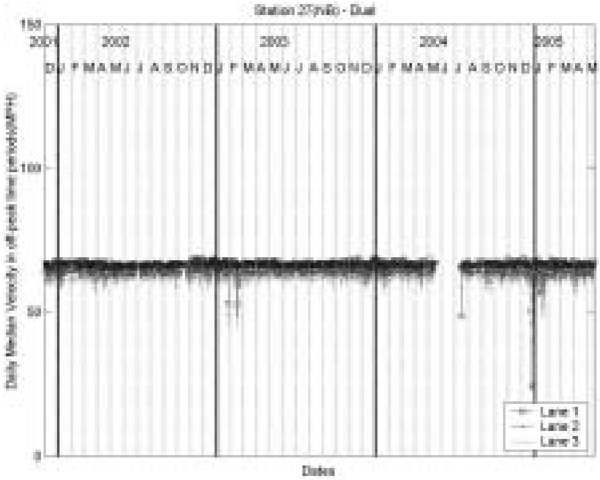

Station 22(NB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4


Station 23(NB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

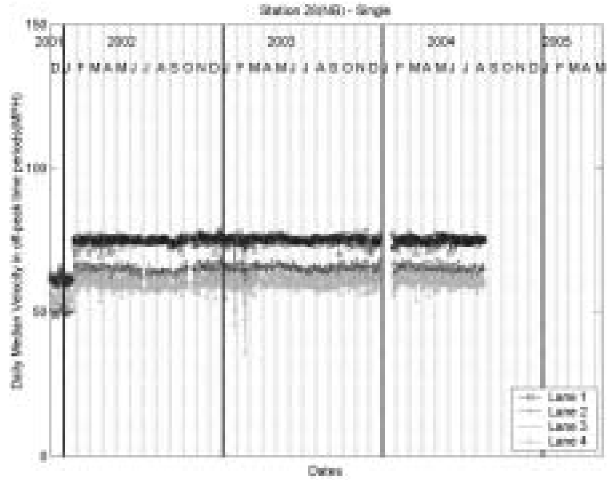

Station 24(NB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4


Station 25(NB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

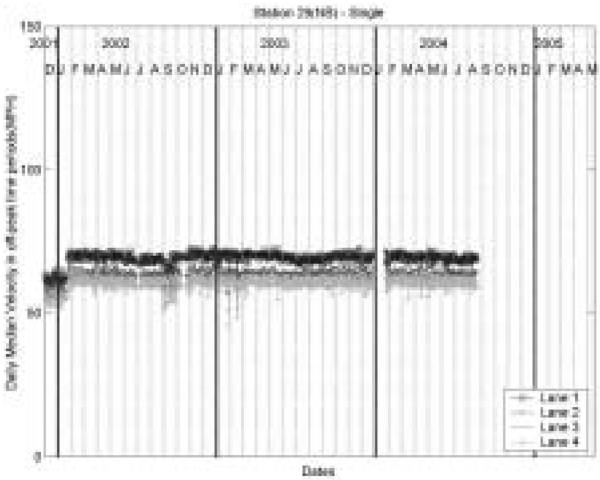

Station 26(NB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4



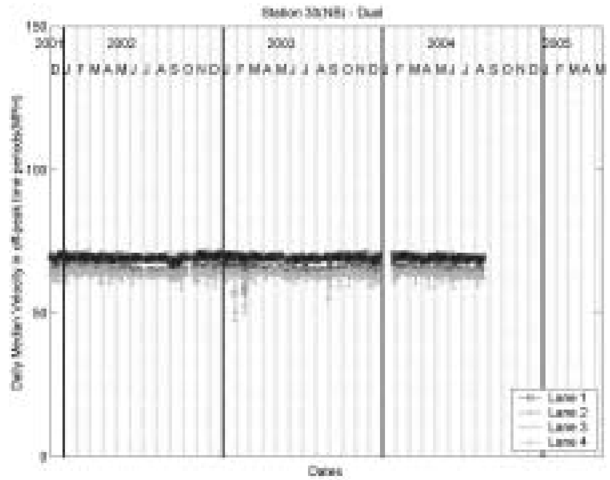
Station 27(NB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3



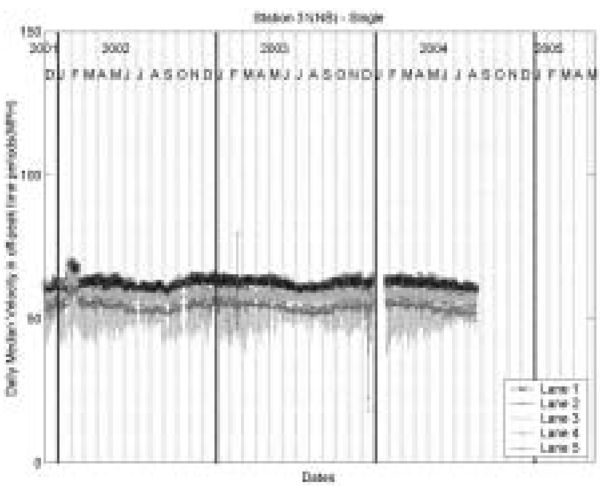
Station 28(NB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4



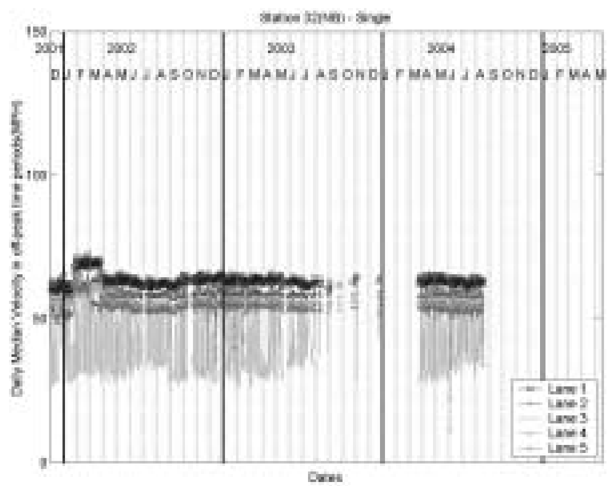
Station 29(NB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4



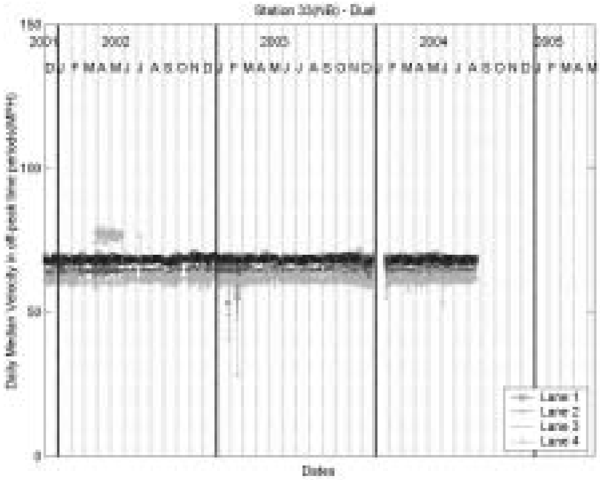
Station 30(NB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

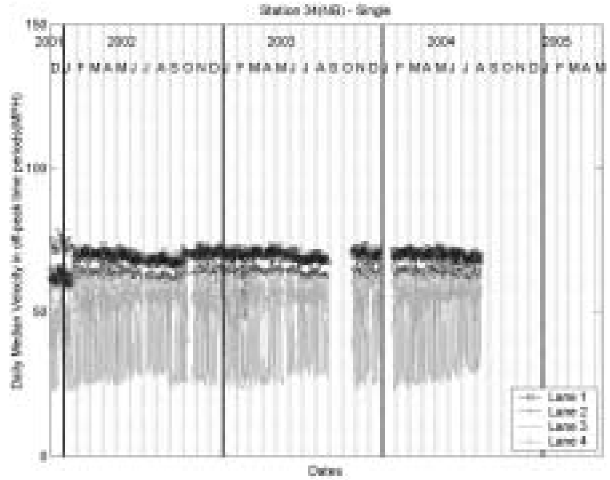


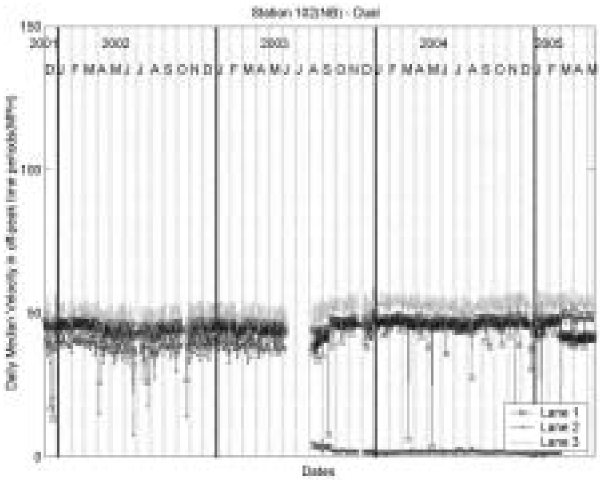
Station 31(NB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4
Lane 5

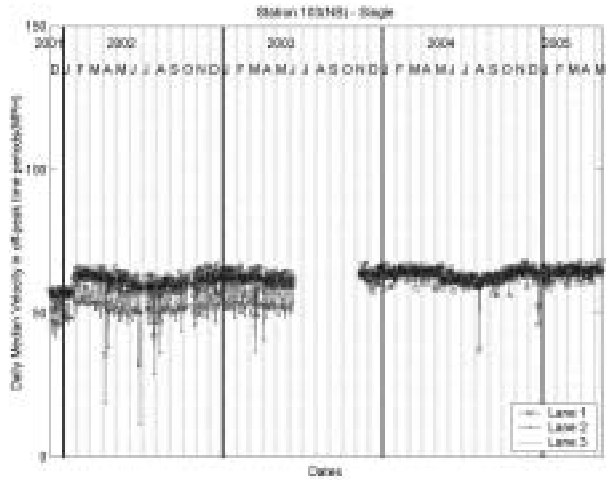


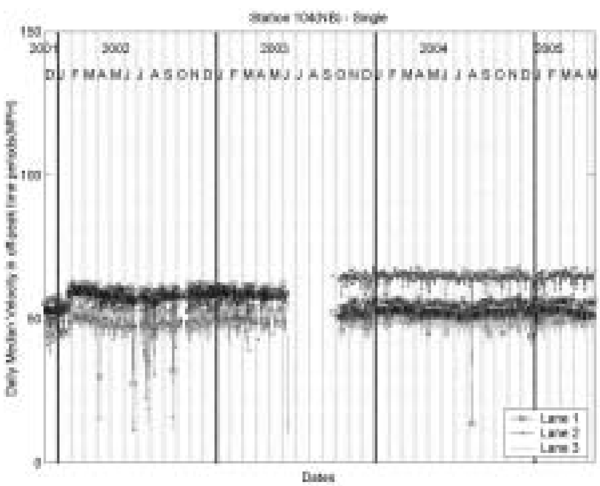
Station 32(NB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4
Lane 5

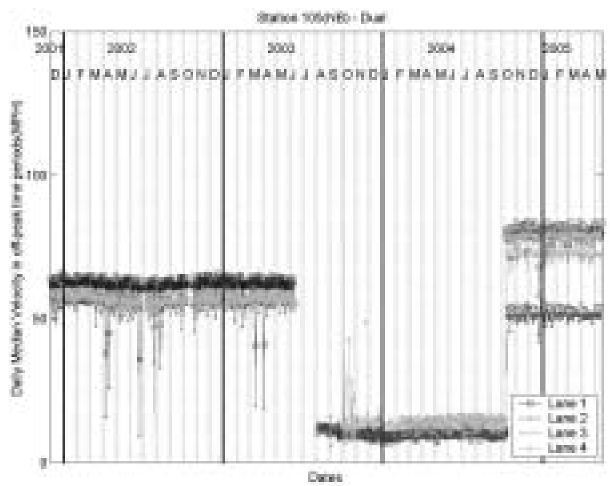

Station 33(NB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

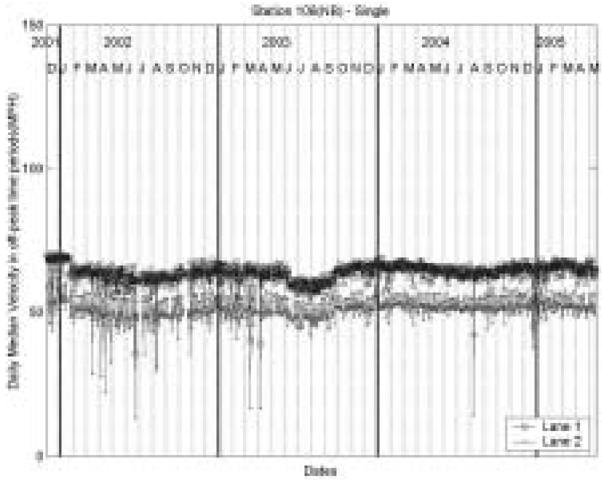

Station 34(NB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

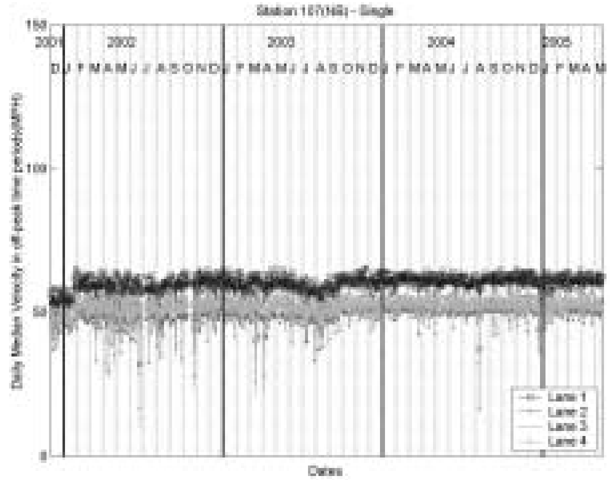

Station 102(NB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

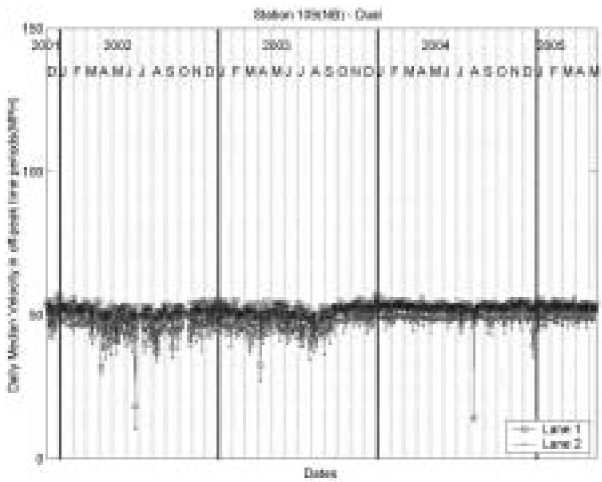

Station 103(NB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

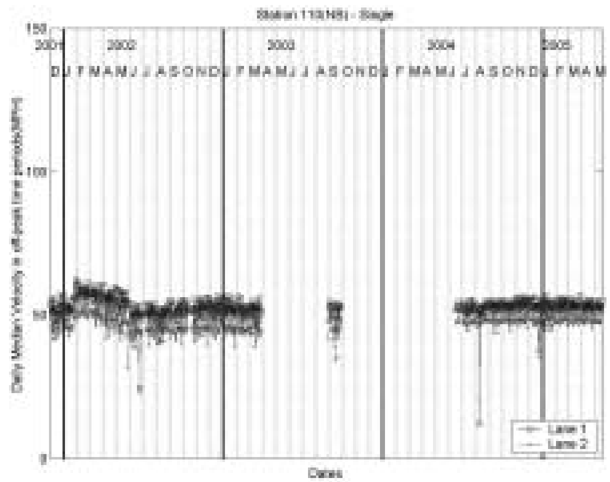

Station 104(NB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3


Station 105(NB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

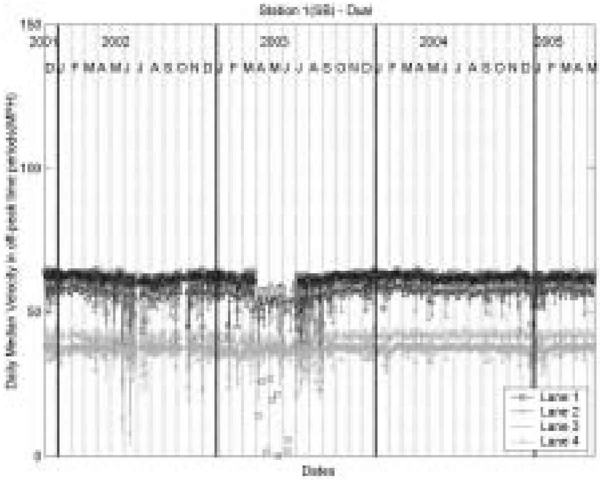

Station 106(NB) - Single
2002
2003
2004
2005
Dates
Lane 1
Lane 2


Station 107(NB) - Single
2002
2003
2004
2005
Dates
Lane 1
Lane 2
Lane 3
Lane 4

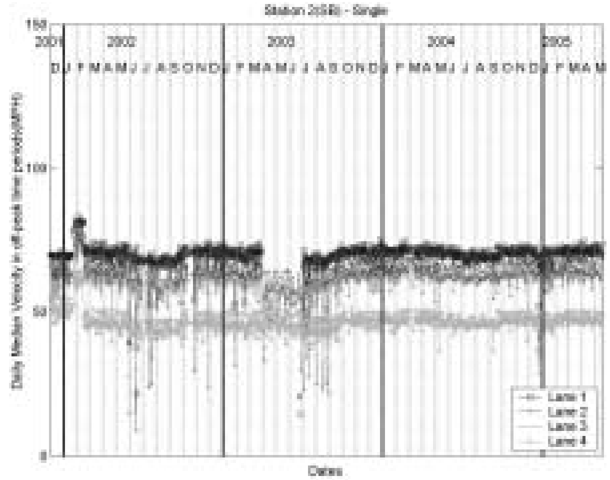

Station 109(NB) - Dual
2002
2003
2004
2005
Dates
Lane 1
Lane 2


Station 110(NB) - Single
2002
2003
2004
2005
Dates
Lane 1
Lane 2

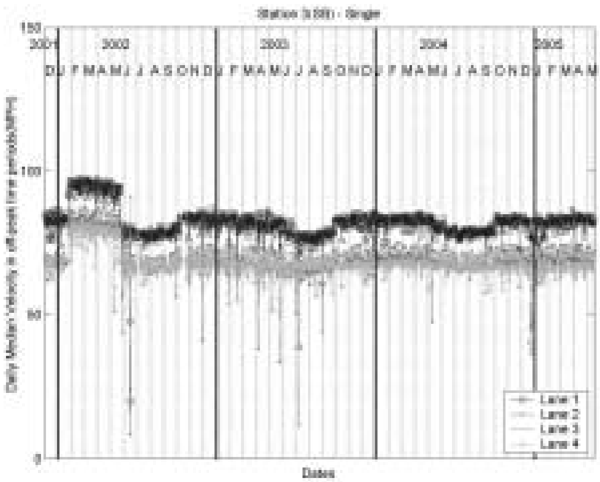
SOUTHBOUND



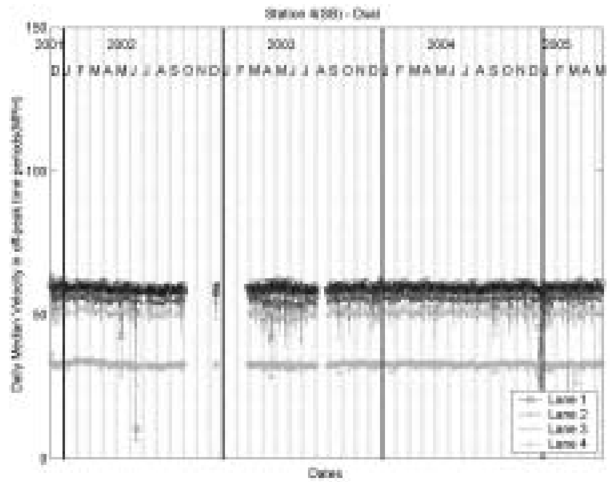
Station 1(SB) - Dual
Dates
Lane 1
Lane 2
Lane 3
Lane 4



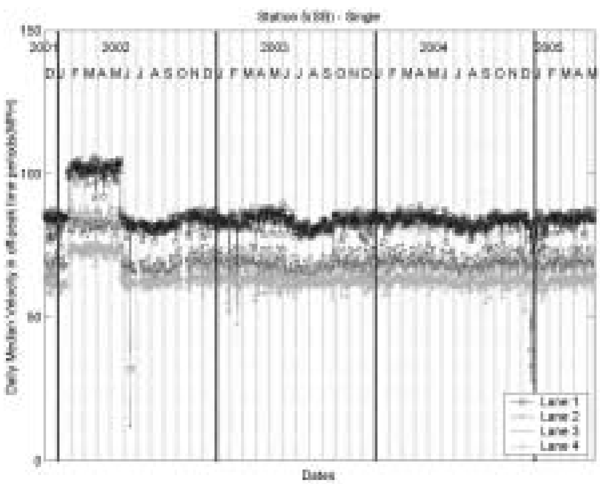
Station 2(SB) - Single
Dates
Lane 1
Lane 2
Lane 3
Lane 4



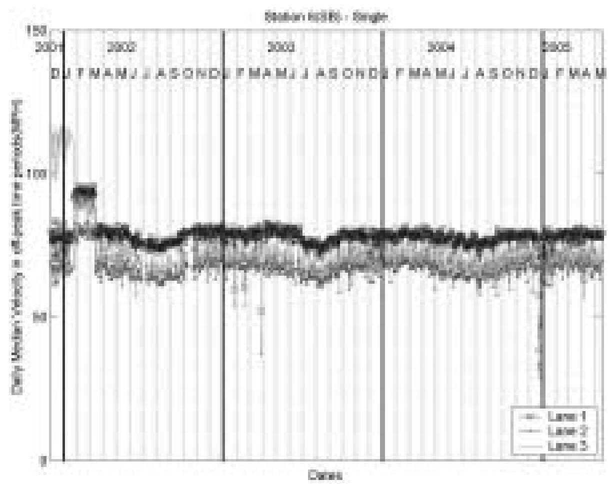
Station 3(SB) - Single
Dates
Lane 1
Lane 2
Lane 3
Lane 4



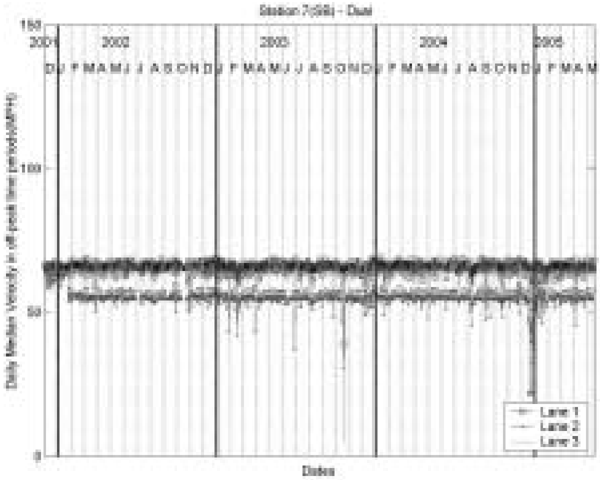
Station 4(SB) - Dual
Dates
Lane 1
Lane 2
Lane 3
Lane 4

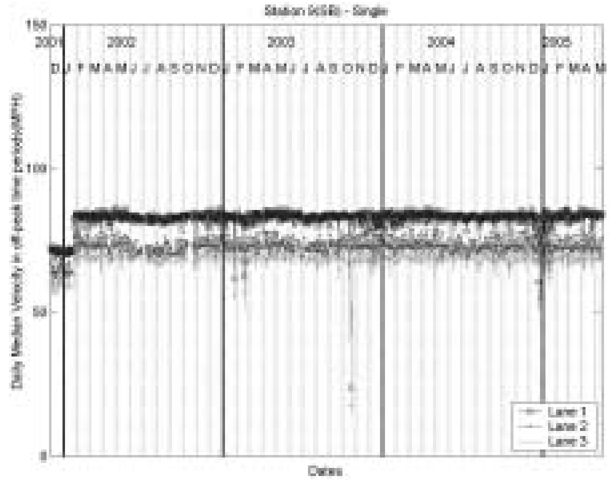


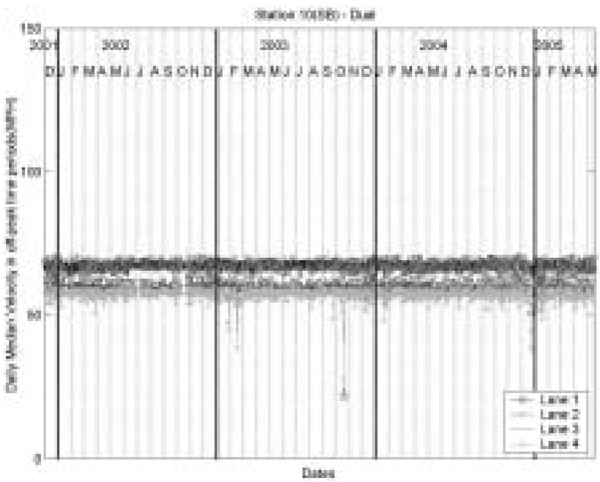
Station 5(SB) - Single
Dates
Lane 1
Lane 2
Lane 3
Lane 4

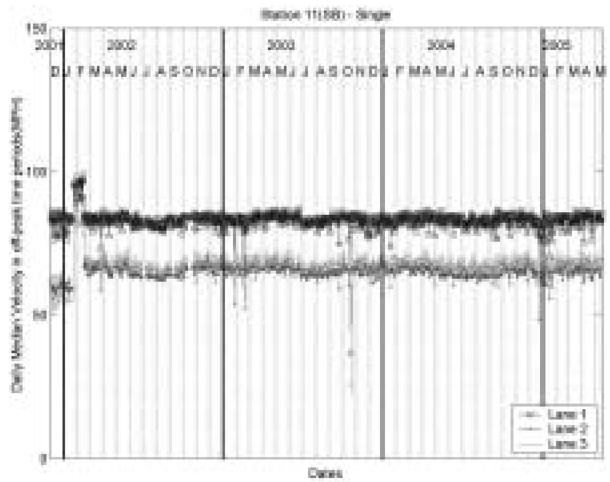


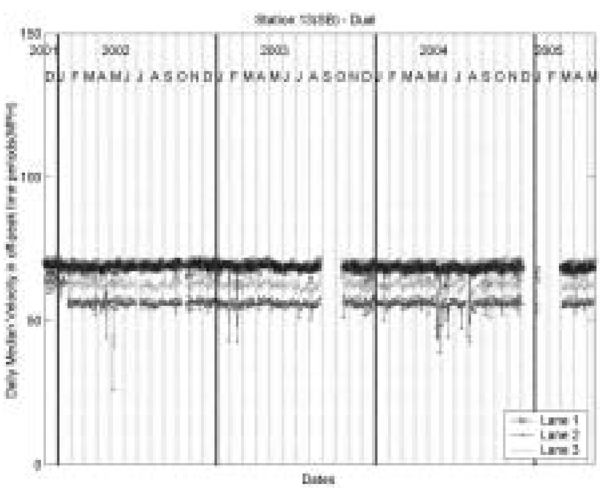
Station 6(SB) - Single
Dates
Lane 1
Lane 2
Lane 3

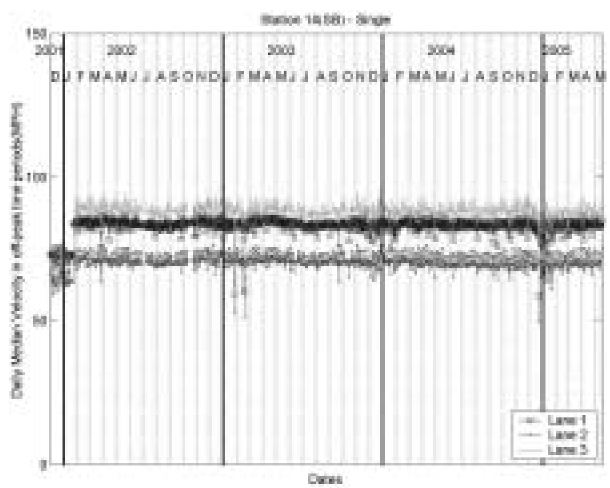

Station 7(SB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

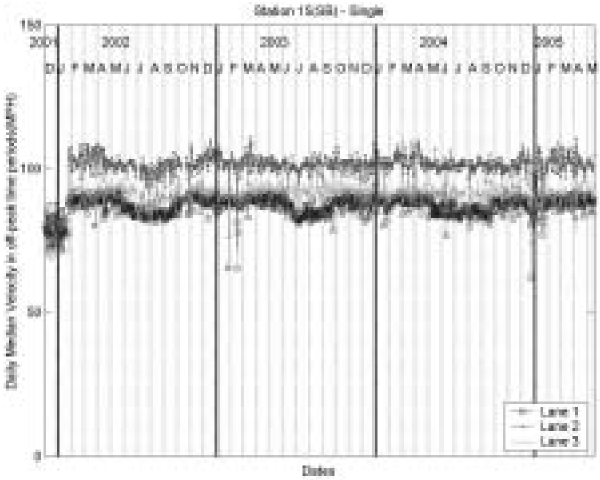

Station 9(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

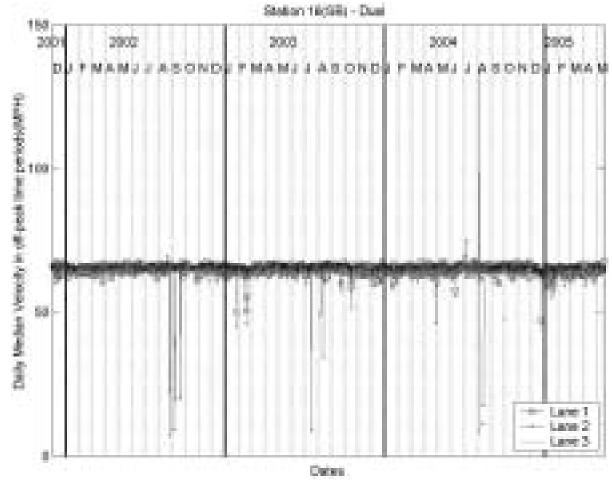

Station 10(SB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

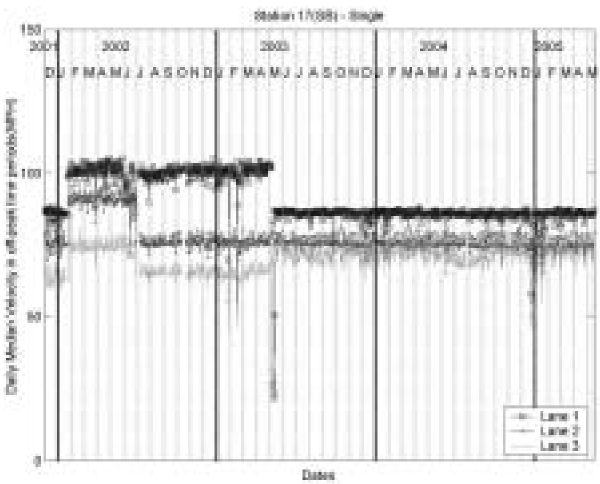

Station 11(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

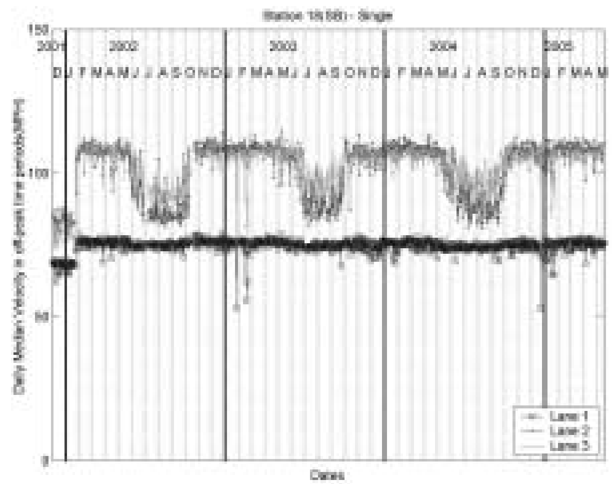

Station 13(SB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

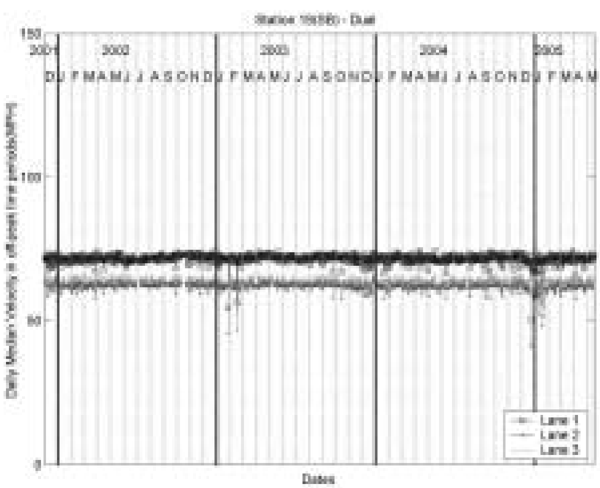

Station 14(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

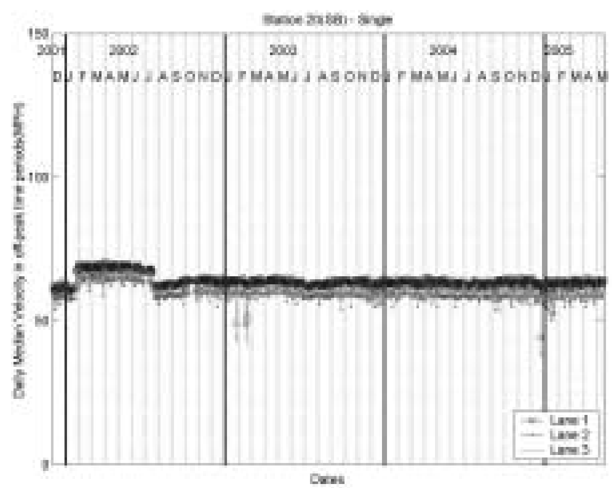

Station 15(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

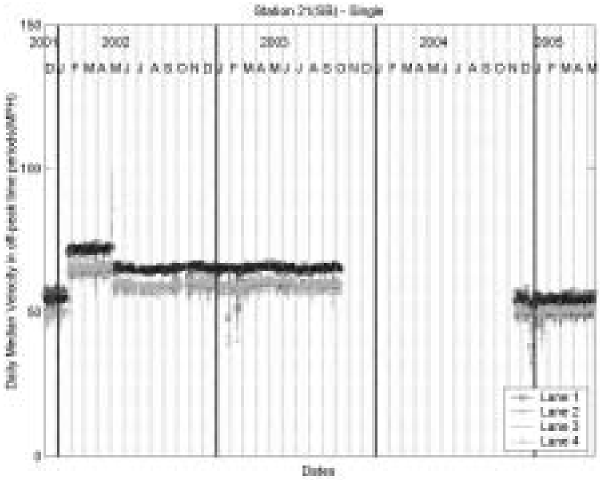

Station 16(SB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

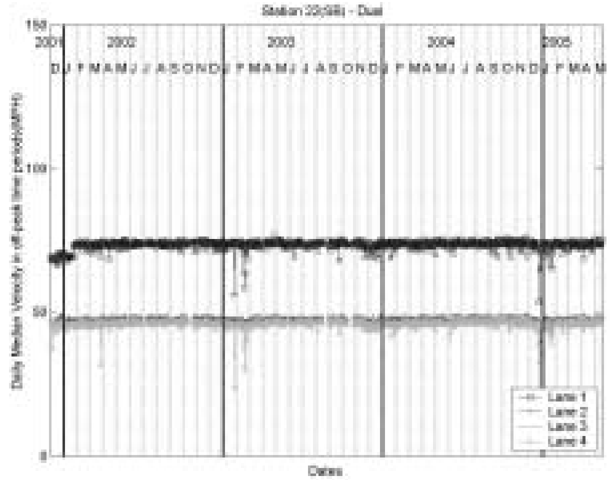

Station 17(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

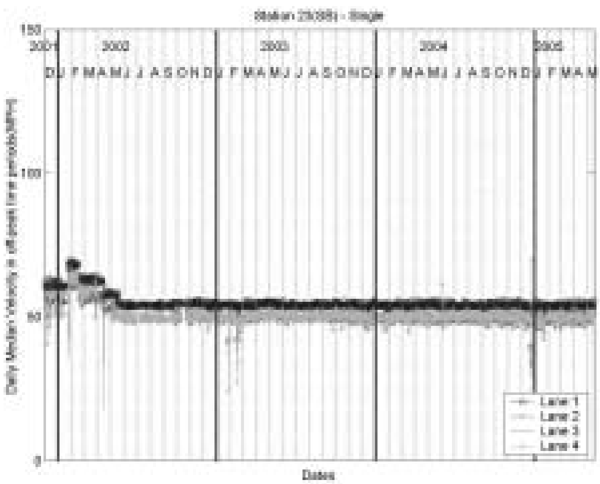

Station 18(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

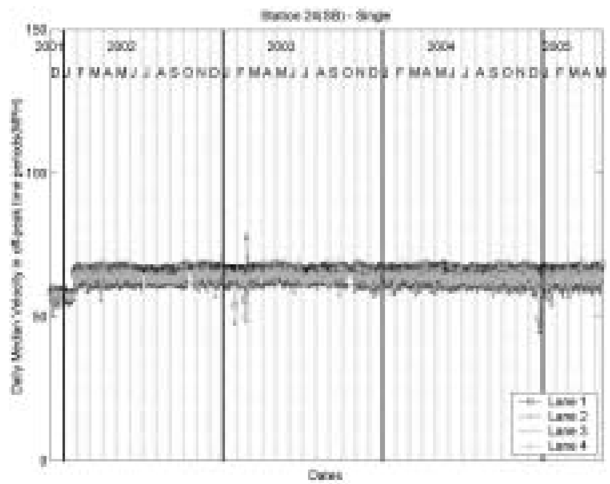

Station 19(SB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

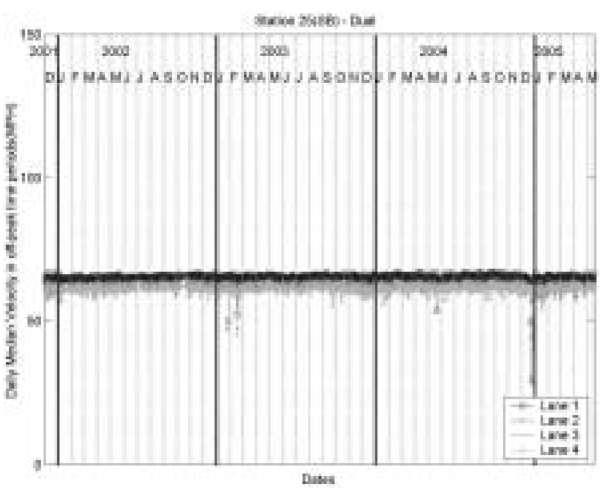

Station 20(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

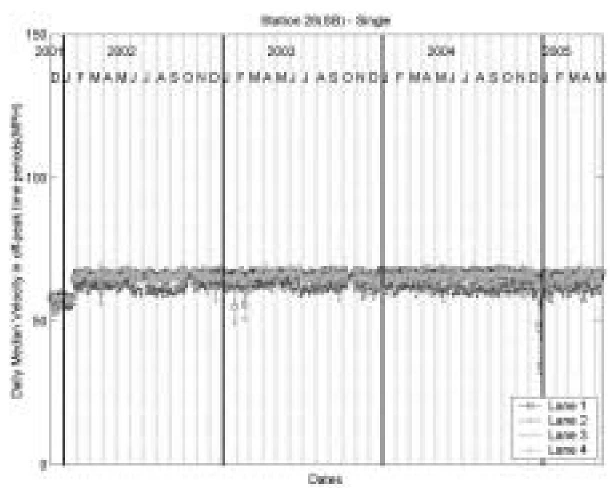

Station 21(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

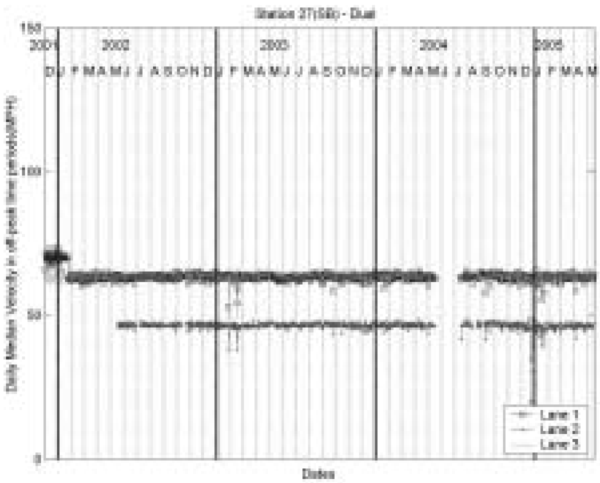

Station 22(SB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

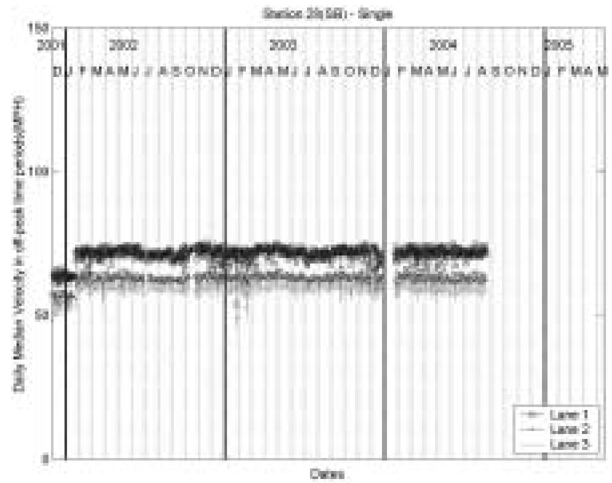

Station 23(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

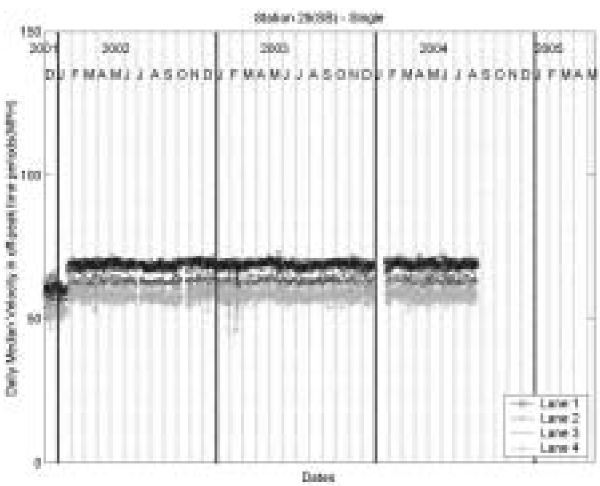

Station 24(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

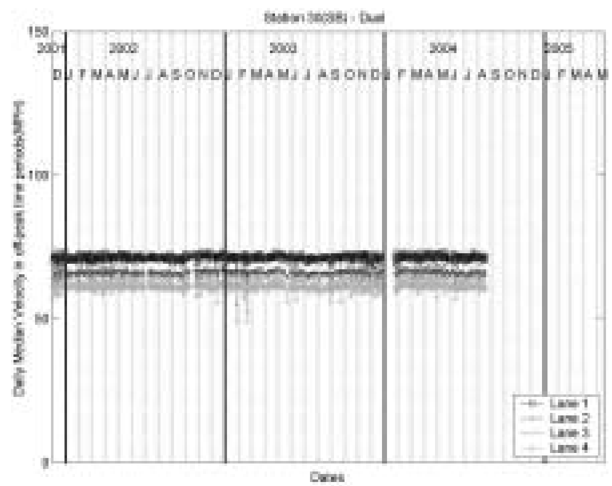

Station 25(SB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

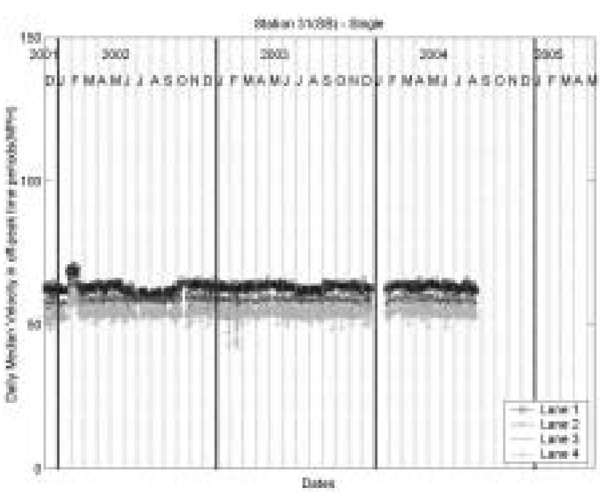

Station 26(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

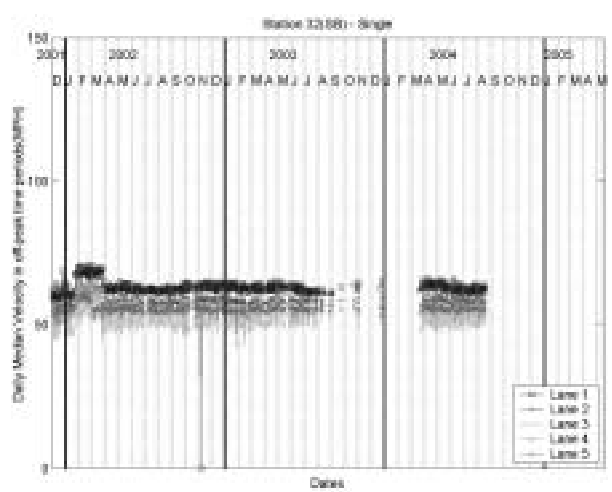

Station 27(SB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

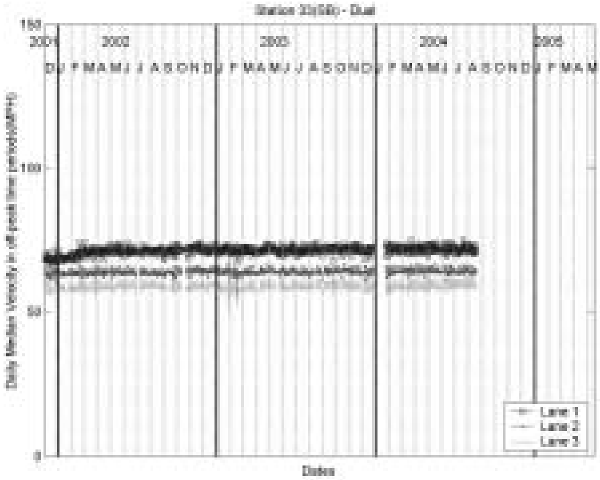

Station 28(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

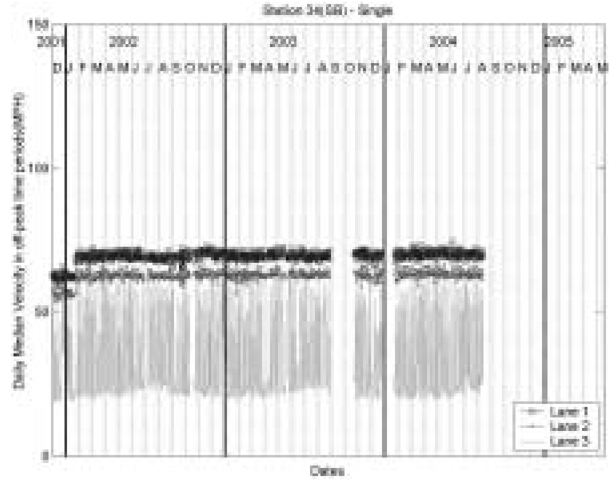

Station 29(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

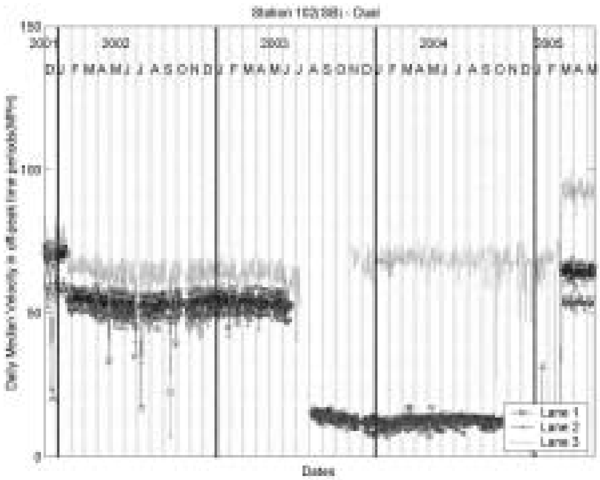

Station 30(SB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

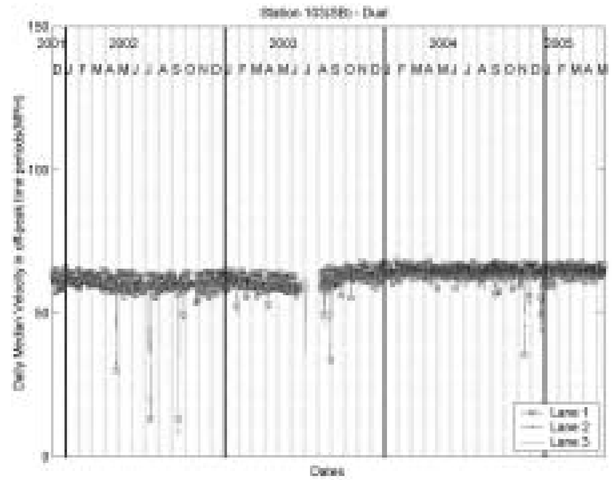

Station 31(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

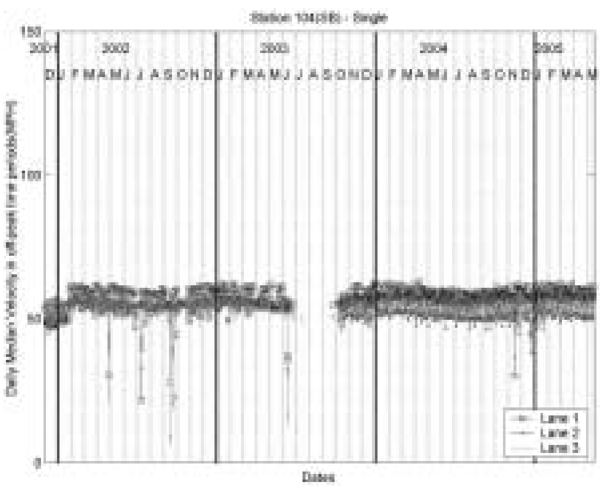

Station 32(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4
Lane 5

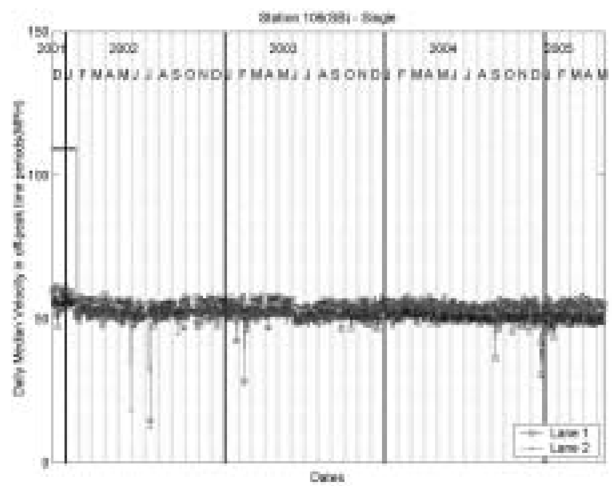

Station 33(SB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

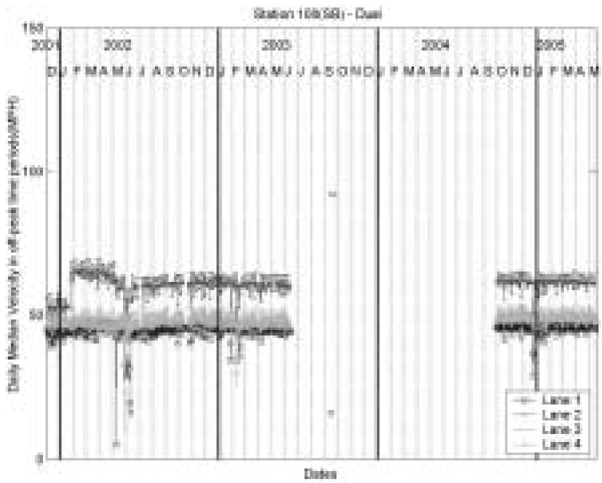

Station 34(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

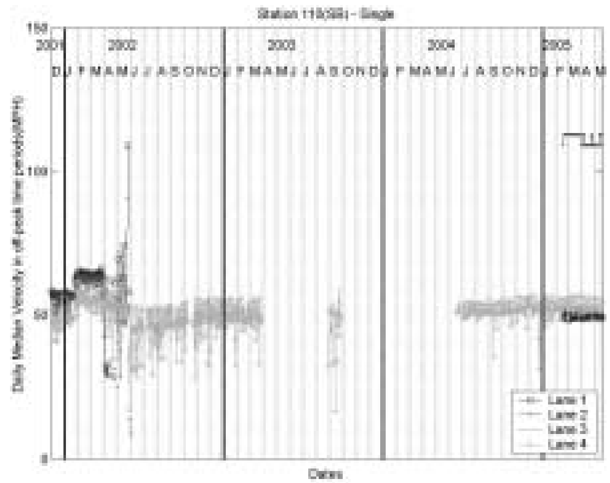

Station 102(SB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3

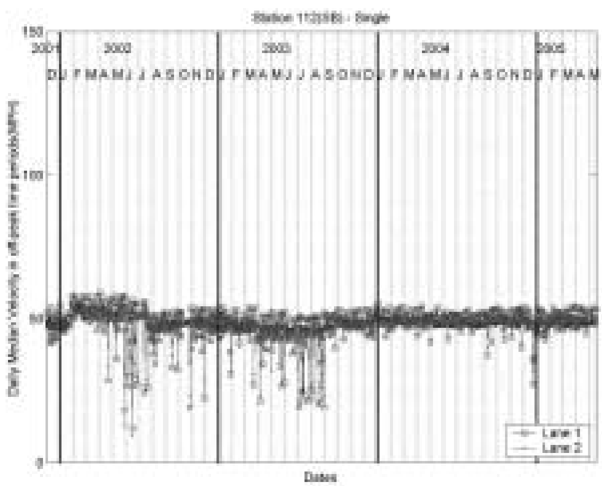

Station 103(SB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3


Station 104(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3


Station 106(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2

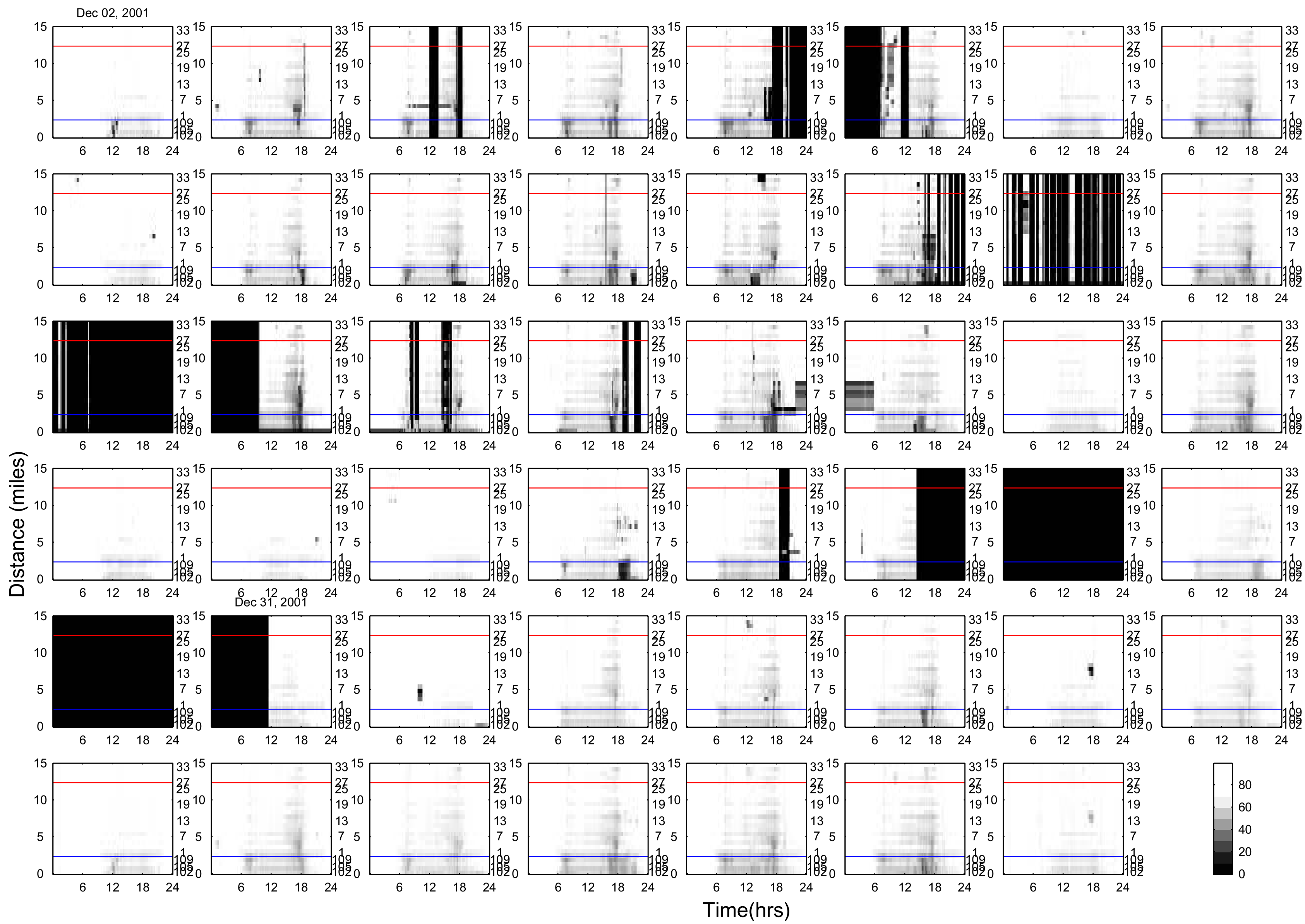

Station 109(SB) - Dual
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4

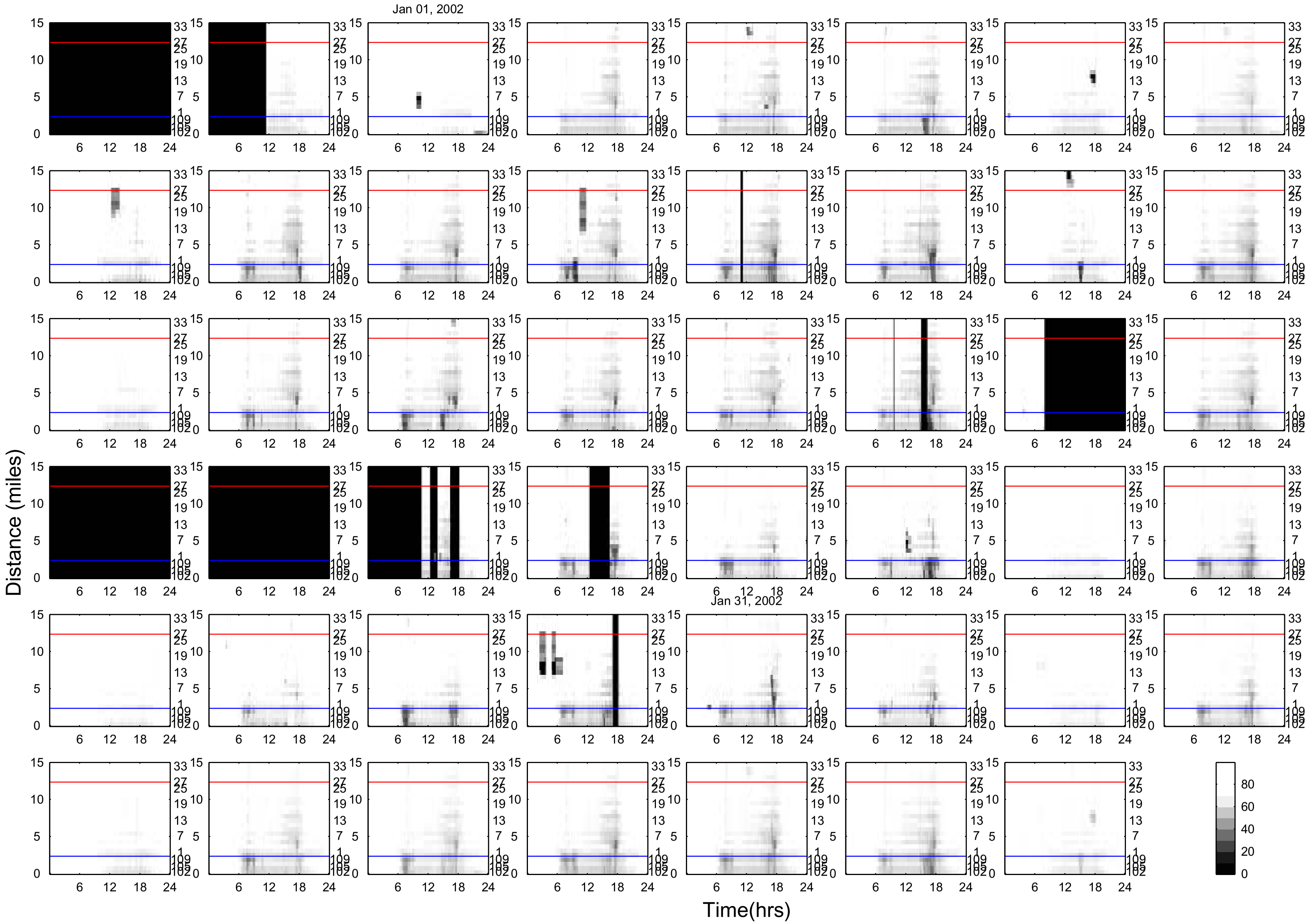

Station 110(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2
Lane 3
Lane 4


Station 112(SB) - Single
Daily Median Velocity in off-peak time periods(MPH)
Dates
Lane 1
Lane 2

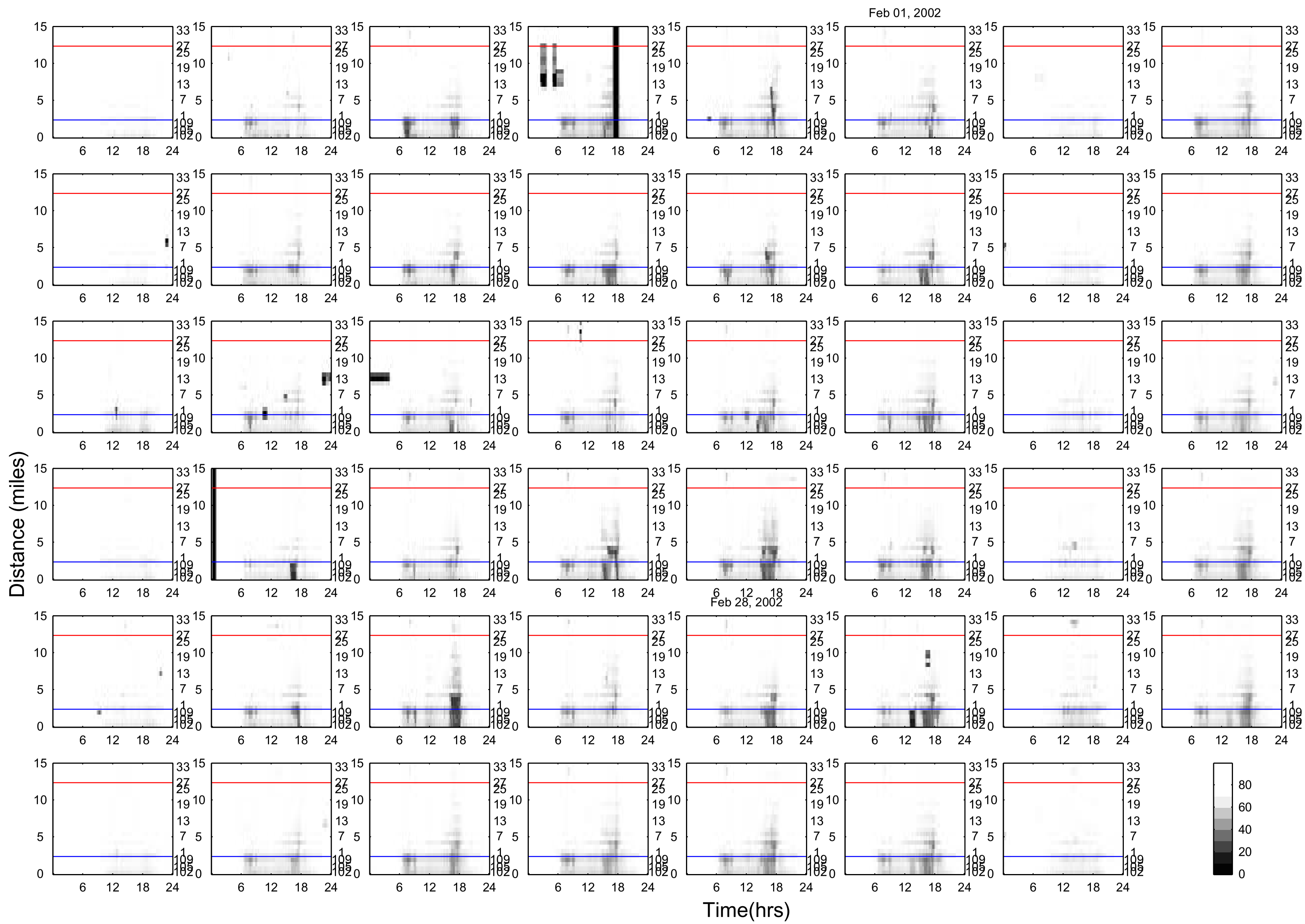
Appendix D: Summary Plots

NORTHBOUND

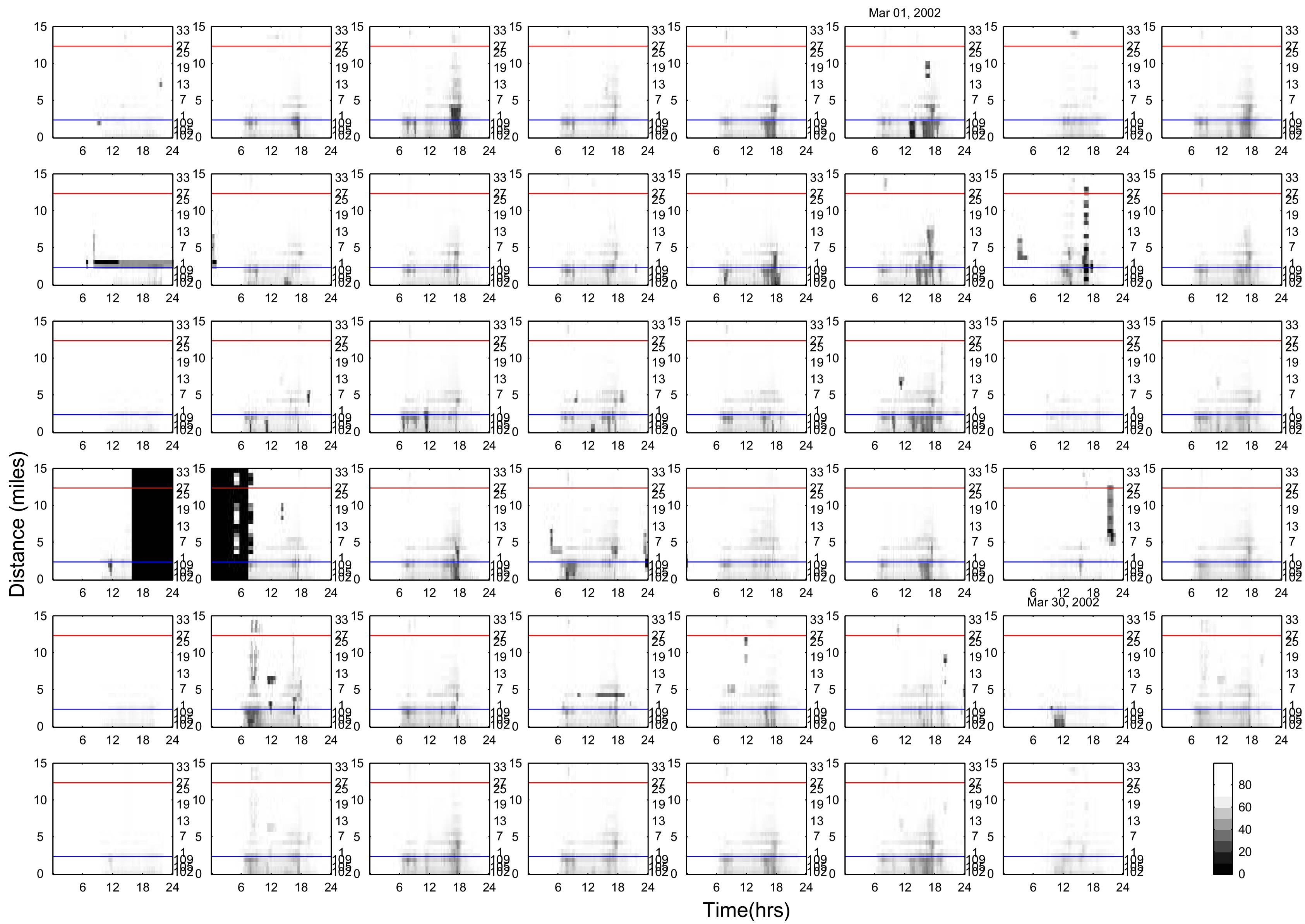

Dec 02, 2001
Dec 31, 2001
Distance (miles)
Time(hrs)
80
60
40
20
0

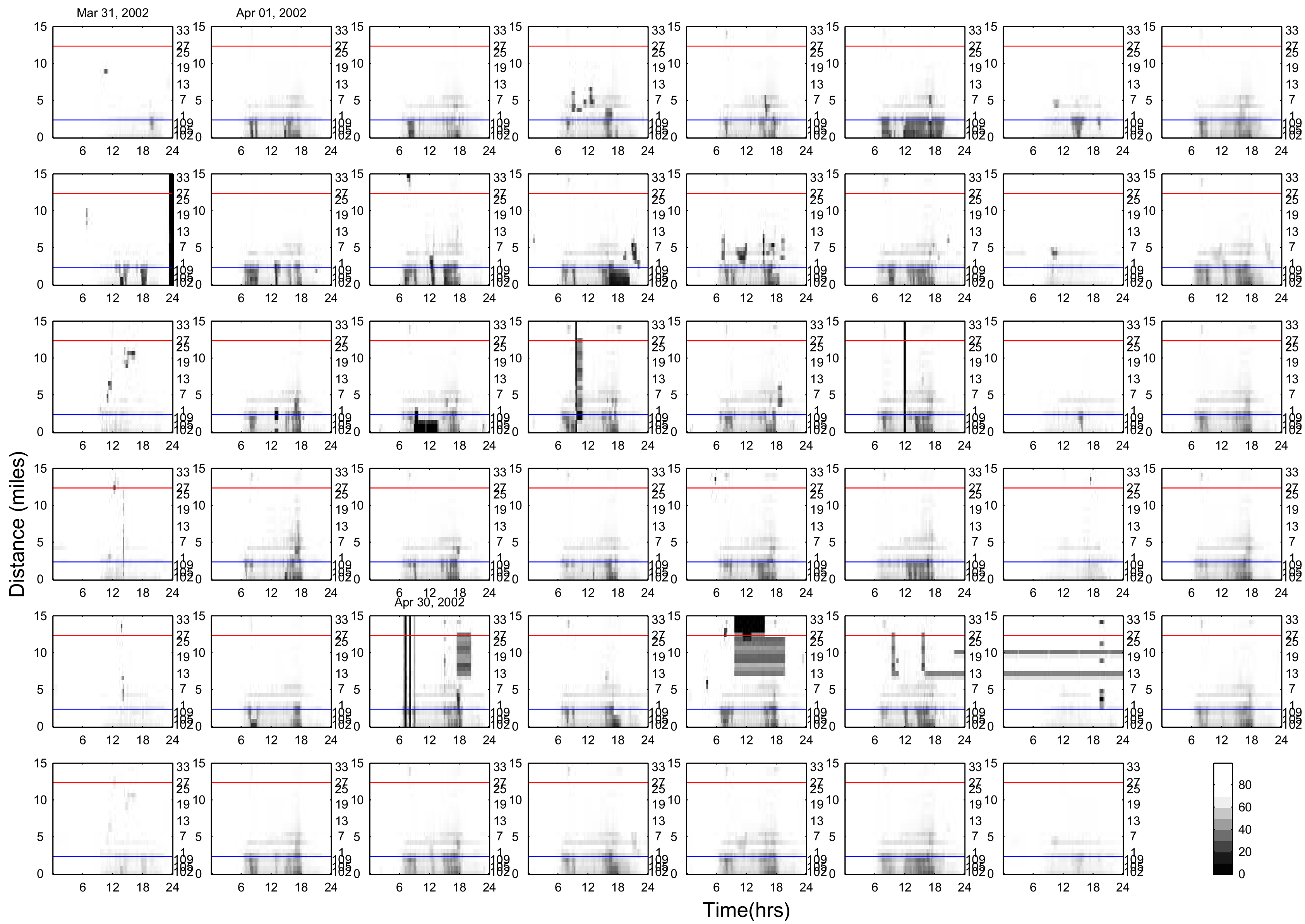


Jan 01, 2002
Jan 31, 2002
Distance (miles)
Time(hrs)

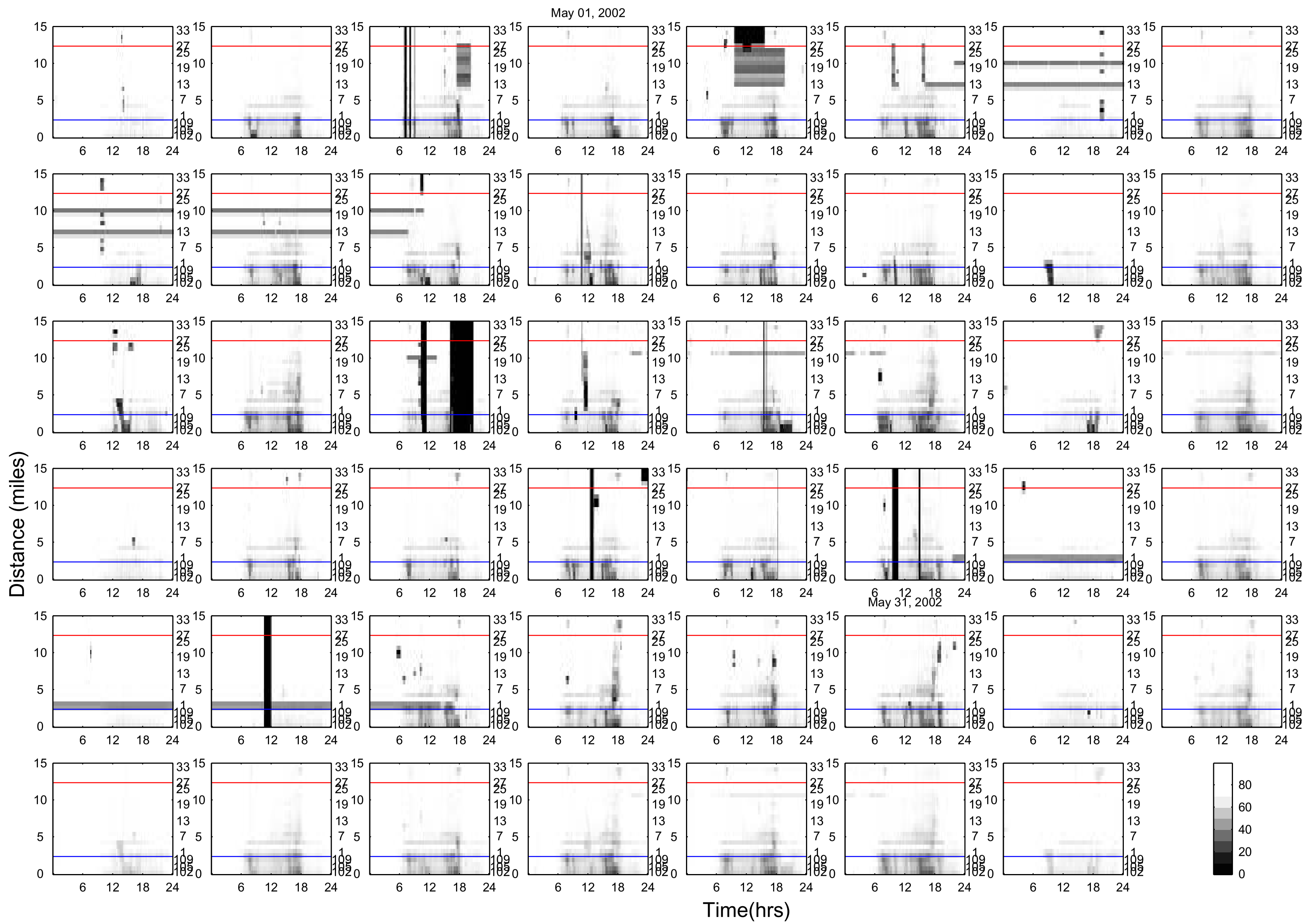


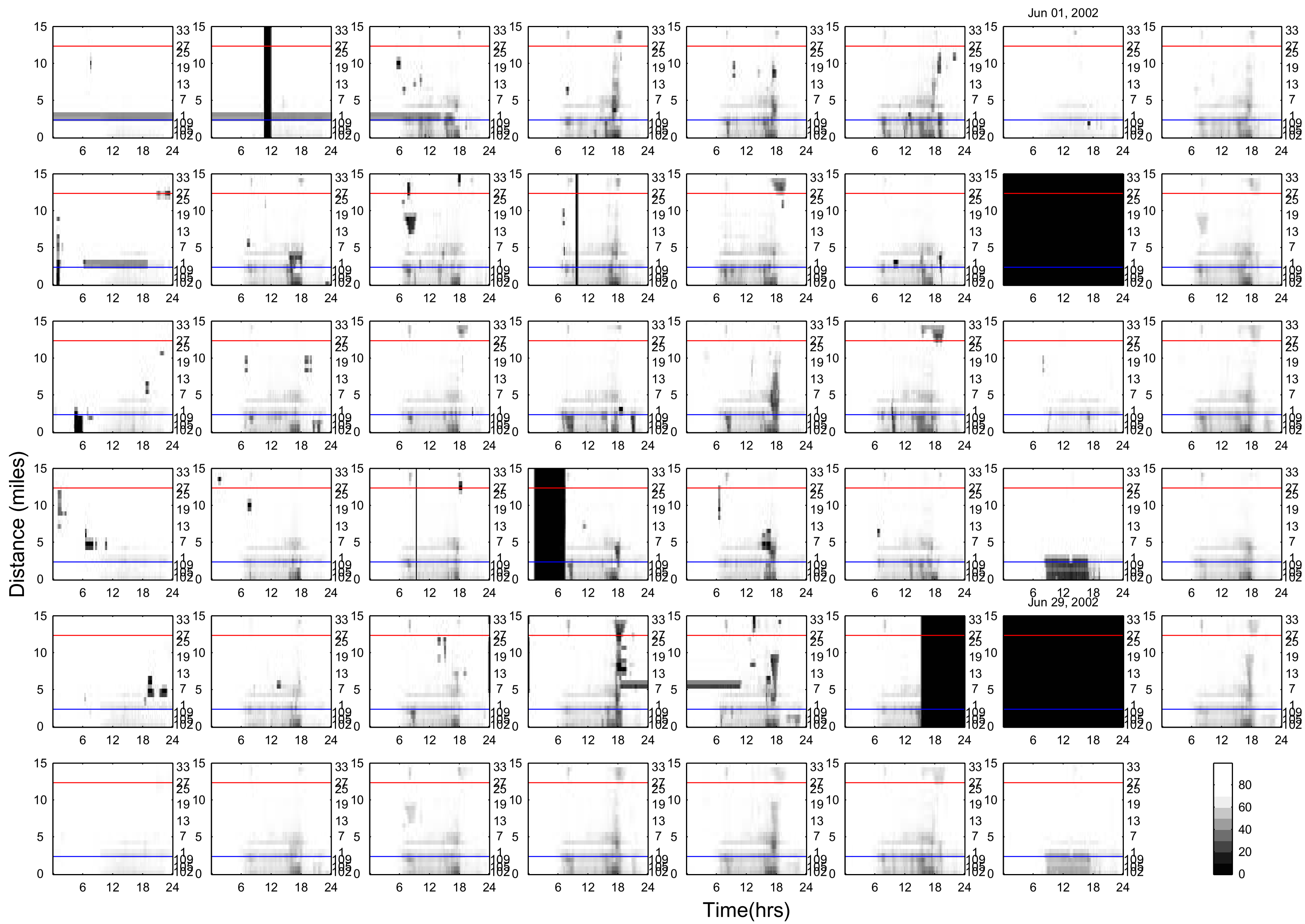
Feb 01, 2002
Feb 28, 2002
Distance (miles)
Time(hrs)


Mar 01, 2002
Mar 30, 2002
Distance (miles)
Time(hrs)

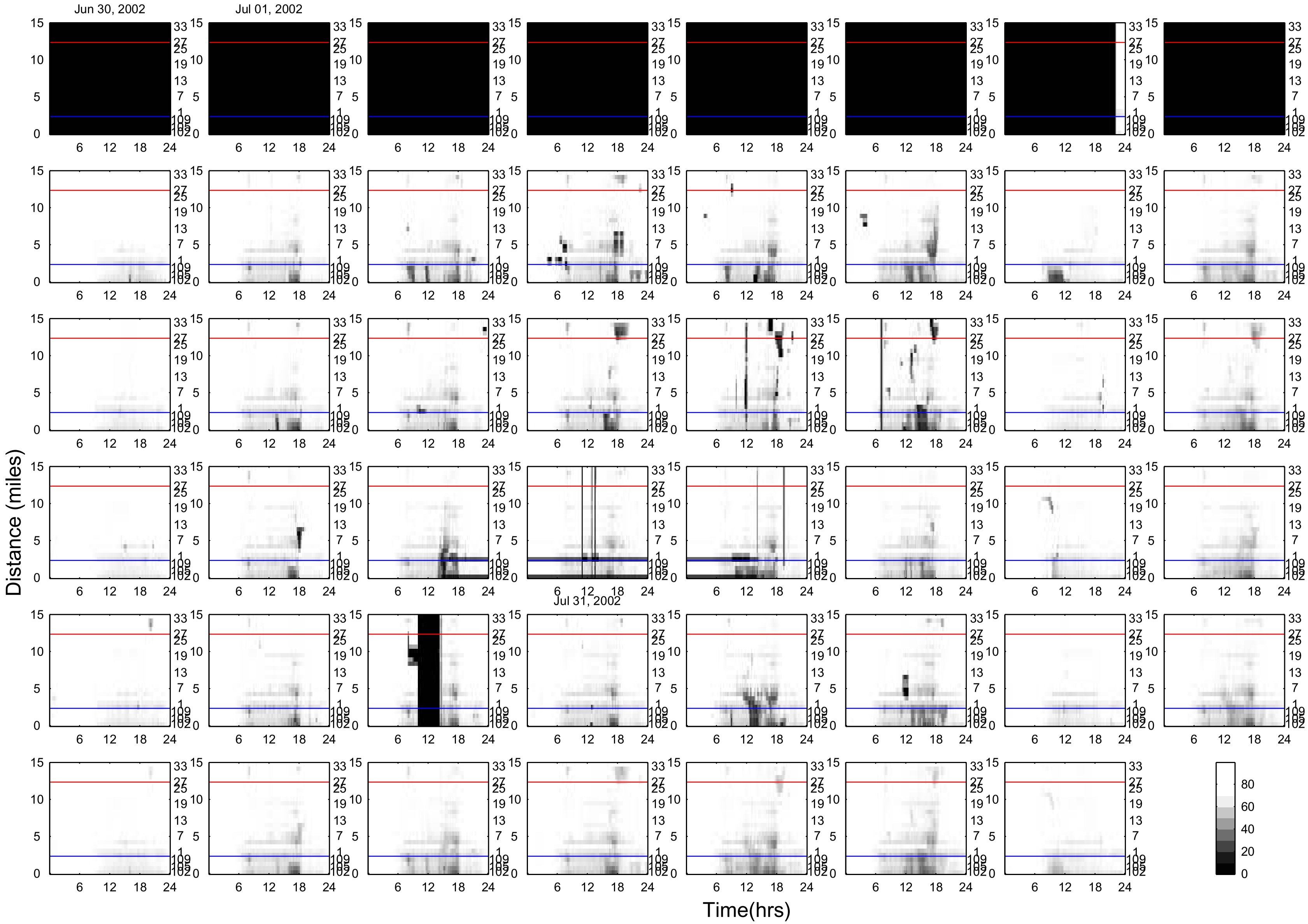


Mar 31, 2002
Apr 01, 2002
Apr 30, 2002
Distance (miles)
Time(hrs)

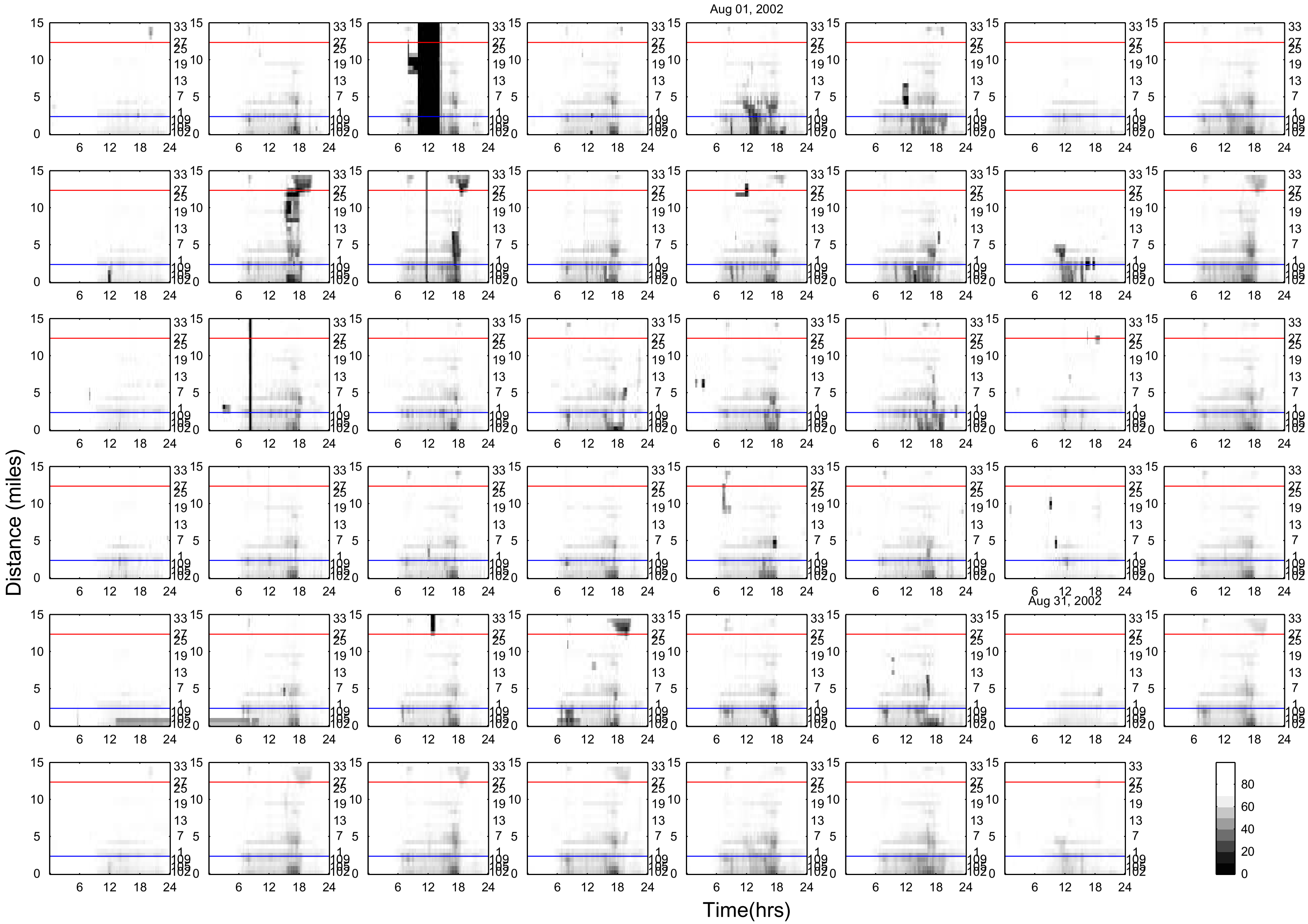

May 01, 2002
May 31, 2002
Distance (miles)
Time(hrs)



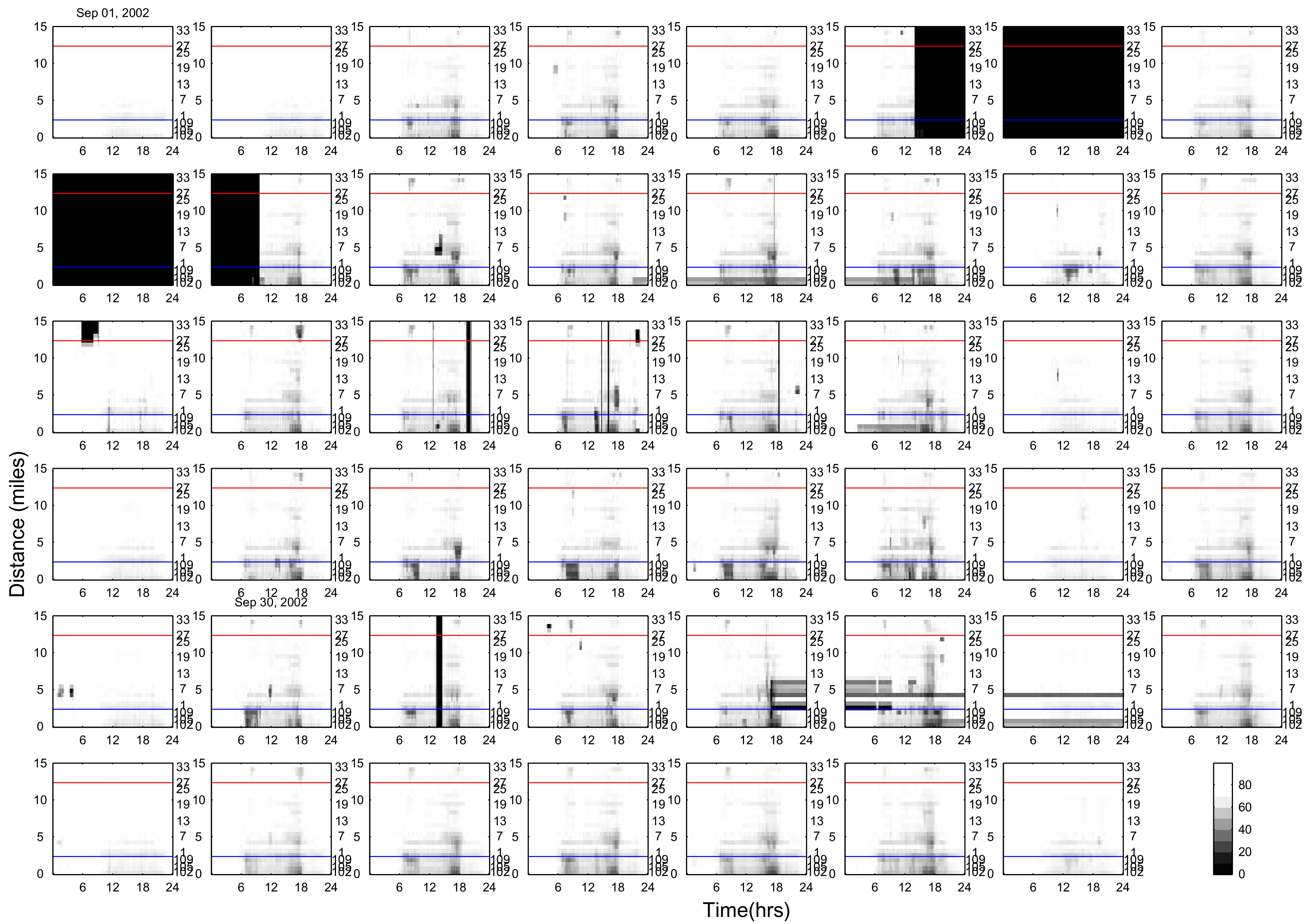
Jun 01, 2002
Jun 29, 2002
Distance (miles)
Time(hrs)
80
60
40
20
0

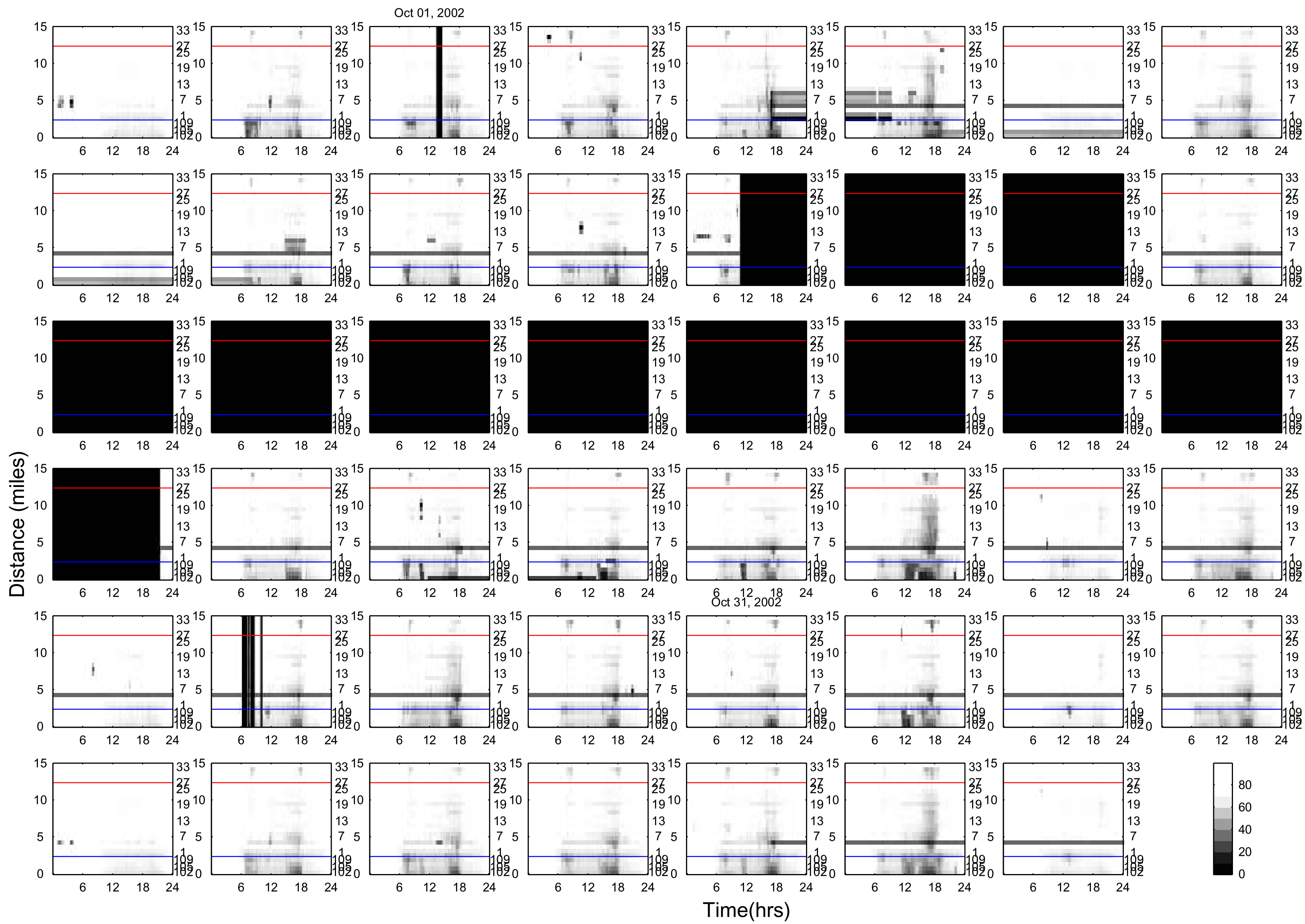


Jun 30, 2002
Jul 01, 2002
Jul 31, 2002
Distance (miles)
Time(hrs)
33
27
25
19
13
7
1
109
105
102
80
60
40
20
0

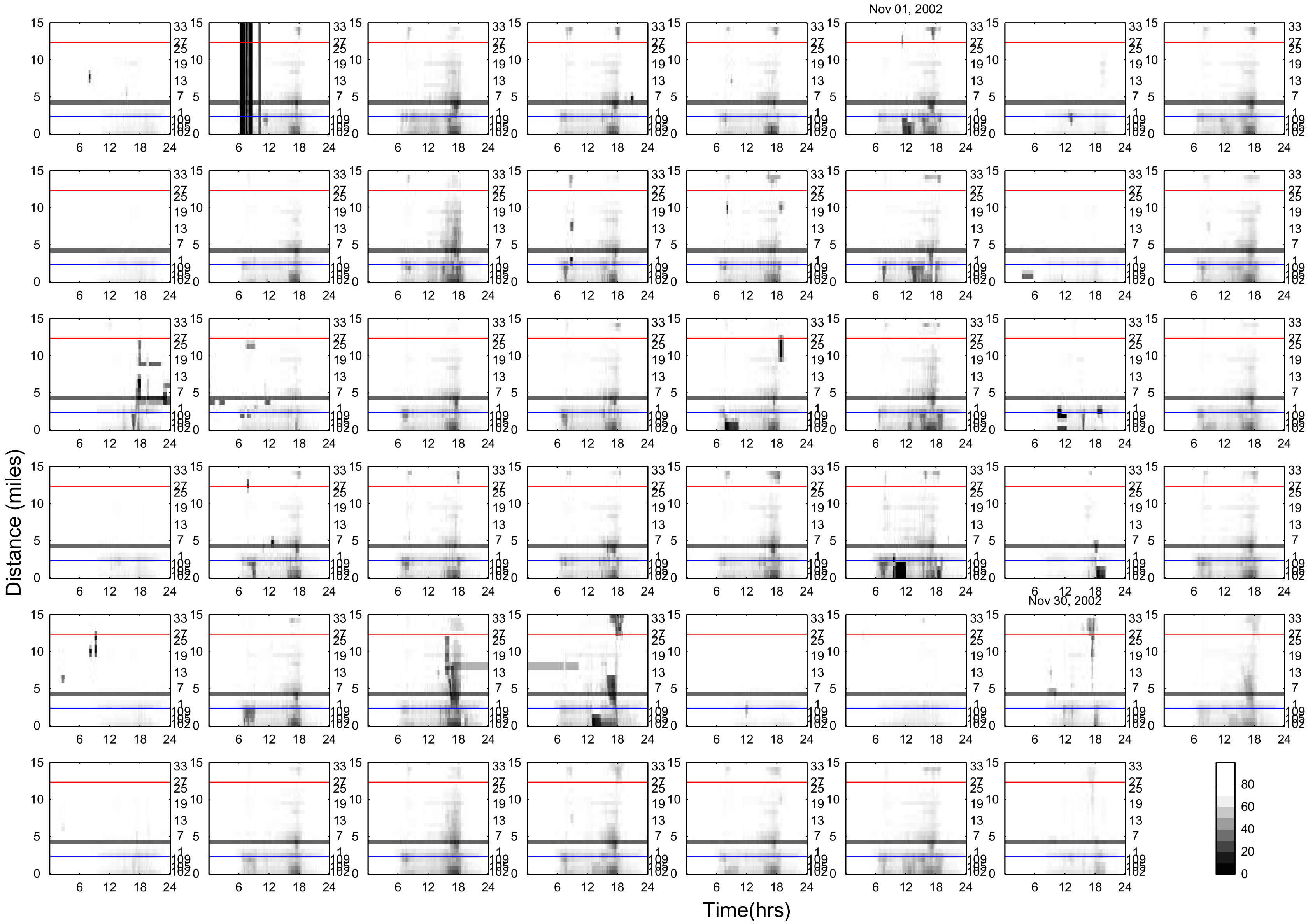


Aug 01, 2002
Aug 31, 2002
Distance (miles)
Time(hrs)

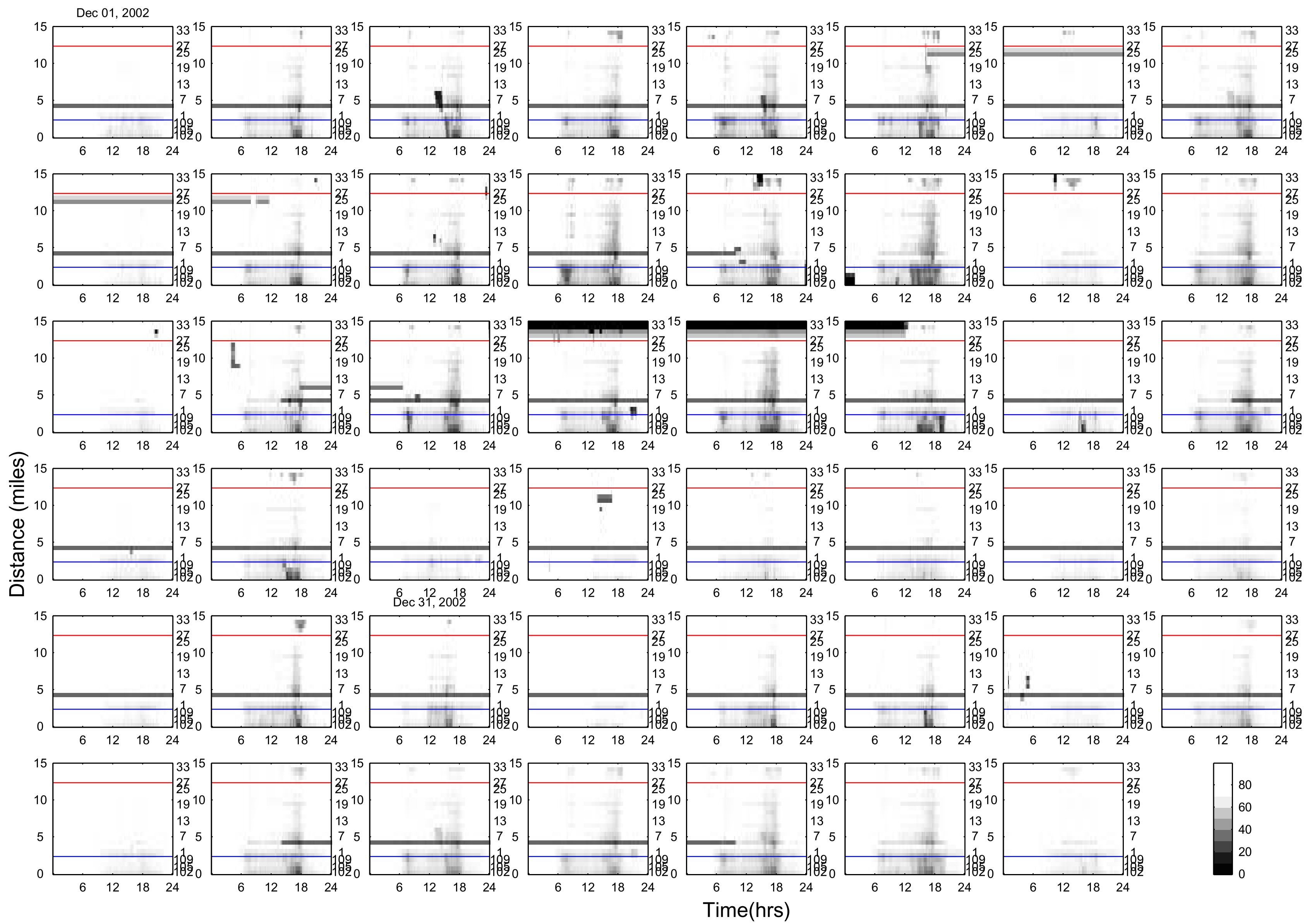

Sep 01, 2002
Sep 30, 2002
Distance (miles)
Time(hrs)
80
60
40
20
0



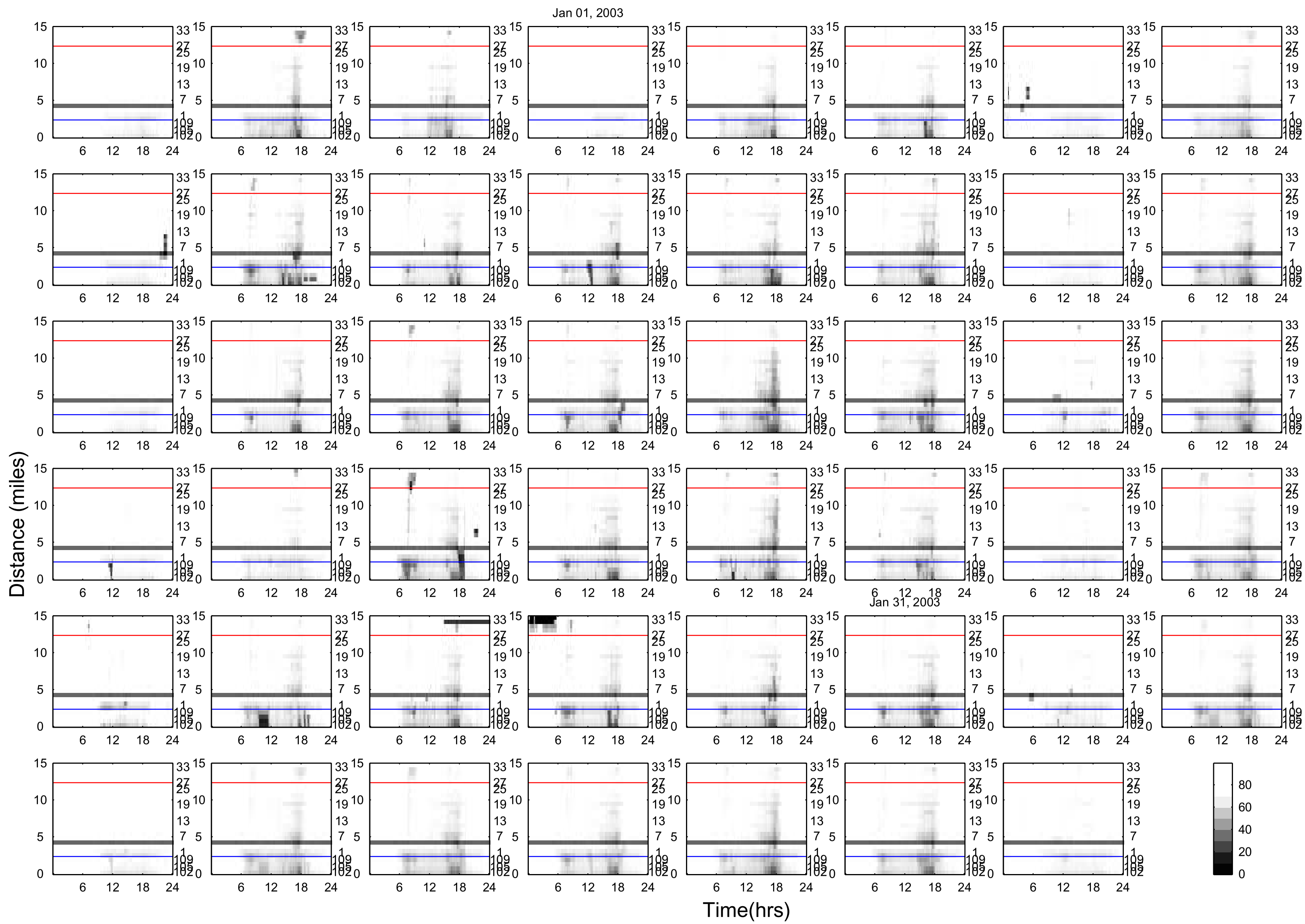
Oct 01, 2002
Oct 31, 2002
Distance (miles)
Time(hrs)



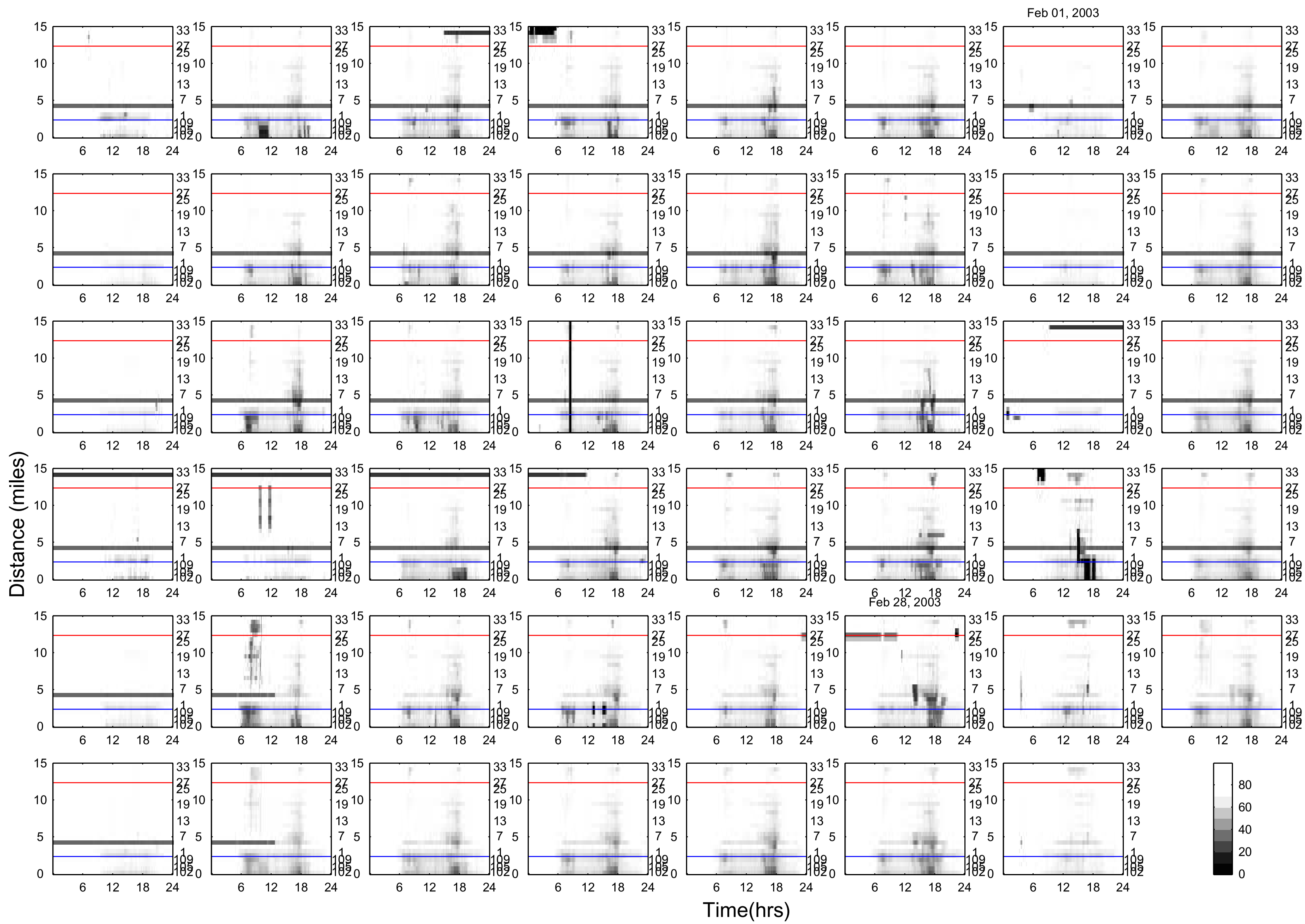
Nov 01, 2002
Nov 30, 2002
Distance (miles)
Time(hrs)

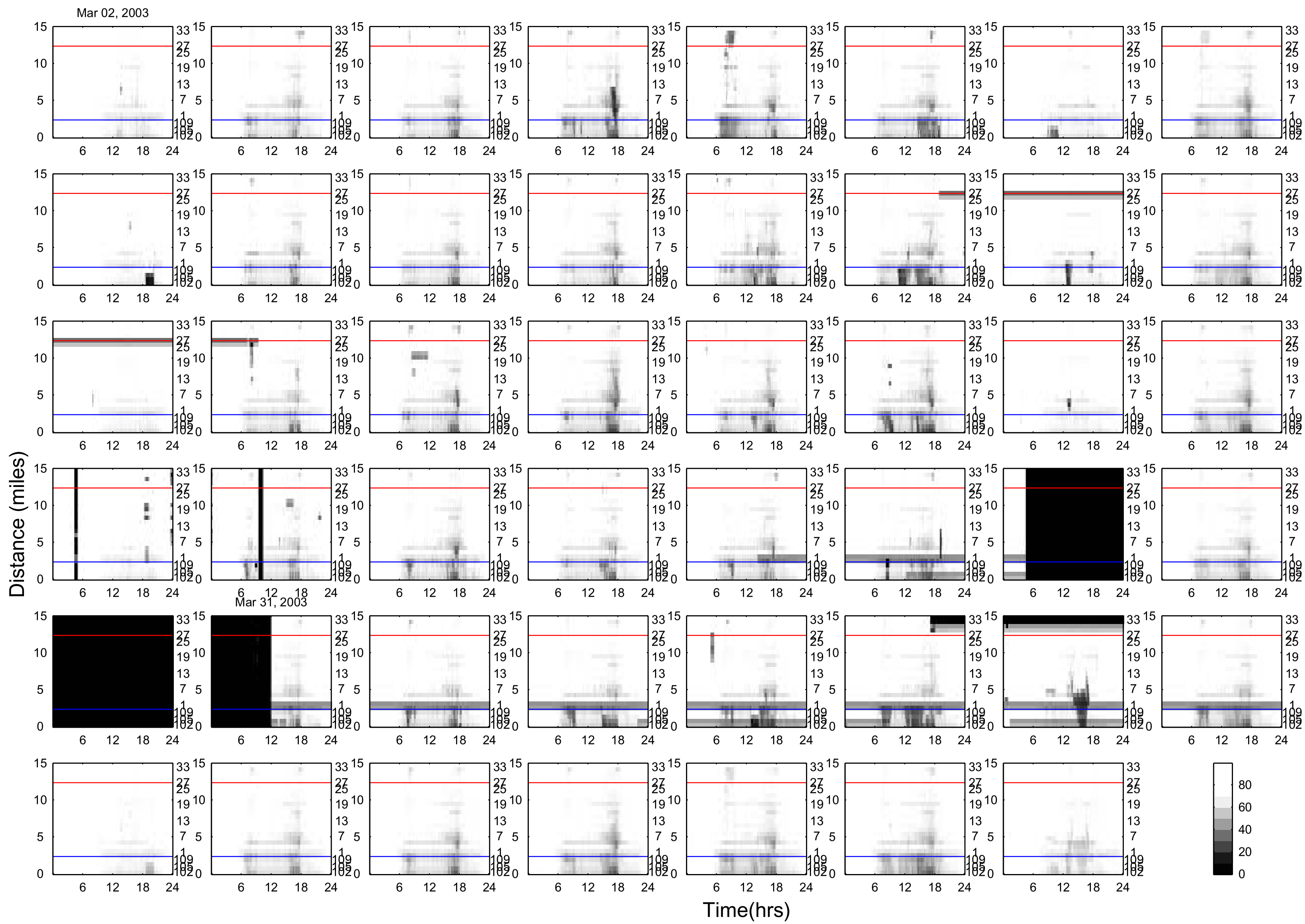


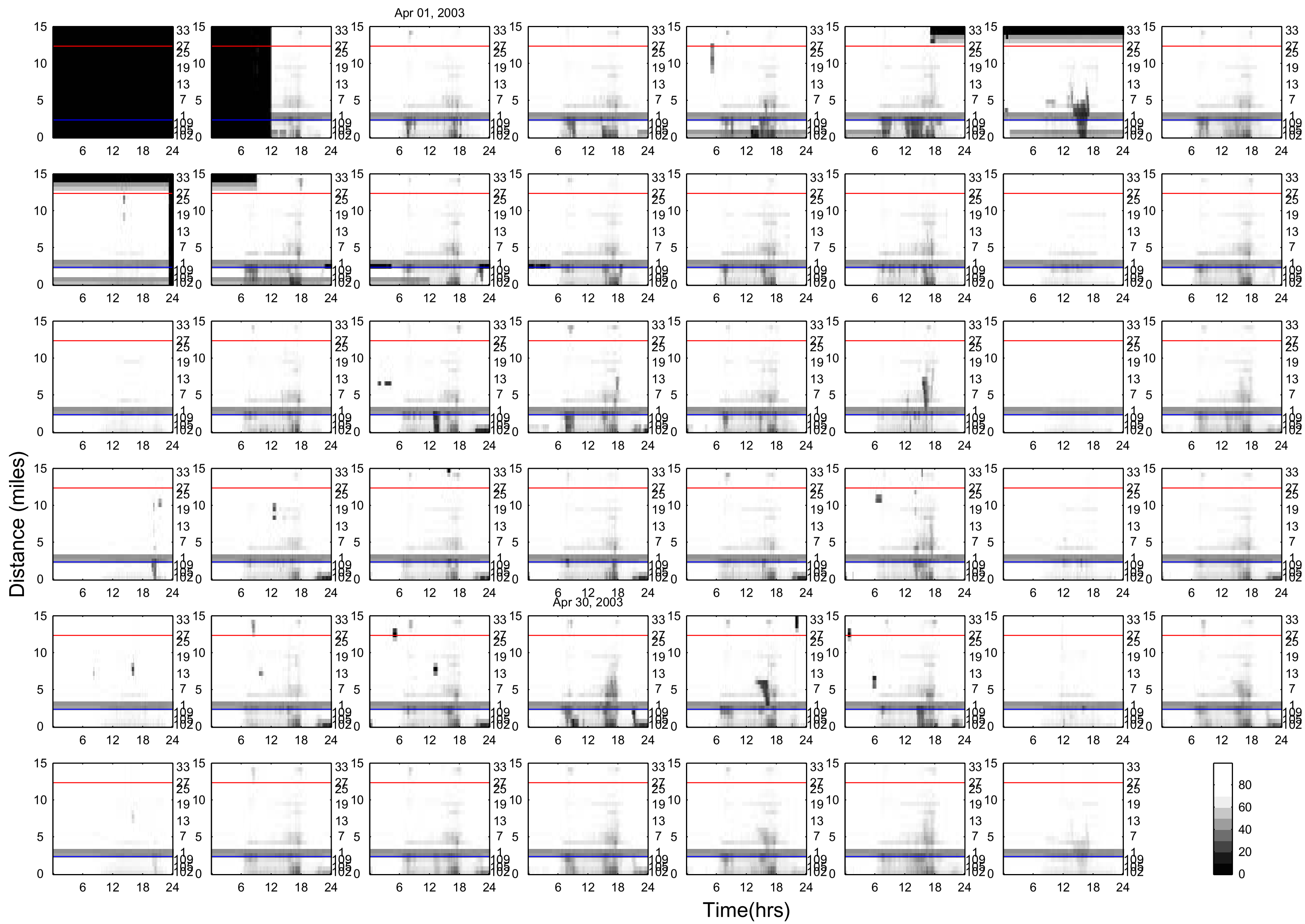
Dec 01, 2002
Dec 31, 2002
Distance (miles)
Time(hrs)

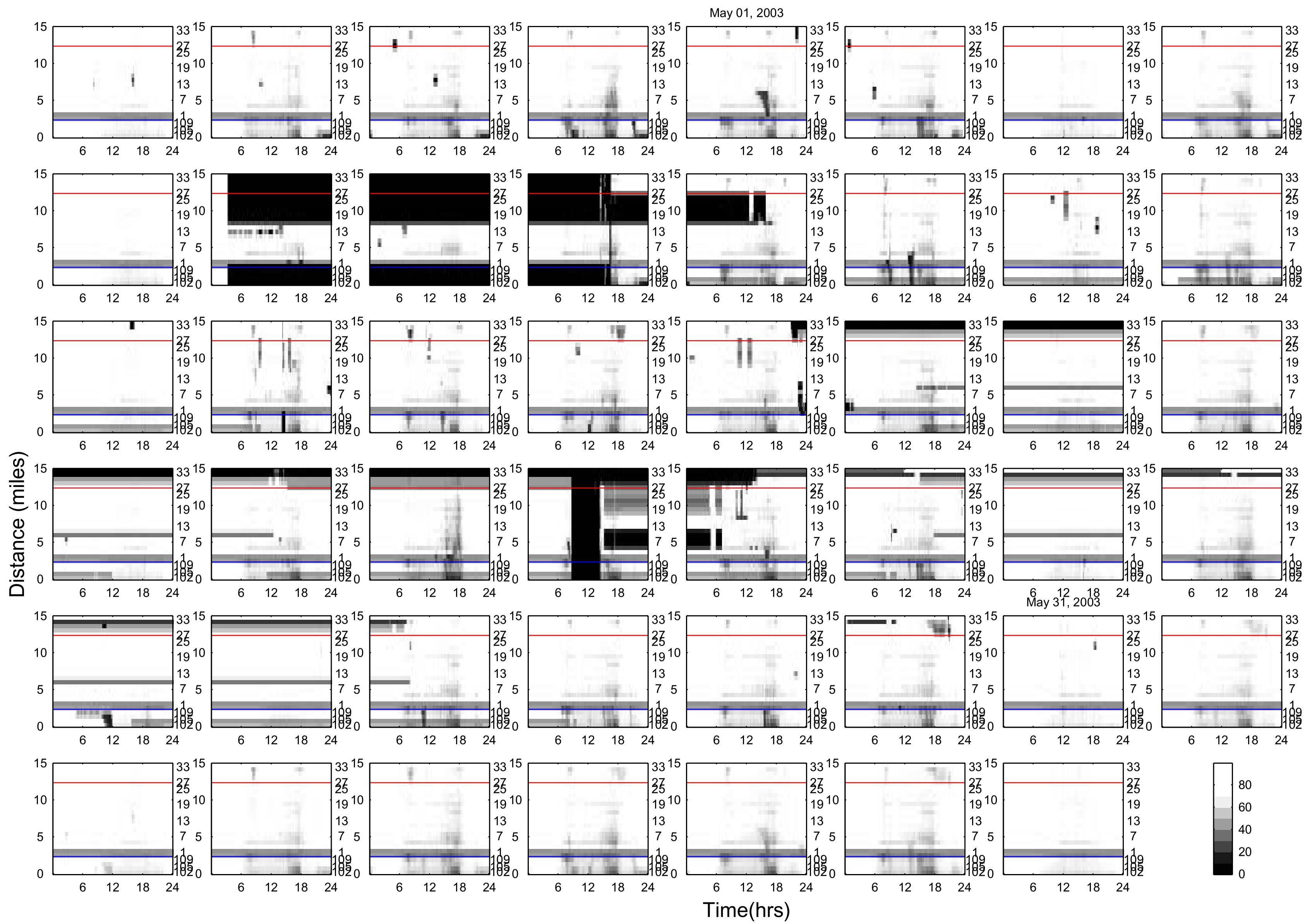


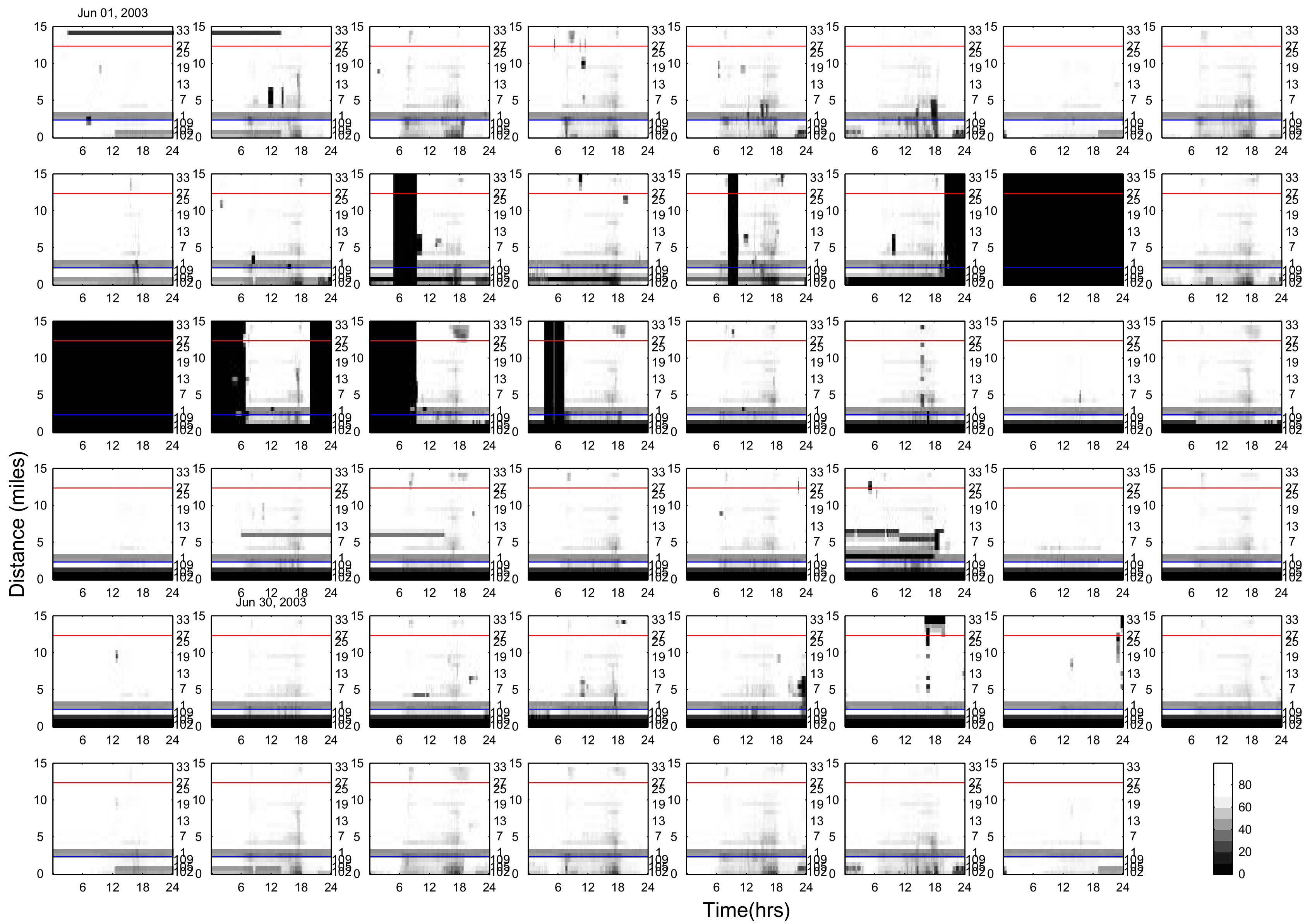
Jan 01, 2003
Jan 31, 2003
Distance (miles)
Time(hrs)
15
10
5
0
6
12
18
24
33
27
25
19
13
7
1
109
105
102
80
60
40
20
0


Feb 01, 2003
Feb 28, 2003
Distance (miles)
Time(hrs)

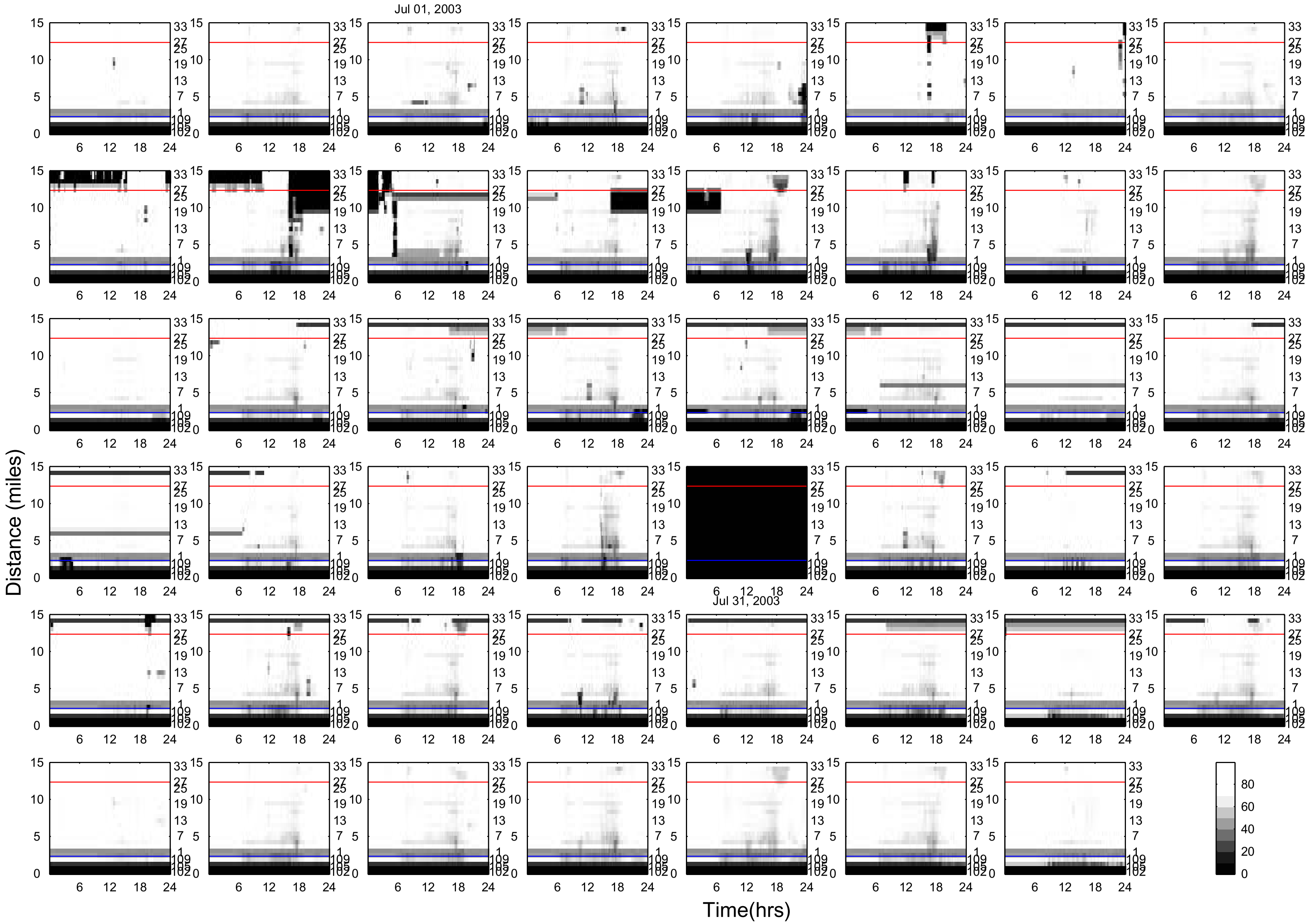

Mar 02, 2003
Mar 31, 2003
Distance (miles)
Time(hrs)


Apr 01, 2003
Apr 30, 2003
Distance (miles)
Time(hrs)
80
60
40
20
0

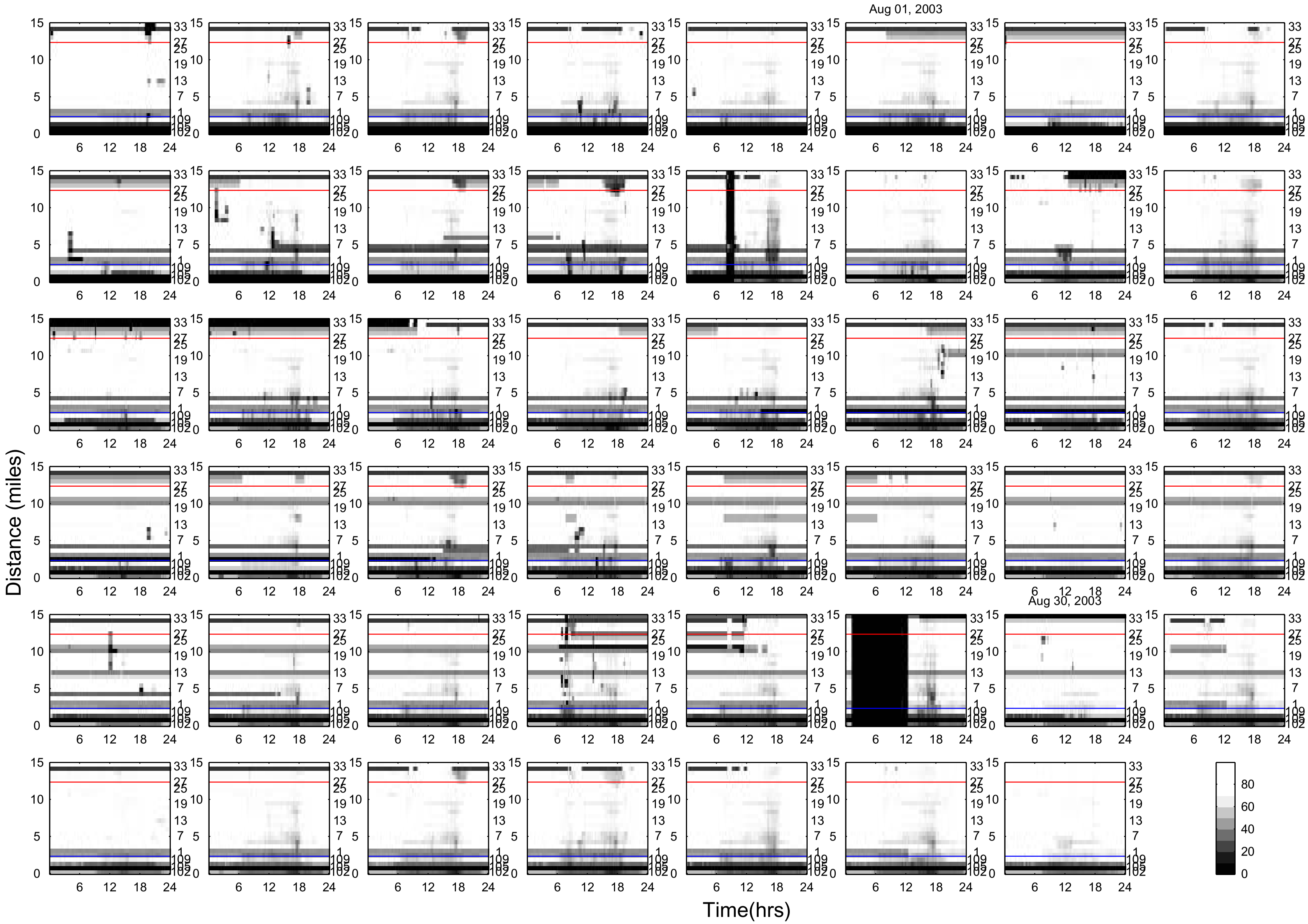

May 01, 2003
May 31, 2003
Distance (miles)
Time(hrs)



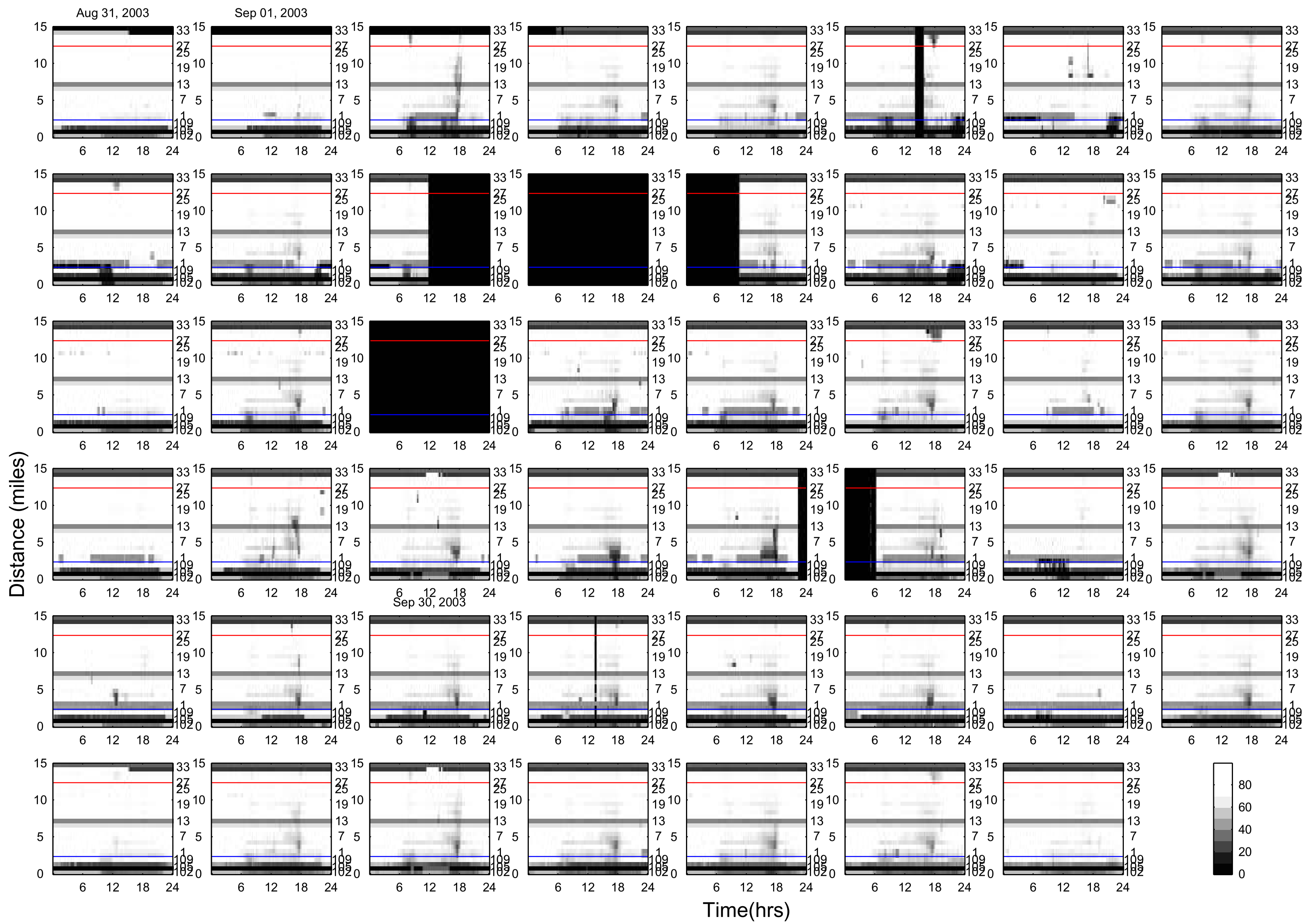
Jun 01, 2003
Jun 30, 2003
Distance (miles)
Time(hrs)



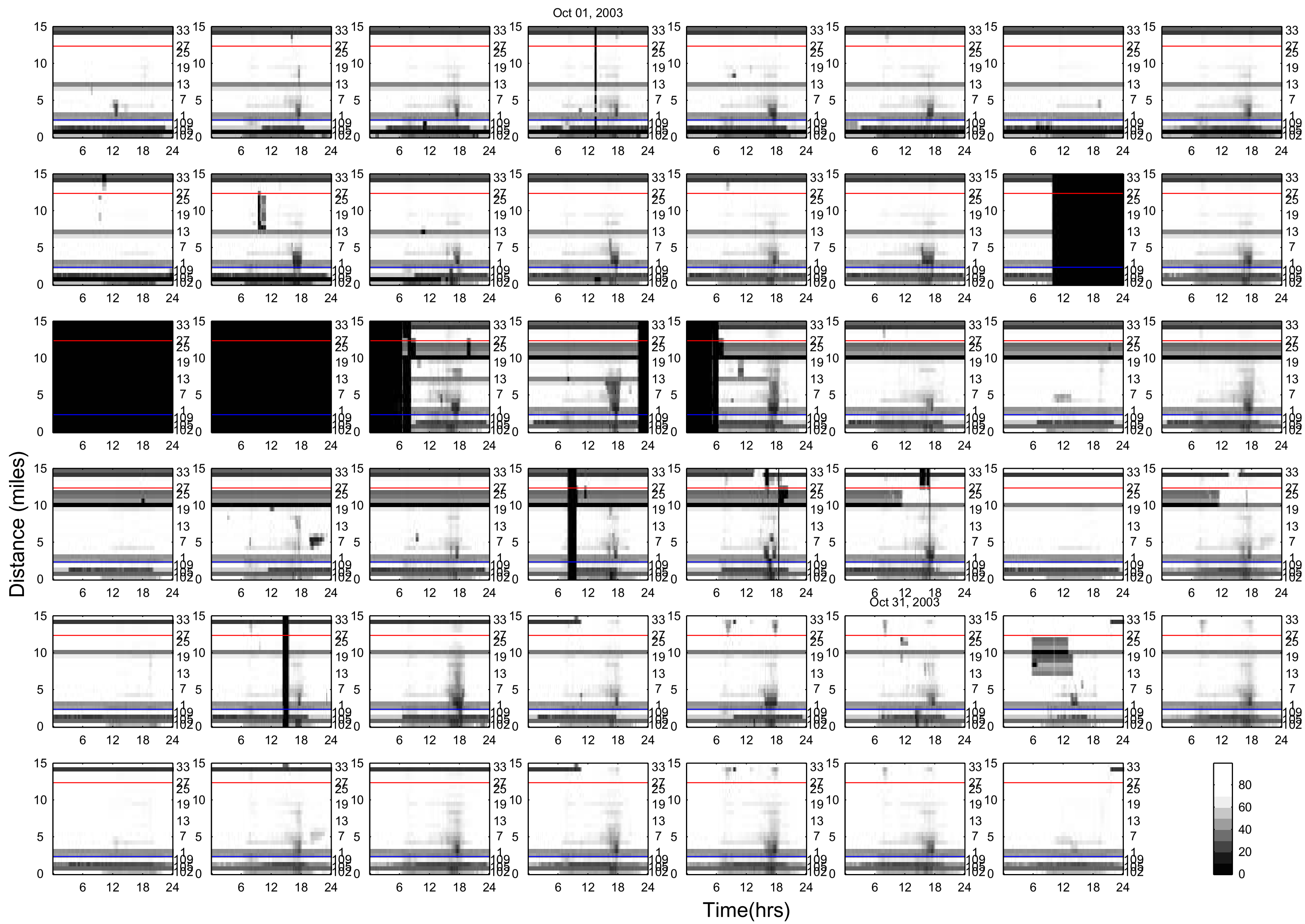
Jul 01, 2003
Jul 31, 2003
Distance (miles)
Time(hrs)



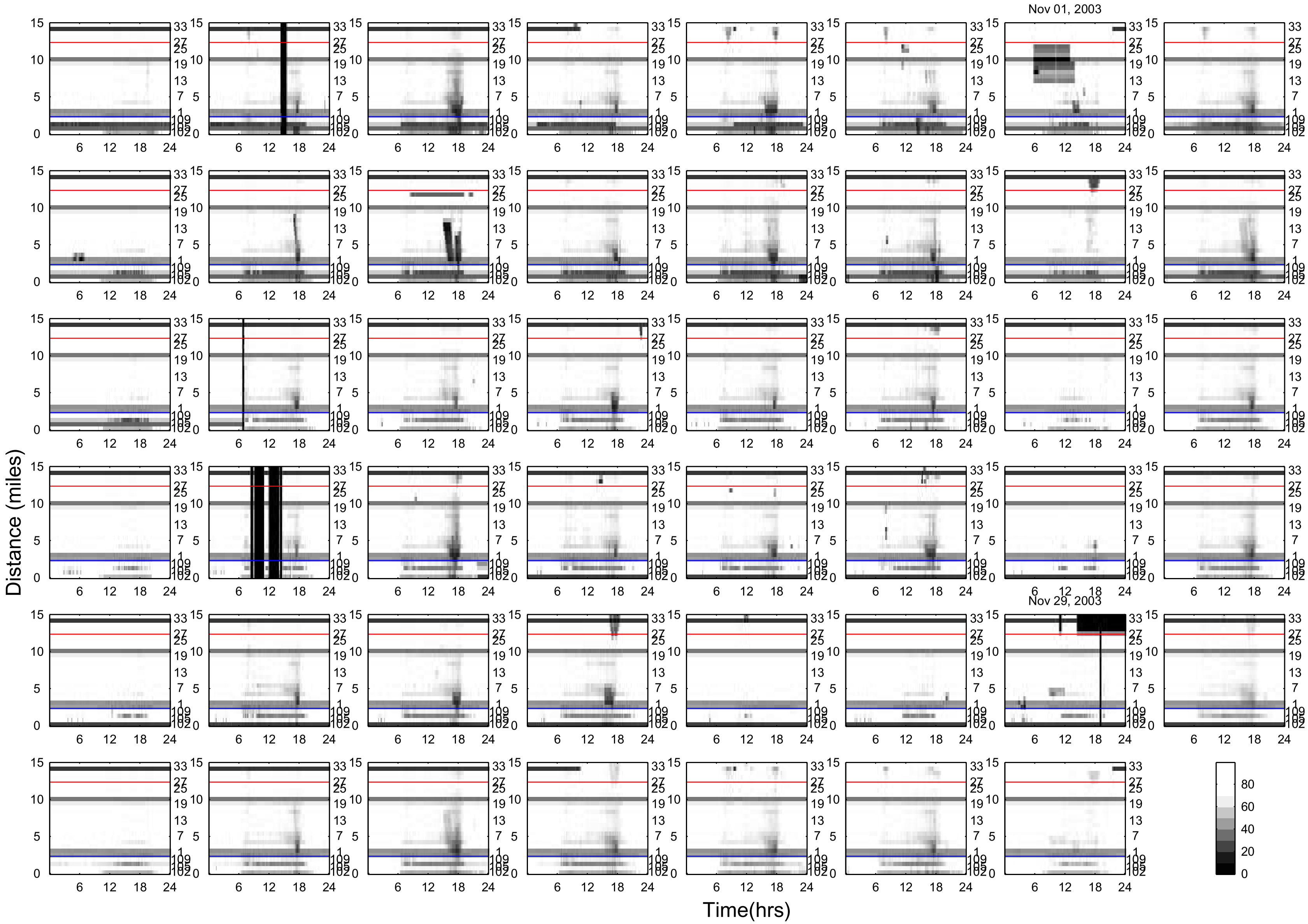
Aug 01, 2003
Aug 30, 2003
Distance (miles)
Time(hrs)



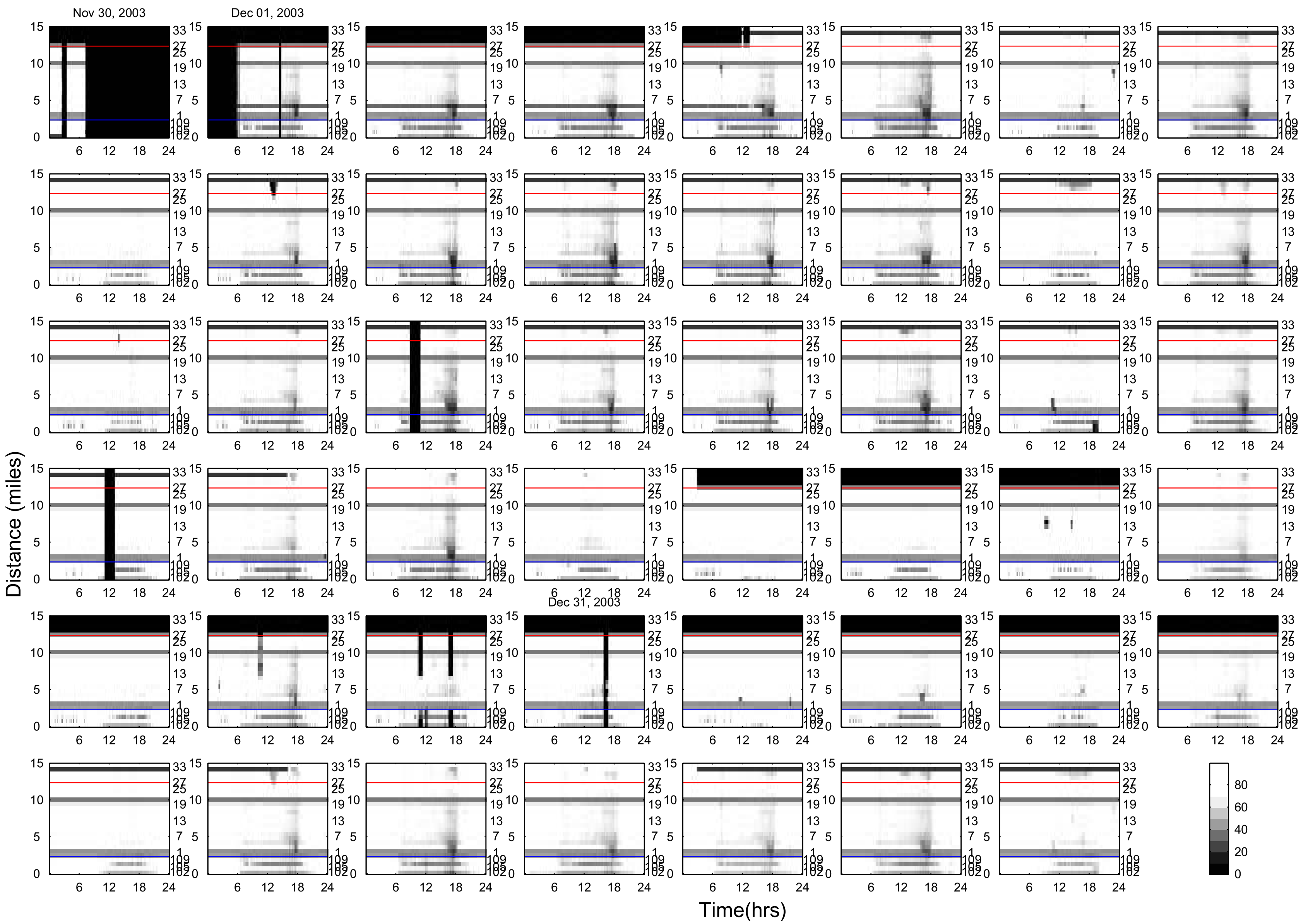
Aug 31, 2003
Sep 01, 2003
Sep 30, 2003
Distance (miles)
Time(hrs)
0
5
10
15
6
12
18
24
33
27
25
19
13
7
1
109
105
102
80
60
40
20
0



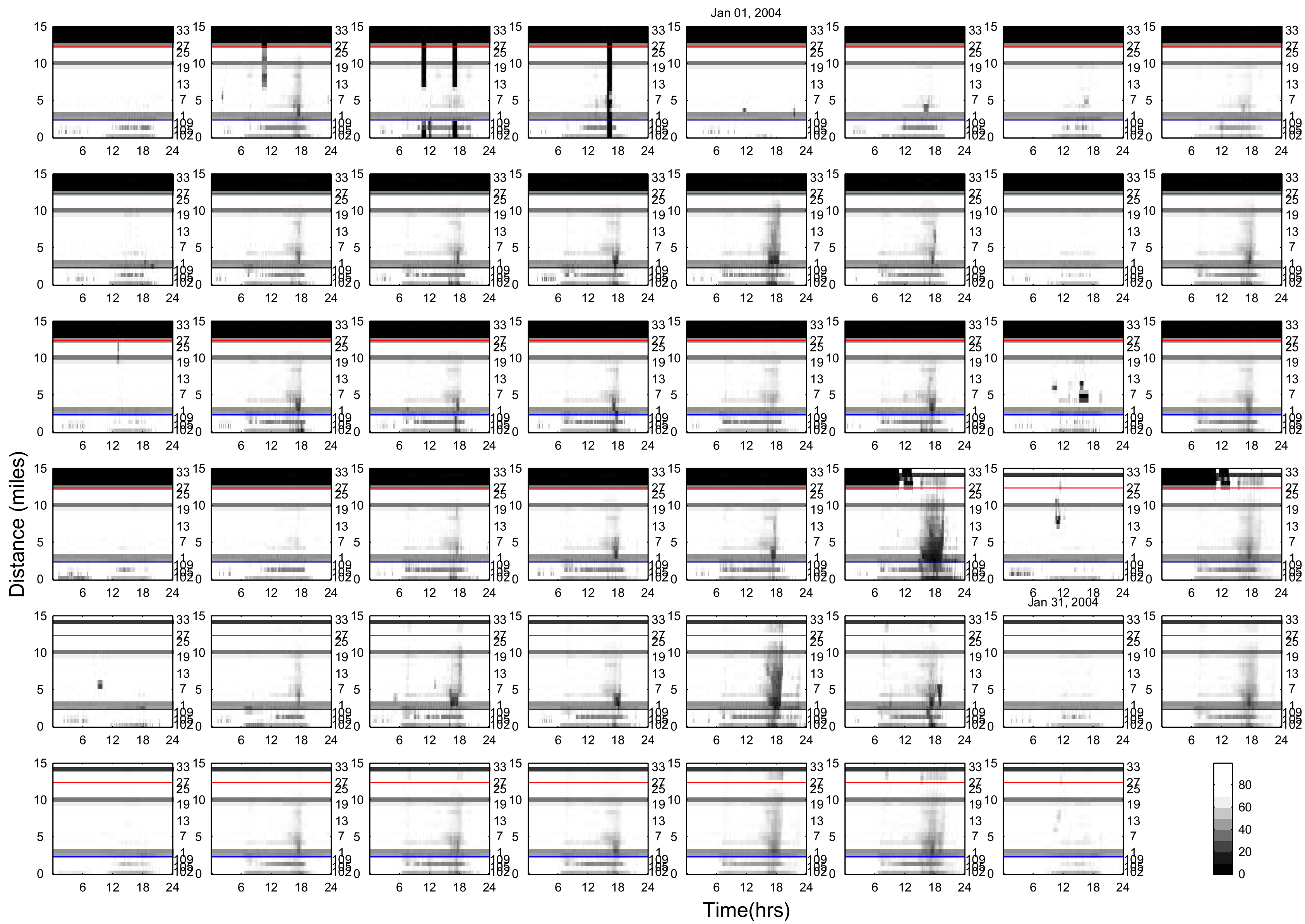
Oct 01, 2003
Oct 31, 2003
Distance (miles)
Time(hrs)



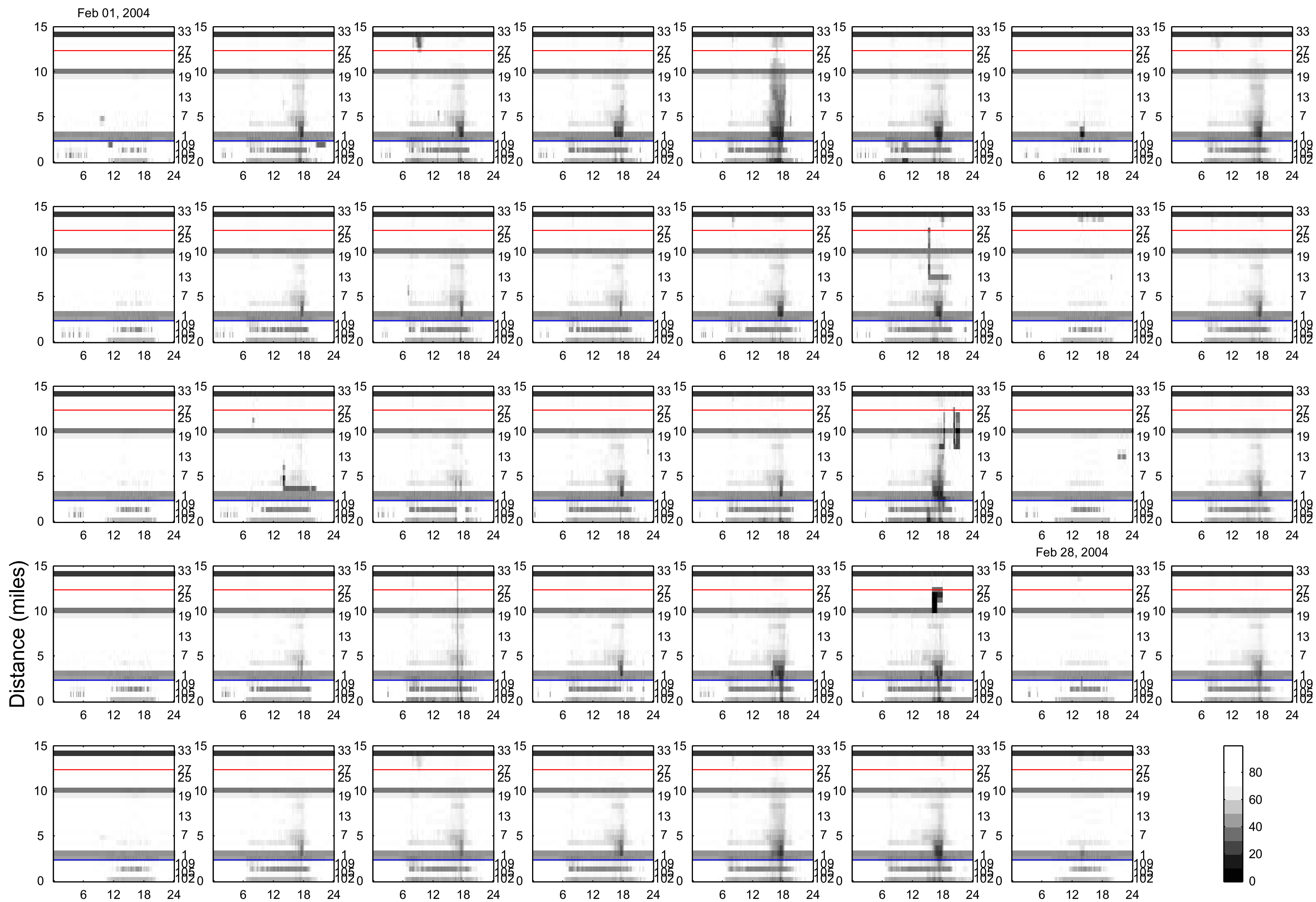
Nov 01, 2003
Nov 29, 2003
Distance (miles)
Time(hrs)

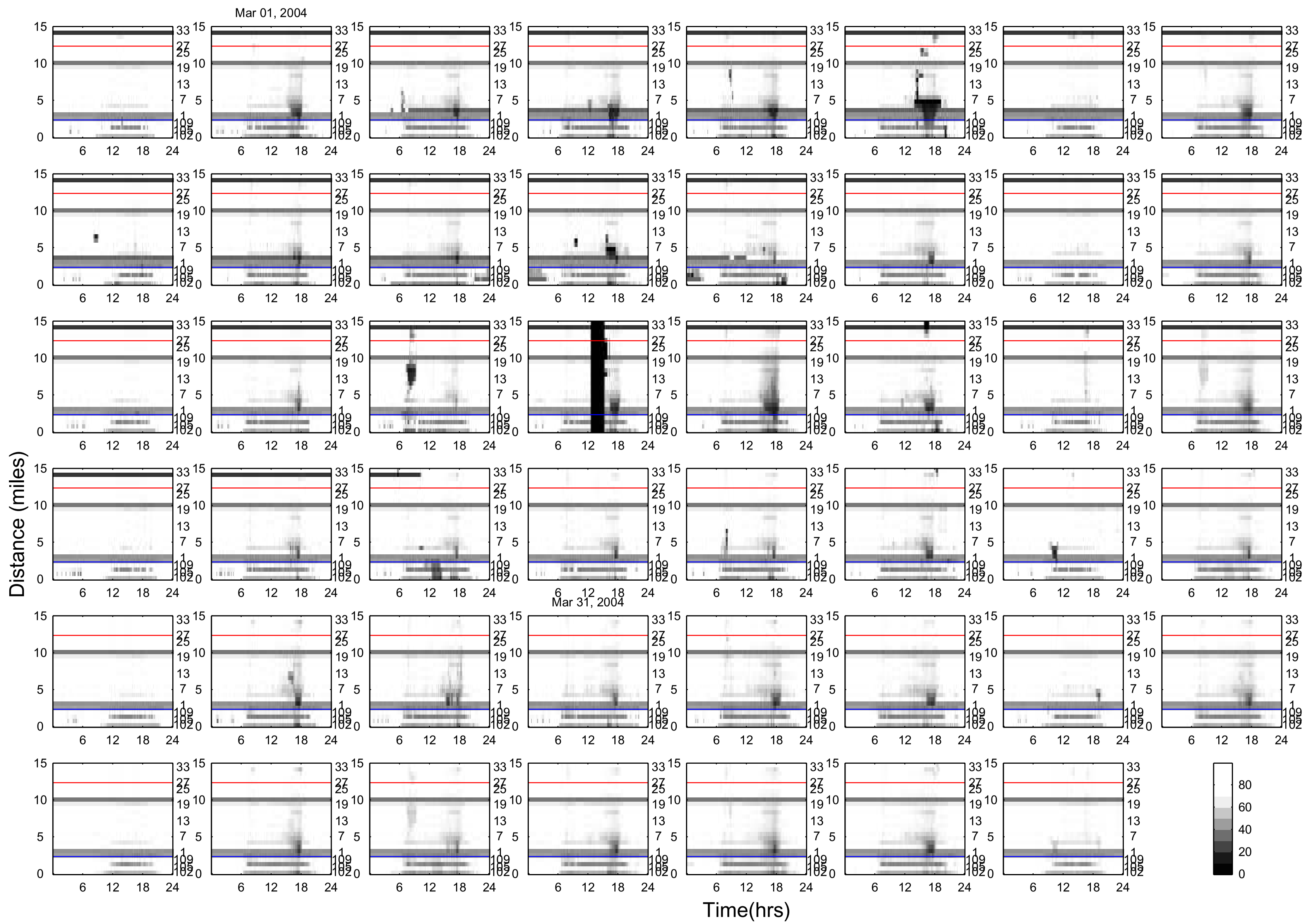


Nov 30, 2003
Dec 01, 2003
Dec 31, 2003
Distance (miles)
Time(hrs)

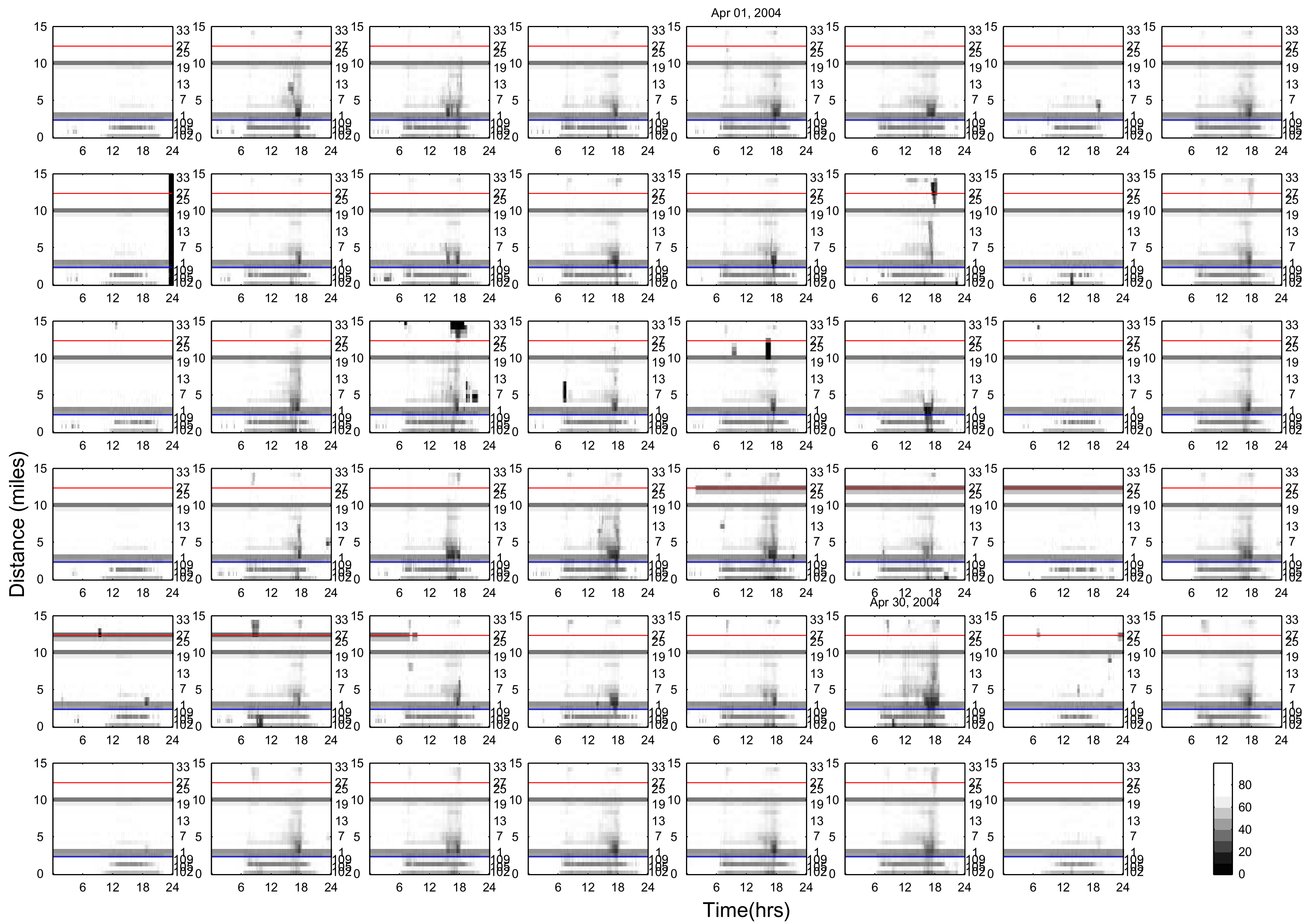


Jan 01, 2004
Jan 31, 2004
Distance (miles)
Time(hrs)

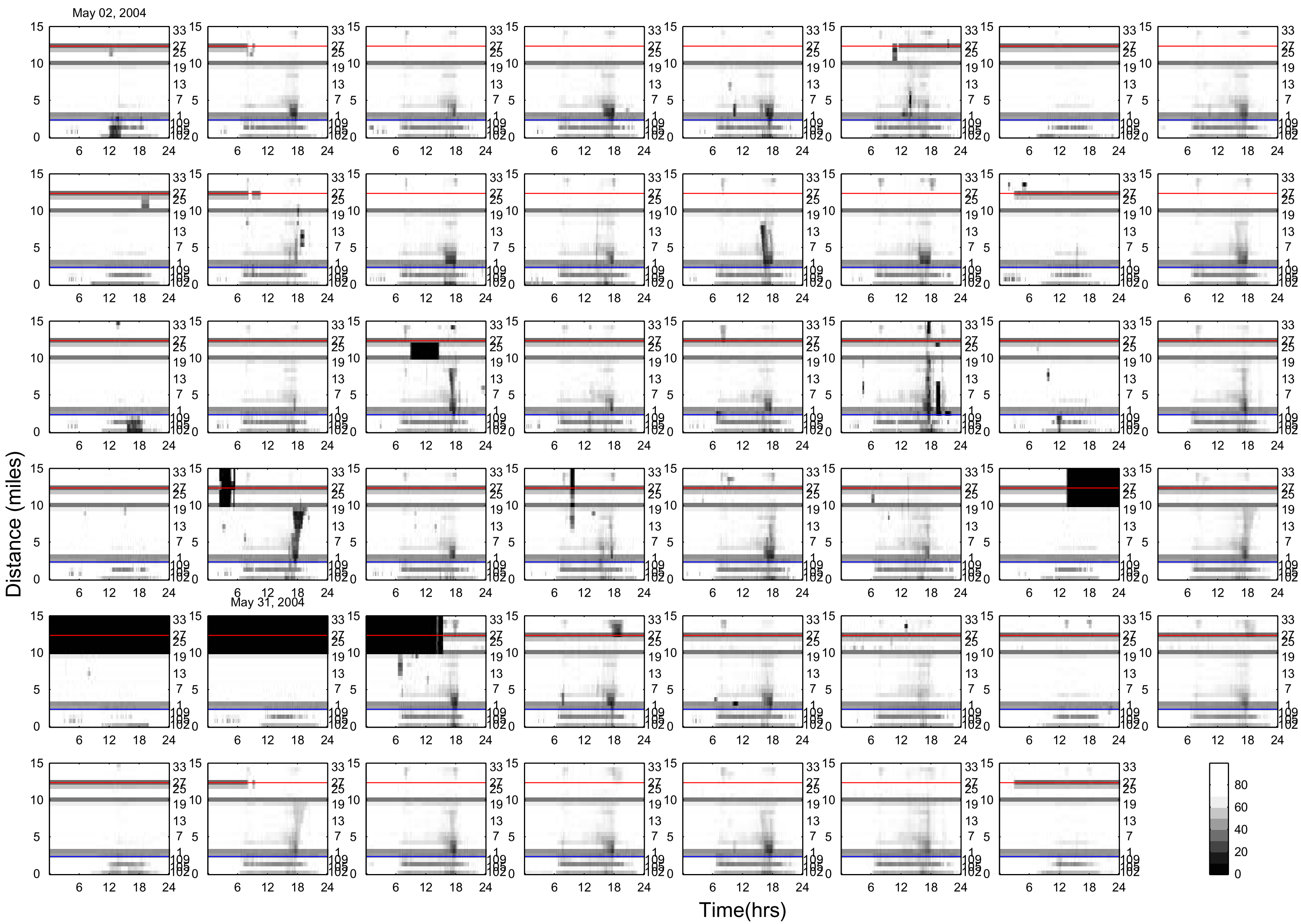

Feb 01, 2004
Feb 28, 2004
Distance (miles)



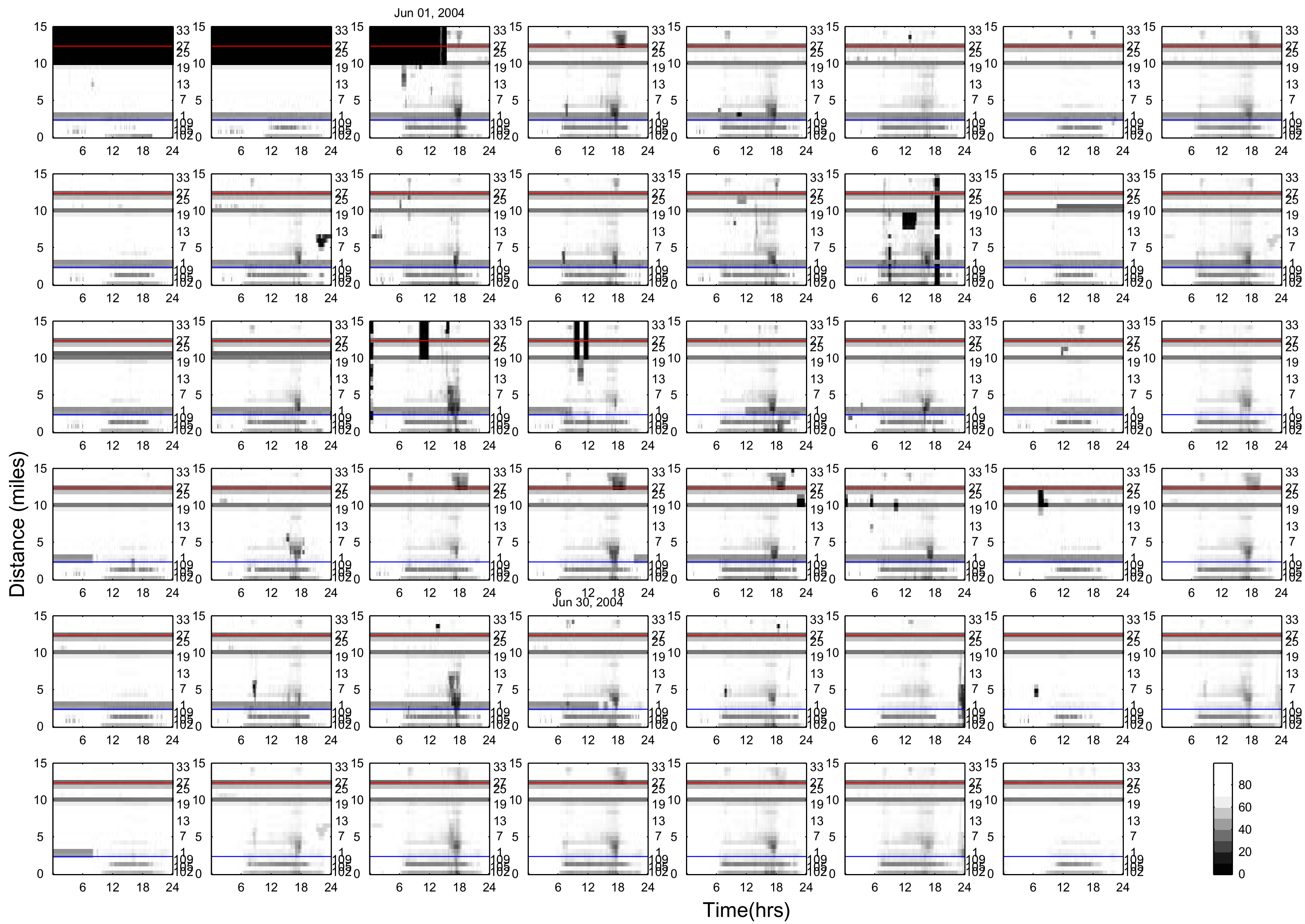
Mar 01, 2004
Mar 31, 2004
Distance (miles)
Time(hrs)
0
5
10
15
6
12
18
24
33
27
25
19
13
7
1
109
105
102
80
60
40
20
0

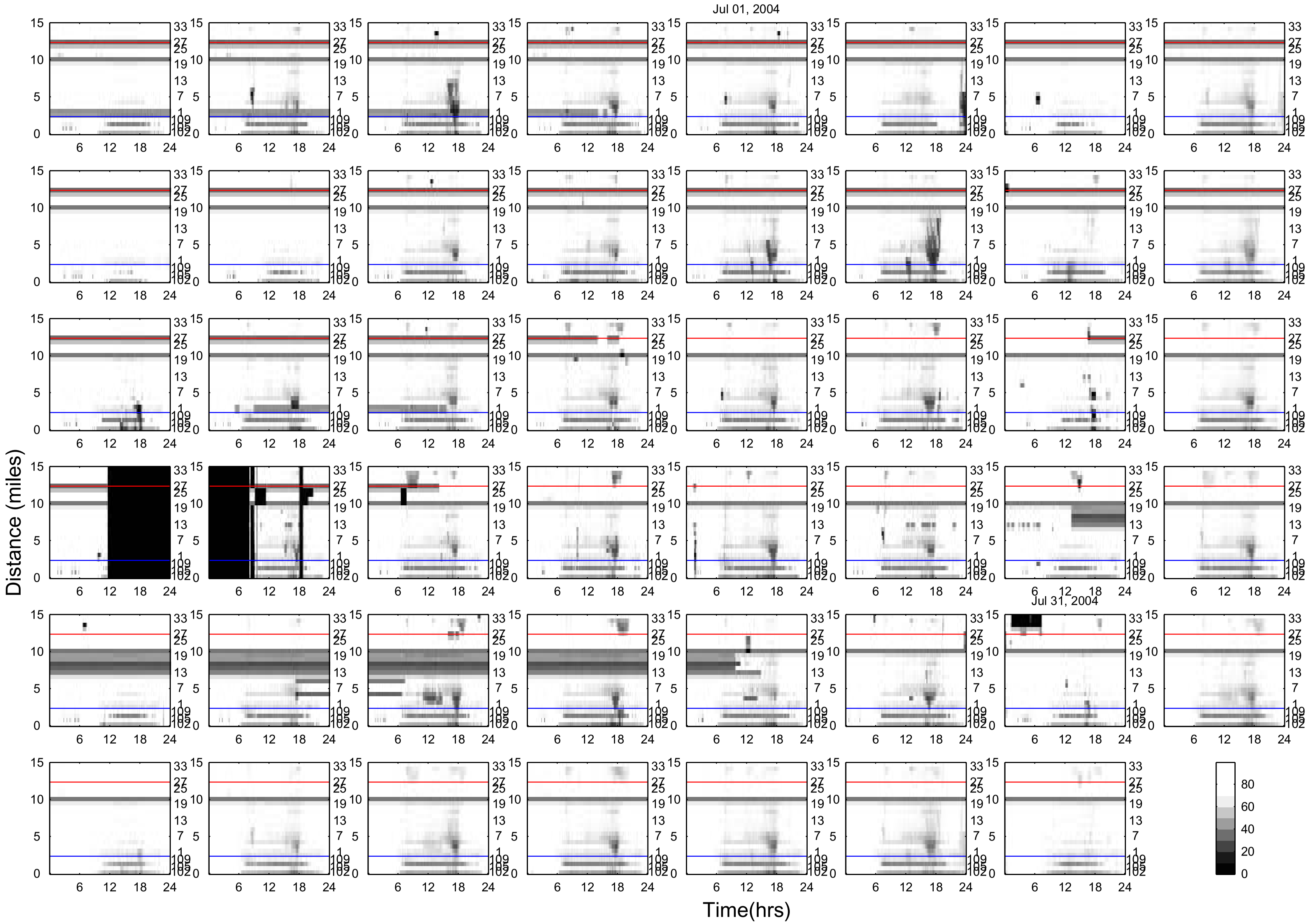


Apr 01, 2004
Apr 30, 2004
Distance (miles)
Time(hrs)

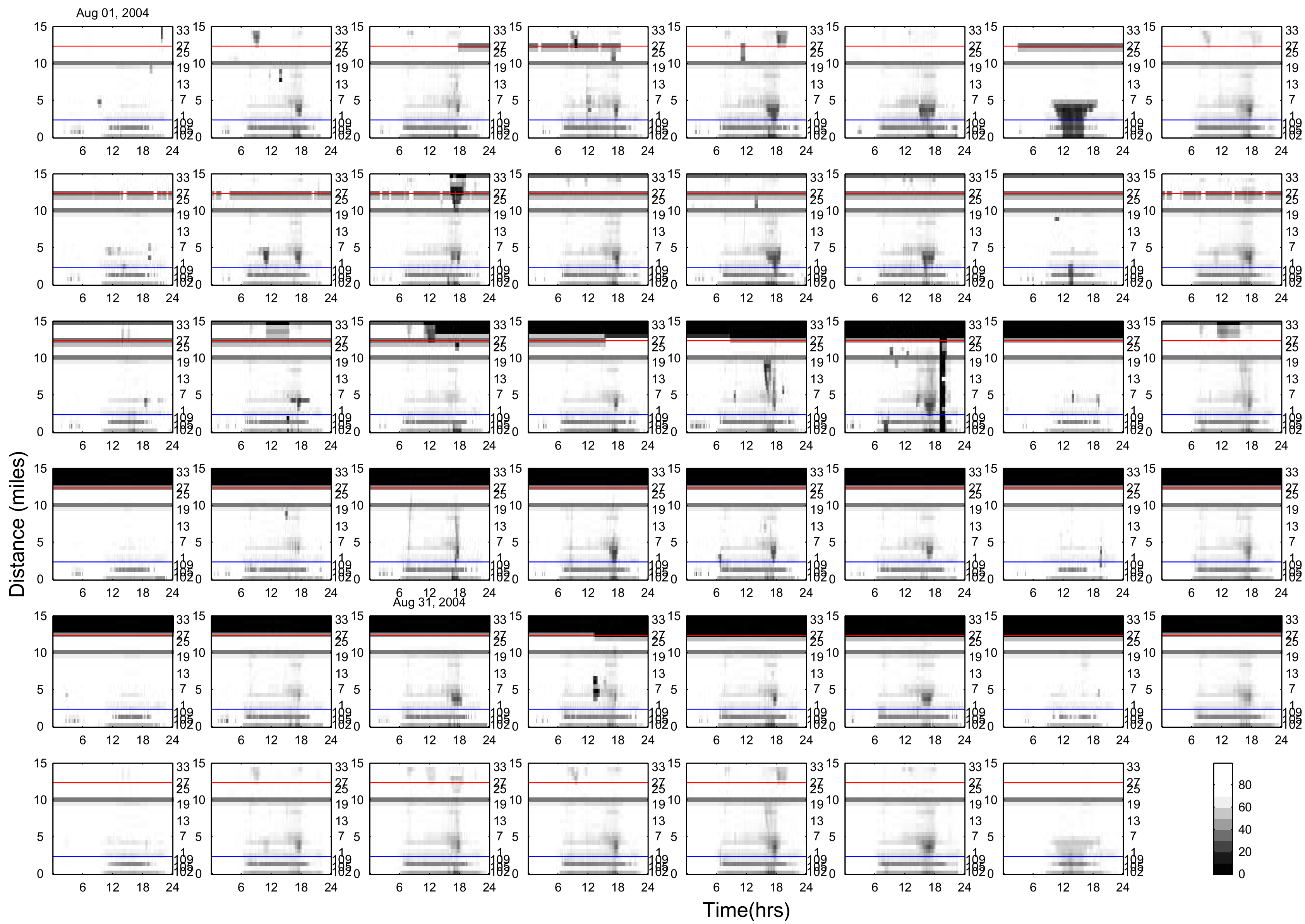


May 02, 2004
May 31, 2004
Distance (miles)
Time(hrs)

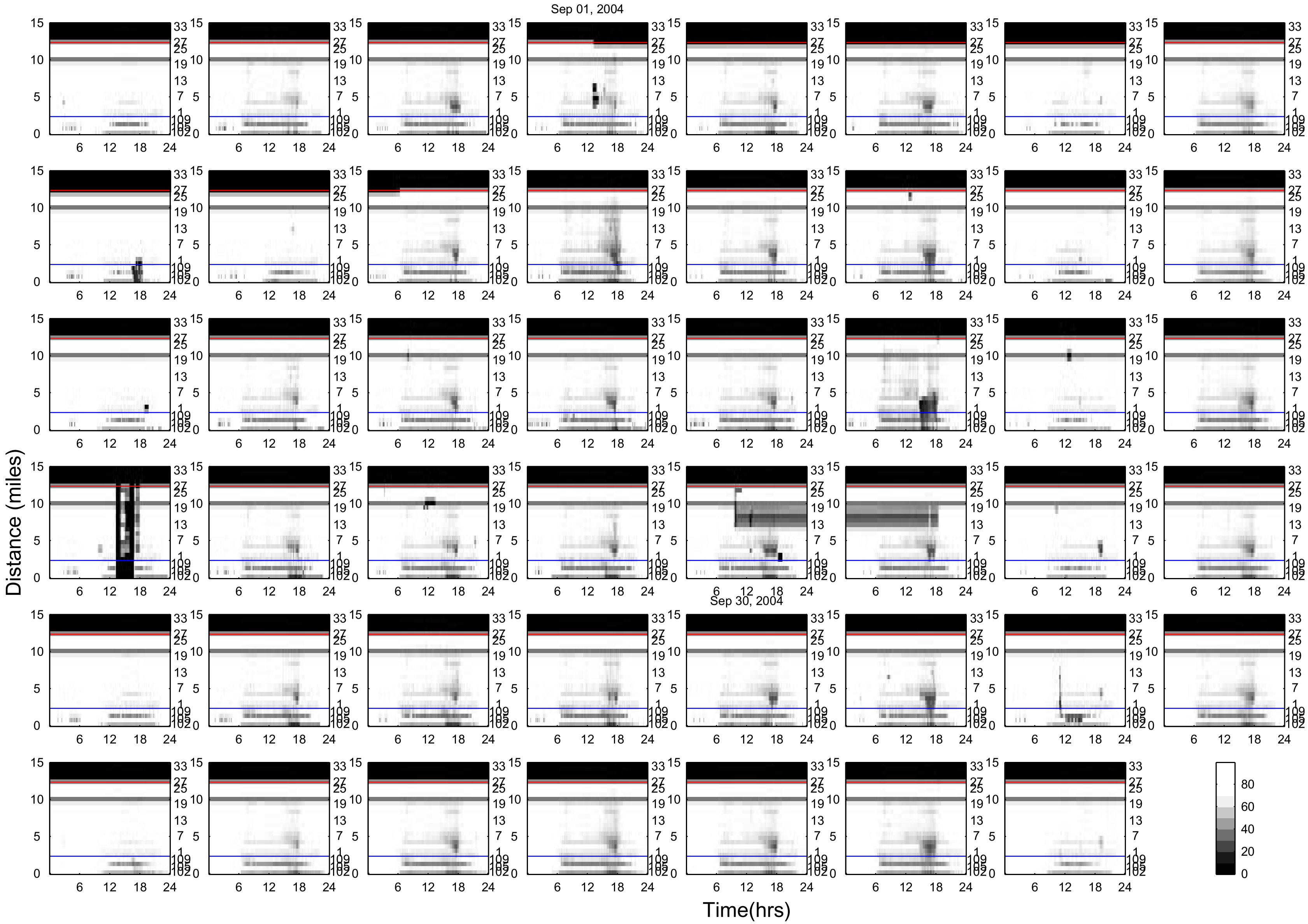

Jun 01, 2004
Jun 30, 2004
Distance (miles)
Time(hrs)
0
5
10
15
6
12
18
24
33
27
25
19
13
7
1
109
105
102
80
60
40
20
0



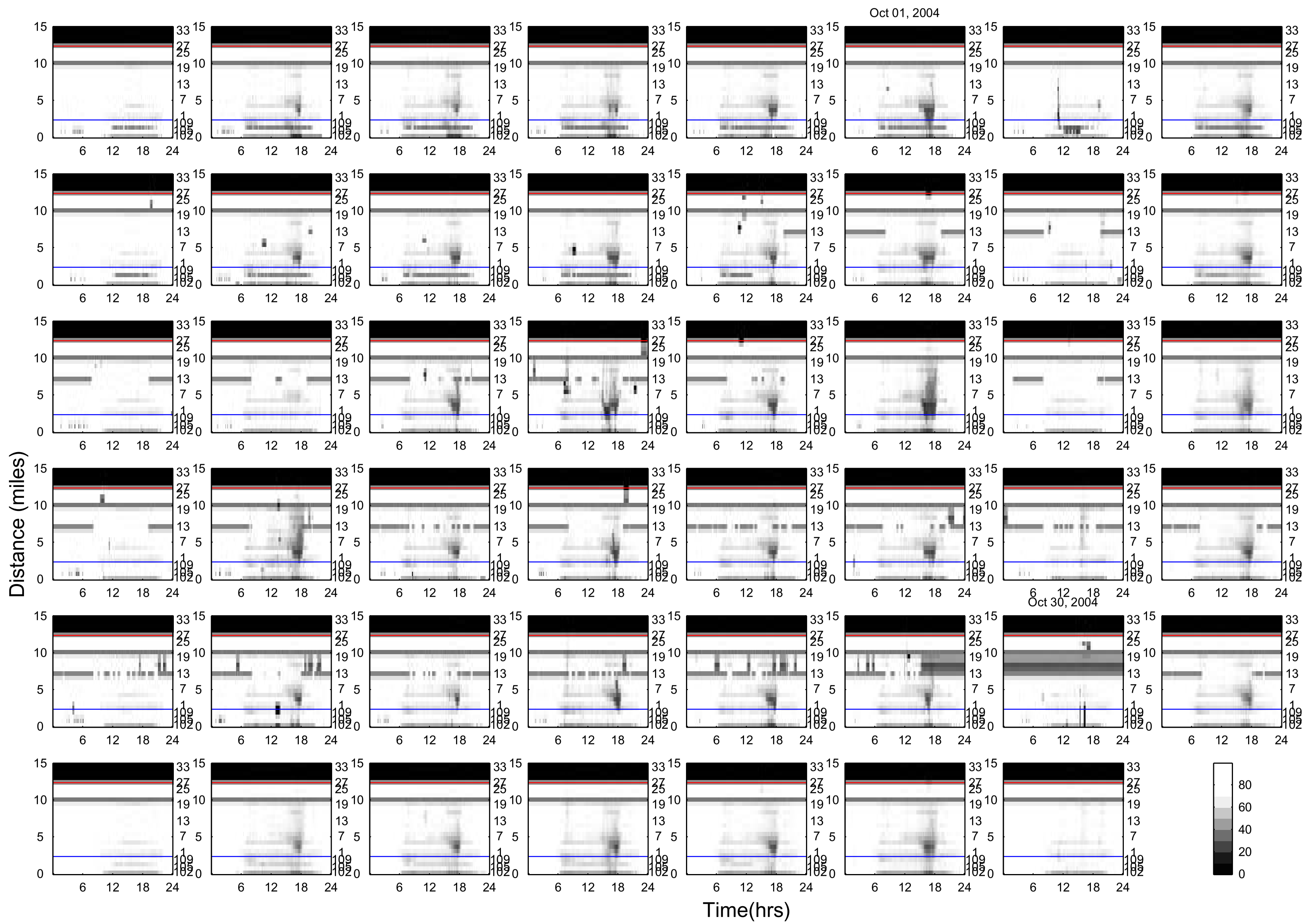
Jul 01, 2004
Jul 31, 2004
Distance (miles)
Time(hrs)

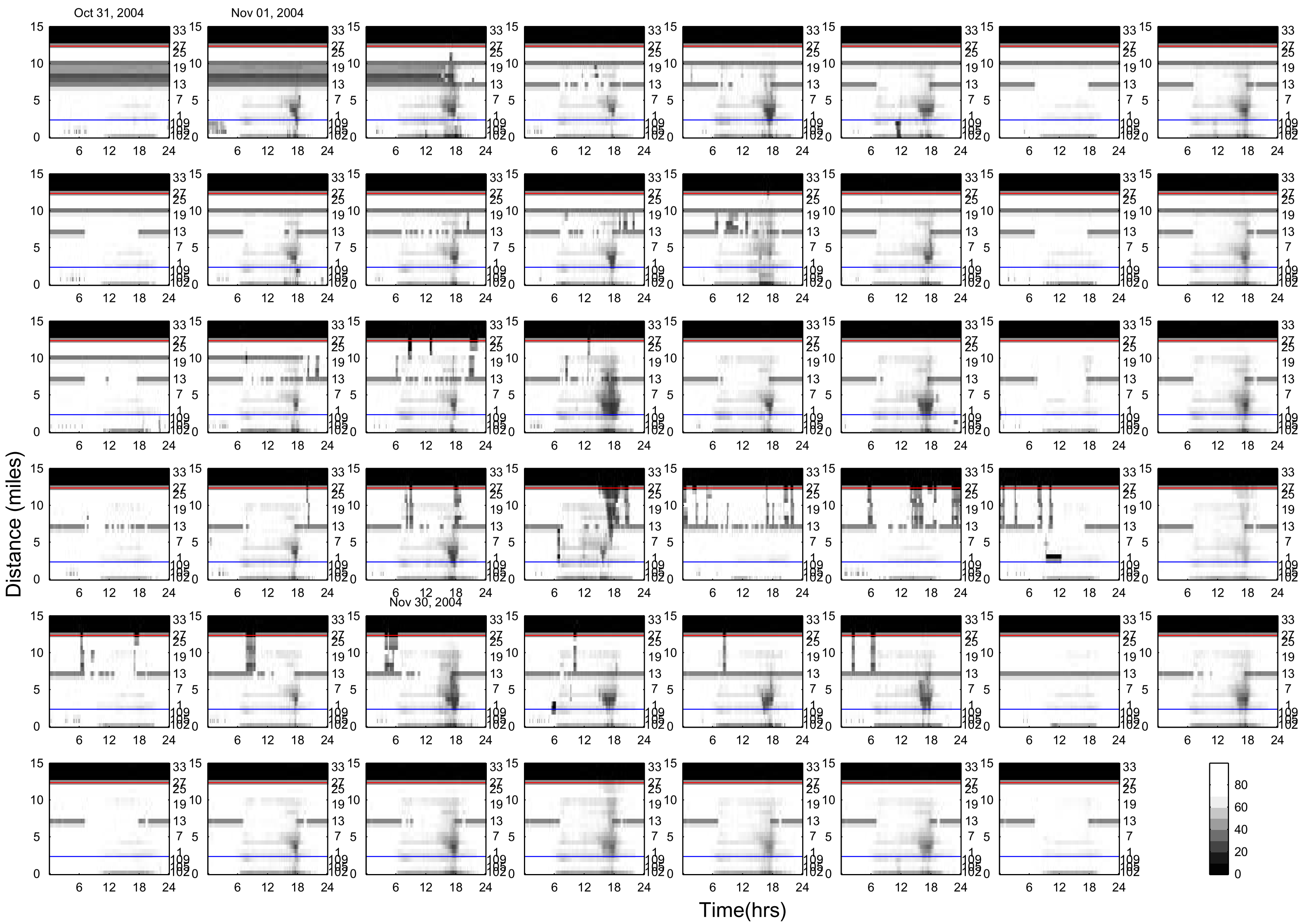


Aug 01, 2004
Aug 31, 2004
Distance (miles)
Time(hrs)

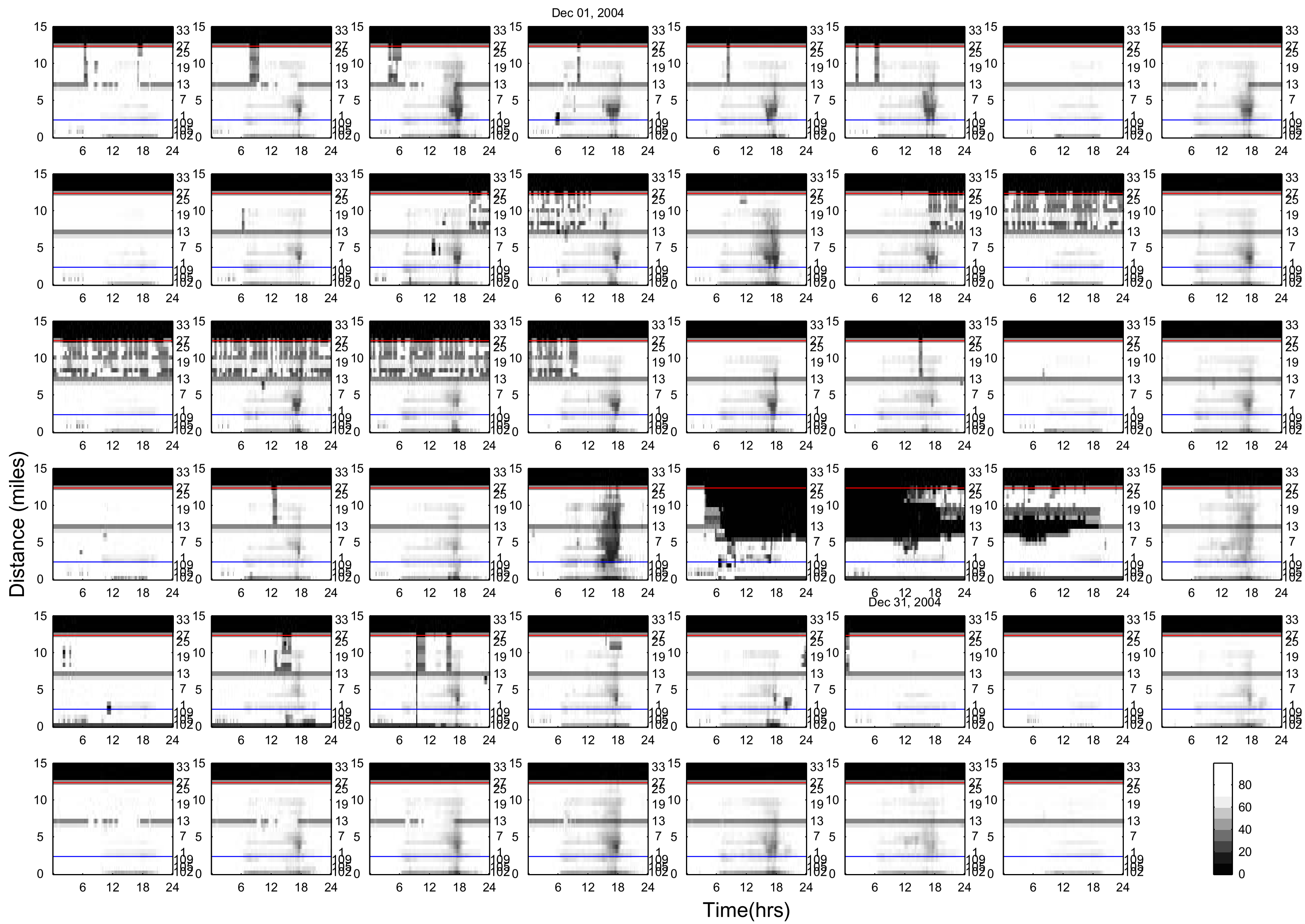


Sep 01, 2004
Sep 30, 2004
Distance (miles)
Time(hrs)

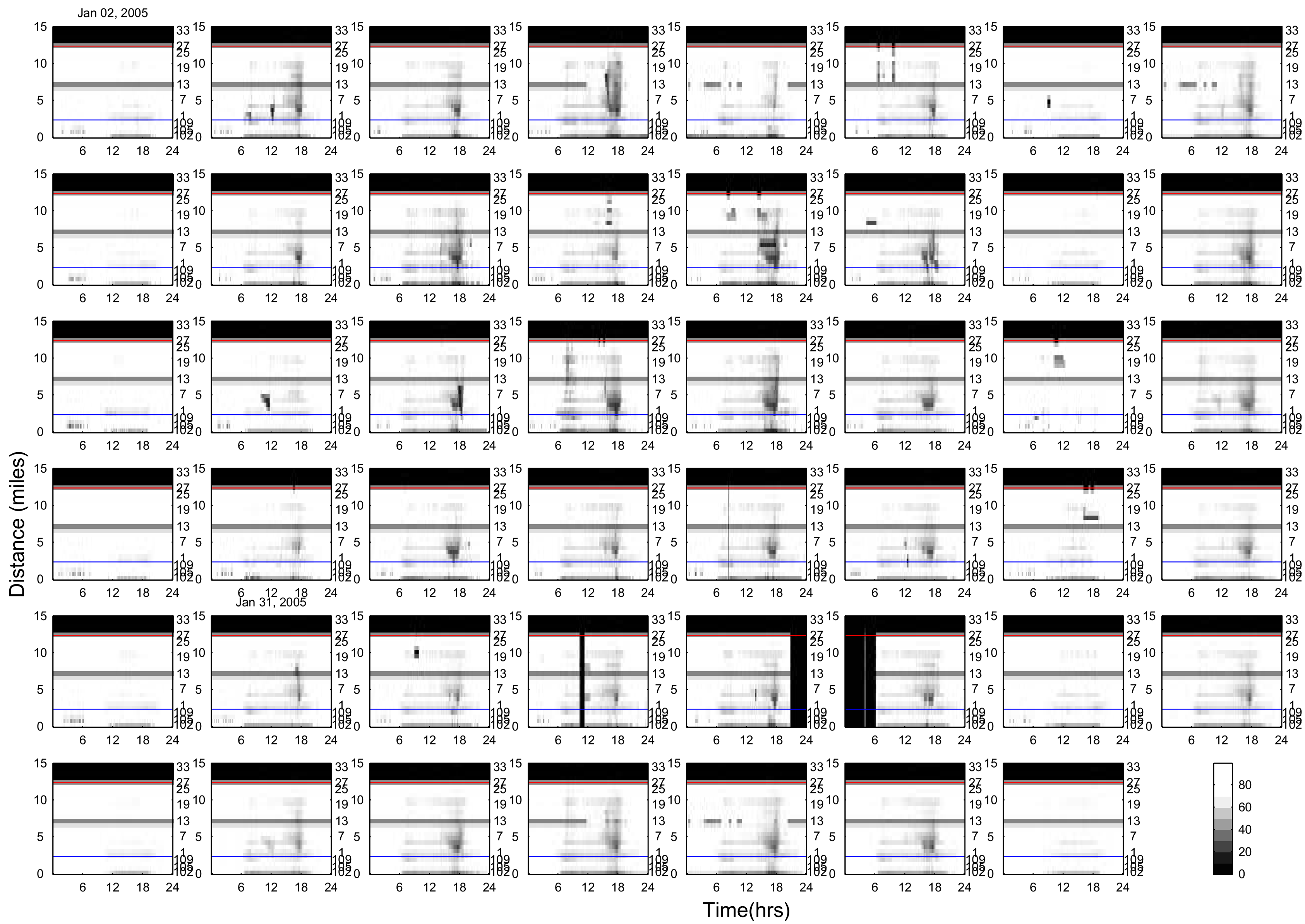

Oct 01, 2004
Oct 30, 2004
Distance (miles)
Time(hrs)

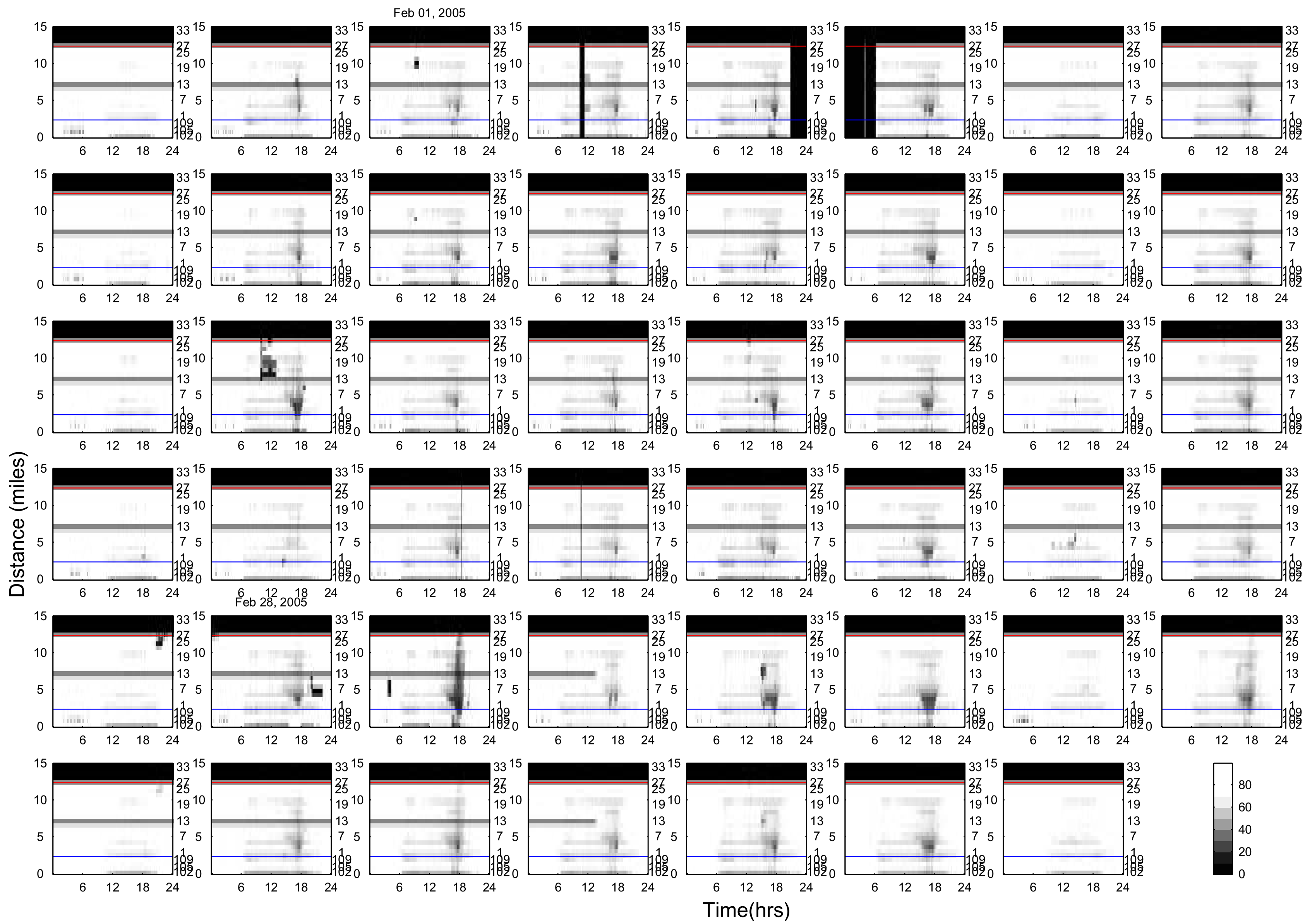


Oct 31, 2004
Nov 01, 2004
Nov 30, 2004
Distance (miles)
Time(hrs)

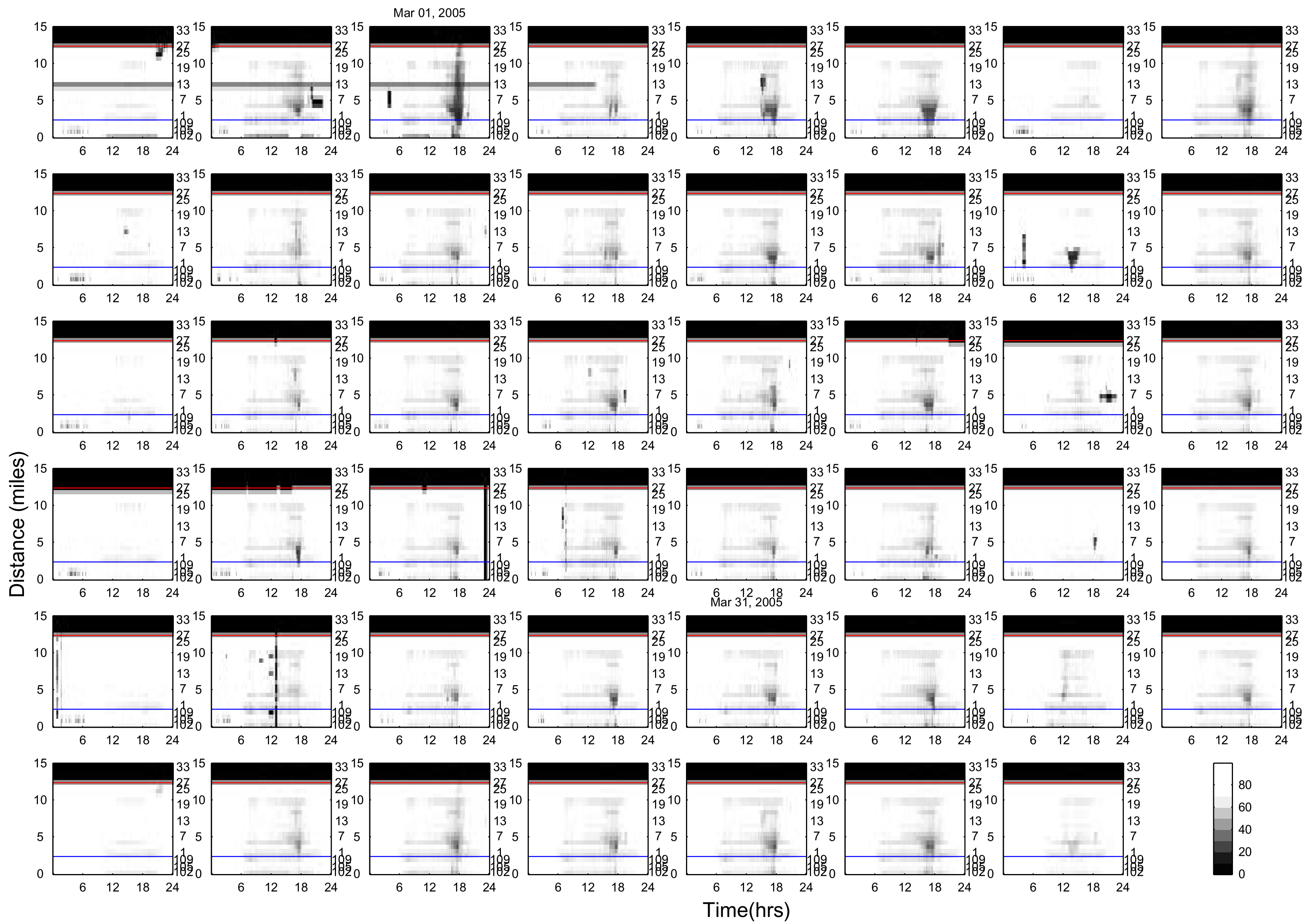


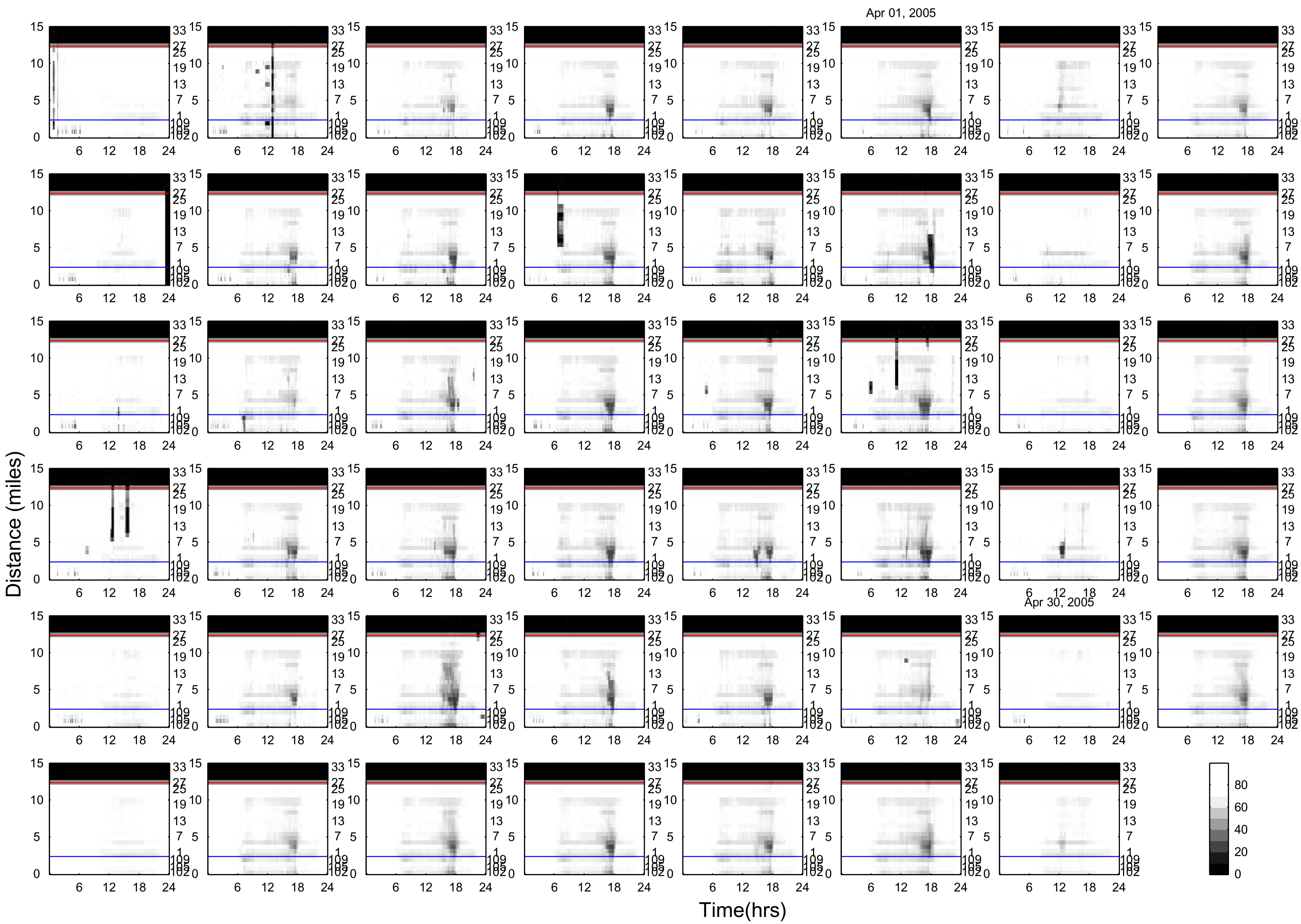
Dec 01, 2004
Dec 31, 2004
Distance (miles)
Time(hrs)


Jan 02, 2005
Jan 31, 2005
Distance (miles)
Time(hrs)

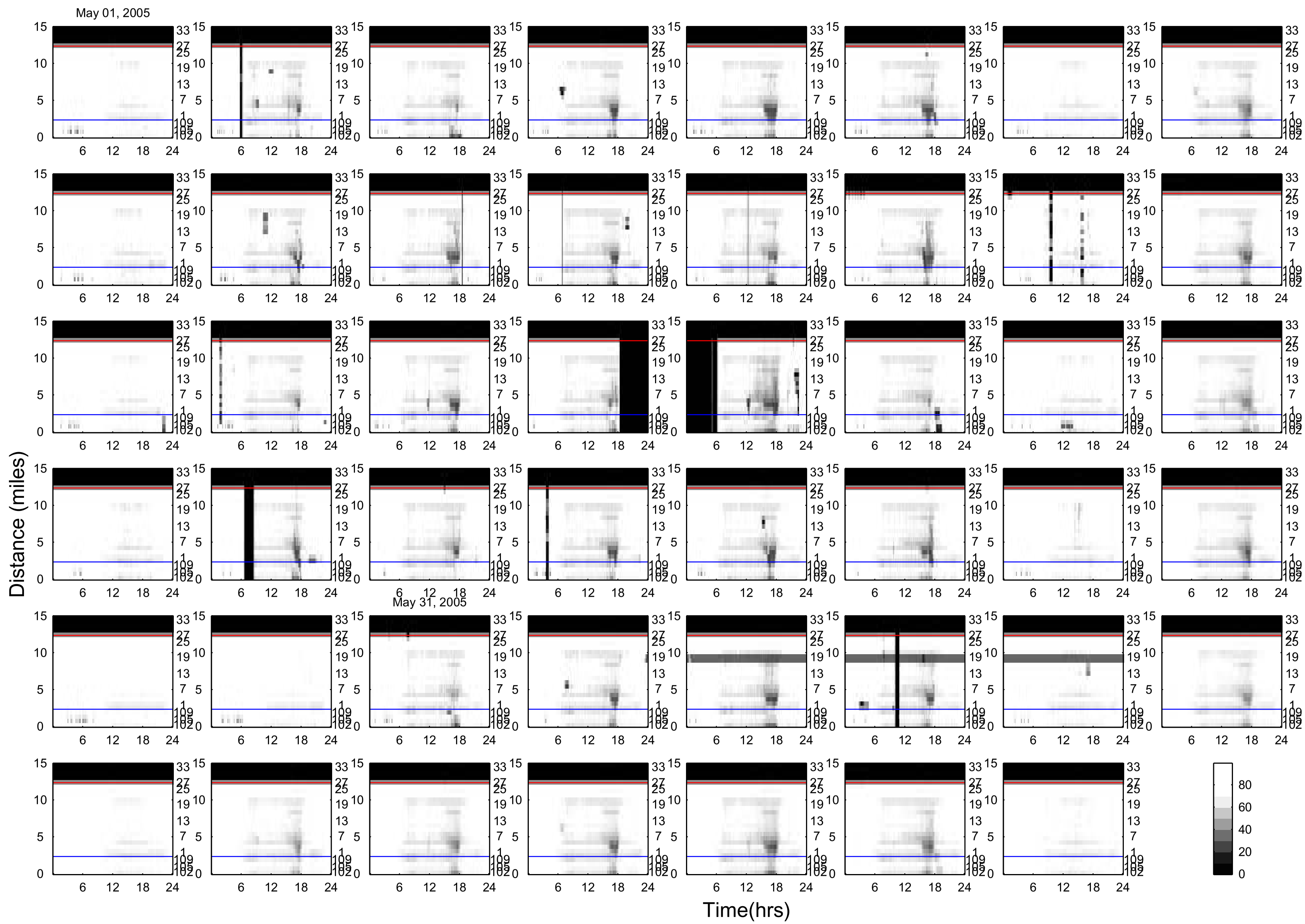


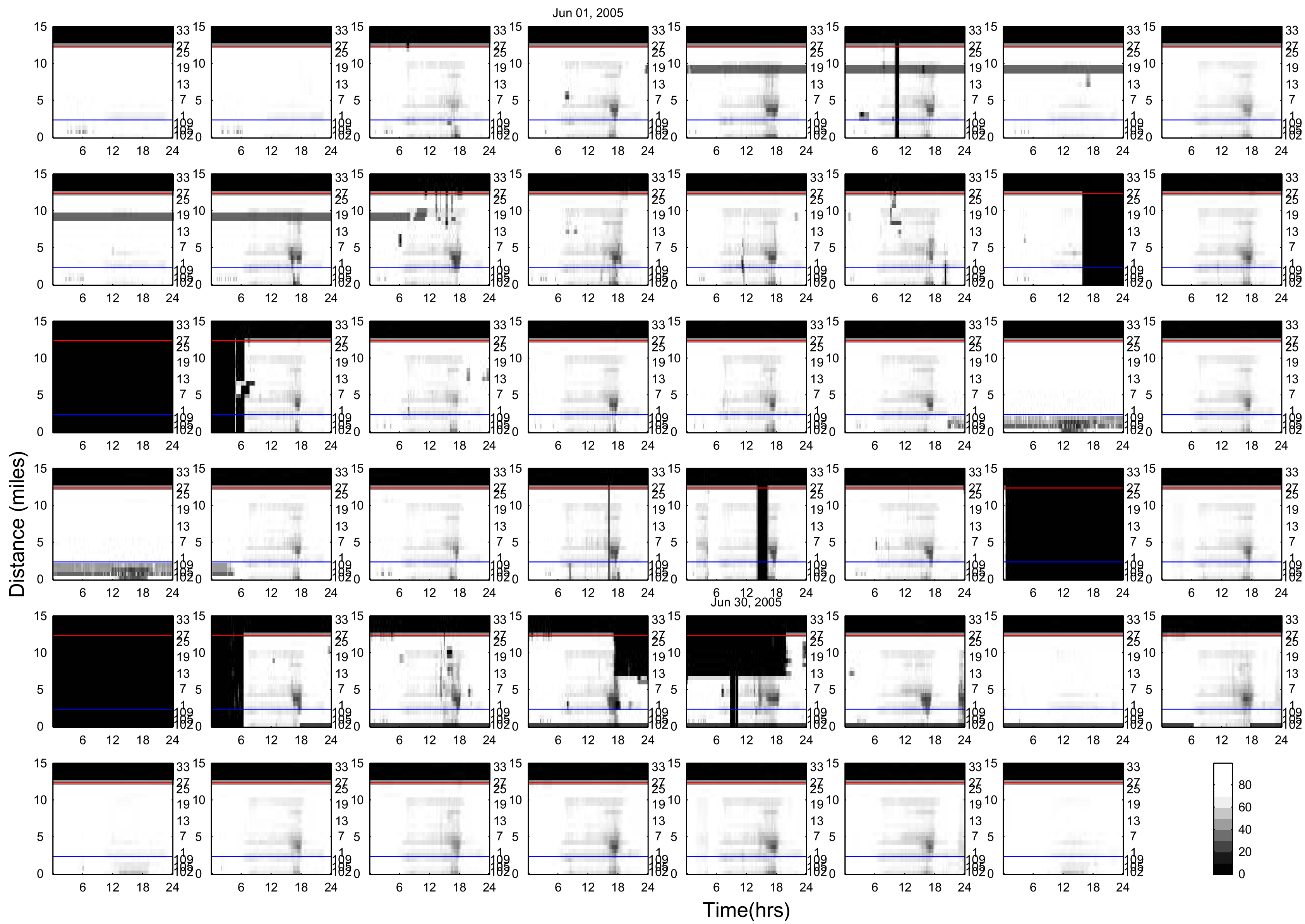
Feb 01, 2005
Feb 28, 2005
Distance (miles)
Time(hrs)

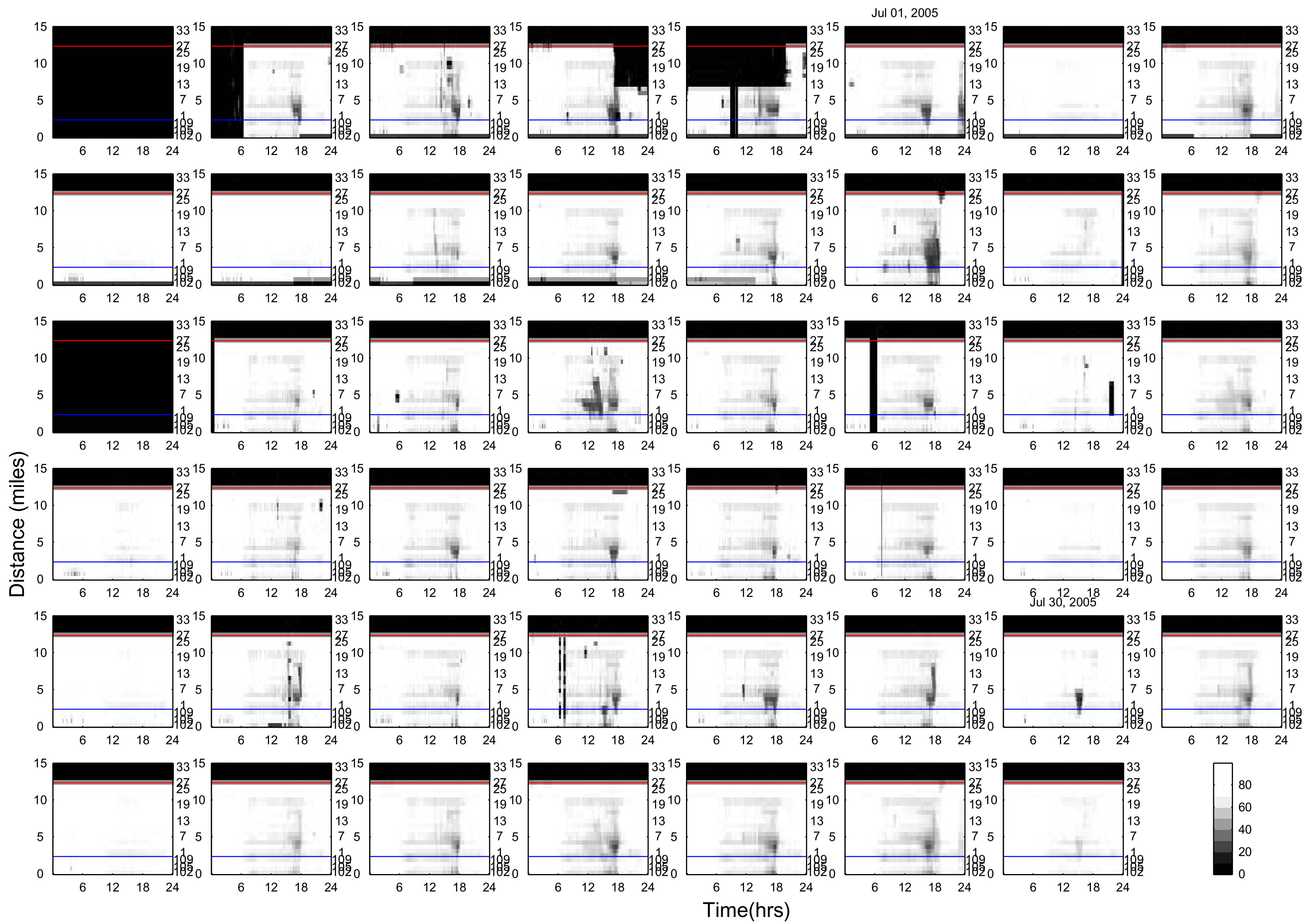

Mar 01, 2005
Mar 31, 2005
Distance (miles)
Time(hrs)



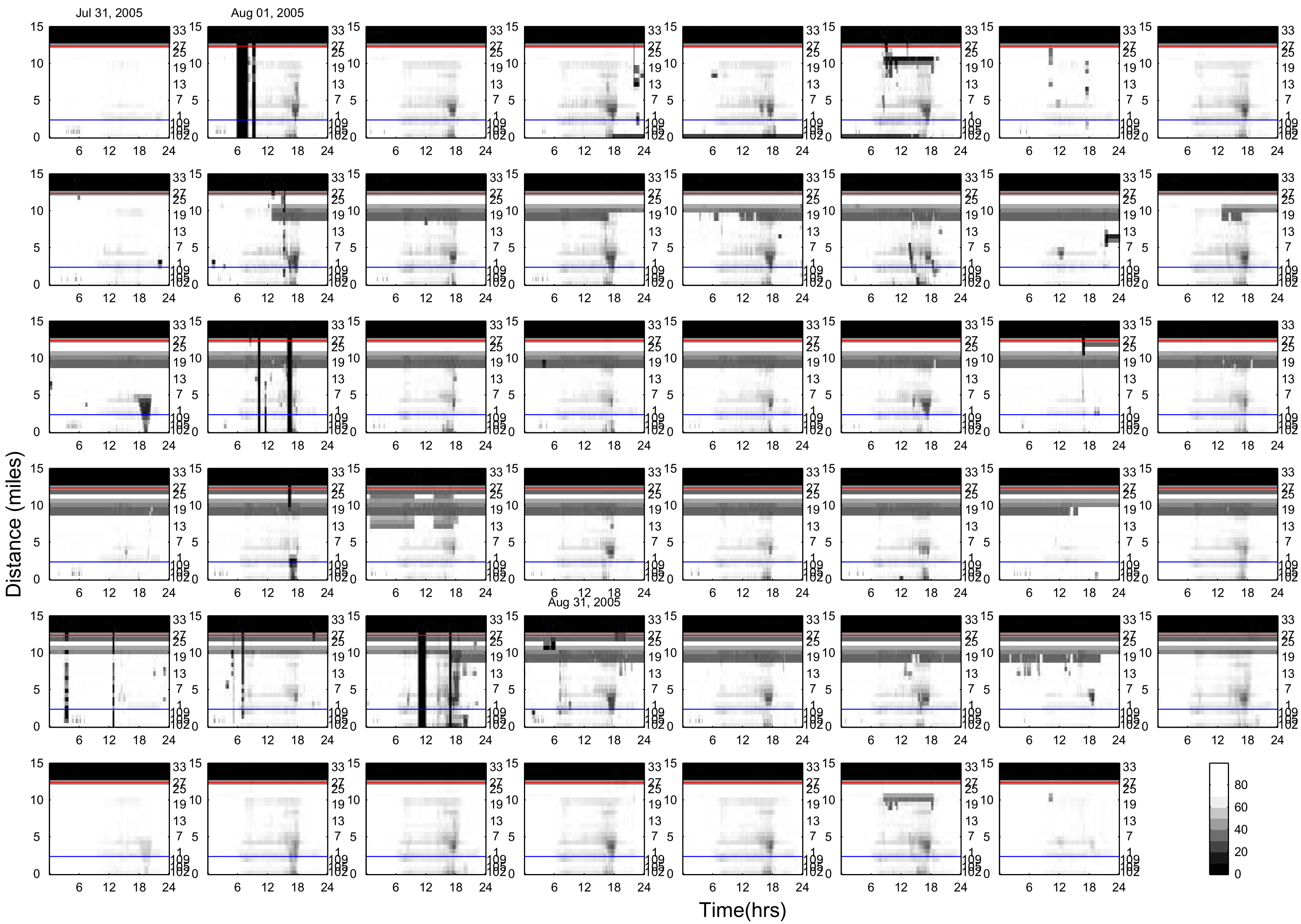
Apr 01, 2005
Apr 30, 2005
Distance (miles)
Time(hrs)

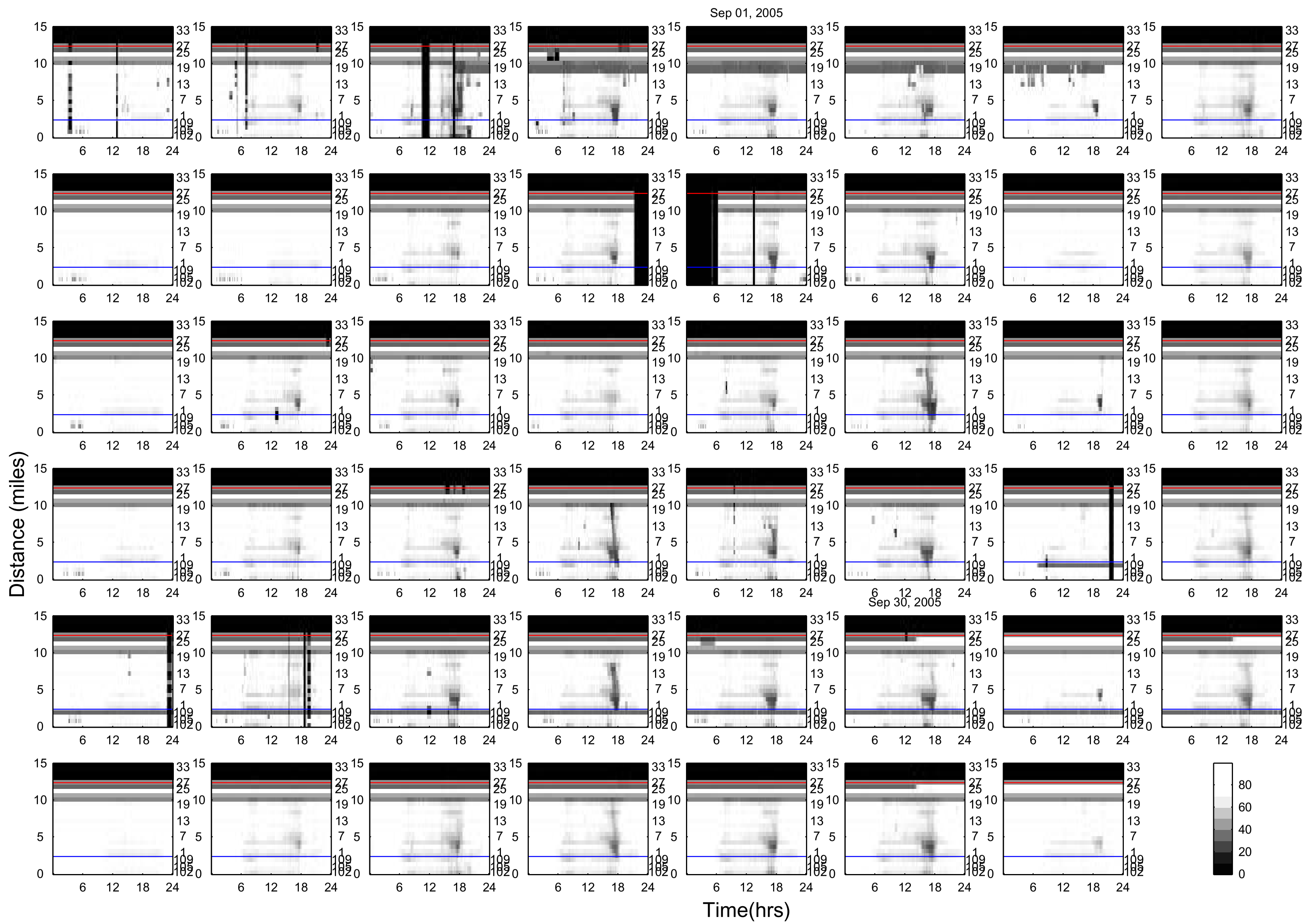

May 01, 2005
May 31, 2005
Distance (miles)
Time(hrs)
80
60
40
20
0


Jun 01, 2005
Jun 30, 2005
Distance (miles)
Time(hrs)



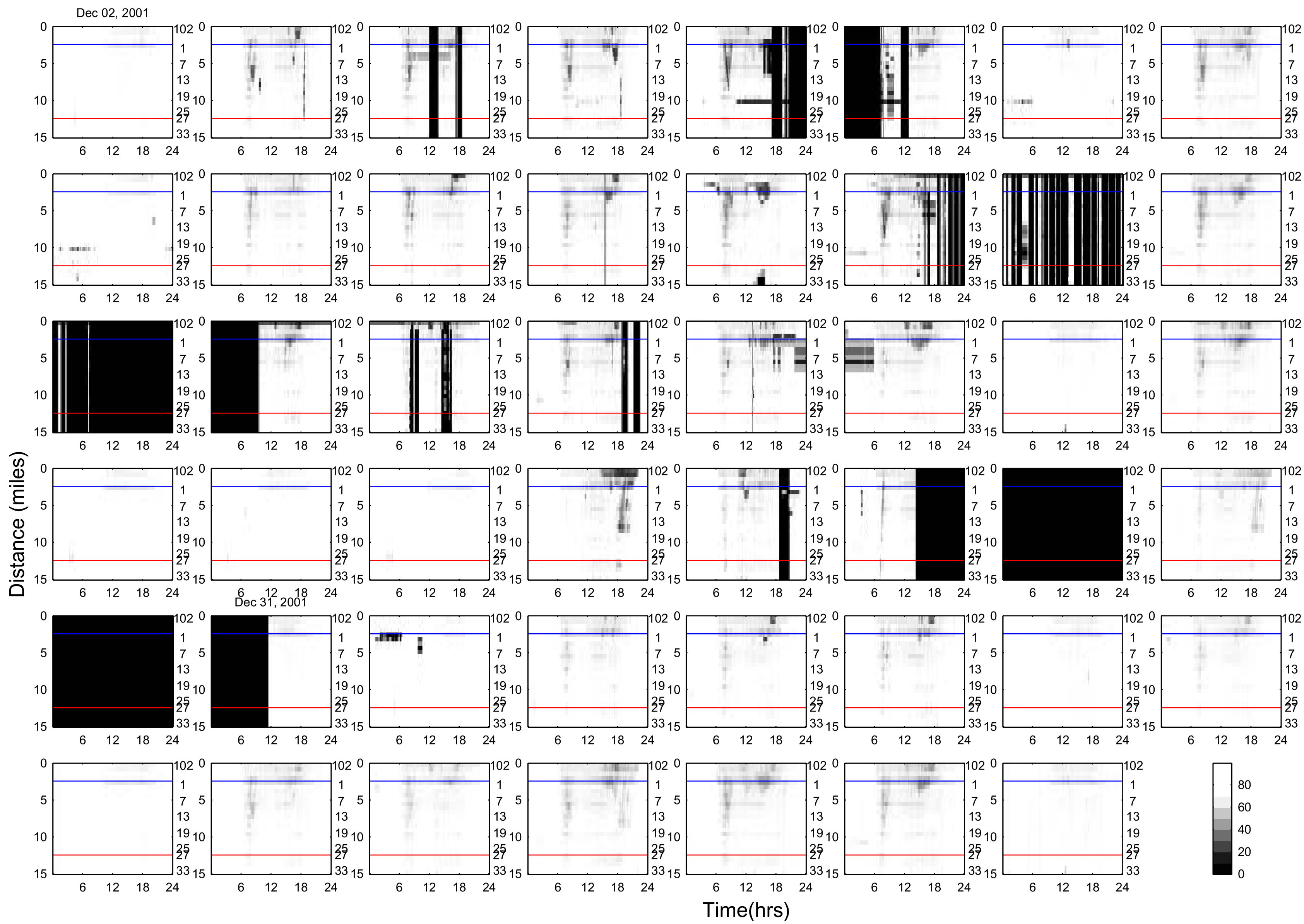
Jul 01, 2005
Jul 30, 2005
Distance (miles)
Time(hrs)


Jul 31, 2005
Aug 01, 2005
Aug 31, 2005
Distance (miles)
Time(hrs)
80
60
40
20
0

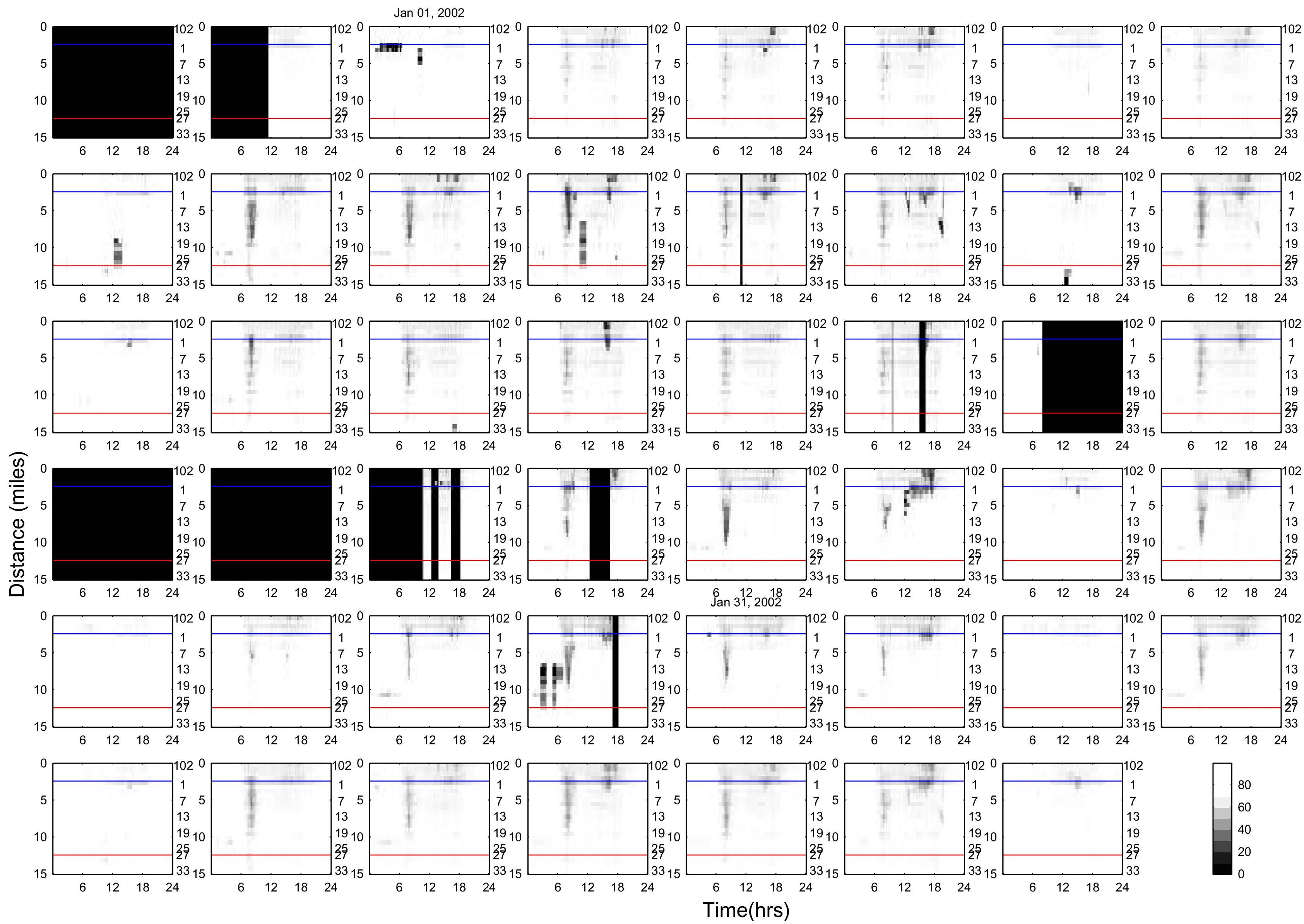


Sep 01, 2005
Sep 30, 2005
Distance (miles)
Time(hrs)

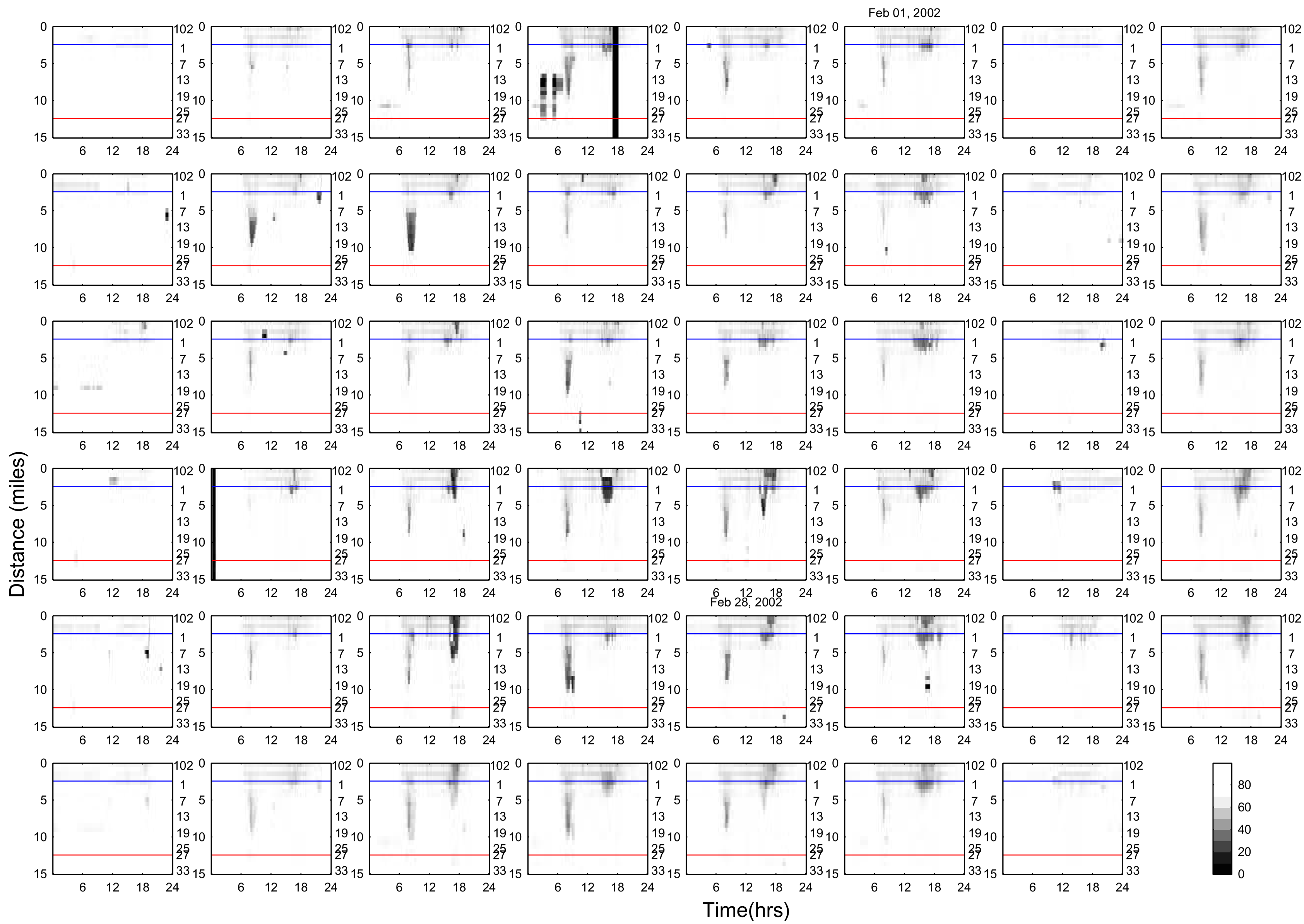
SOUTHBOUND



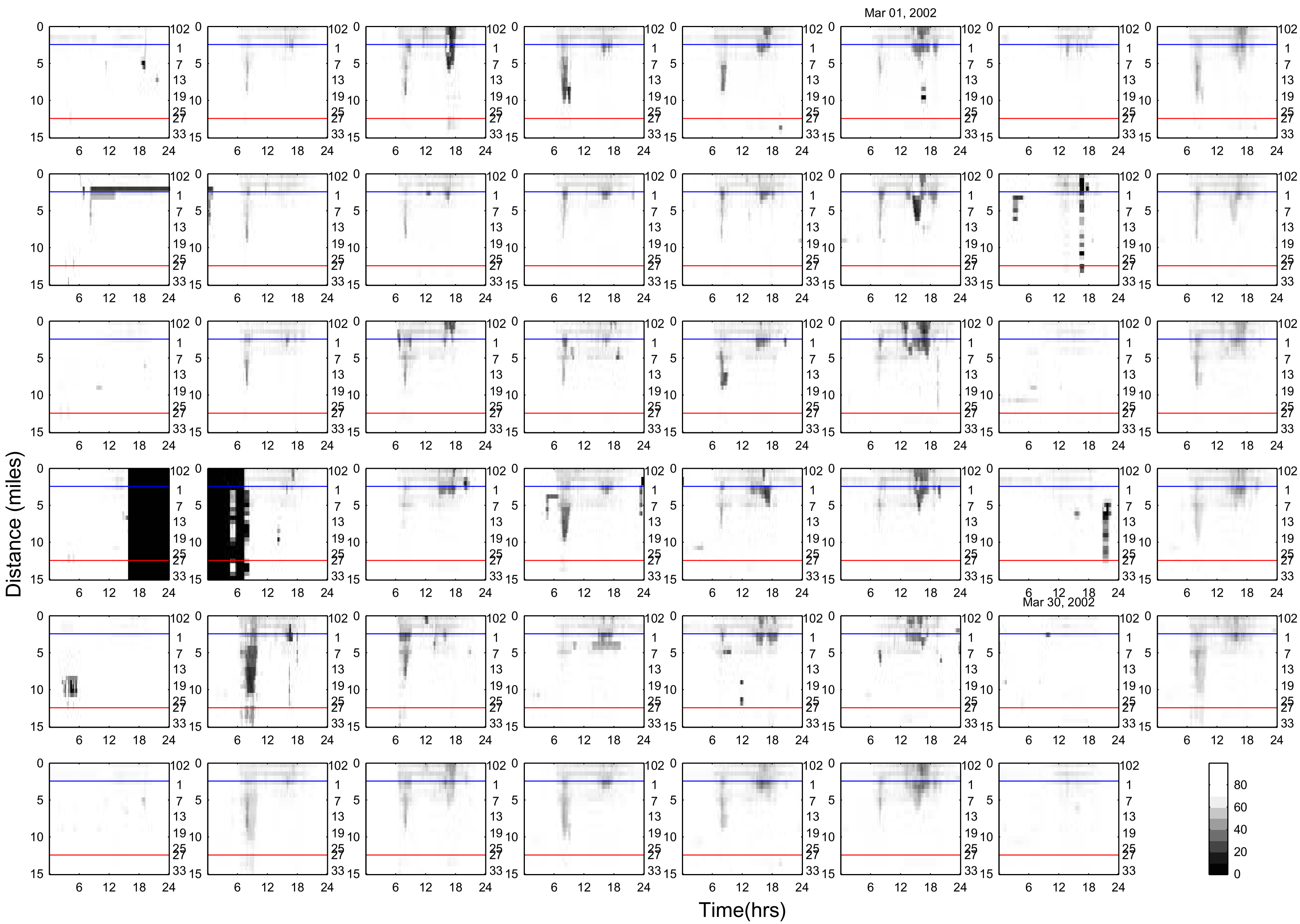
Dec 02, 2001
Dec 31, 2001
Distance (miles)
Time(hrs)



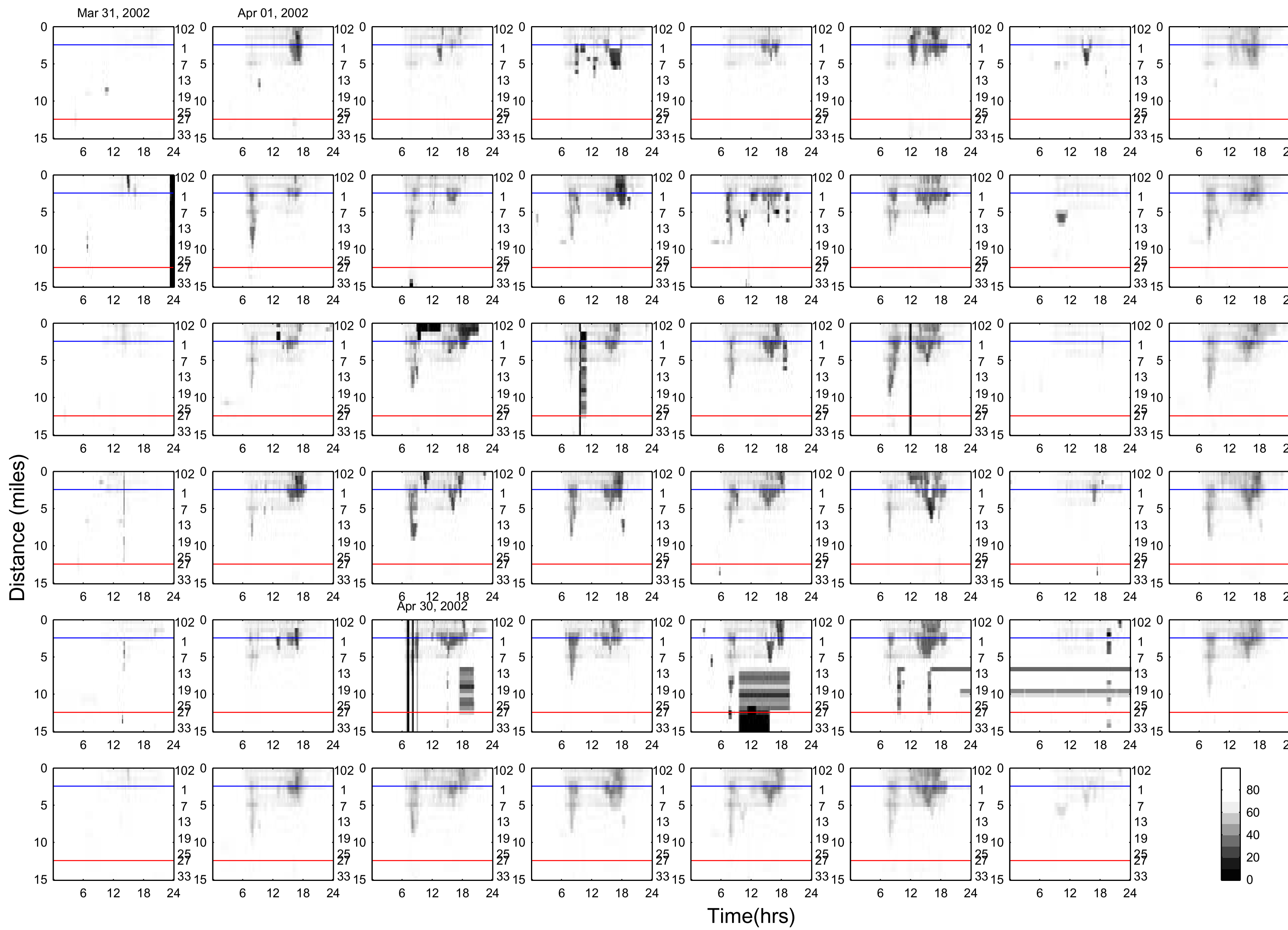
Jan 01, 2002
Jan 31, 2002
Distance (miles)
Time(hrs)

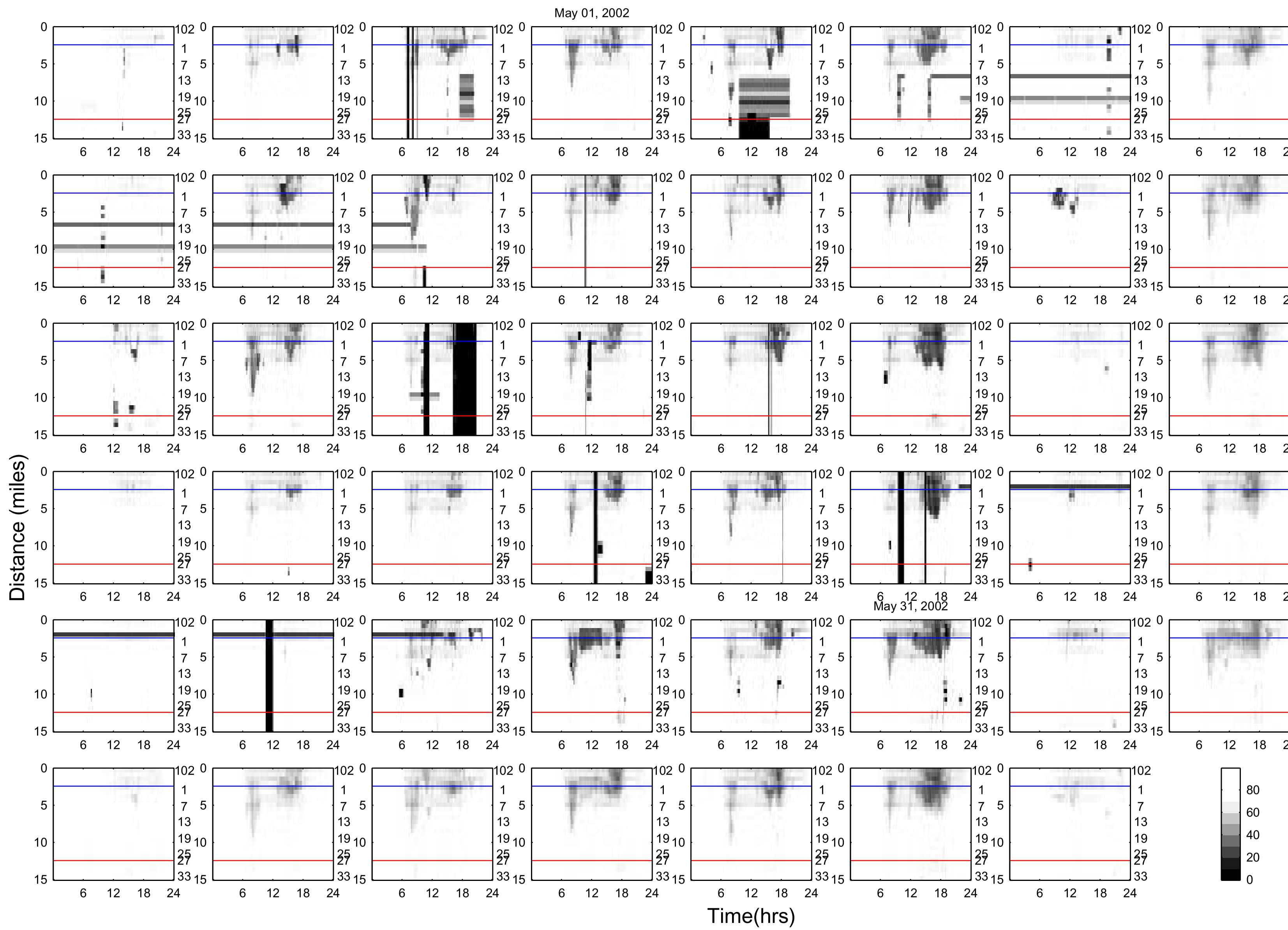


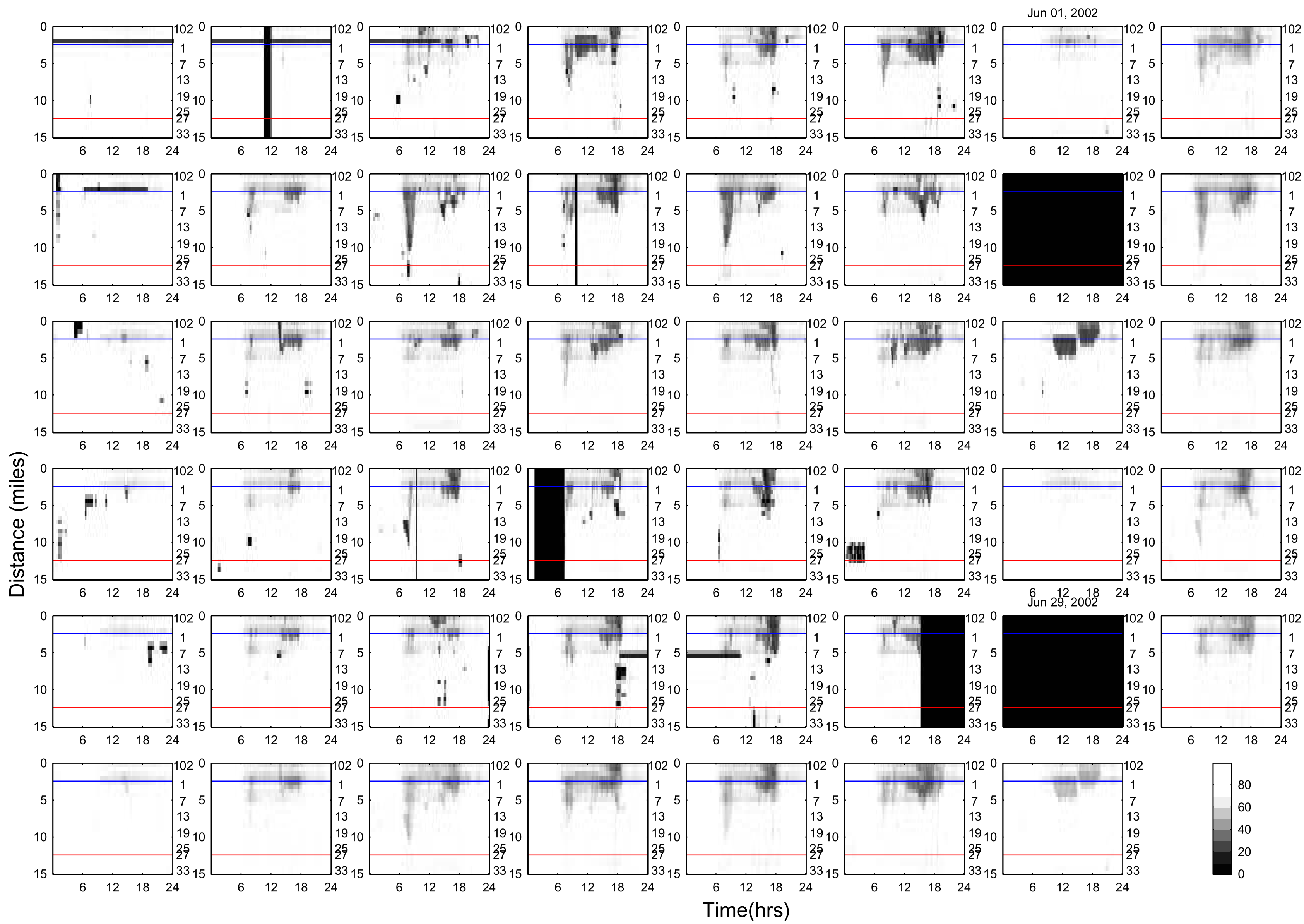
Feb 01, 2002
Feb 28, 2002
Distance (miles)
Time(hrs)
0
5
10
15
6
12
18
24
102
1
7
13
19
25
27
33
80
60
40
20
0



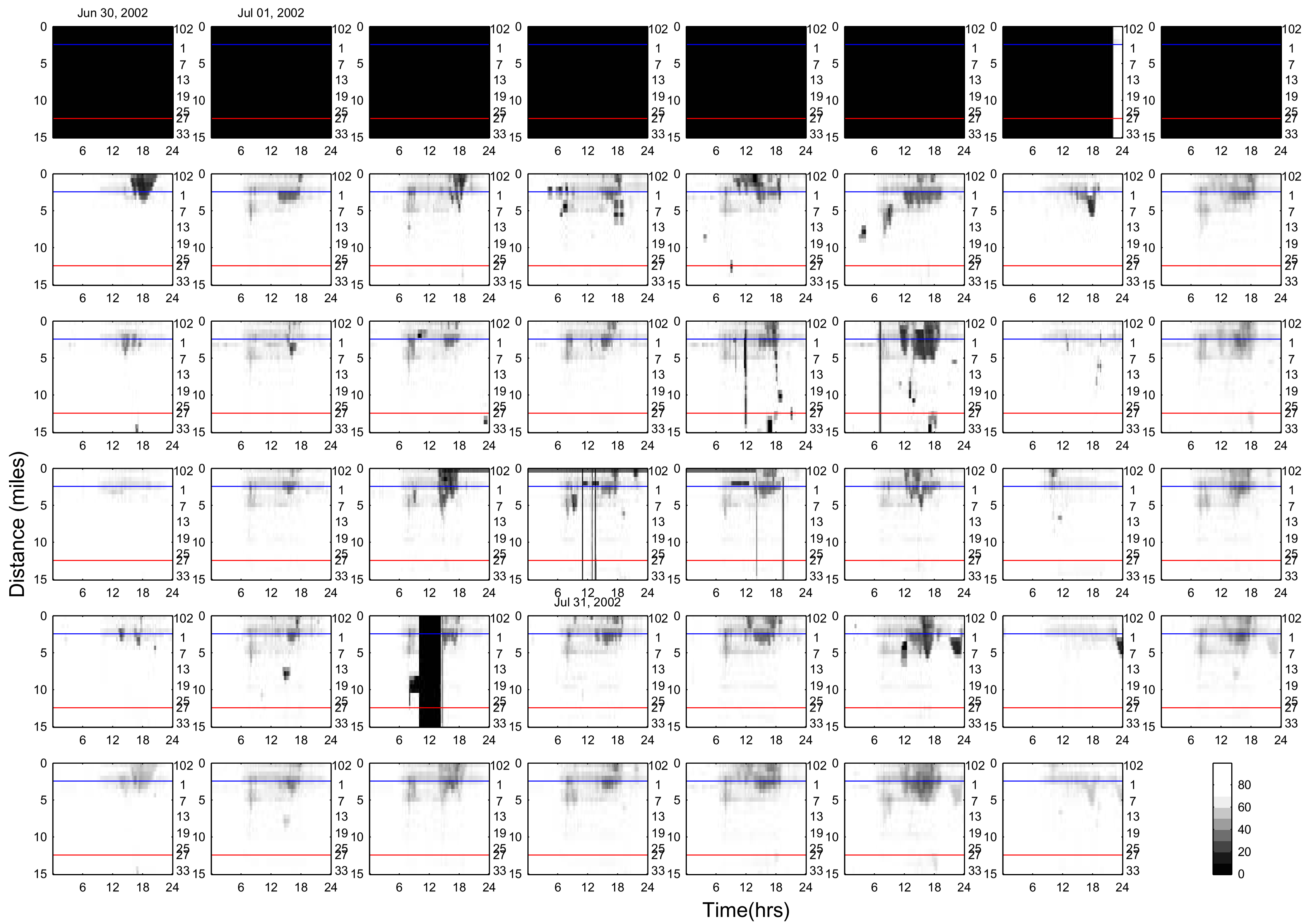
Mar 01, 2002
Mar 30, 2002
Distance (miles)
Time(hrs)
0
20
40
60
80


Mar 31, 2002
Apr 01, 2002
Apr 30, 2002
Distance (miles)
Time(hrs)

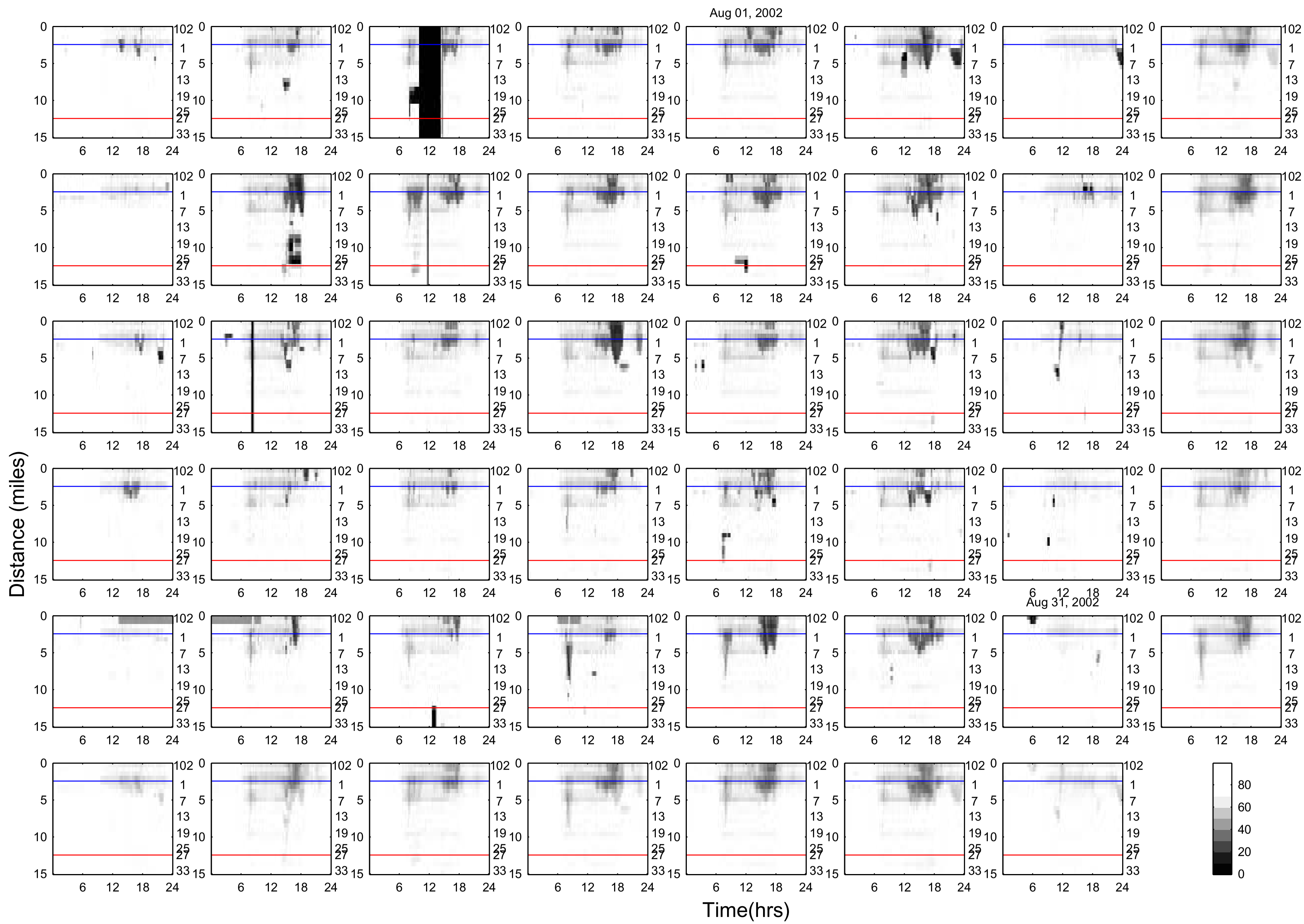

May 01, 2002
May 31, 2002
Distance (miles)
Time(hrs)
0
20
40
60
80

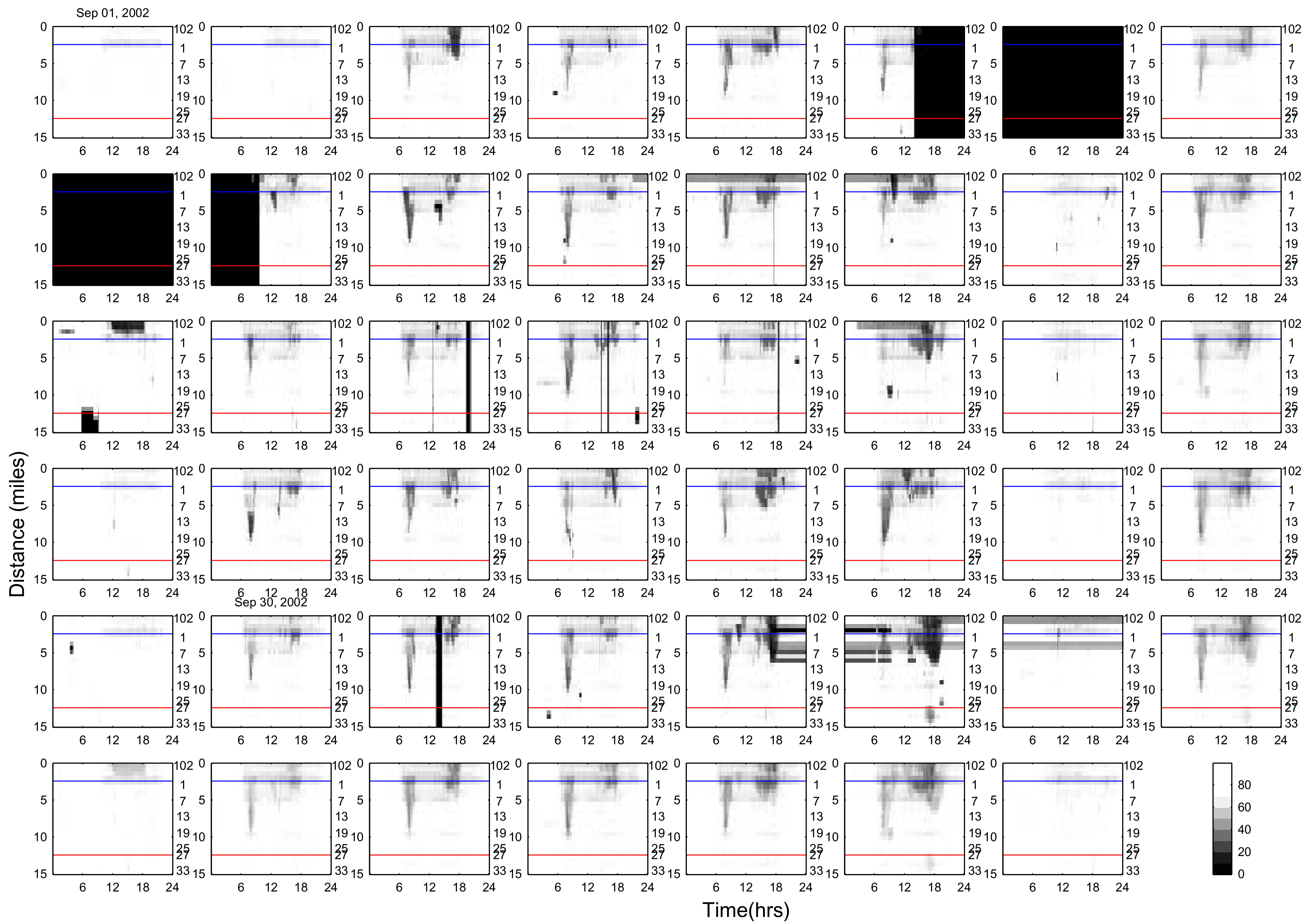


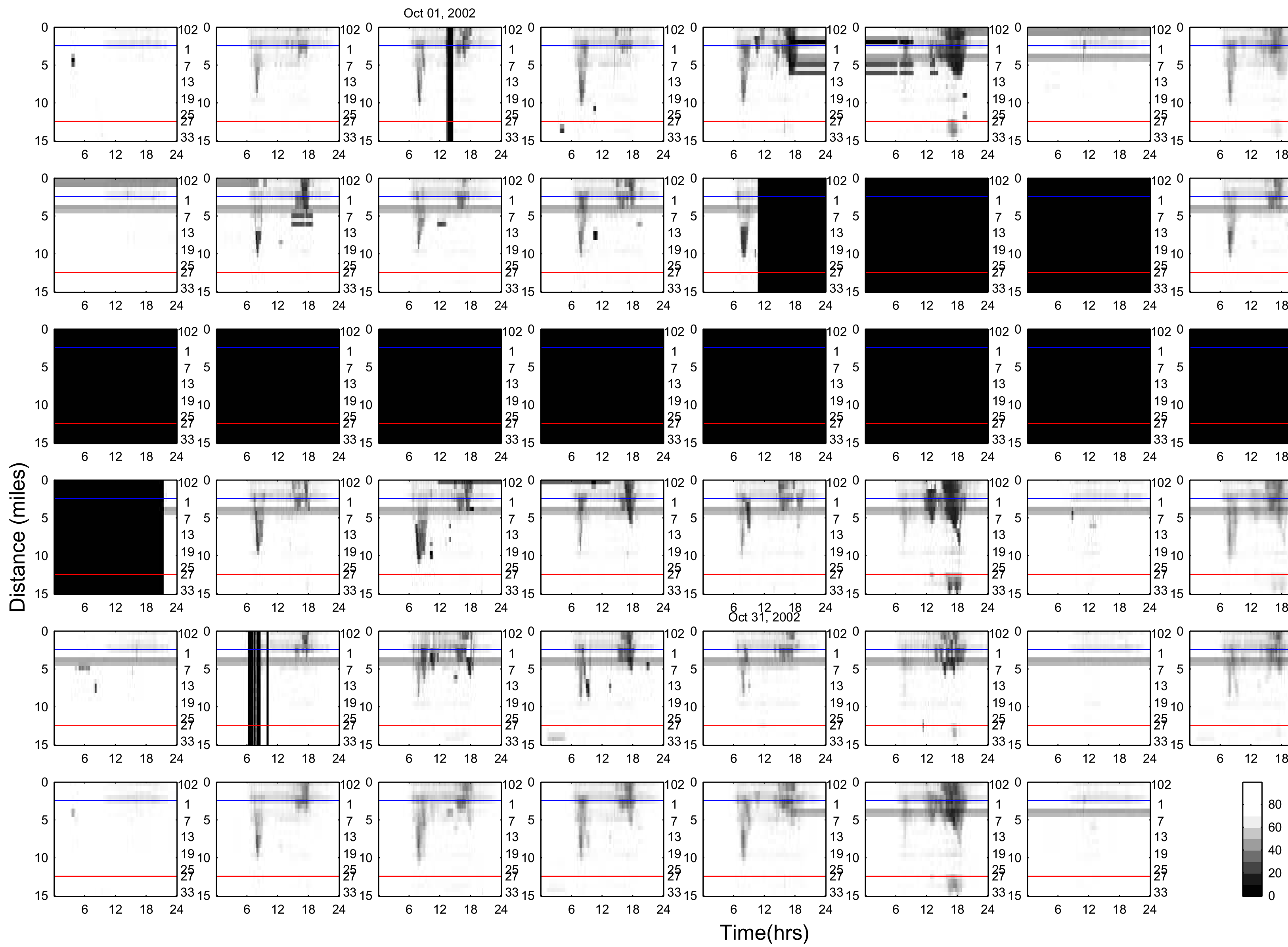
Jun 01, 2002
Jun 29, 2002
Distance (miles)
Time(hrs)
80
60
40
20
0



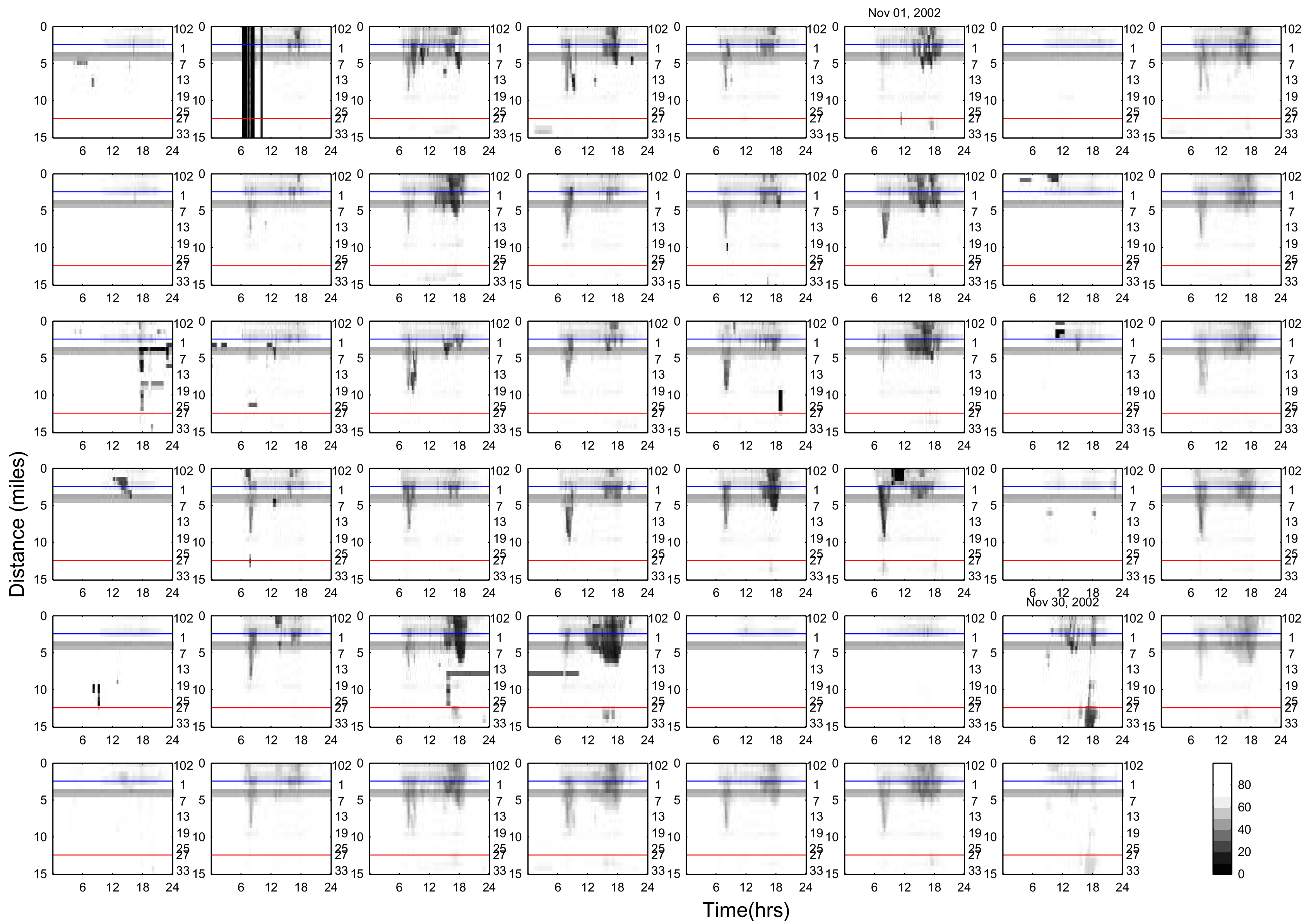
Jun 30, 2002
Jul 01, 2002
Jul 31, 2002
Distance (miles)
Time(hrs)
0
5
10
15
6
12
18
24
102
1
7
13
19
25
27
33
80
60
40
20
0


Aug 01, 2002
Aug 31, 2002
Distance (miles)
Time(hrs)

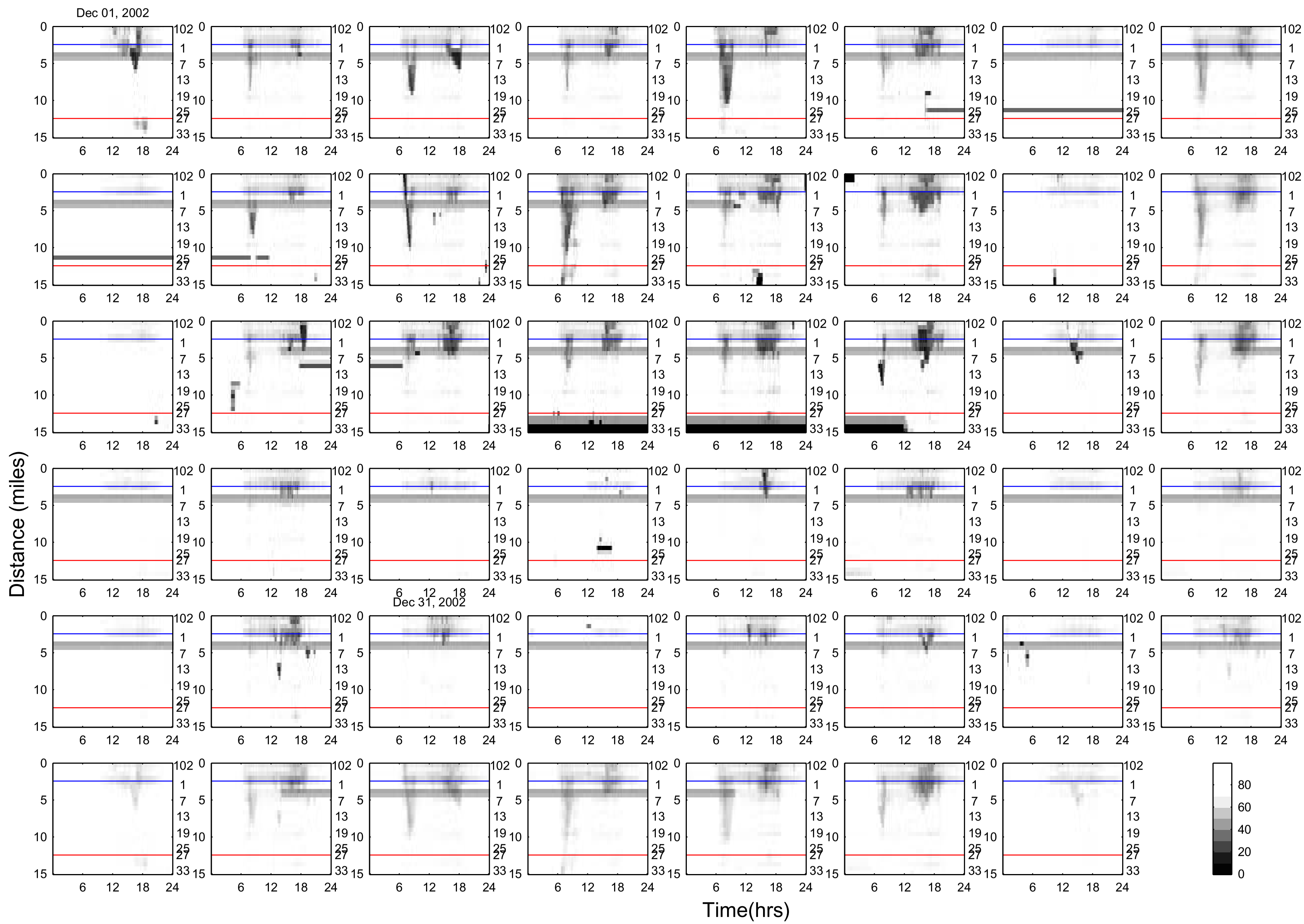

Sep 01, 2002
Sep 30, 2002
Distance (miles)
Time(hrs)



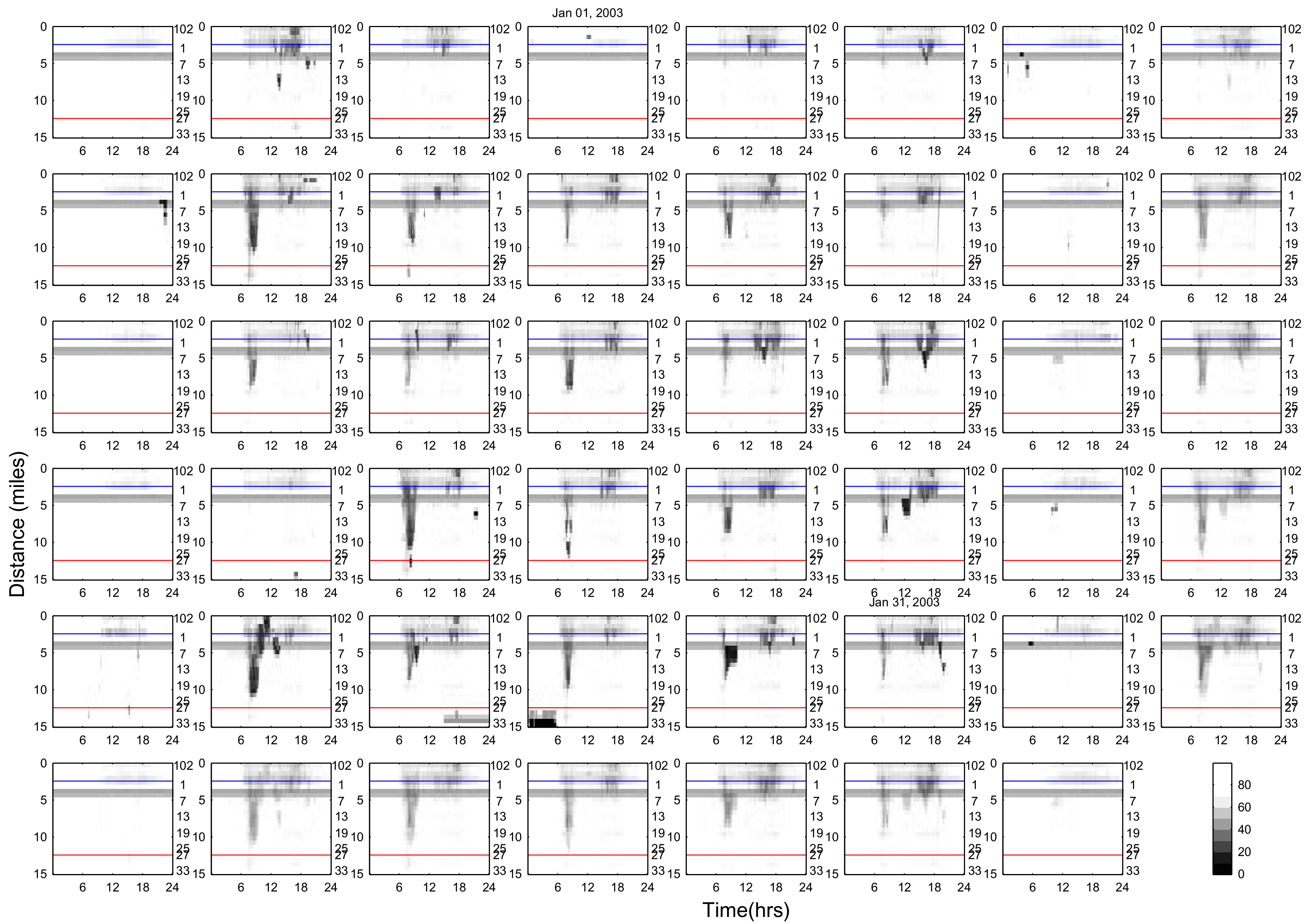
Oct 01, 2002
Oct 31, 2002
Distance (miles)
Time(hrs)
80
60
40
20
0



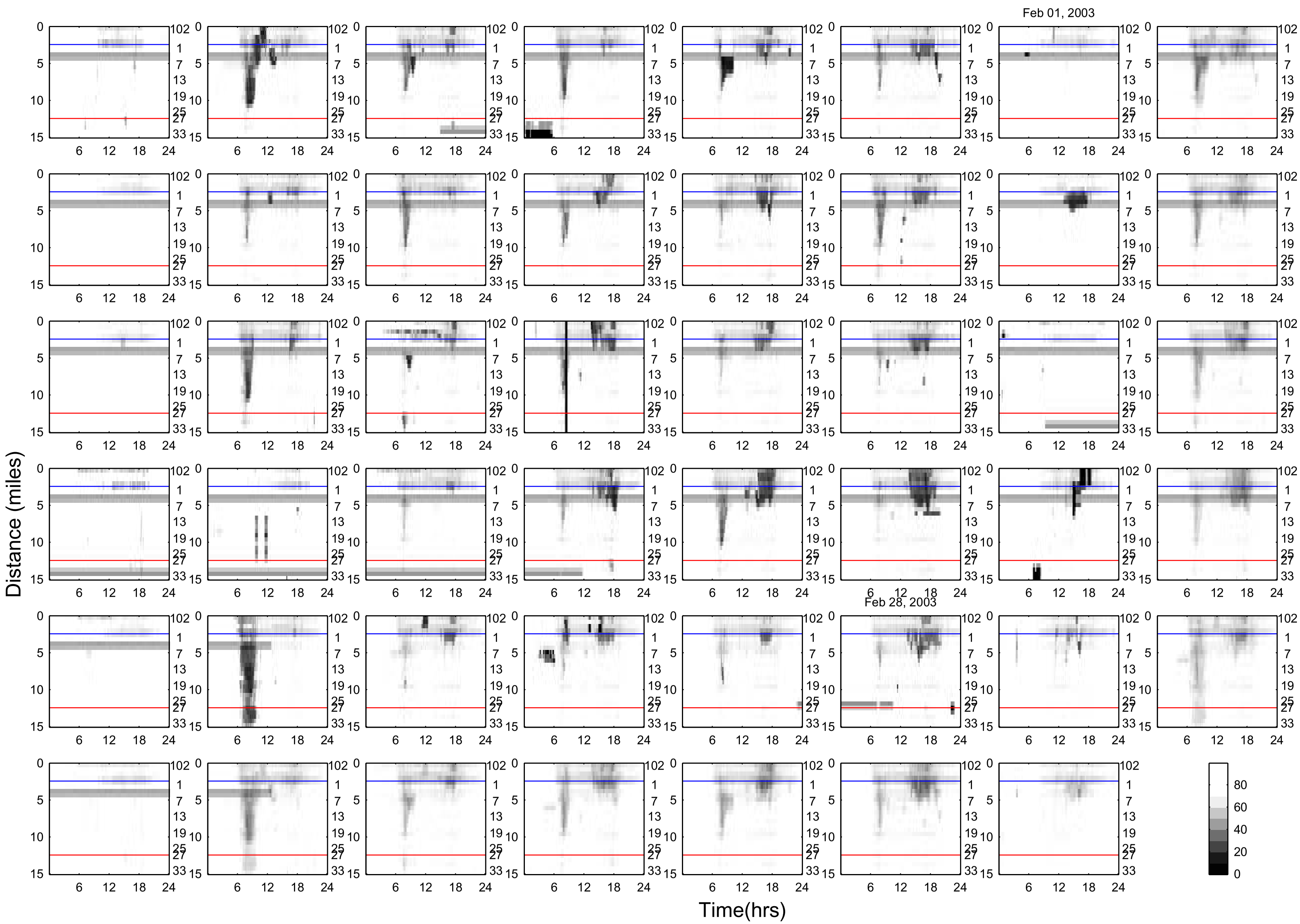
Nov 01, 2002
Nov 30, 2002
Distance (miles)
Time(hrs)

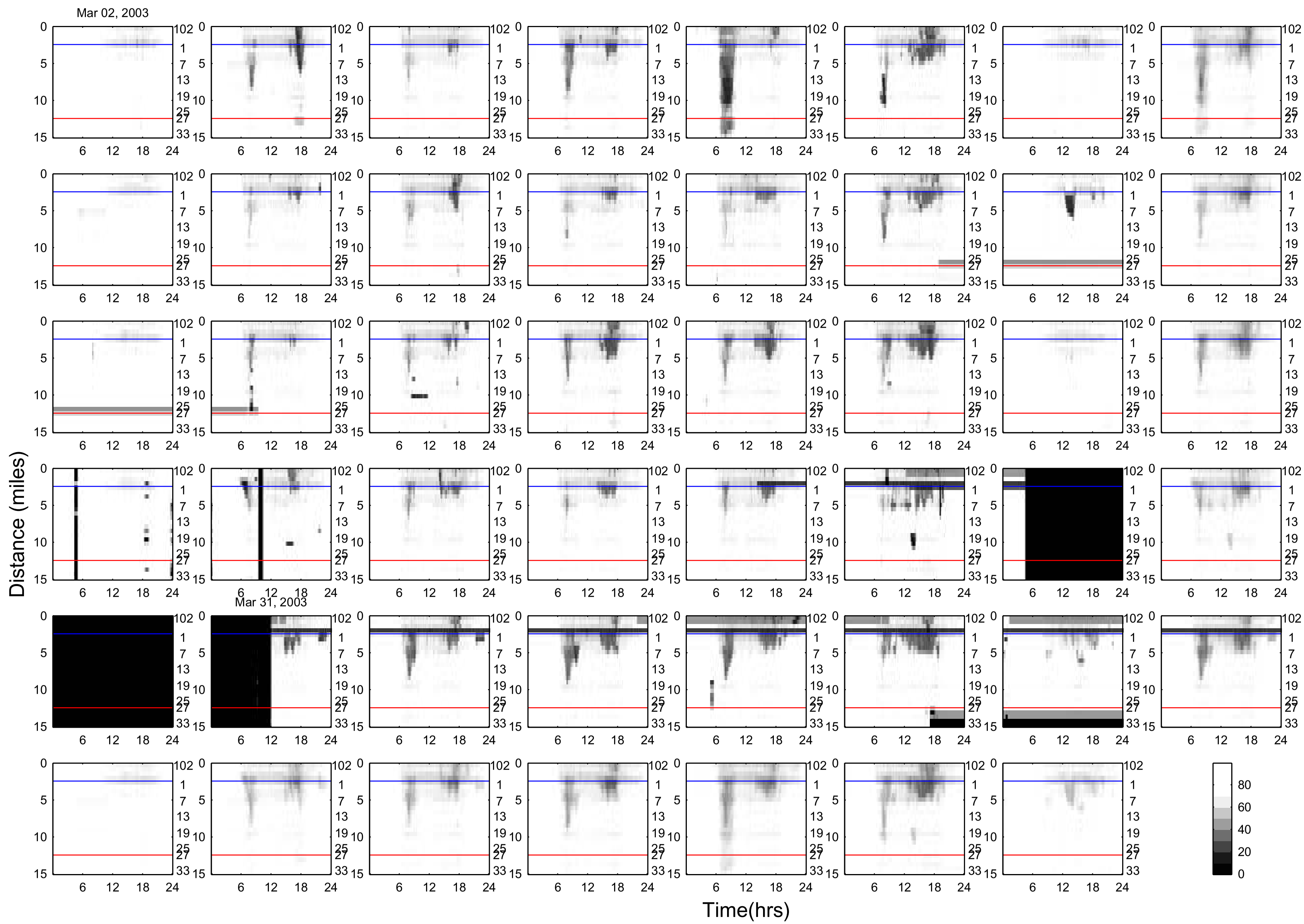


Dec 01, 2002
Dec 31, 2002
Distance (miles)
Time(hrs)
0
5
10
15
6
12
18
24
102
1
7
13
19
25
27
33
80
60
40
20
0

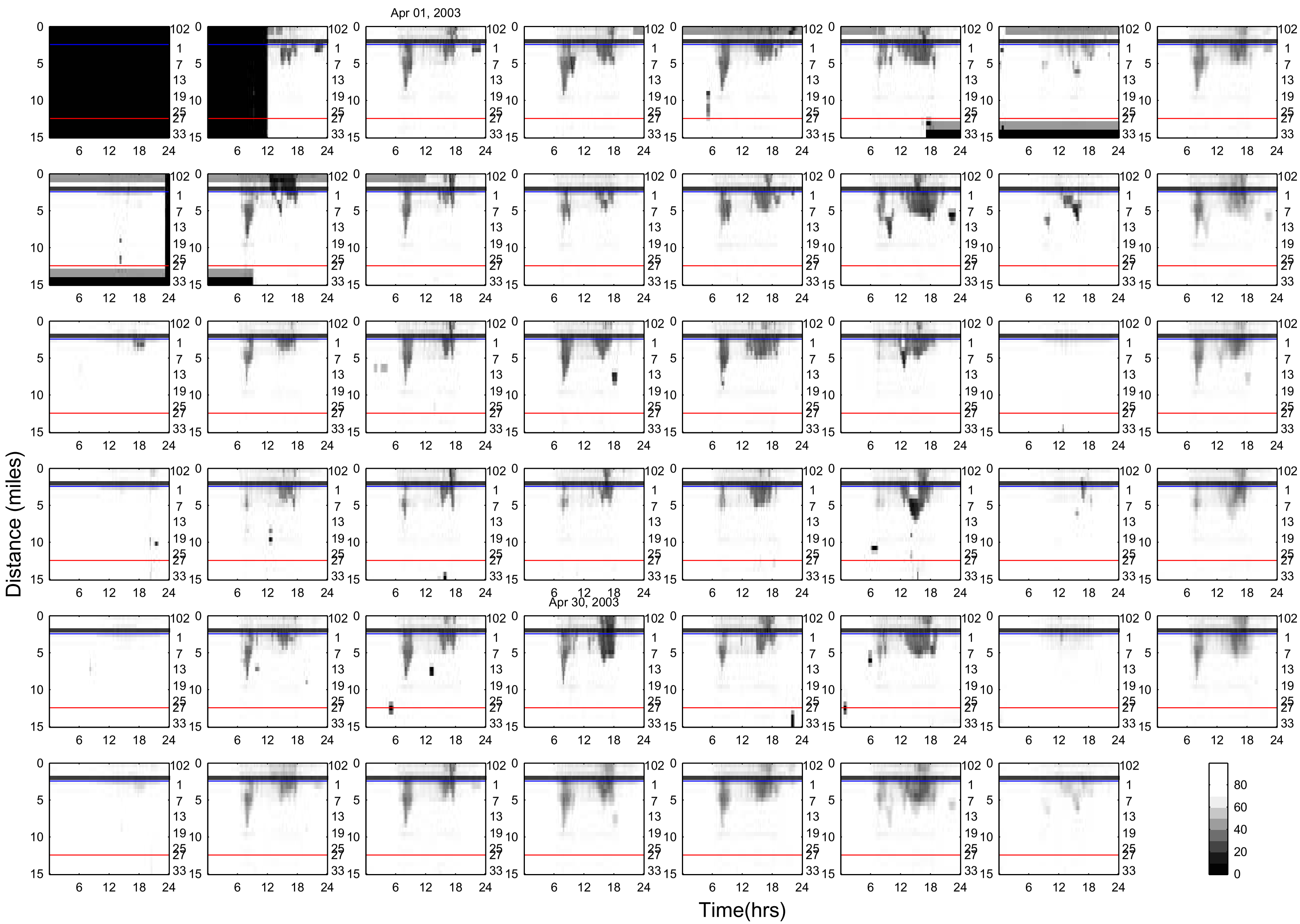


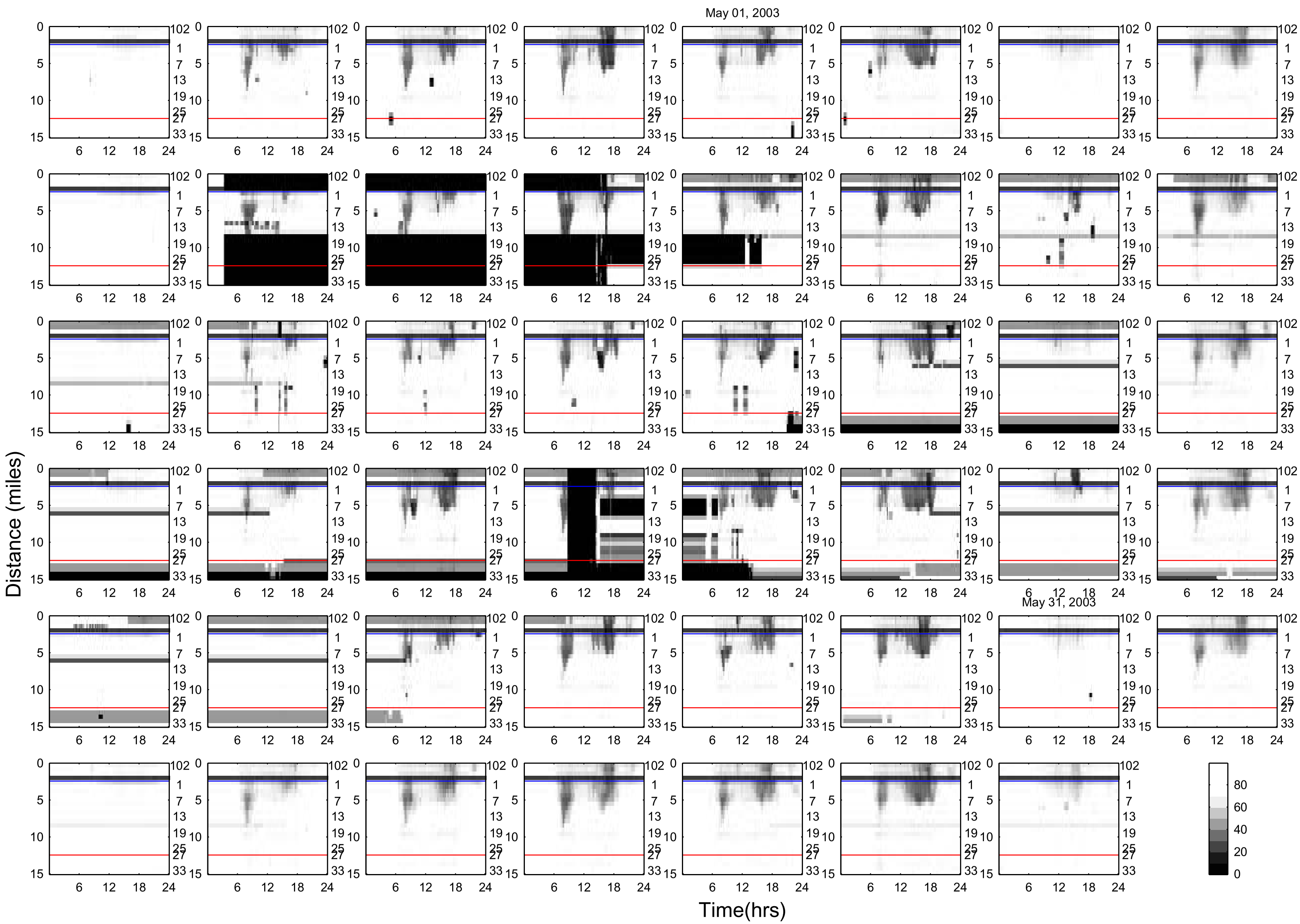
Jan 01, 2003
Jan 31, 2003
Distance (miles)
Time(hrs)

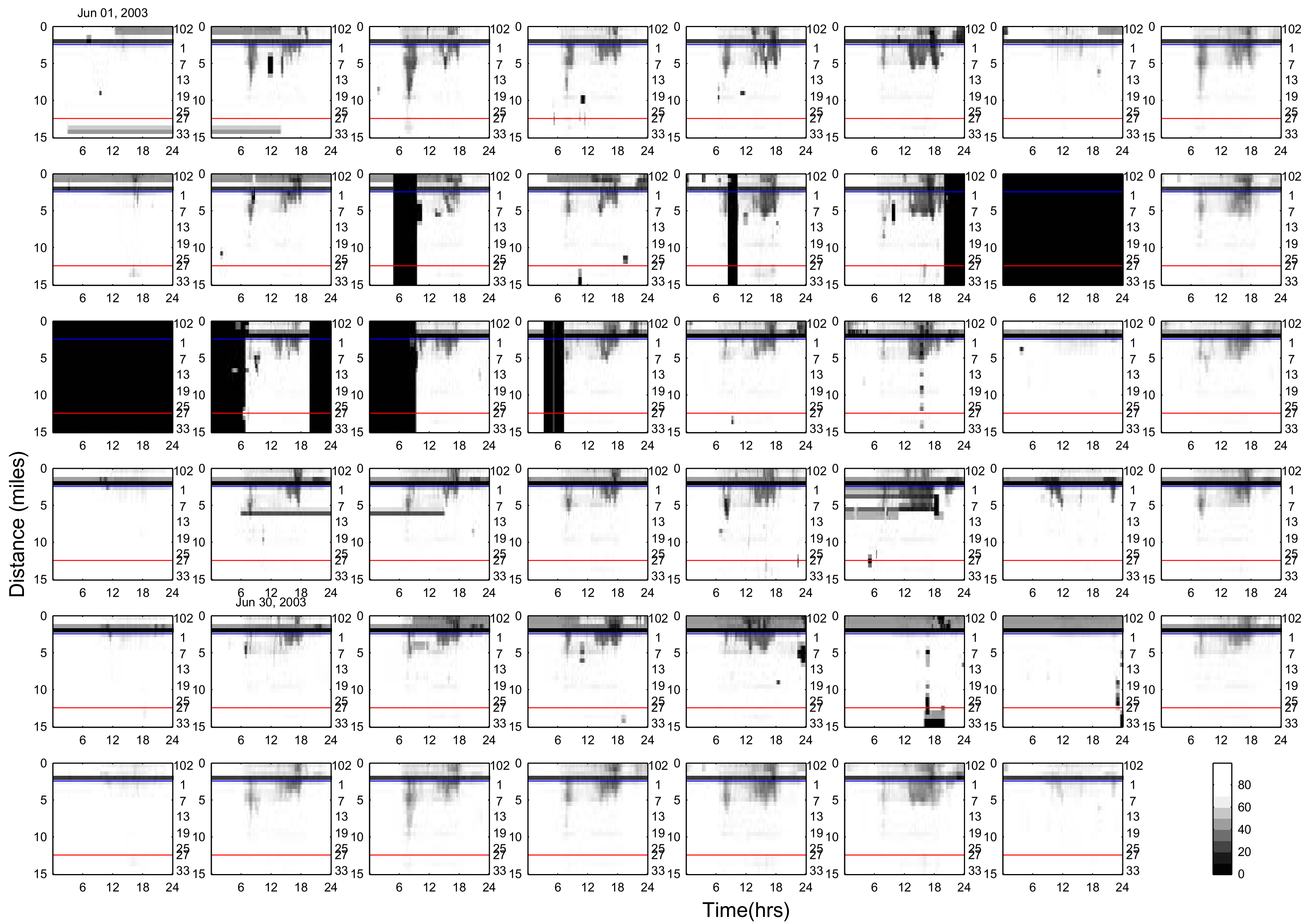

Feb 01, 2003
Feb 28, 2003
Distance (miles)
Time(hrs)
80
60
40
20
0



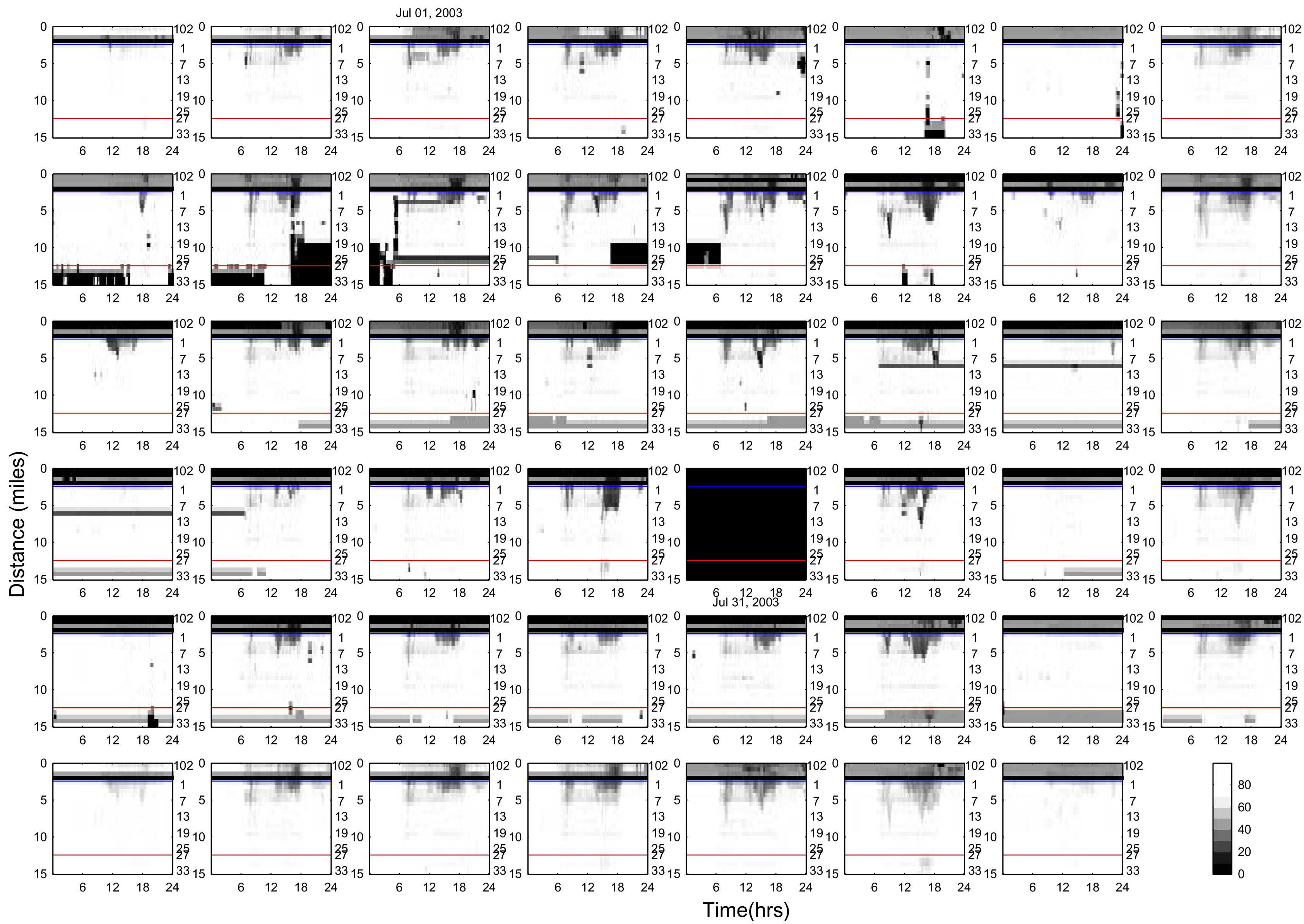
Mar 02, 2003
Mar 31, 2003
Distance (miles)
Time(hrs)
80
60
40
20
0


Apr 01, 2003
Apr 30, 2003
Distance (miles)
Time(hrs)
80
60
40
20
0

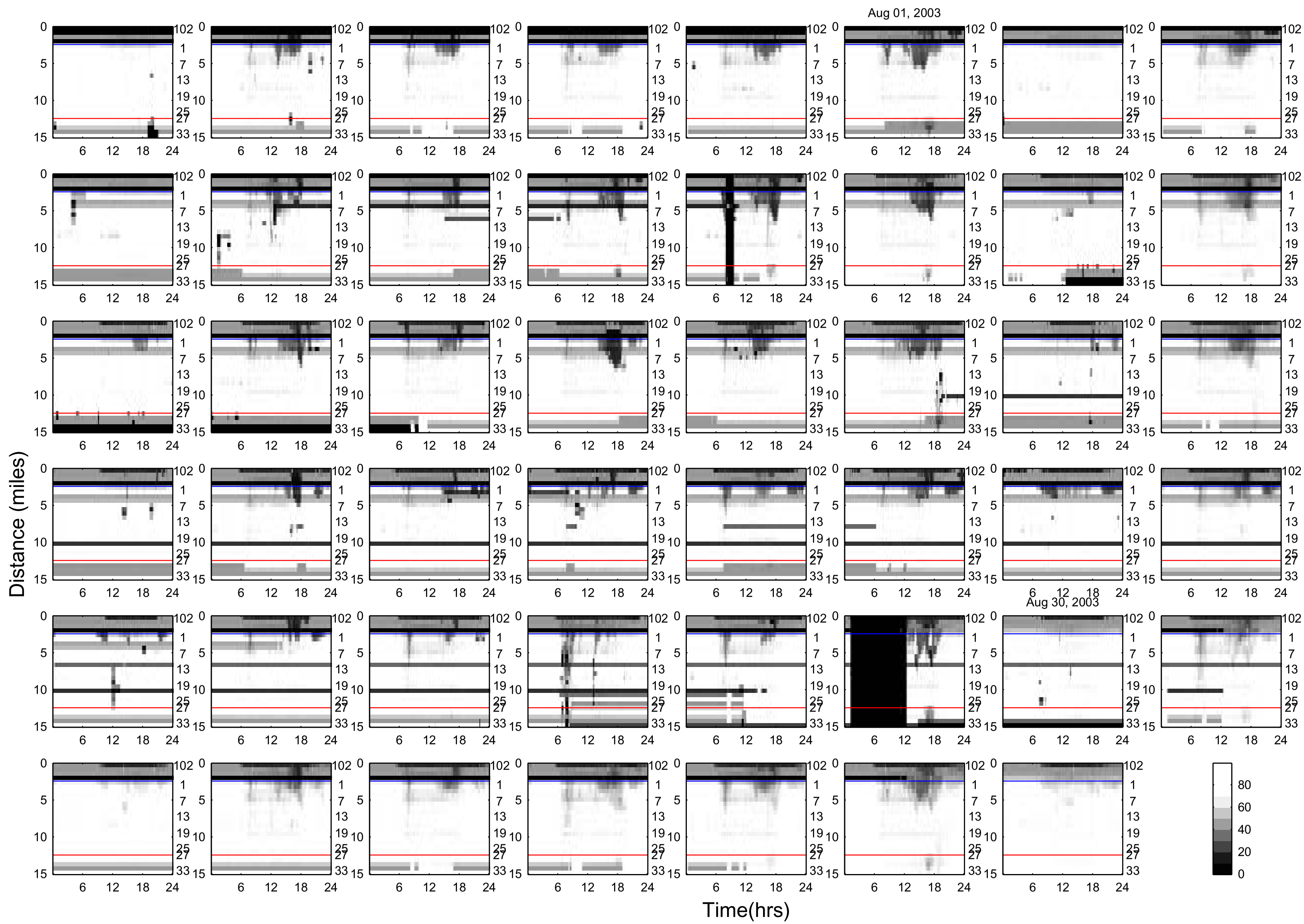

May 01, 2003
May 31, 2003
Distance (miles)
Time(hrs)
80
60
40
20
0



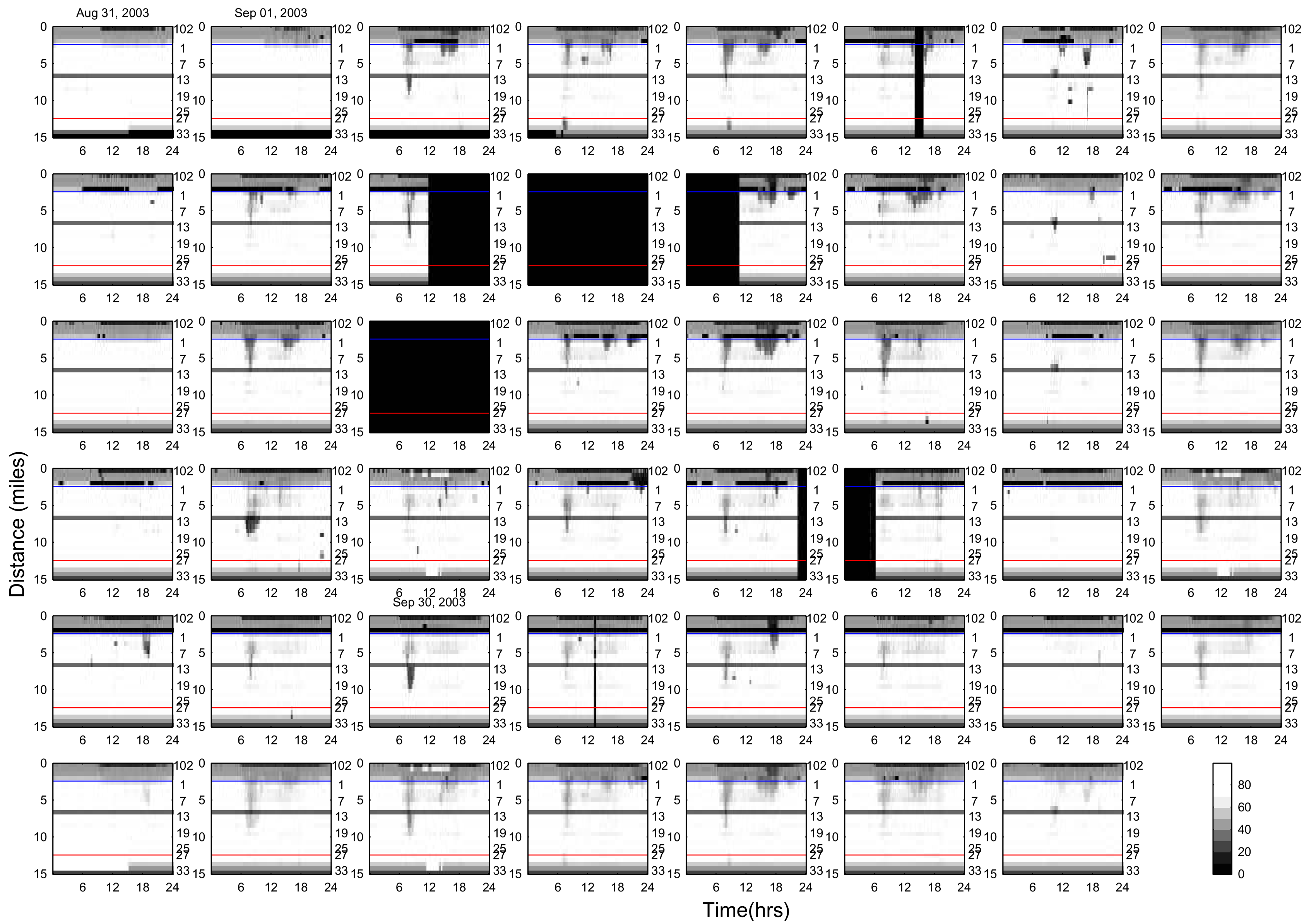
Jun 01, 2003
Jun 30, 2003
Distance (miles)
Time(hrs)
0
5
10
15
6
12
18
24
102
1
7
13
19
25
27
33
80
60
40
20
0



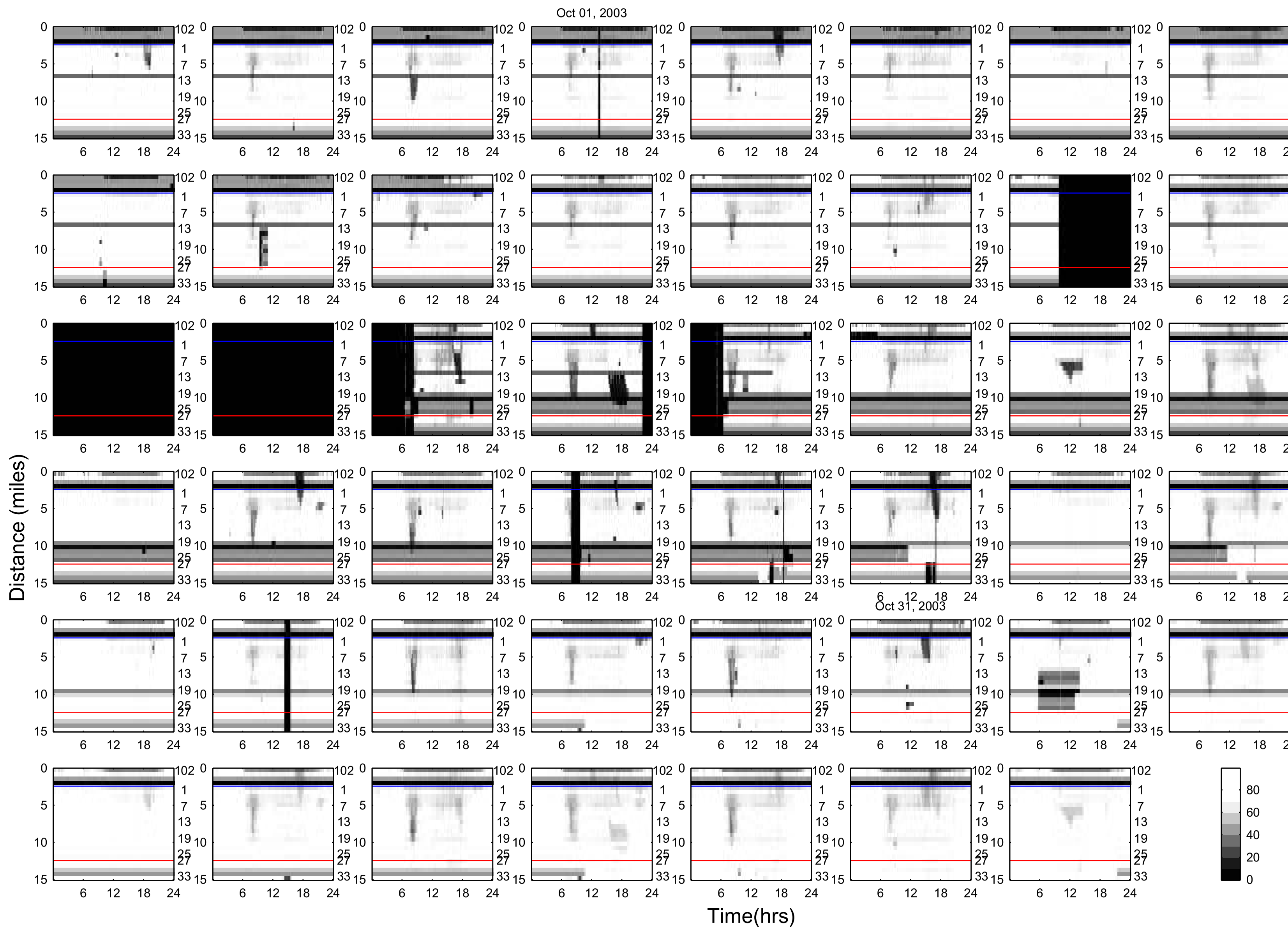
Jul 01, 2003
Jul 31, 2003
Distance (miles)
Time(hrs)



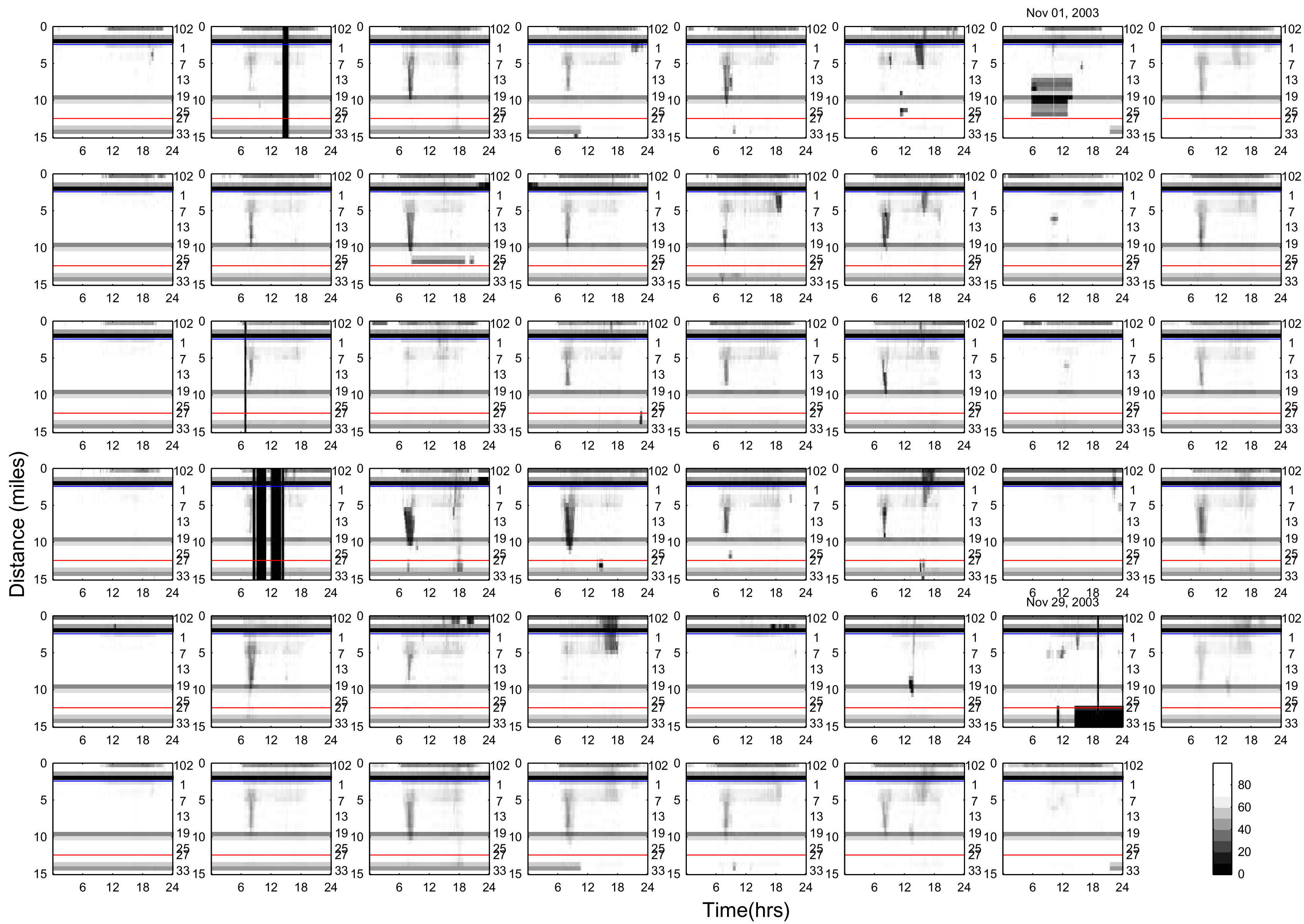
Aug 01, 2003
Aug 30, 2003
Distance (miles)
Time(hrs)

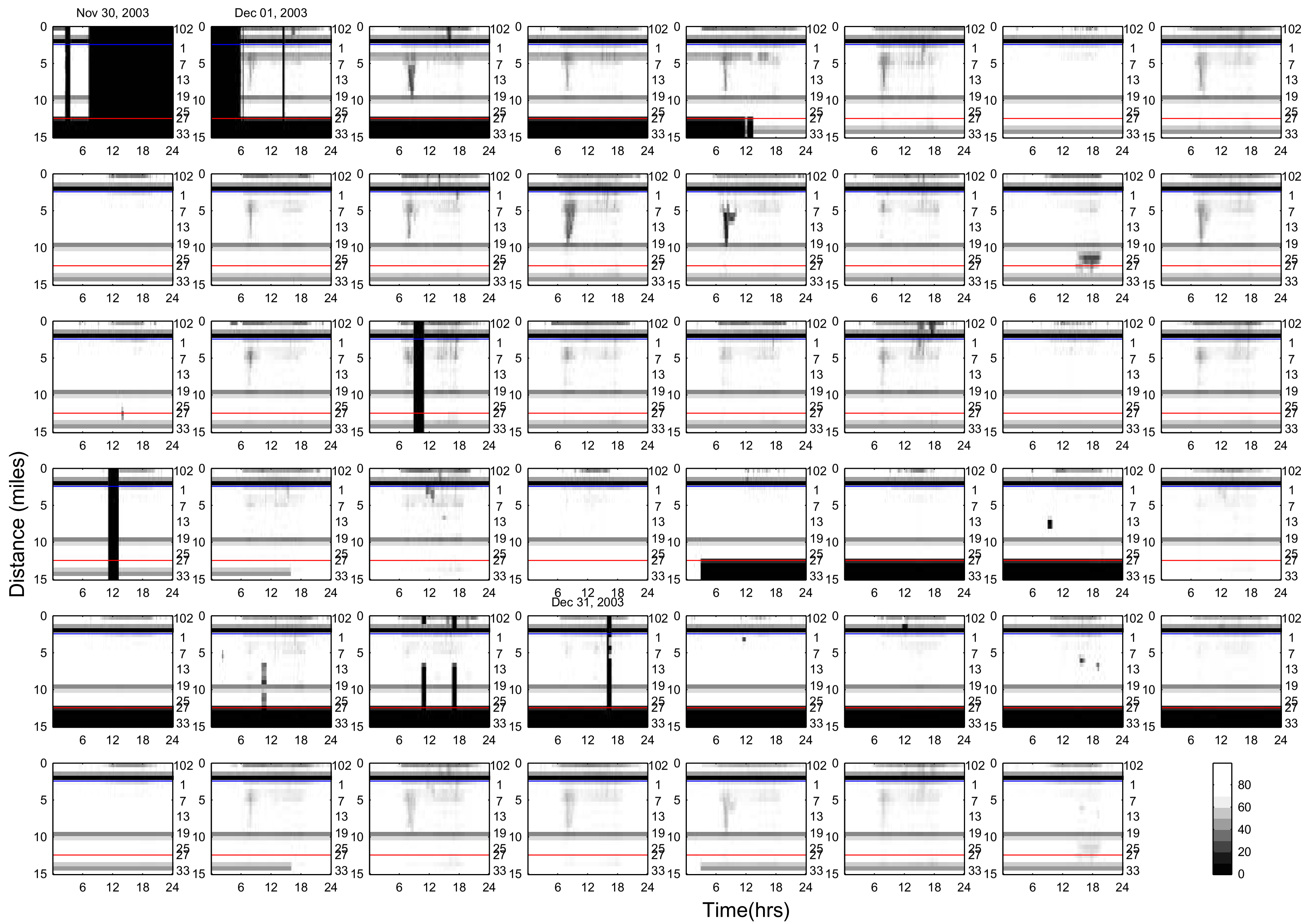


Aug 31, 2003
Sep 01, 2003
Sep 30, 2003
Distance (miles)
Time(hrs)

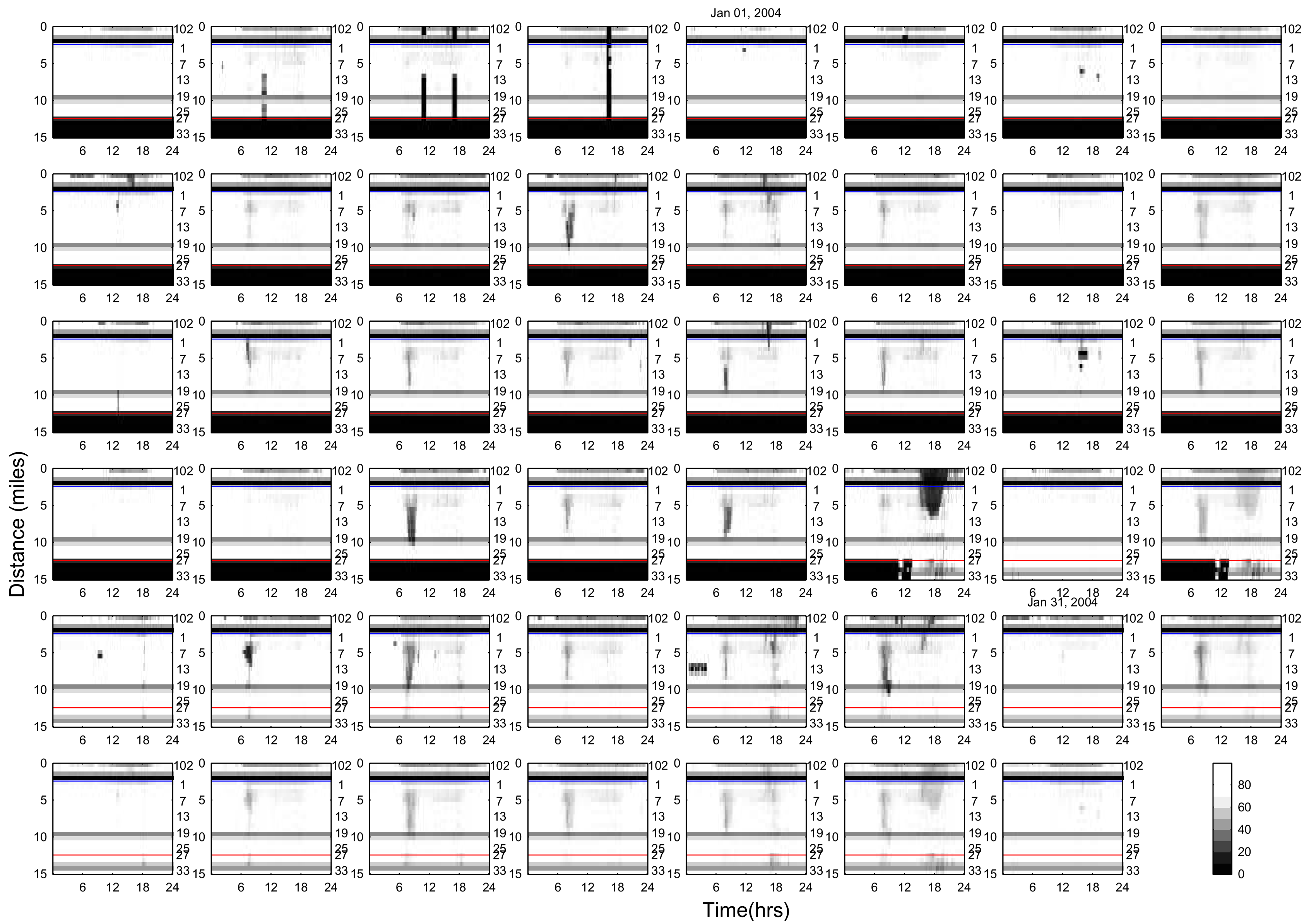


Oct 01, 2003
Oct 31, 2003
Distance (miles)
Time(hrs)

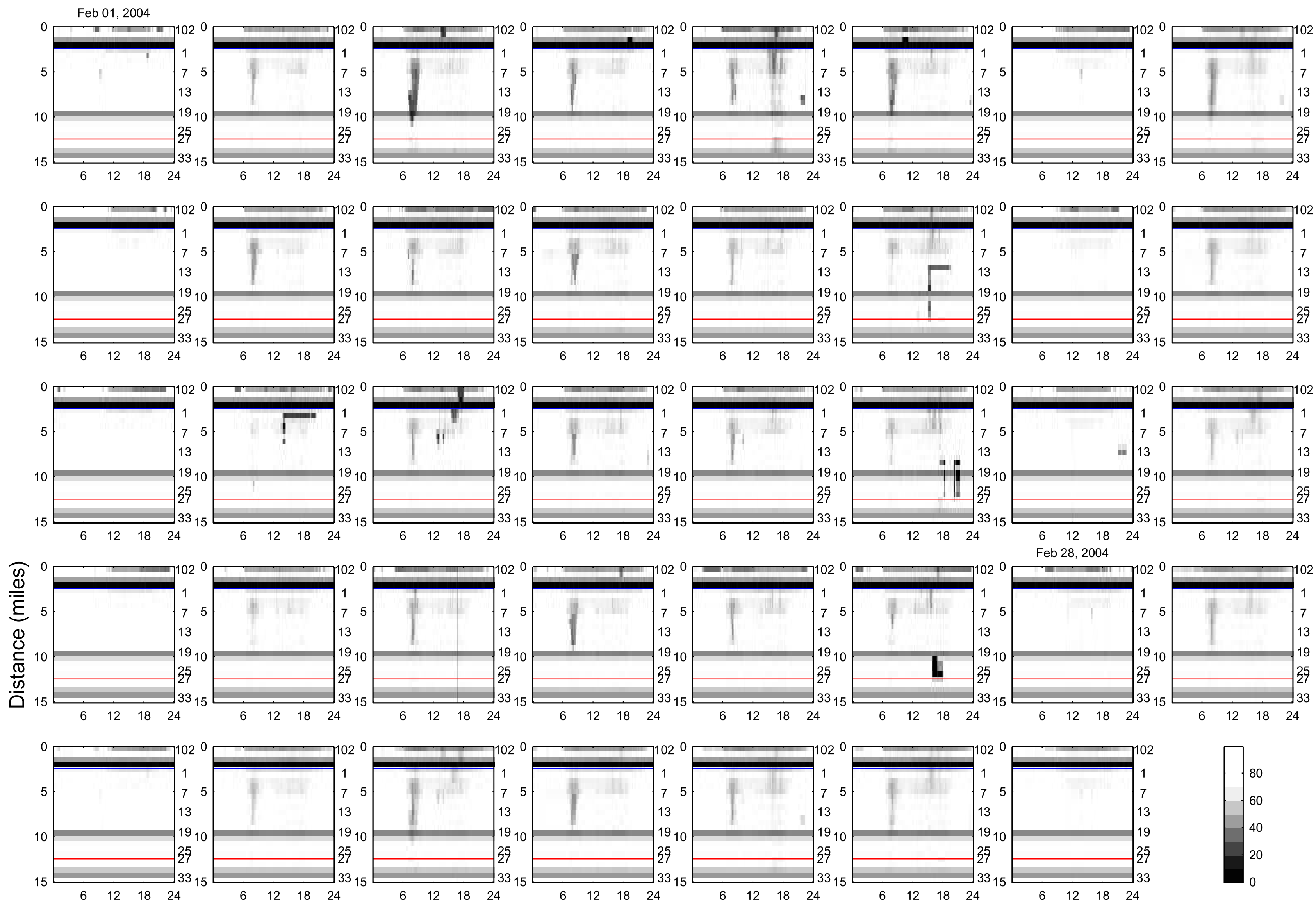

Nov 01, 2003
Nov 29, 2003
Distance (miles)
Time(hrs)

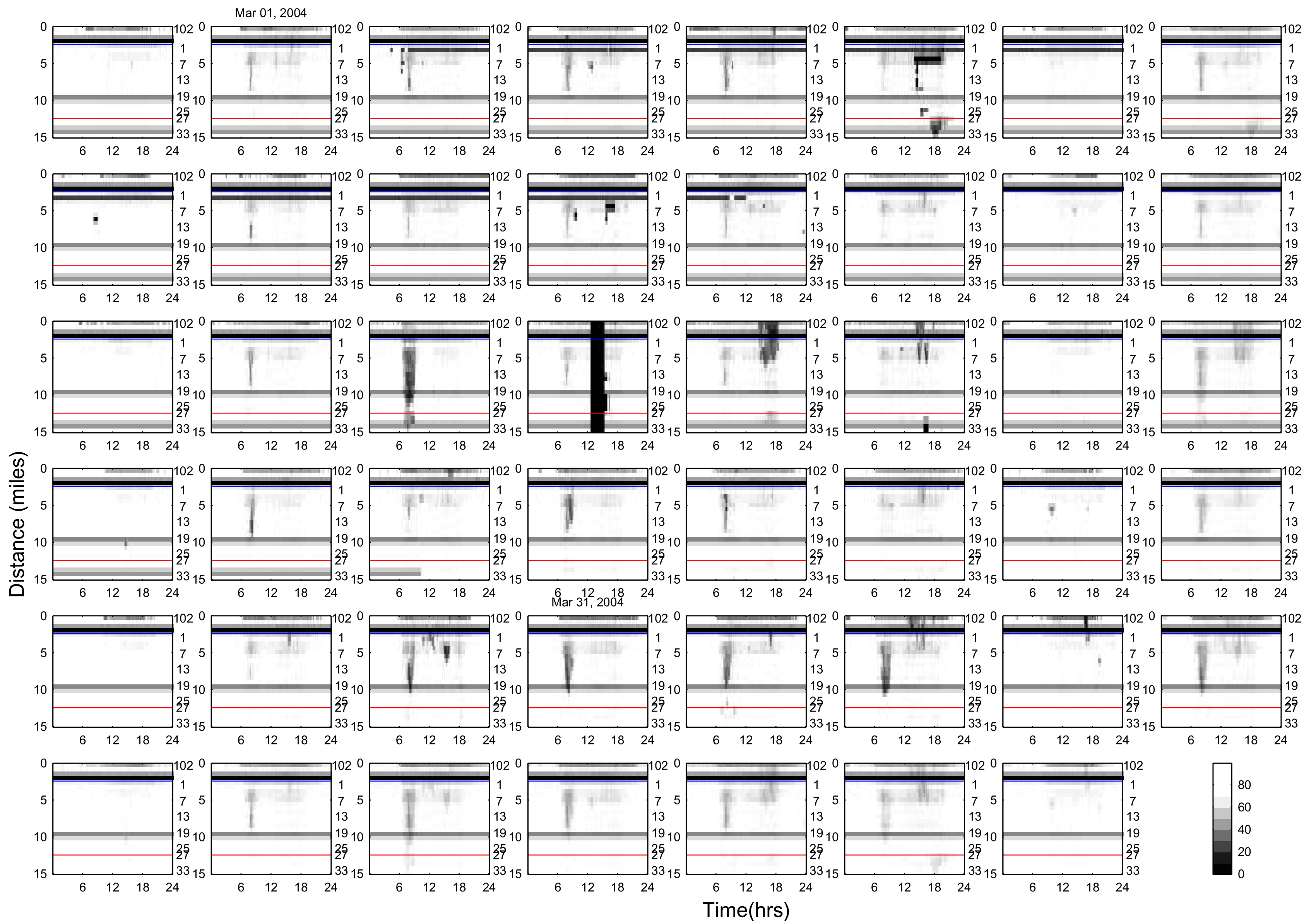


Nov 30, 2003
Dec 01, 2003
Dec 31, 2003
Distance (miles)
Time(hrs)

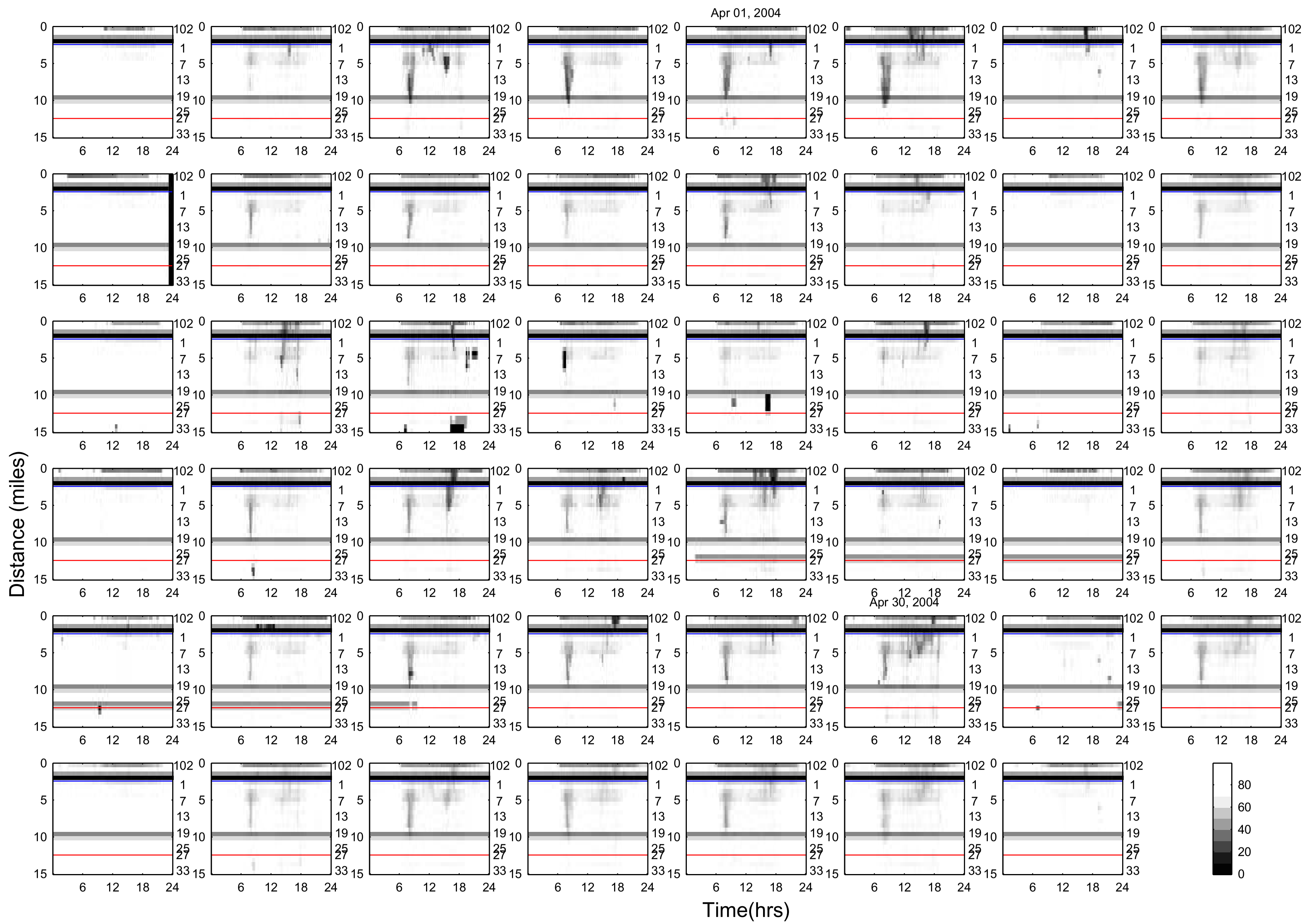


Jan 01, 2004
Jan 31, 2004
Distance (miles)
Time(hrs)

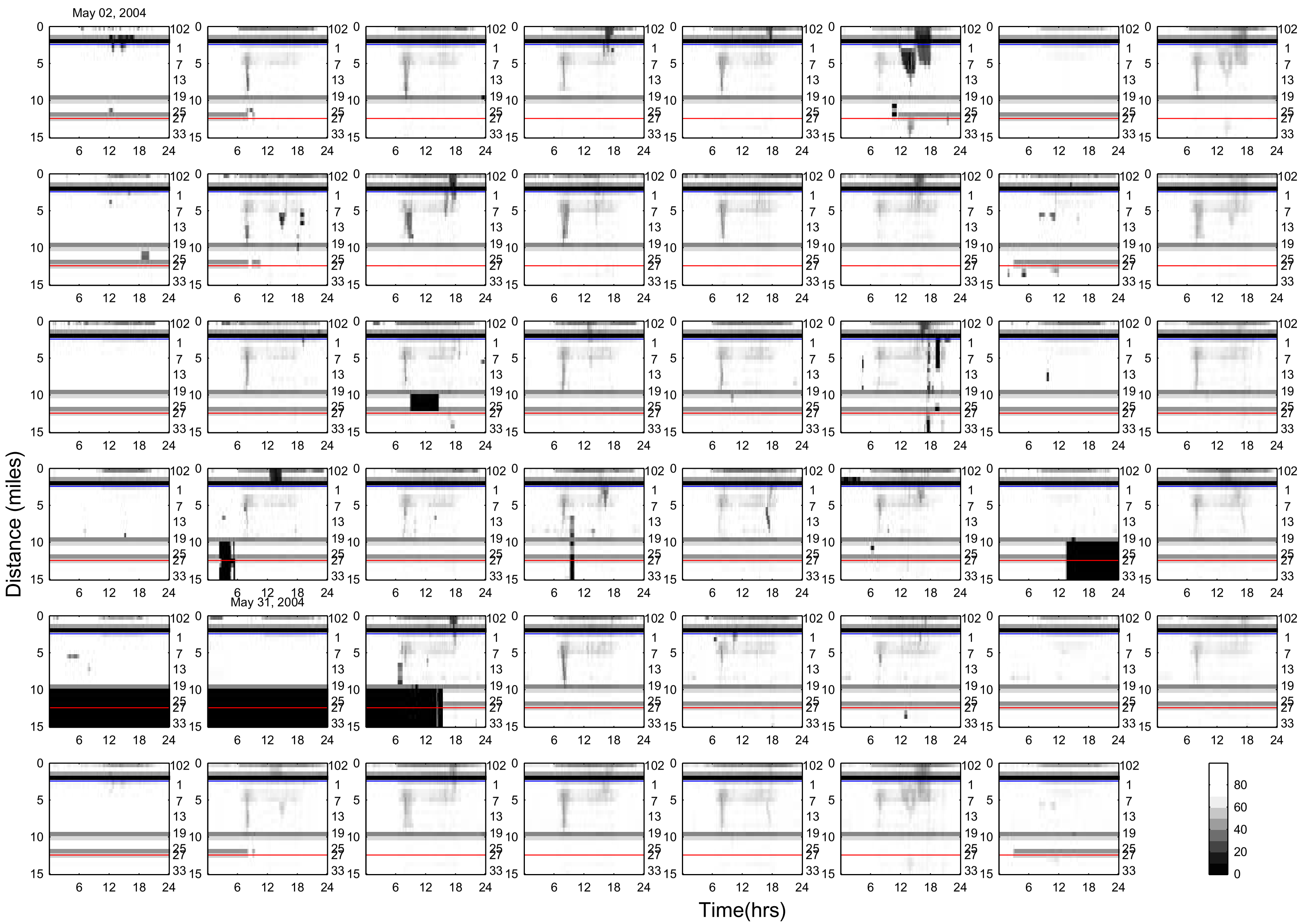

Feb 01, 2004
Feb 28, 2004
Distance (miles)
0
5
10
15
6
12
18
24
102
1
7
13
19
25
27
33
80
60
40
20
0

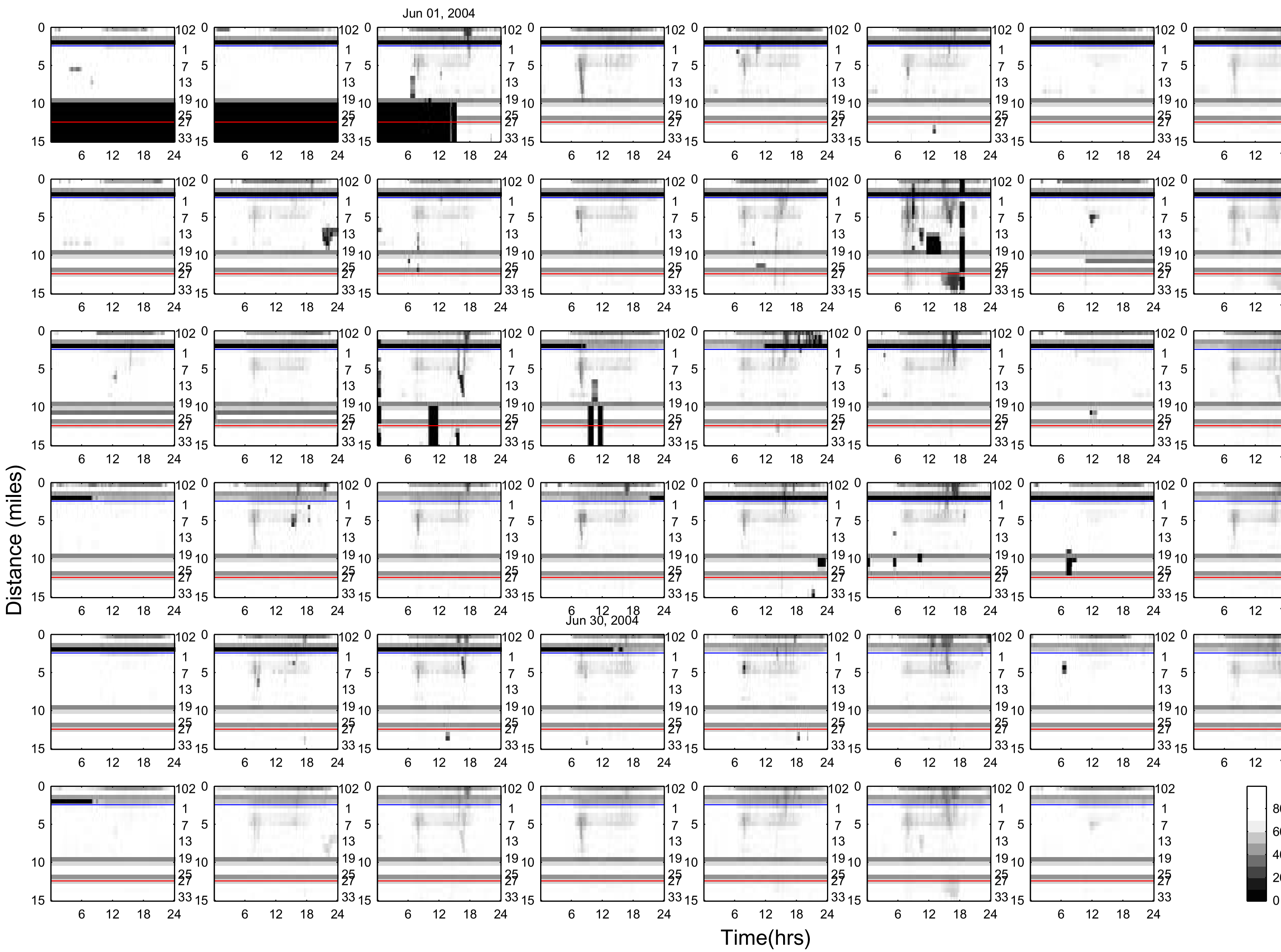


Mar 01, 2004
Mar 31, 2004
Distance (miles)
Time(hrs)
0
5
10
15
6
12
18
24
102
1
7
13
19
25
27
33
80
60
40
20
0



Apr 01, 2004
Apr 30, 2004
Distance (miles)
Time(hrs)


May 02, 2004
May 31, 2004
Distance (miles)
Time(hrs)
80
60
40
20
0



Jun 01, 2004
Jun 30, 2004
Distance (miles)
Time(hrs)
0
5
10
15
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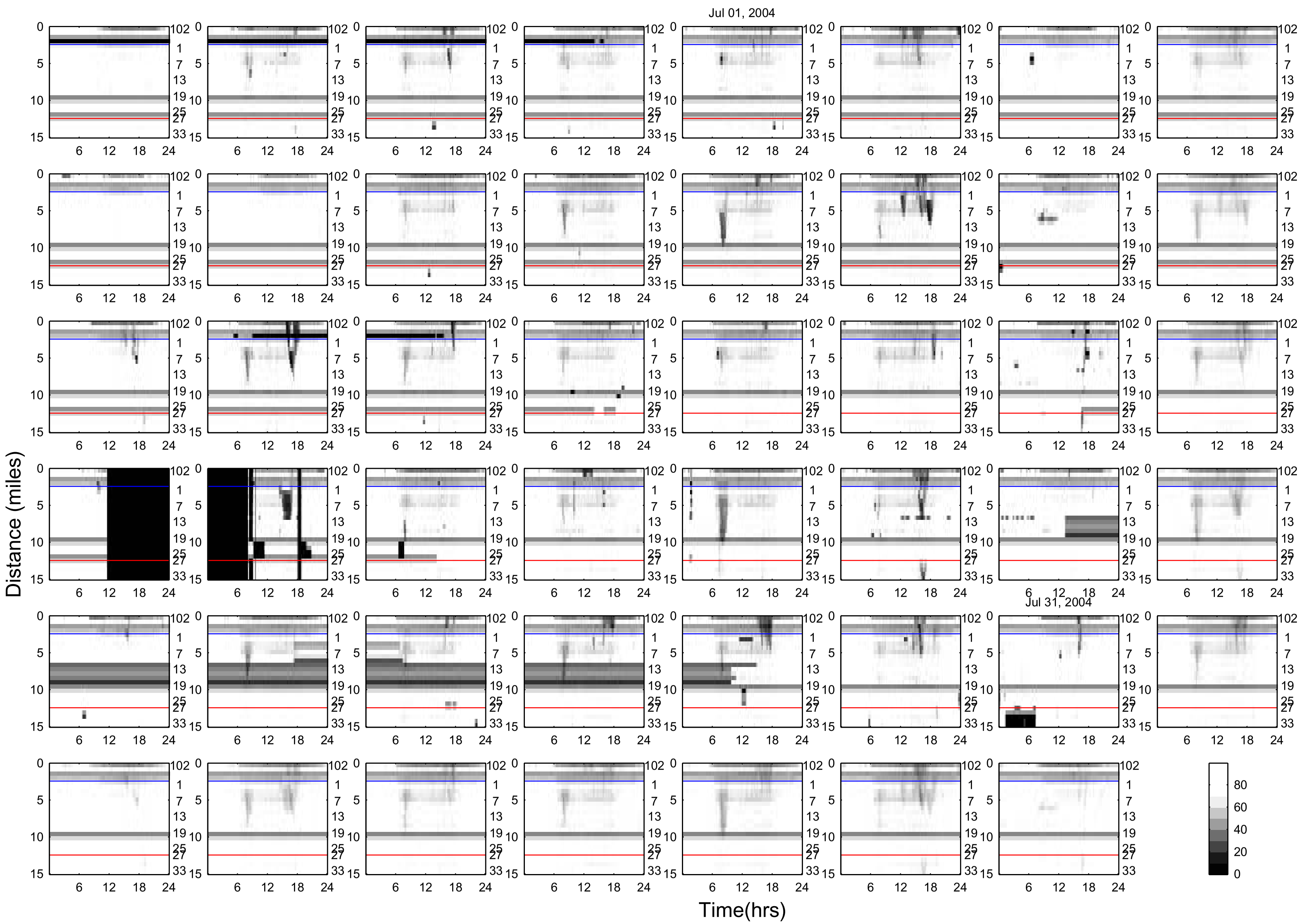
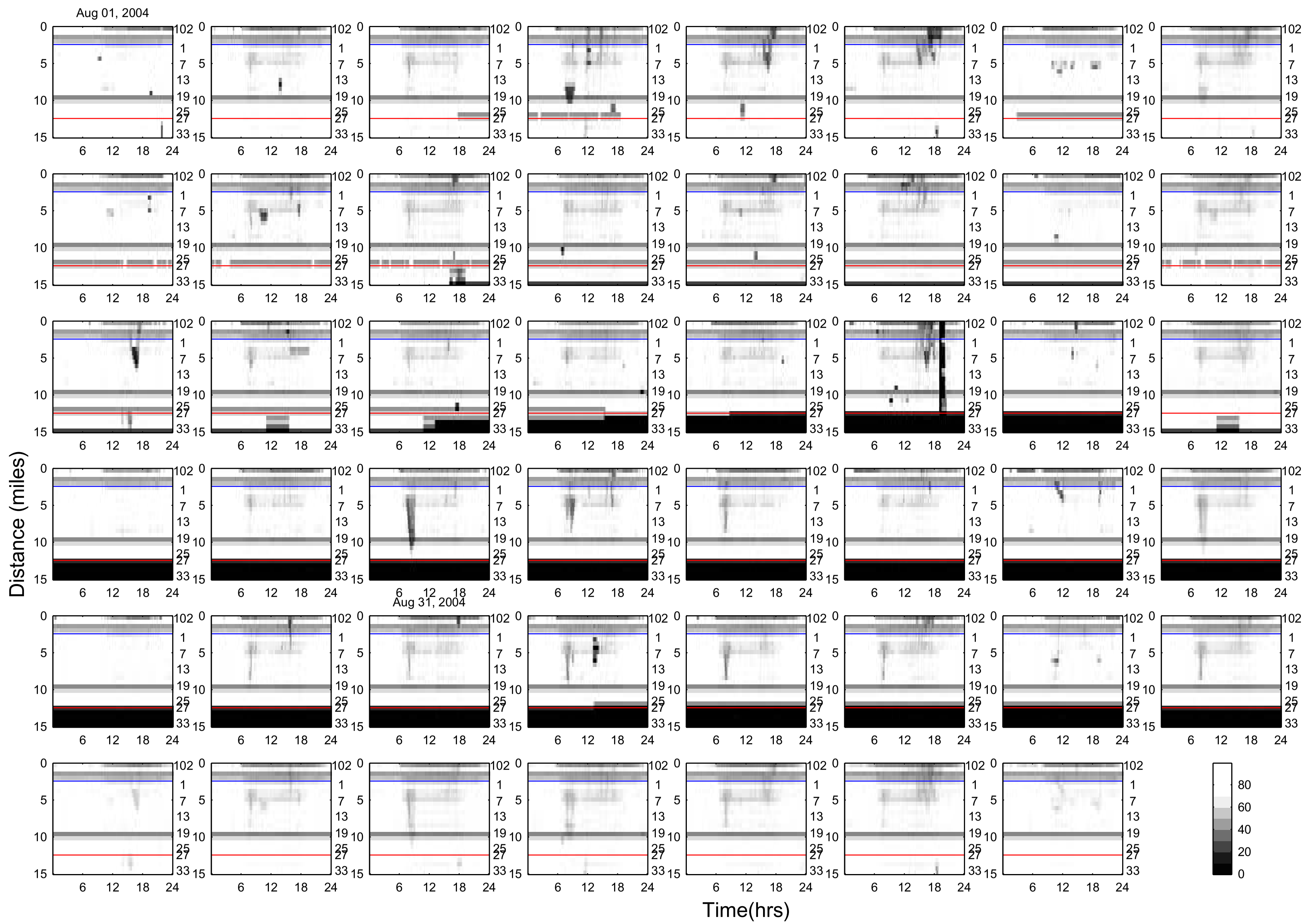
12
18
24
102
1
7
13
19
25
27
33
80
60
40
20
0



Jul 01, 2004
Jul 31, 2004
Distance (miles)
Time(hrs)


Aug 01, 2004
Aug 31, 2004
Distance (miles)
Time(hrs)
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10
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18
24
102
1
7
13
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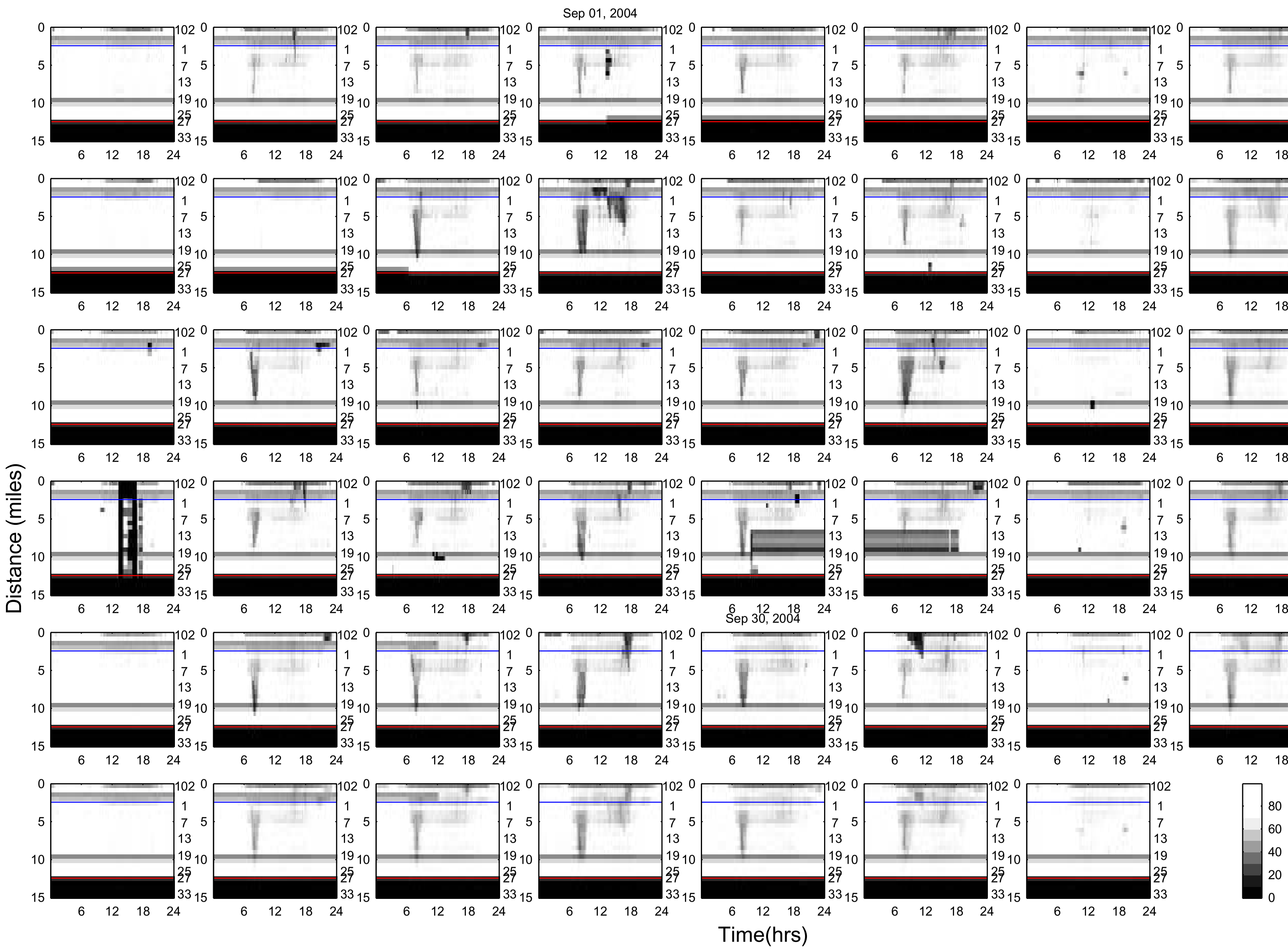
25
27
33
80
60
40
20
0


Sep 01, 2004
Sep 30, 2004
Distance (miles)
Time(hrs)
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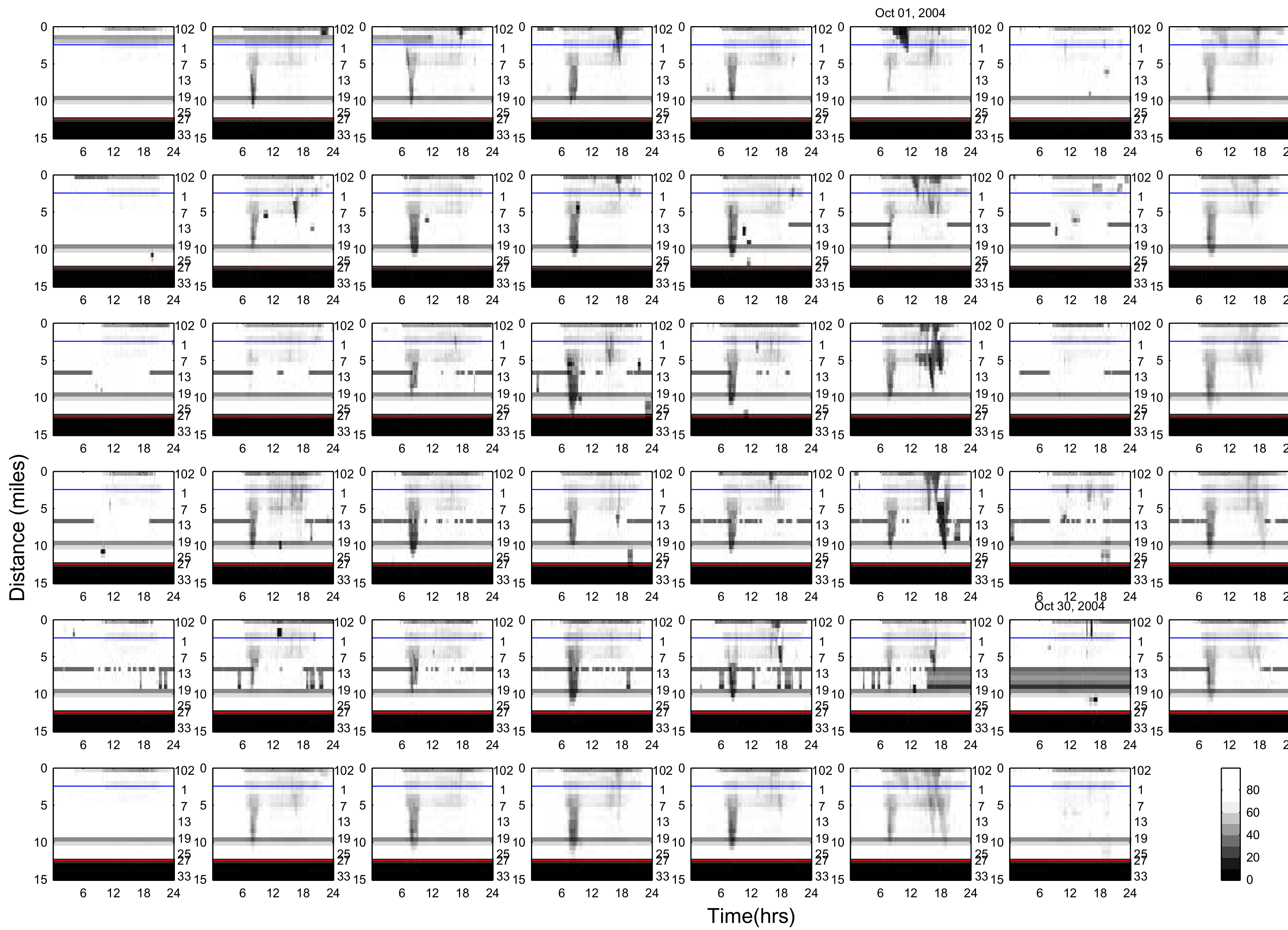
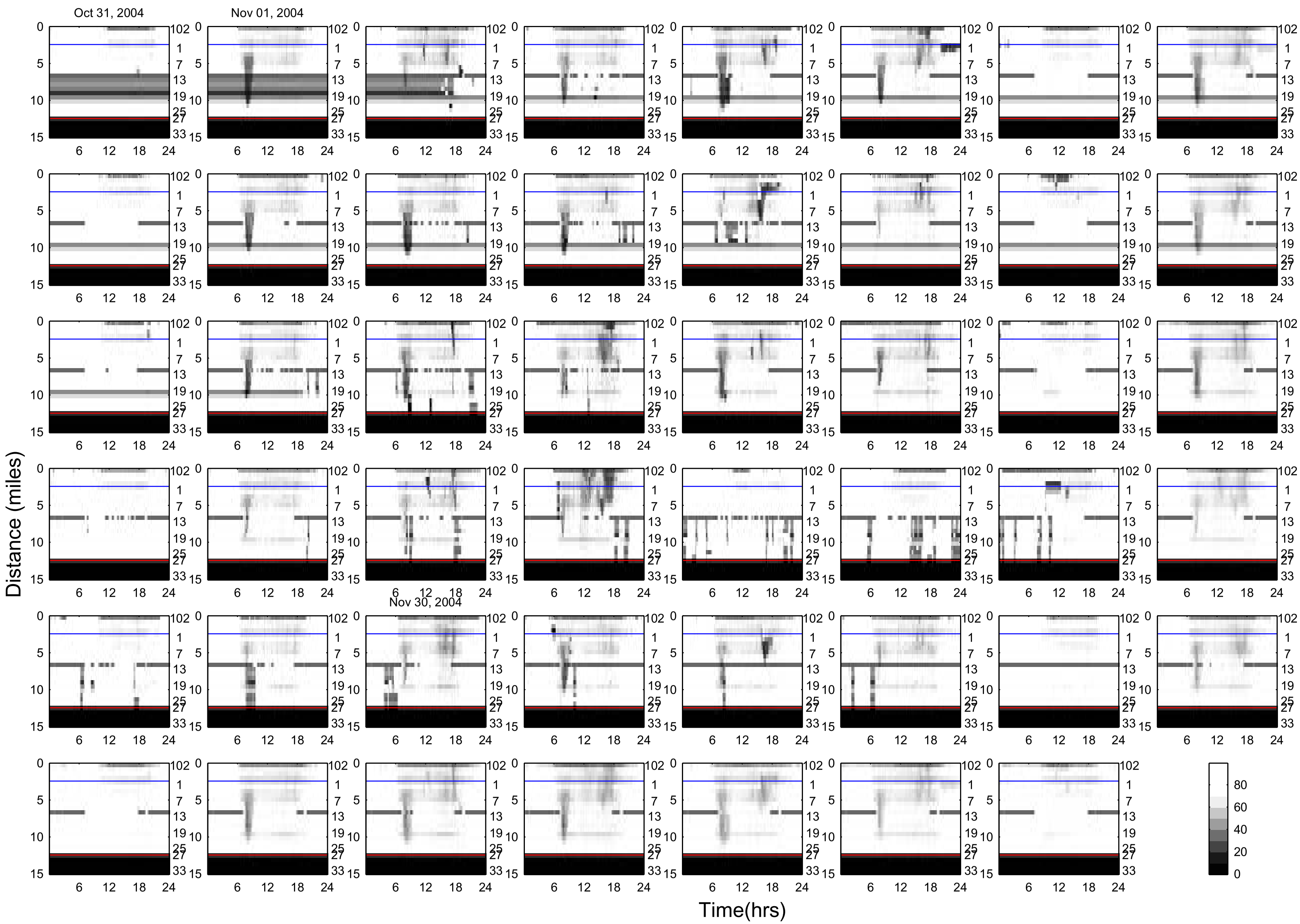
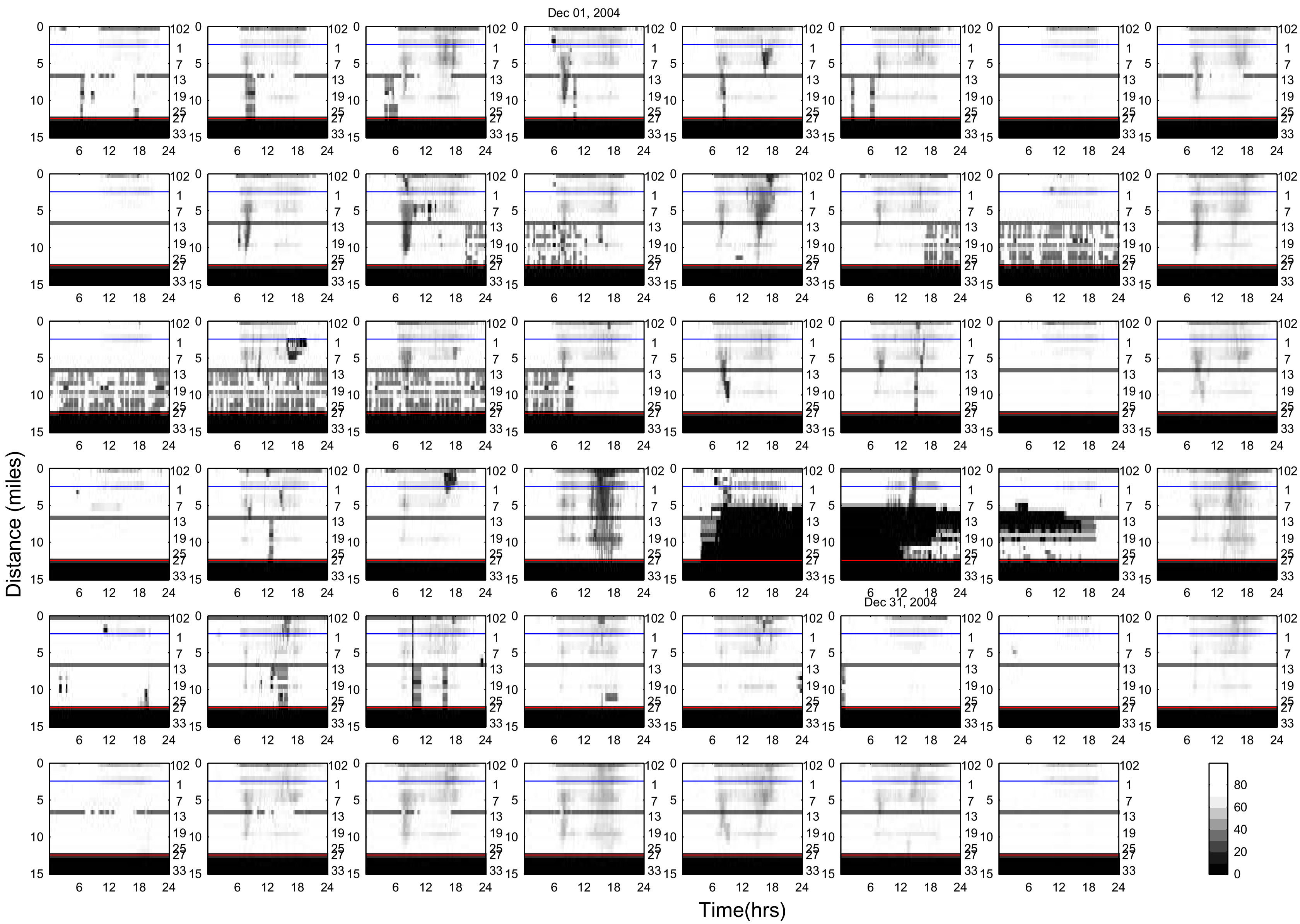
60
40
20
0



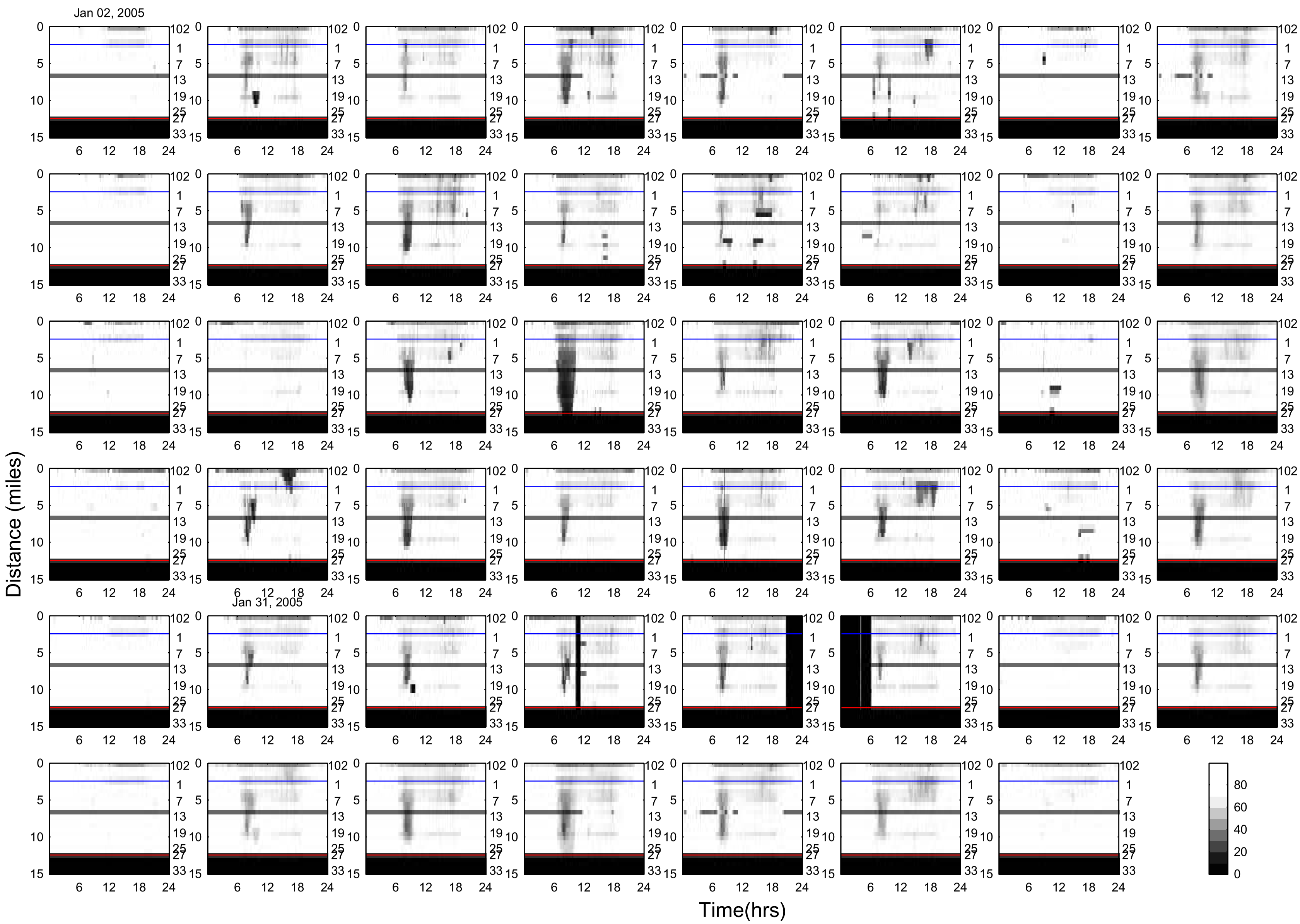
Oct 01, 2004
Oct 30, 2004
Distance (miles)
Time(hrs)



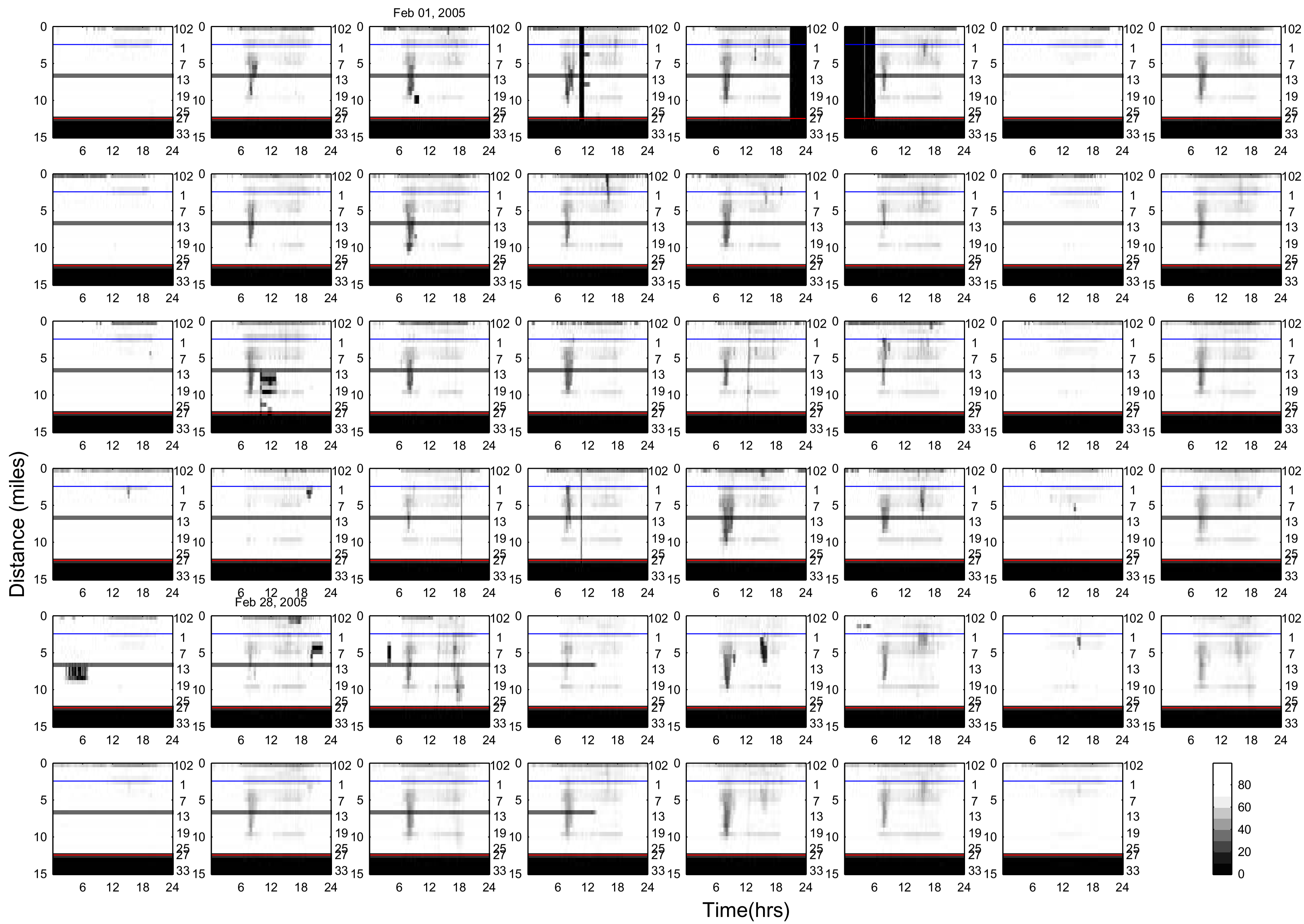
Oct 31, 2004
Nov 01, 2004
Nov 30, 2004
Distance (miles)
Time(hrs)



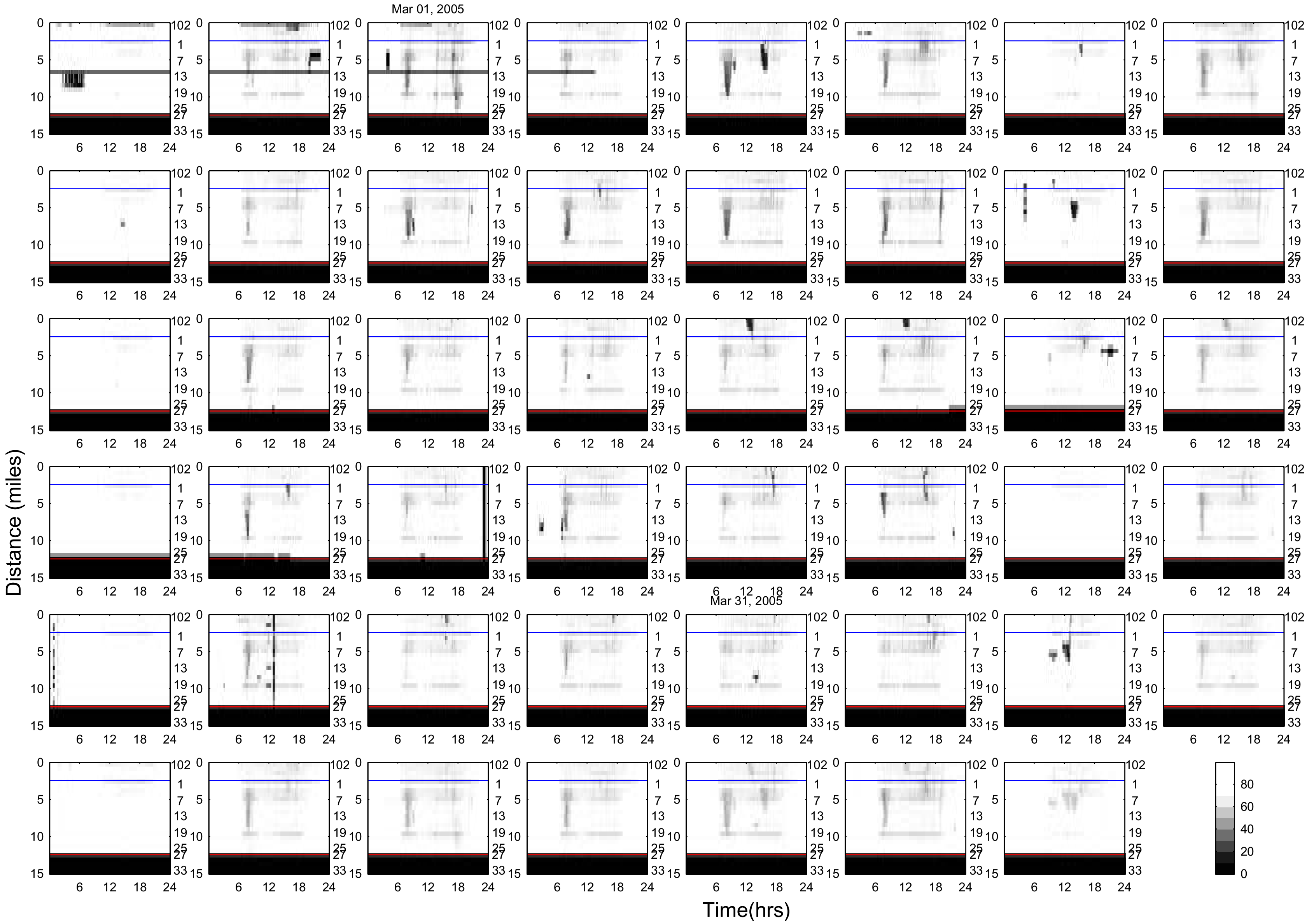
Dec 01, 2004
Dec 31, 2004
Distance (miles)
Time(hrs)
80
60
40
20
0



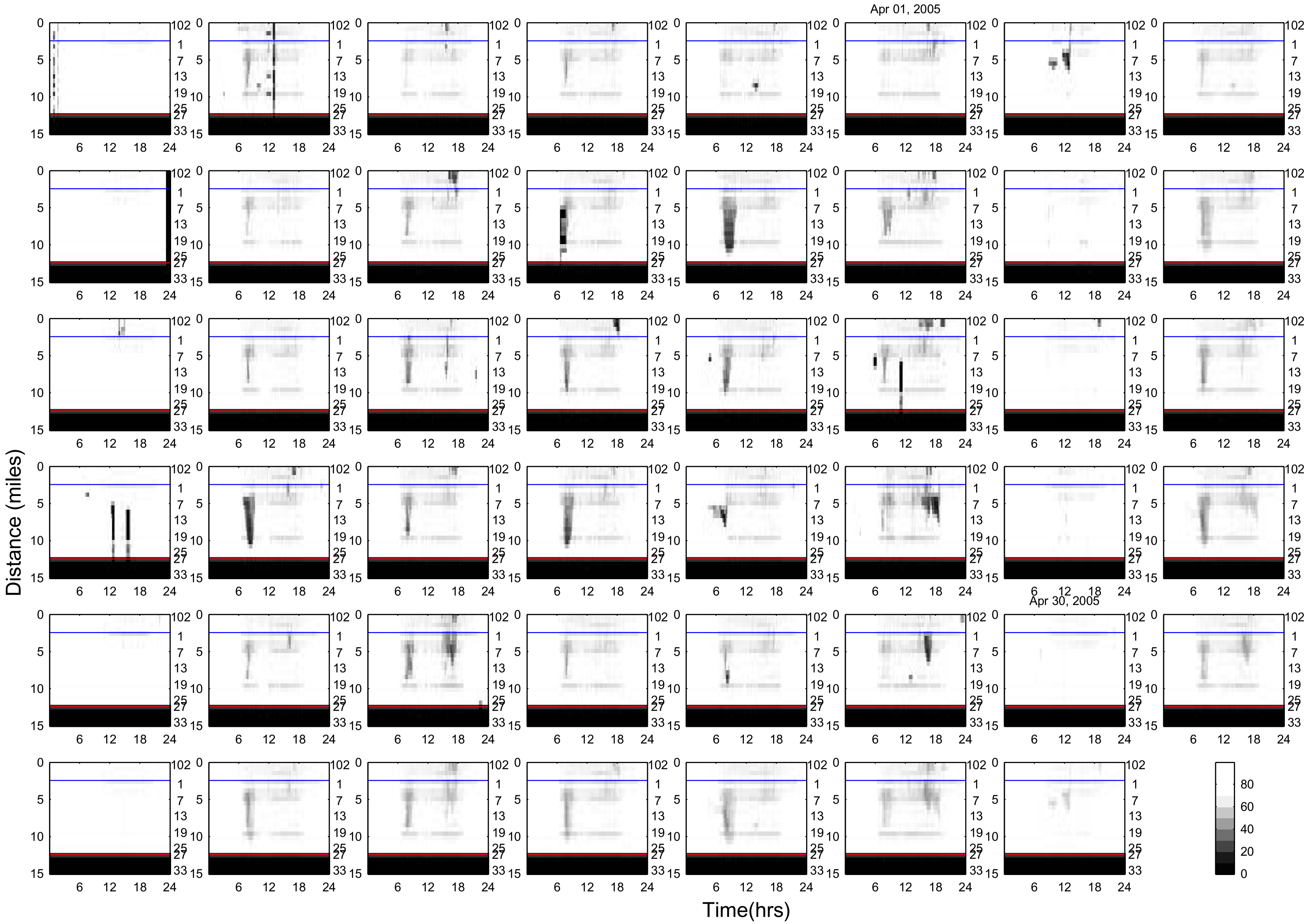
Jan 02, 2005
Jan 31, 2005
Distance (miles)
Time(hrs)

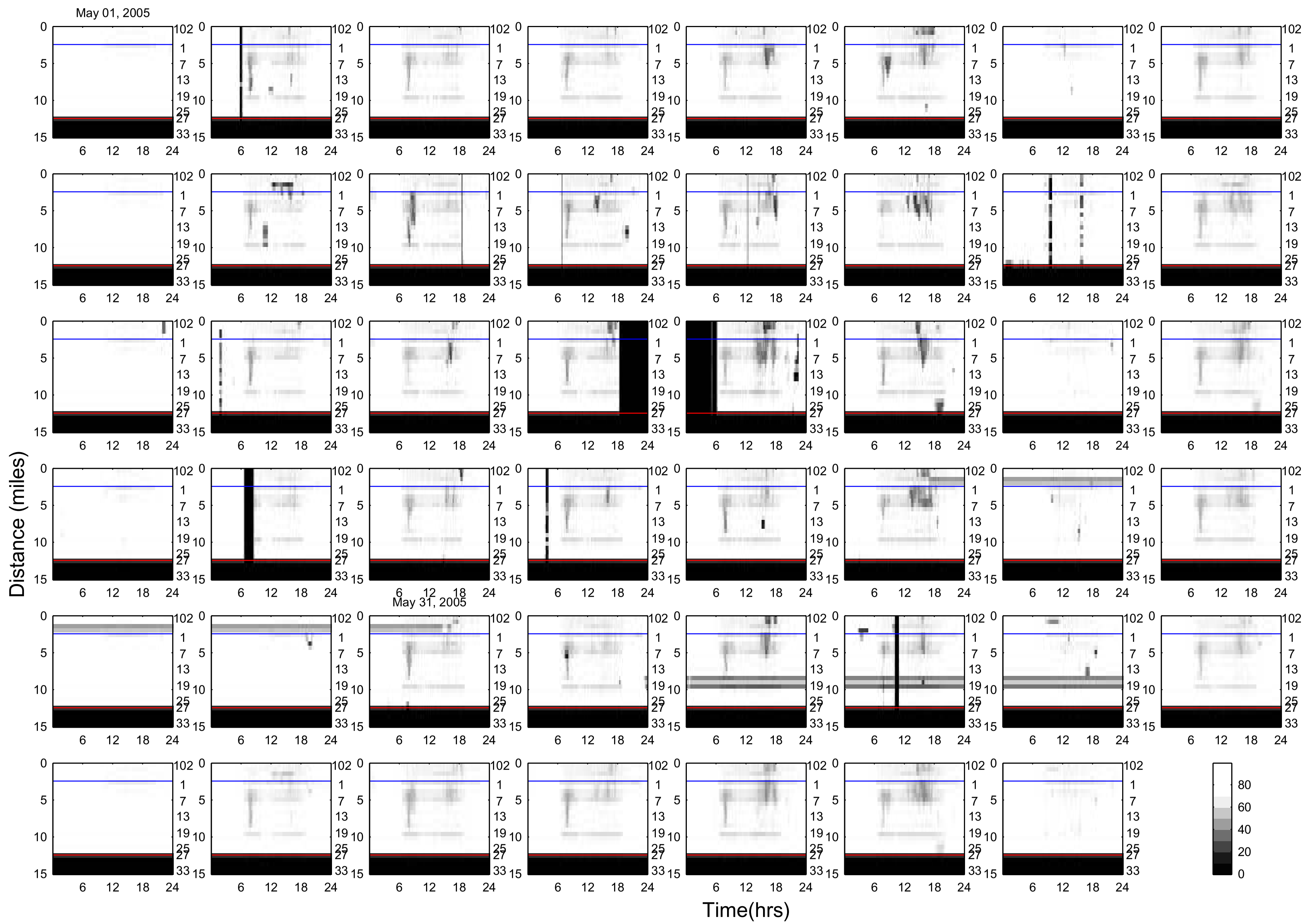


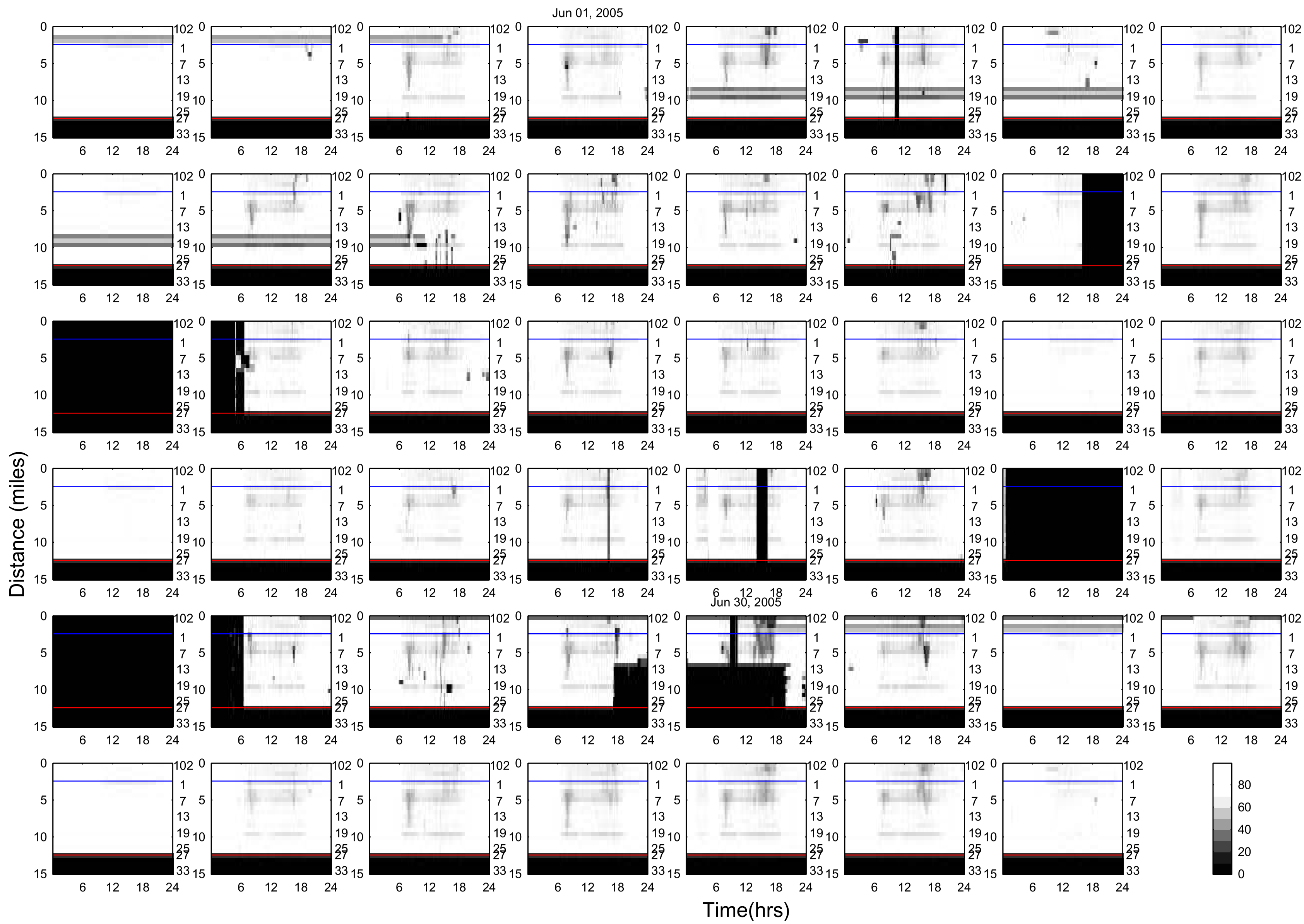
Feb 01, 2005
Feb 28, 2005
Distance (miles)
Time(hrs)



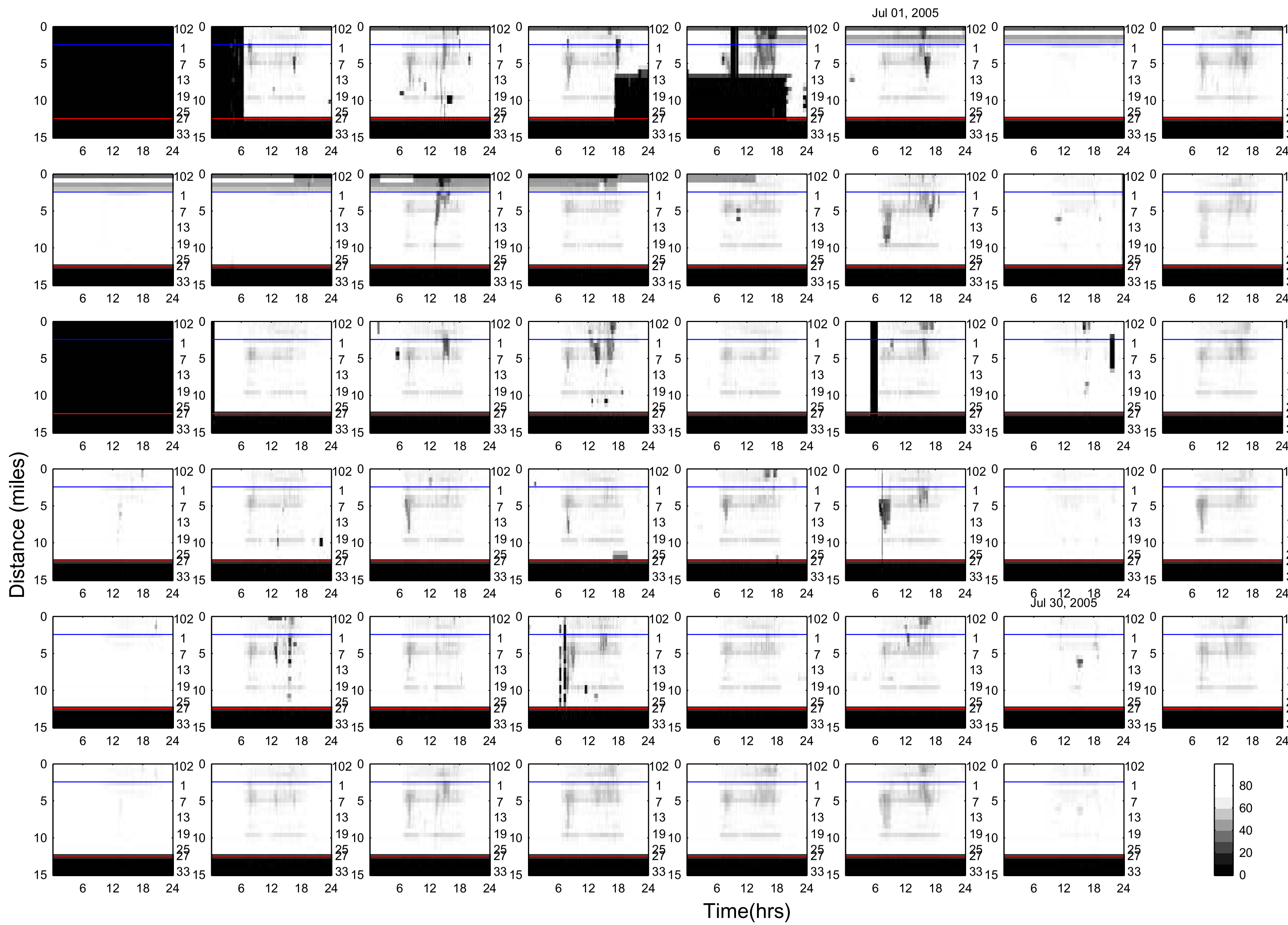
Mar 01, 2005
Mar 31, 2005
Distance (miles)
Time(hrs)

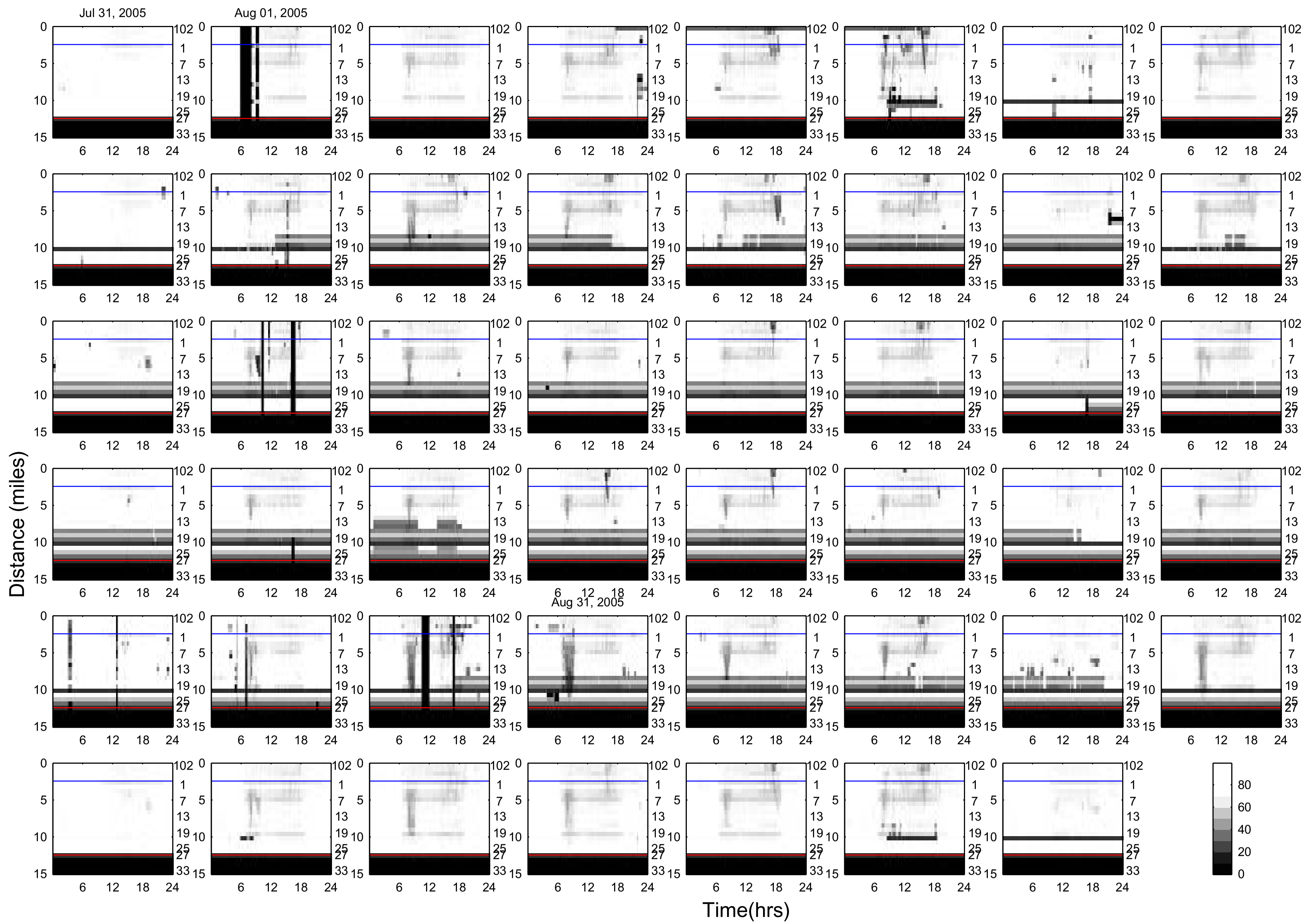

Apr 01, 2005
Apr 30, 2005
Distance (miles)
Time(hrs)


May 01, 2005
May 31, 2005
Distance (miles)
Time(hrs)
80
60
40
20
0

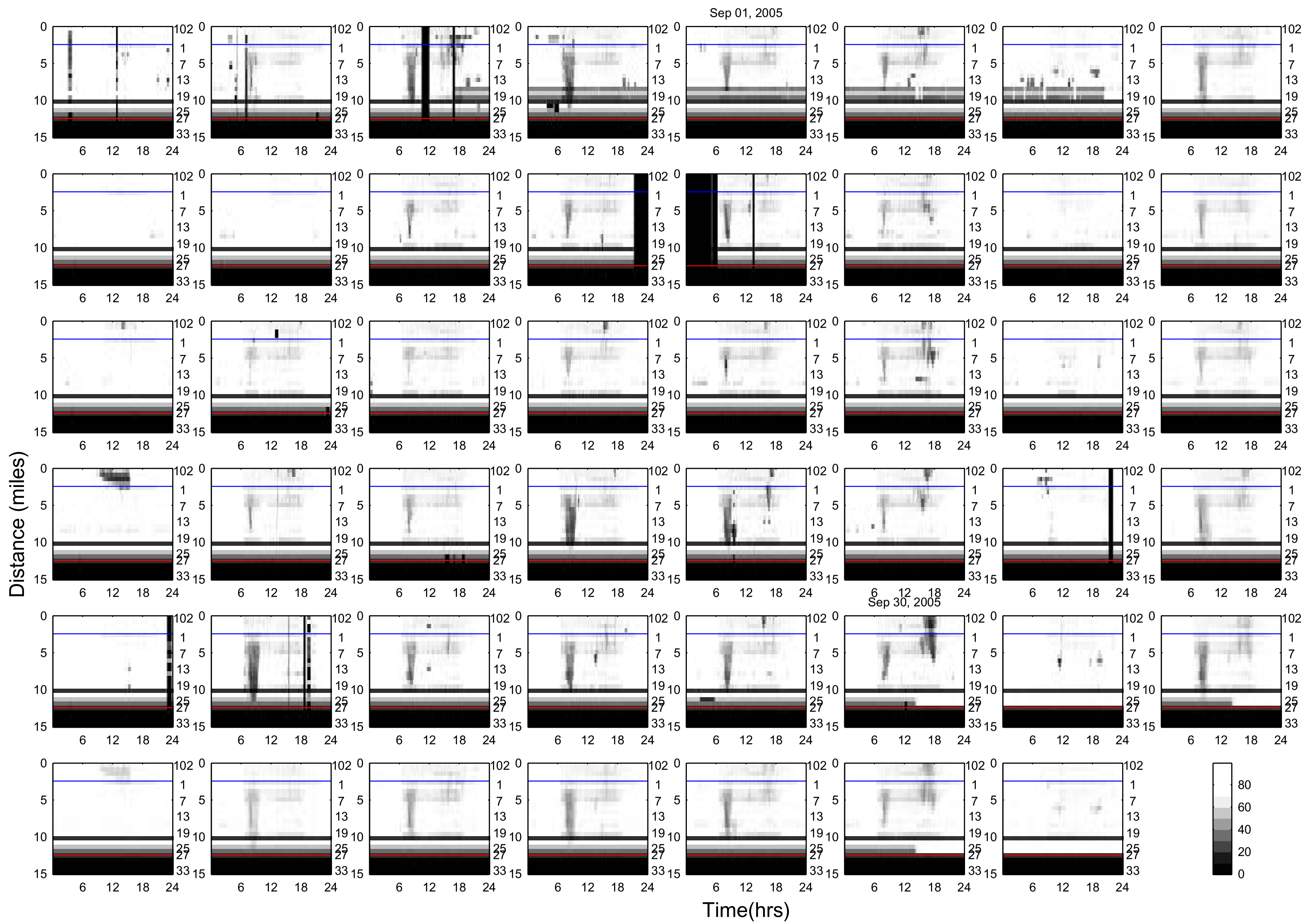


Jun 01, 2005
Jun 30, 2005
Distance (miles)
Time(hrs)


Jul 01, 2005
Jul 30, 2005
Distance (miles)
Time(hrs)



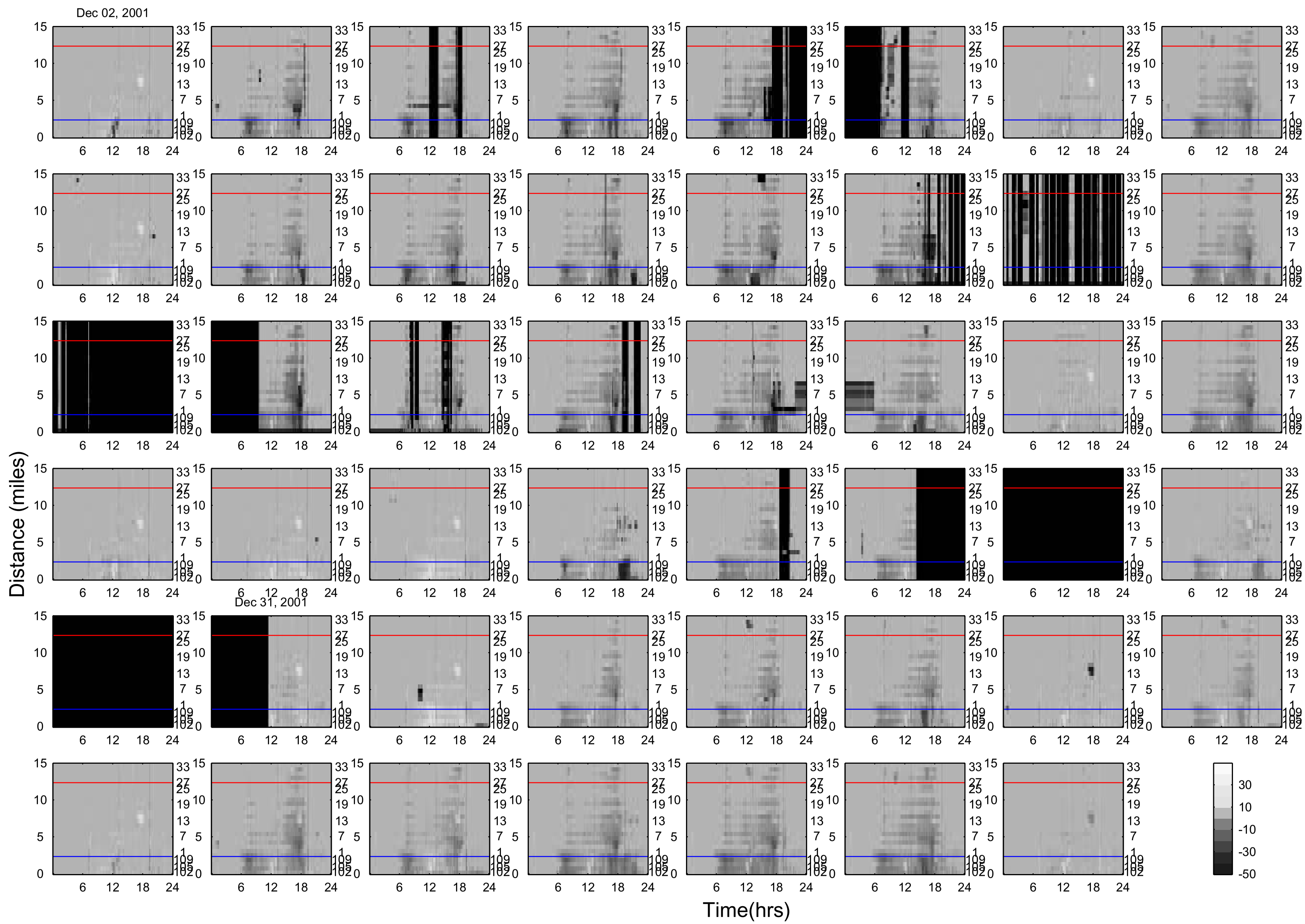
Jul 31, 2005
Aug 01, 2005
Aug 31, 2005
Distance (miles)
Time(hrs)



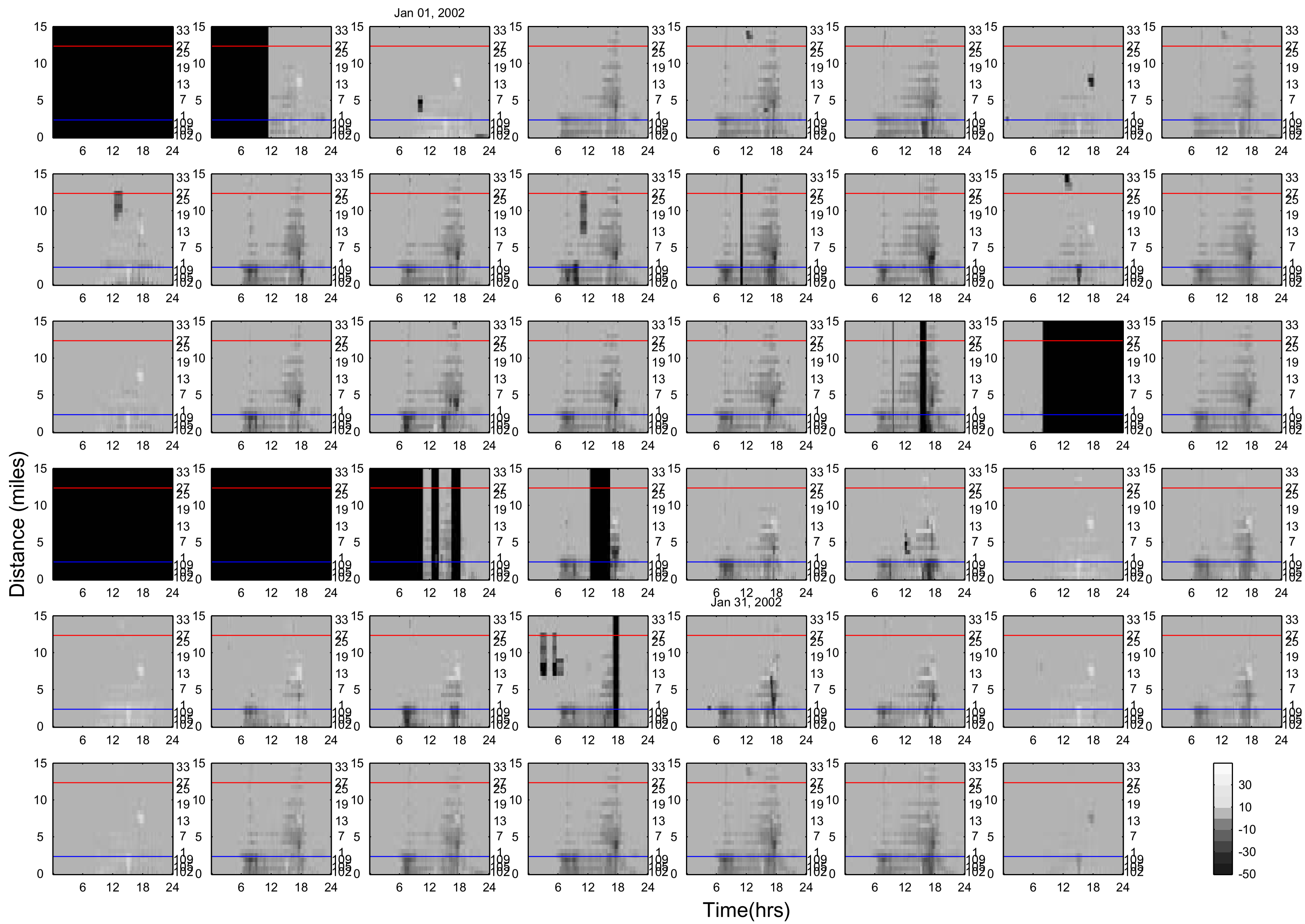
Sep 01, 2005
Sep 30, 2005
Distance (miles)
Time(hrs)

APPENDIX E: SUMMARY DIFFERENCE PLOTS

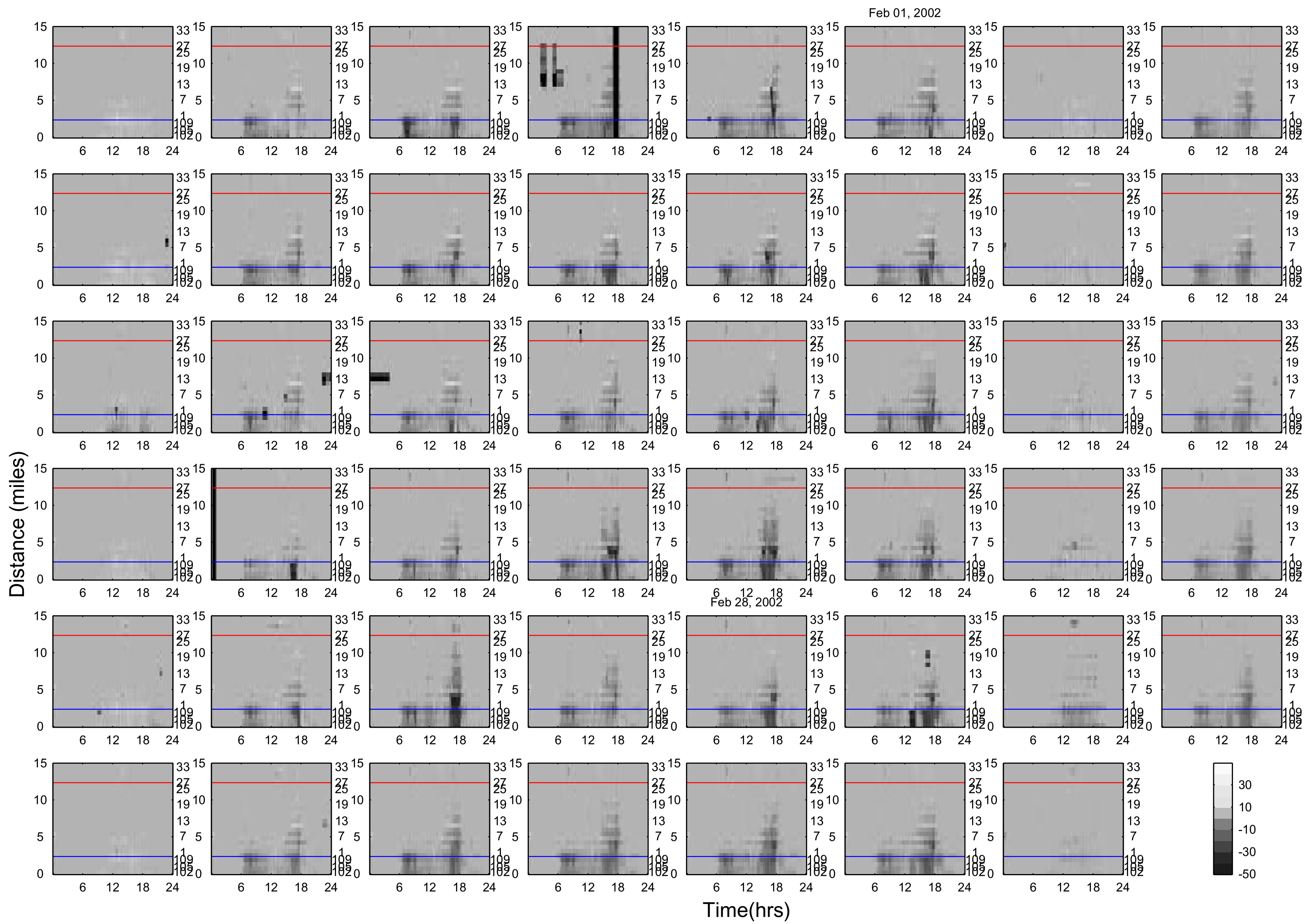
NORTHBOUND

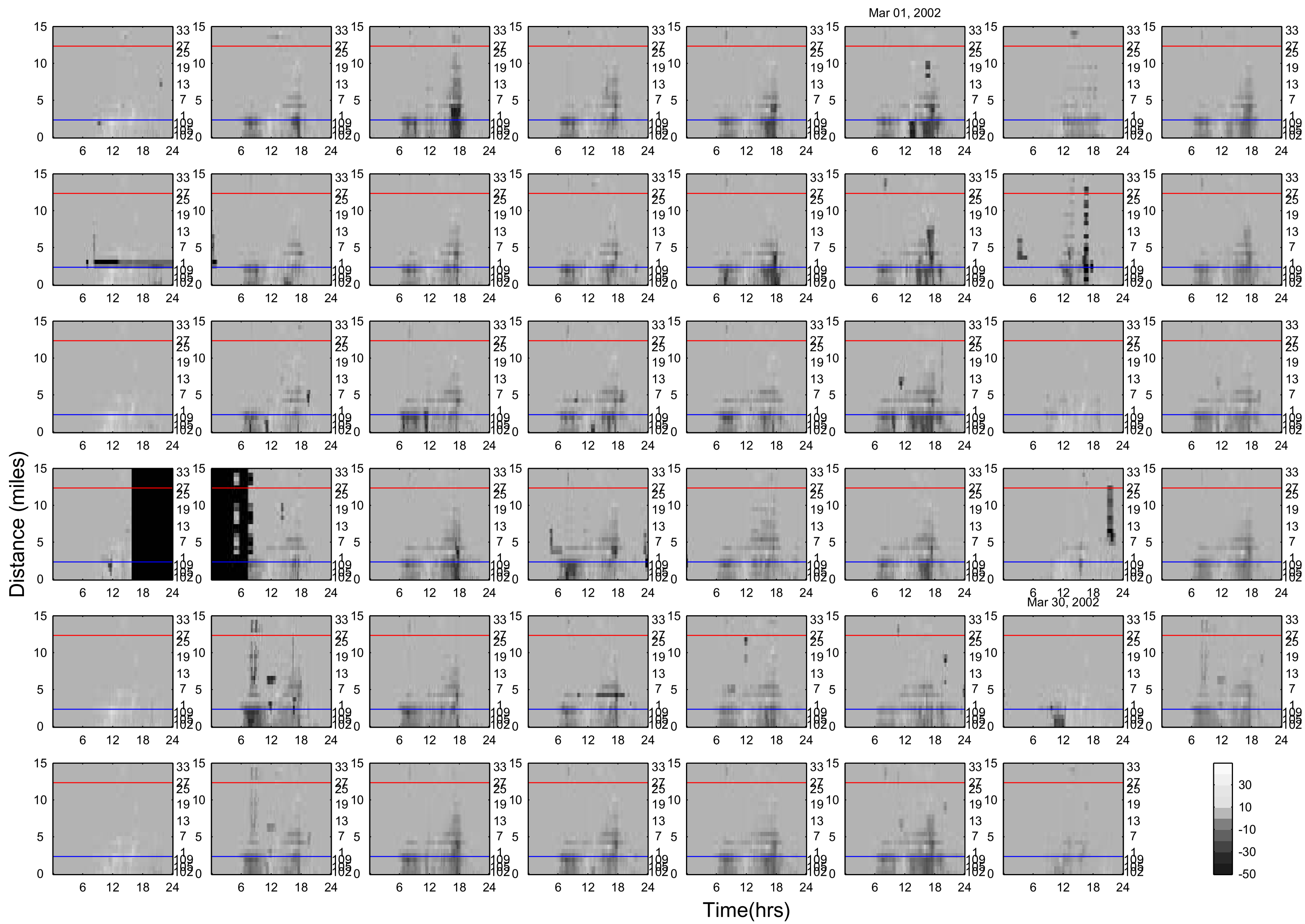


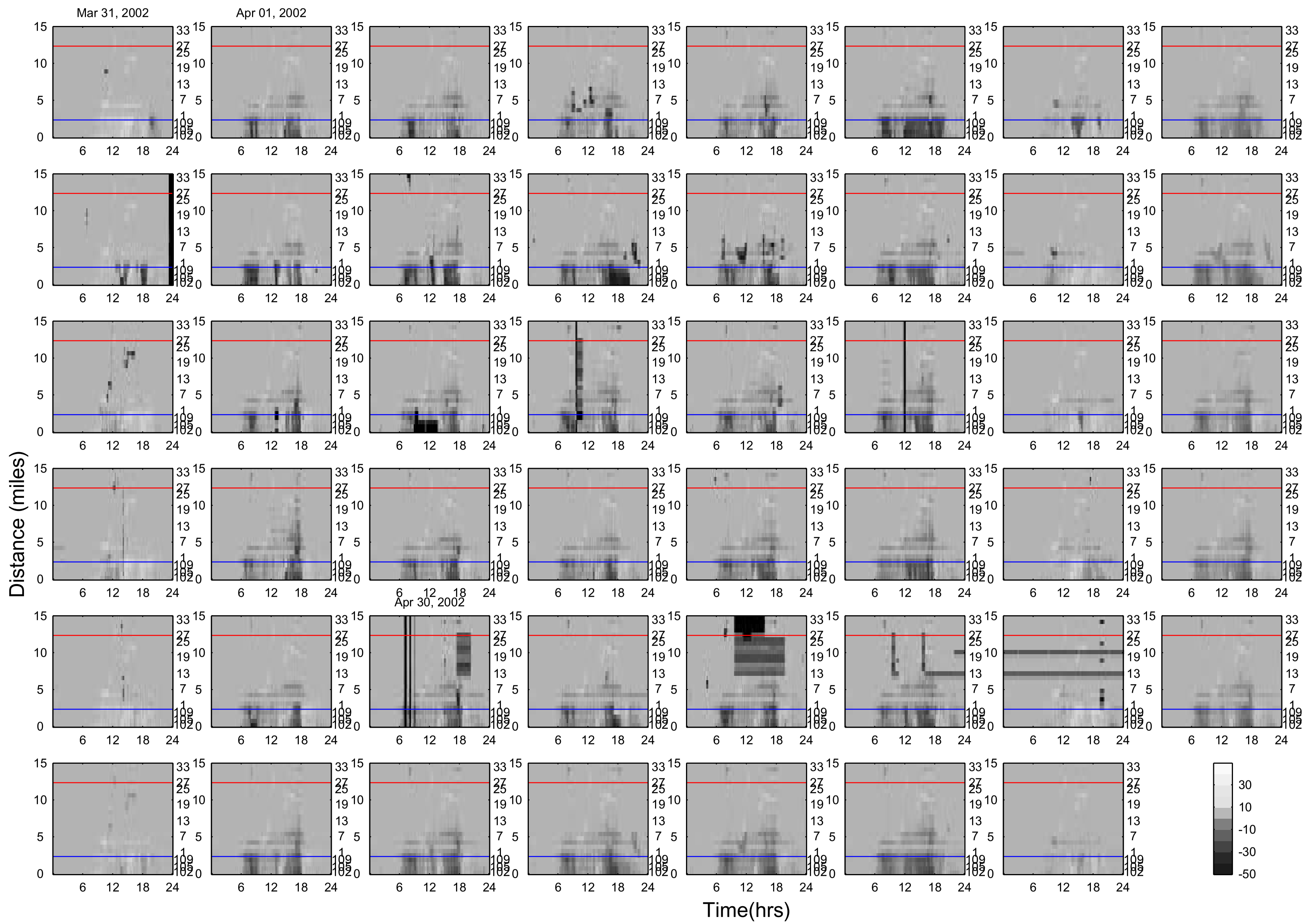
Dec 02, 2001
Dec 31, 2001
Distance (miles)
Time(hrs)
30
10
-10
-30
-50



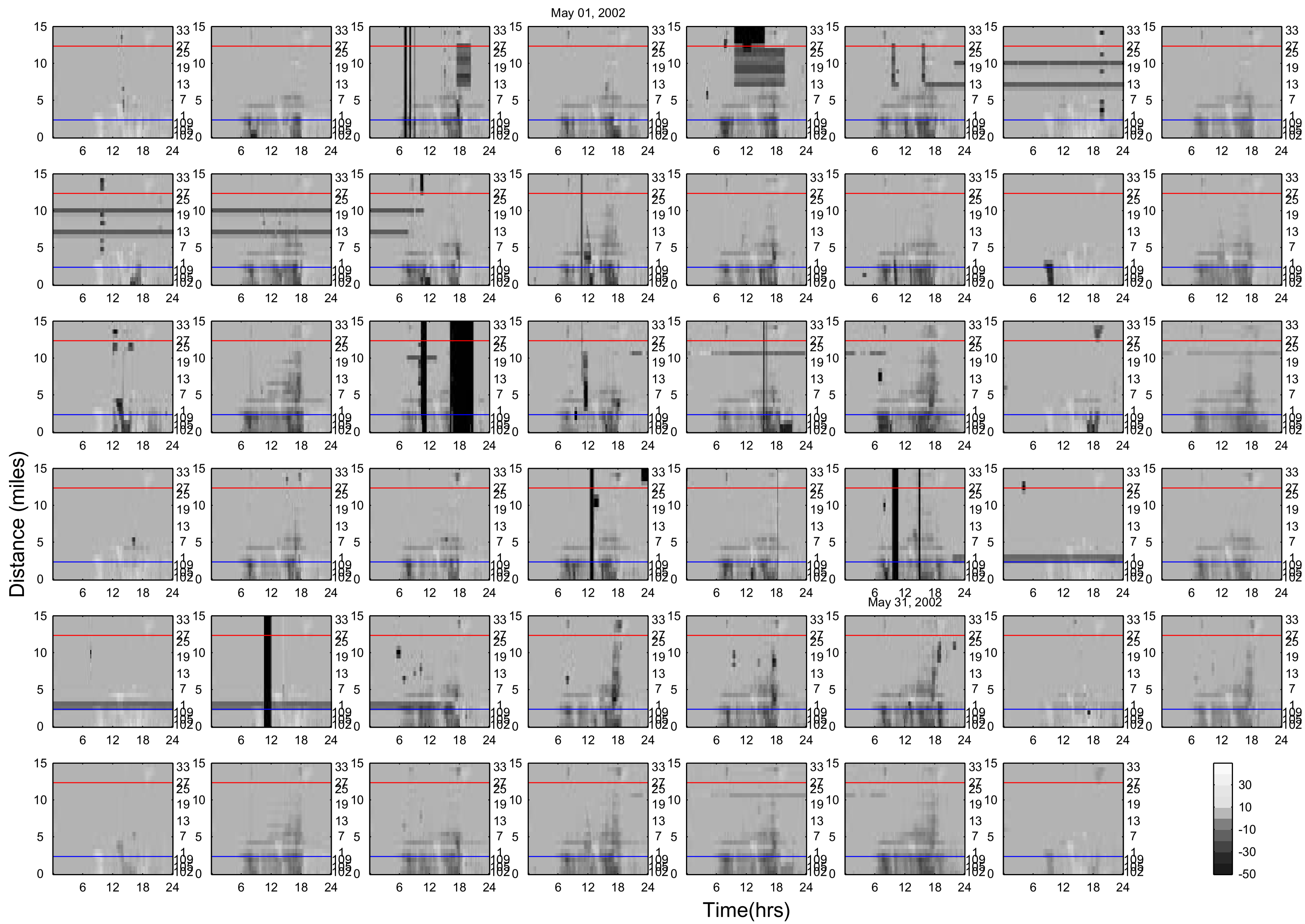
Jan 01, 2002
Jan 31, 2002
Distance (miles)
Time(hrs)

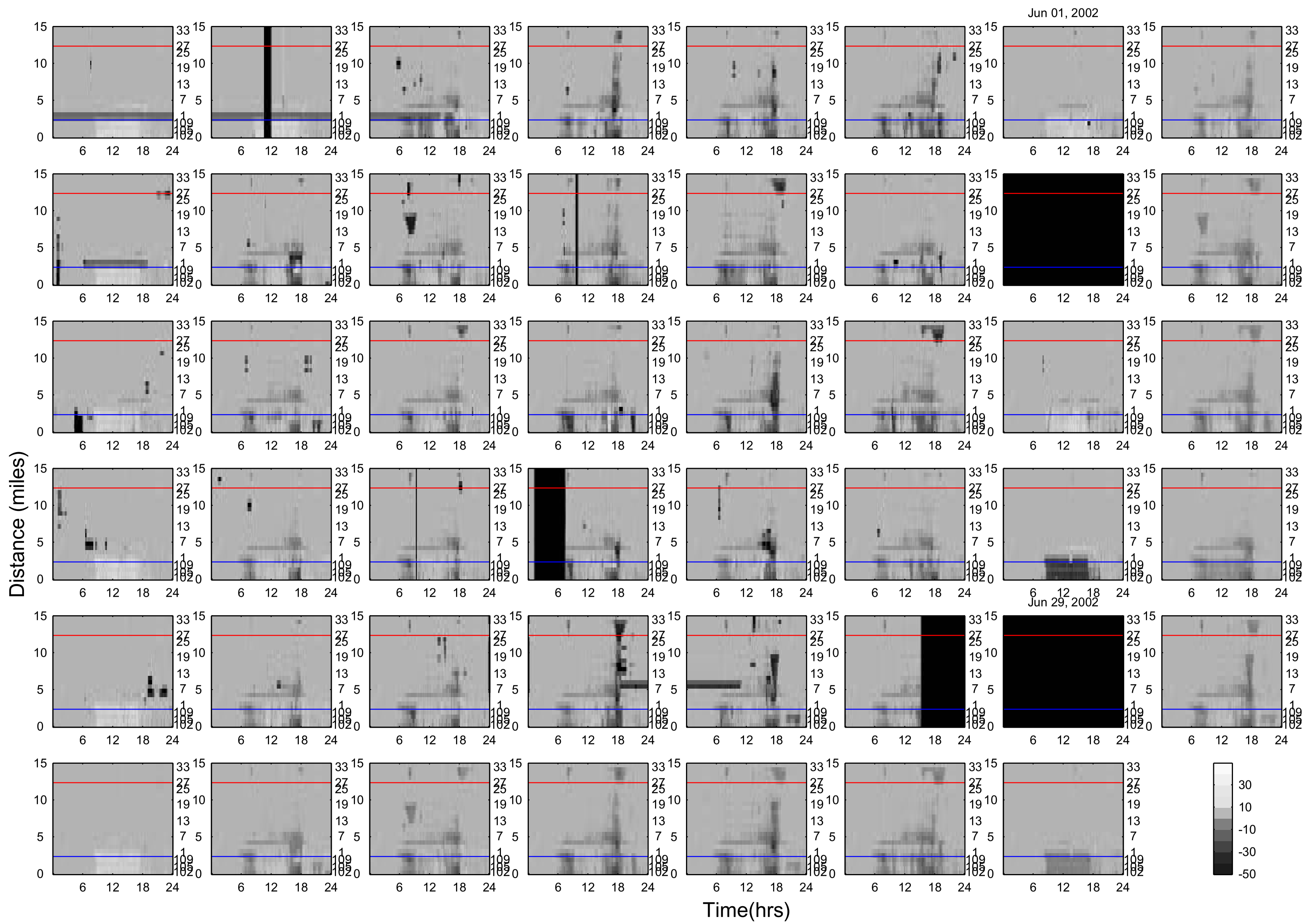

Feb 01, 2002
Feb 28, 2002
Distance (miles)
Time(hrs)

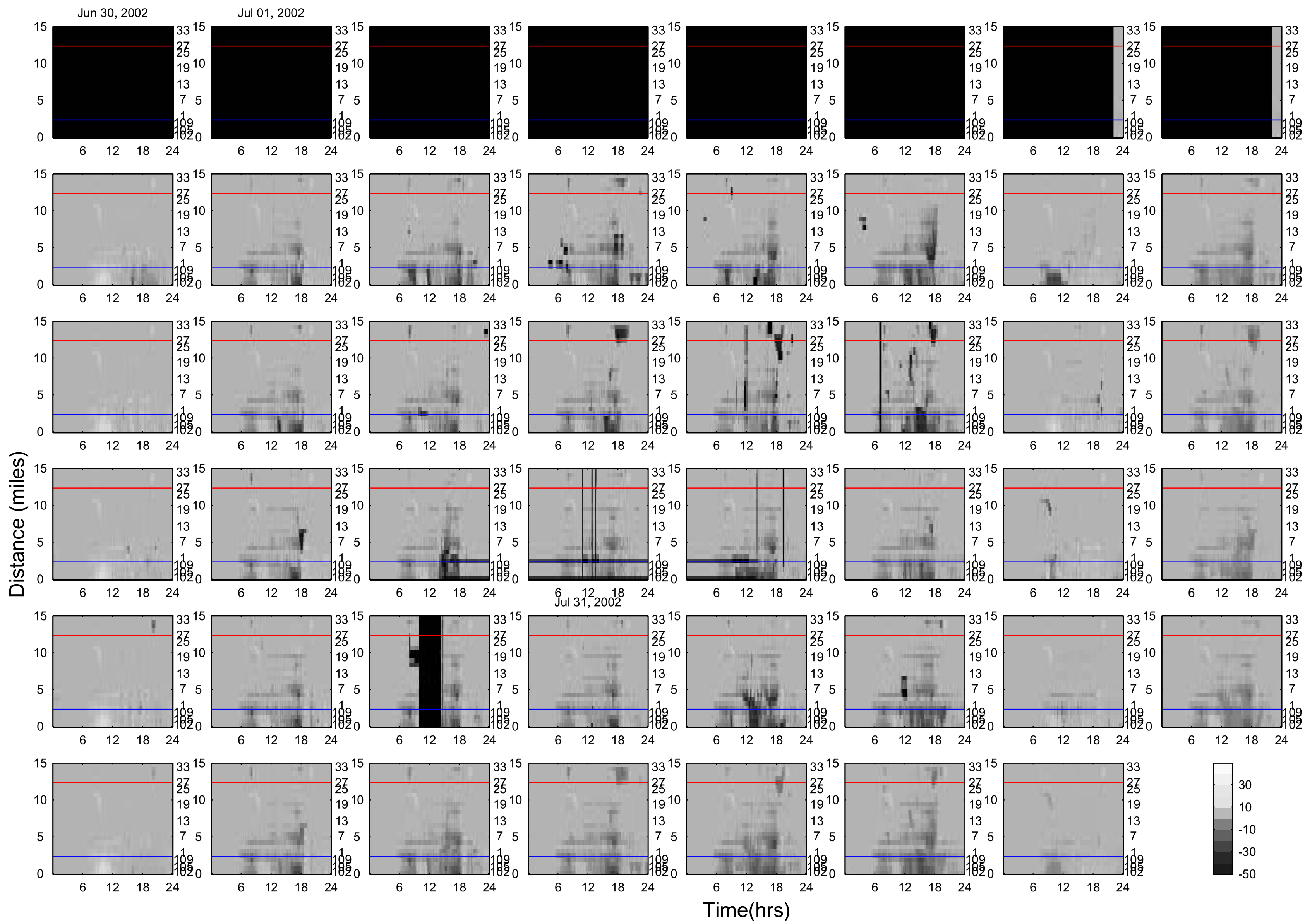

Mar 01, 2002
Mar 30, 2002
Distance (miles)
Time(hrs)
30
10
-10
-30
-50



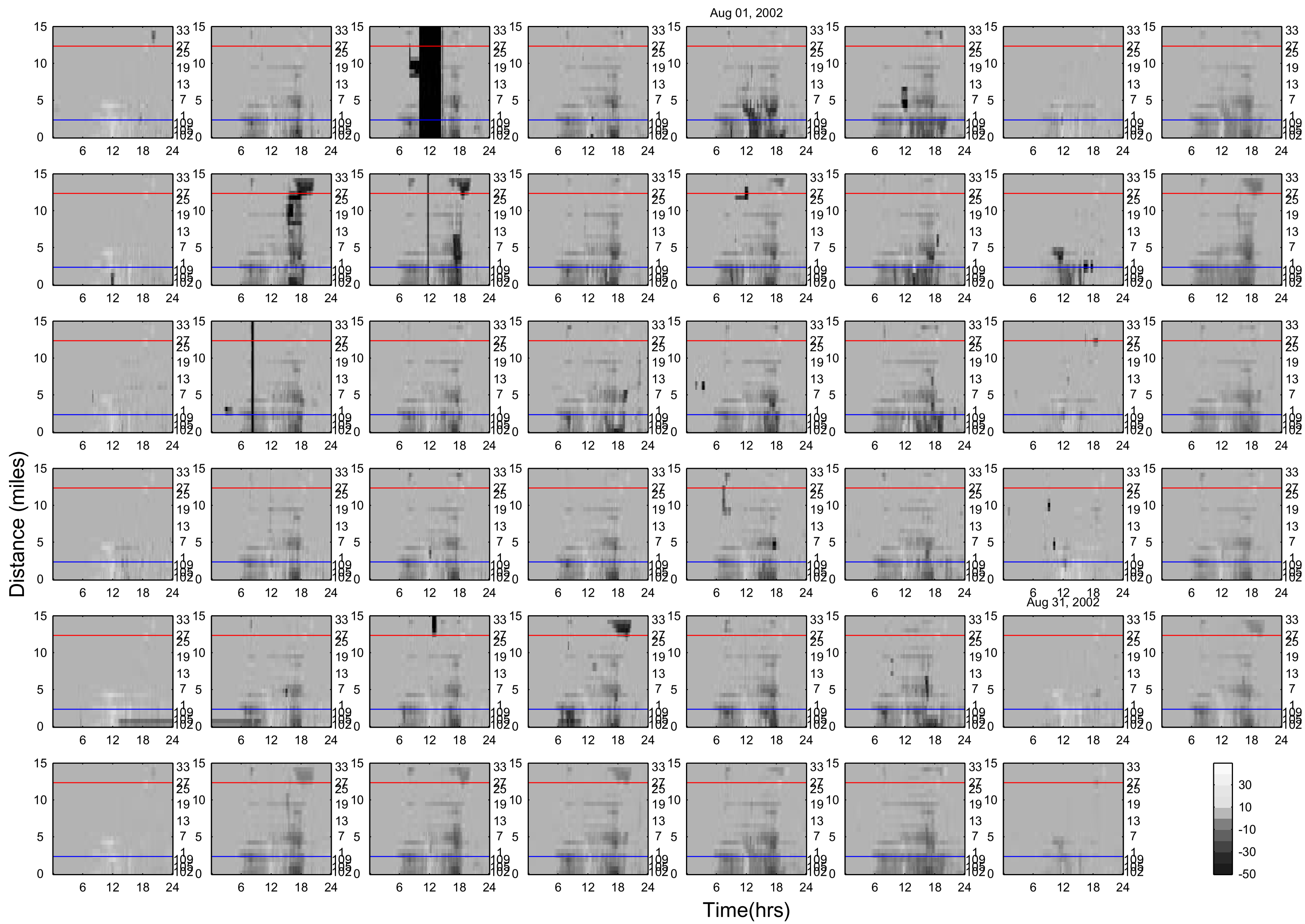
Mar 31, 2002
Apr 01, 2002
Apr 30, 2002
Distance (miles)
Time(hrs)
30
10
-10
-30
-50


May 01, 2002
May 31, 2002
Distance (miles)
Time(hrs)
30
10
-10
-30
-50


Jun 01, 2002
Jun 29, 2002
Distance (miles)
Time(hrs)
30
10
-10
-30
-50



Jun 30, 2002
Jul 01, 2002
Jul 31, 2002
Distance (miles)
Time(hrs)
30
10
-10
-30
-50



Aug 01, 2002
Aug 31, 2002
Distance (miles)
Time(hrs)
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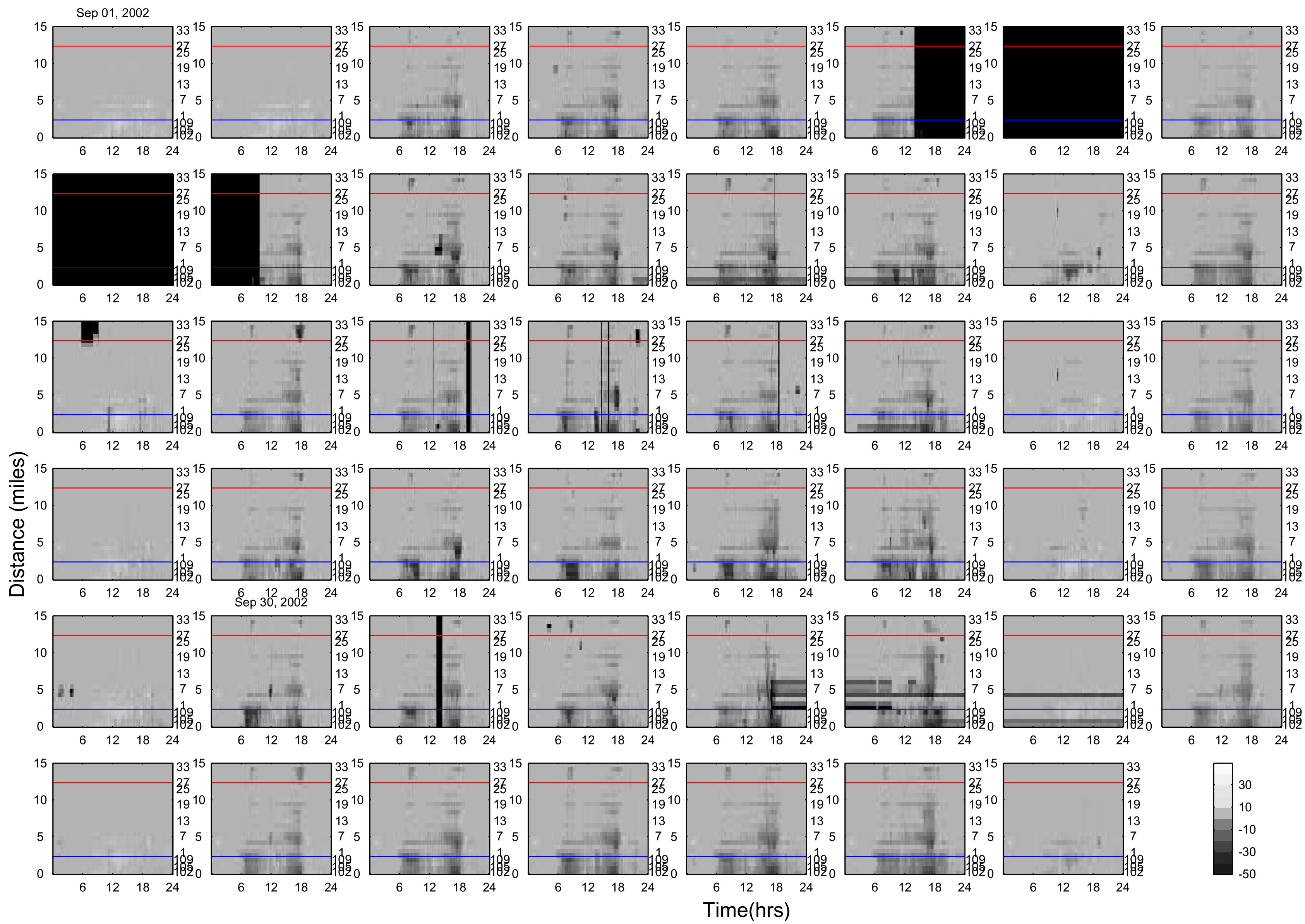
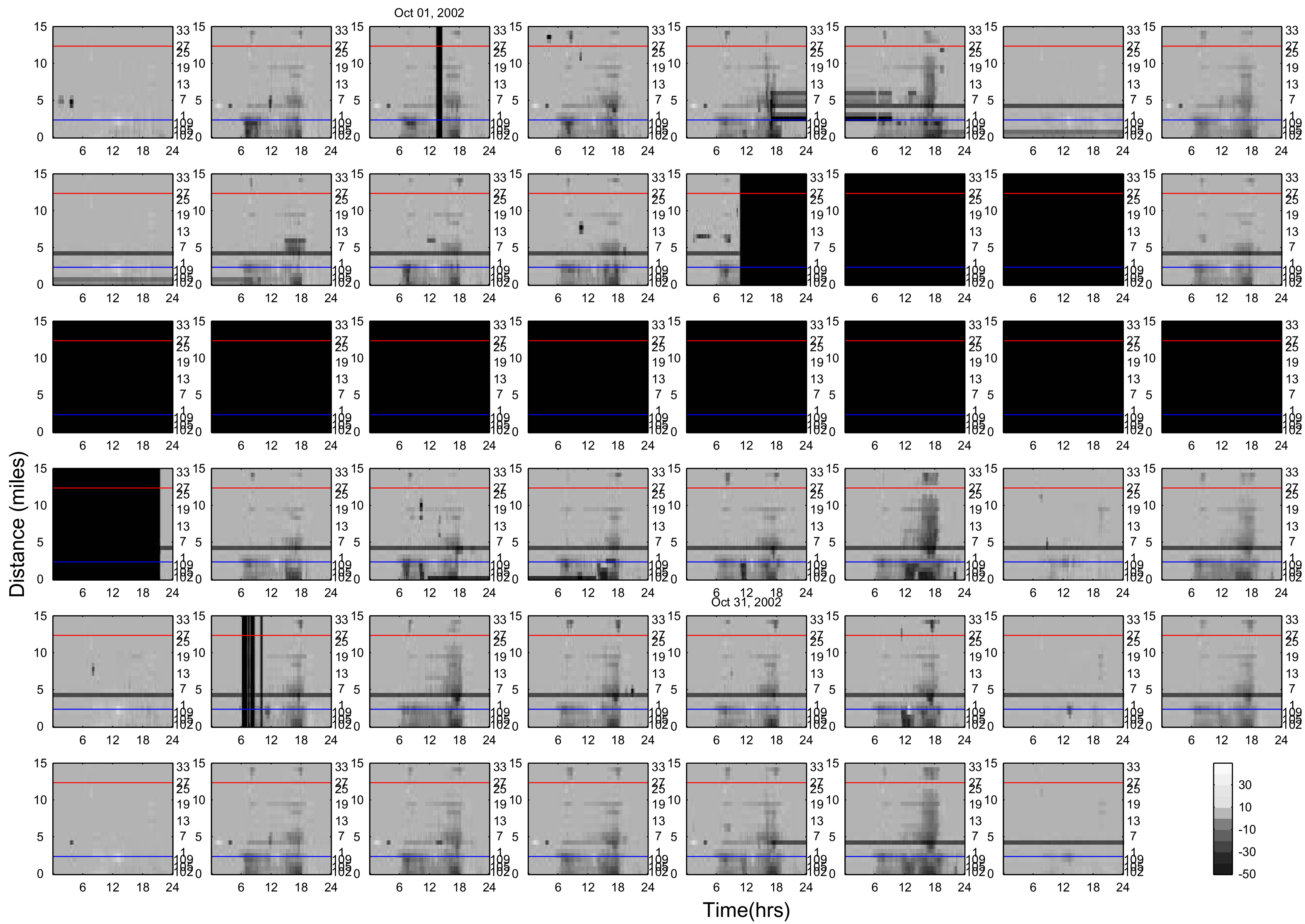
10
-10
-30
-50



Sep 01, 2002
Sep 30, 2002
Distance (miles)
Time(hrs)



Oct 01, 2002
Oct 31, 2002
Distance (miles)
Time(hrs)
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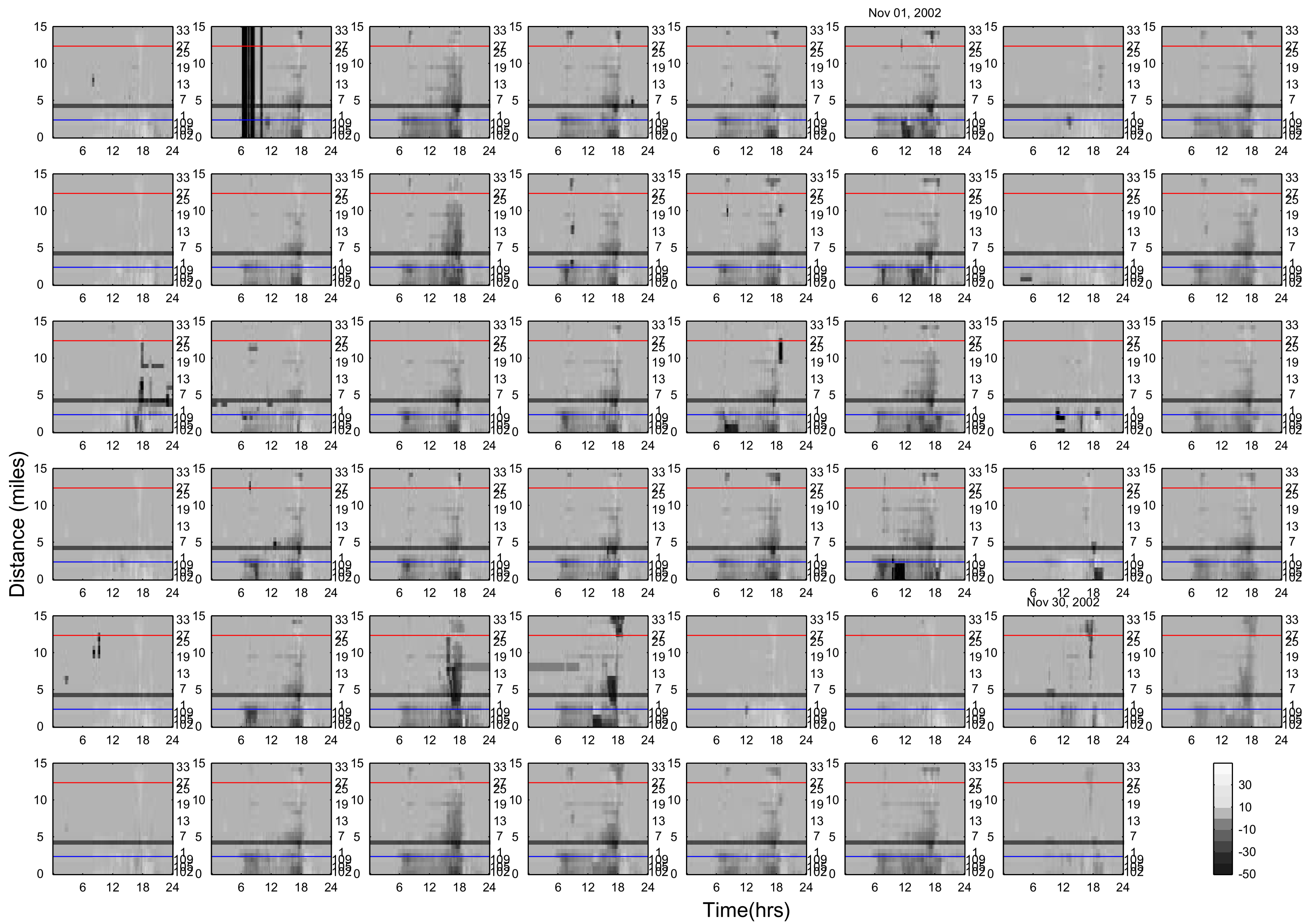
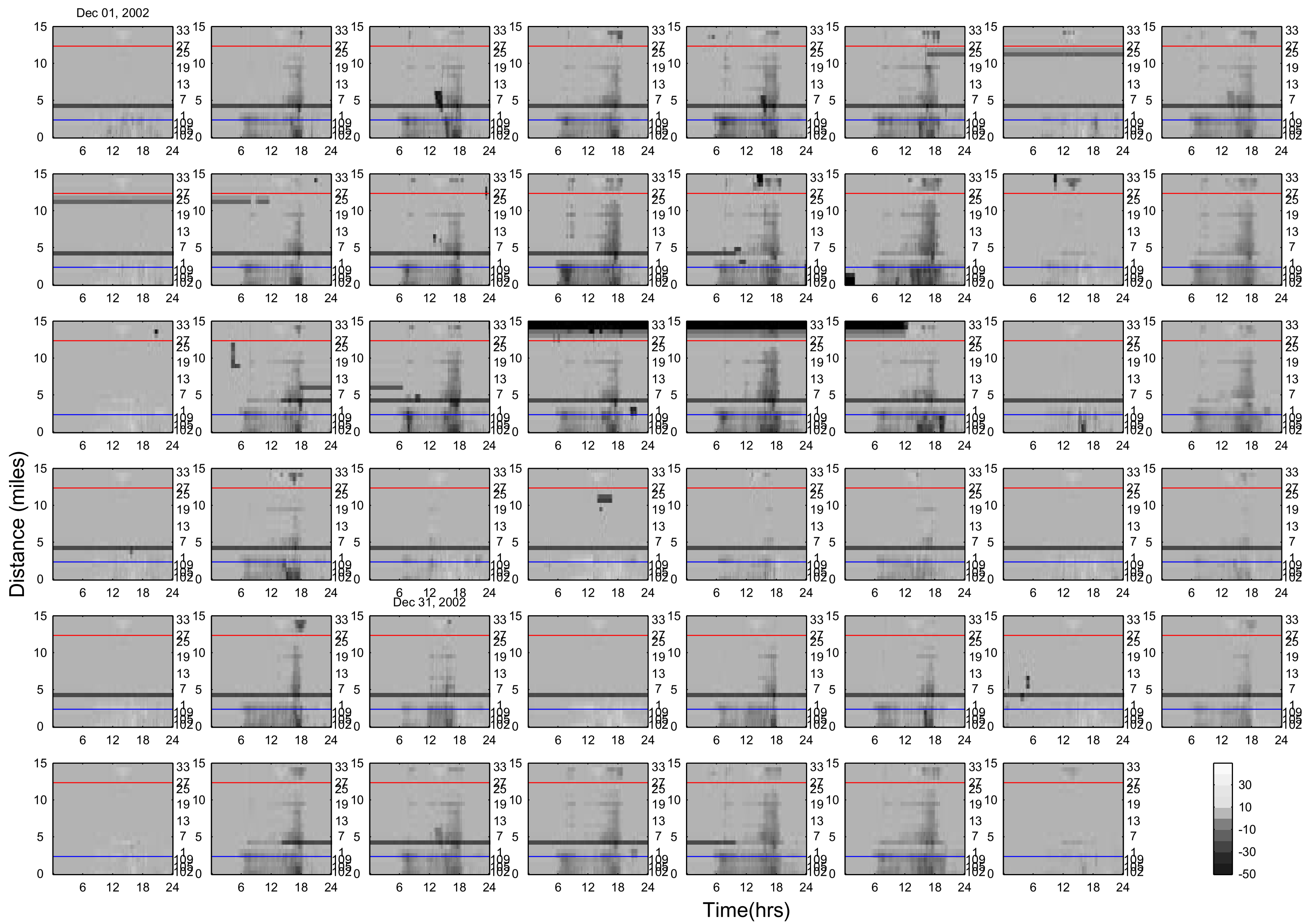
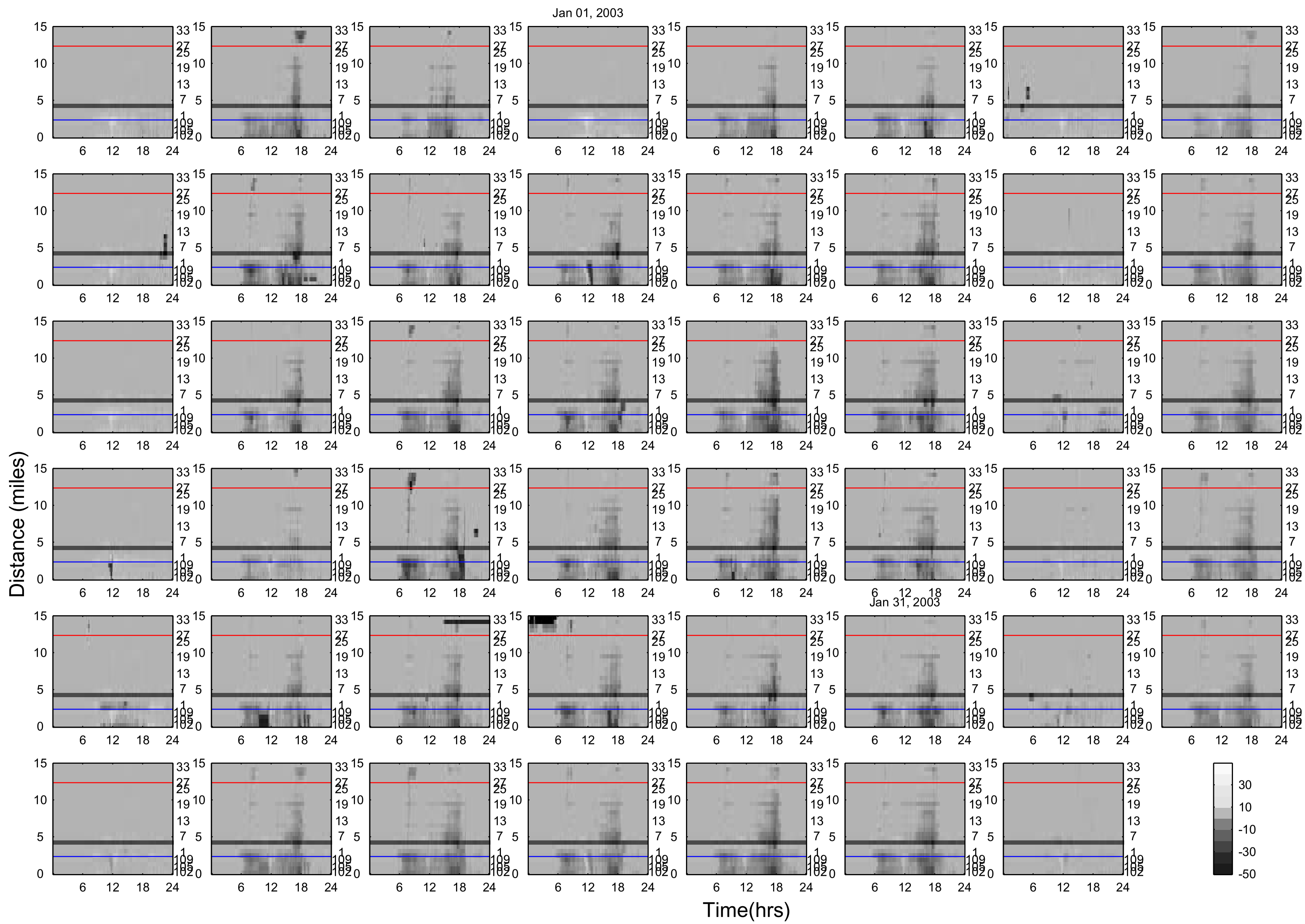
10
-10
-30
-50



Nov 01, 2002
Nov 30, 2002
Distance (miles)
Time(hrs)
30
10
-10
-30
-50


Dec 01, 2002
Dec 31, 2002
Distance (miles)
Time(hrs)
30
10
-10
-30
-50


Jan 01, 2003
Jan 31, 2003
Distance (miles)
Time(hrs)
30
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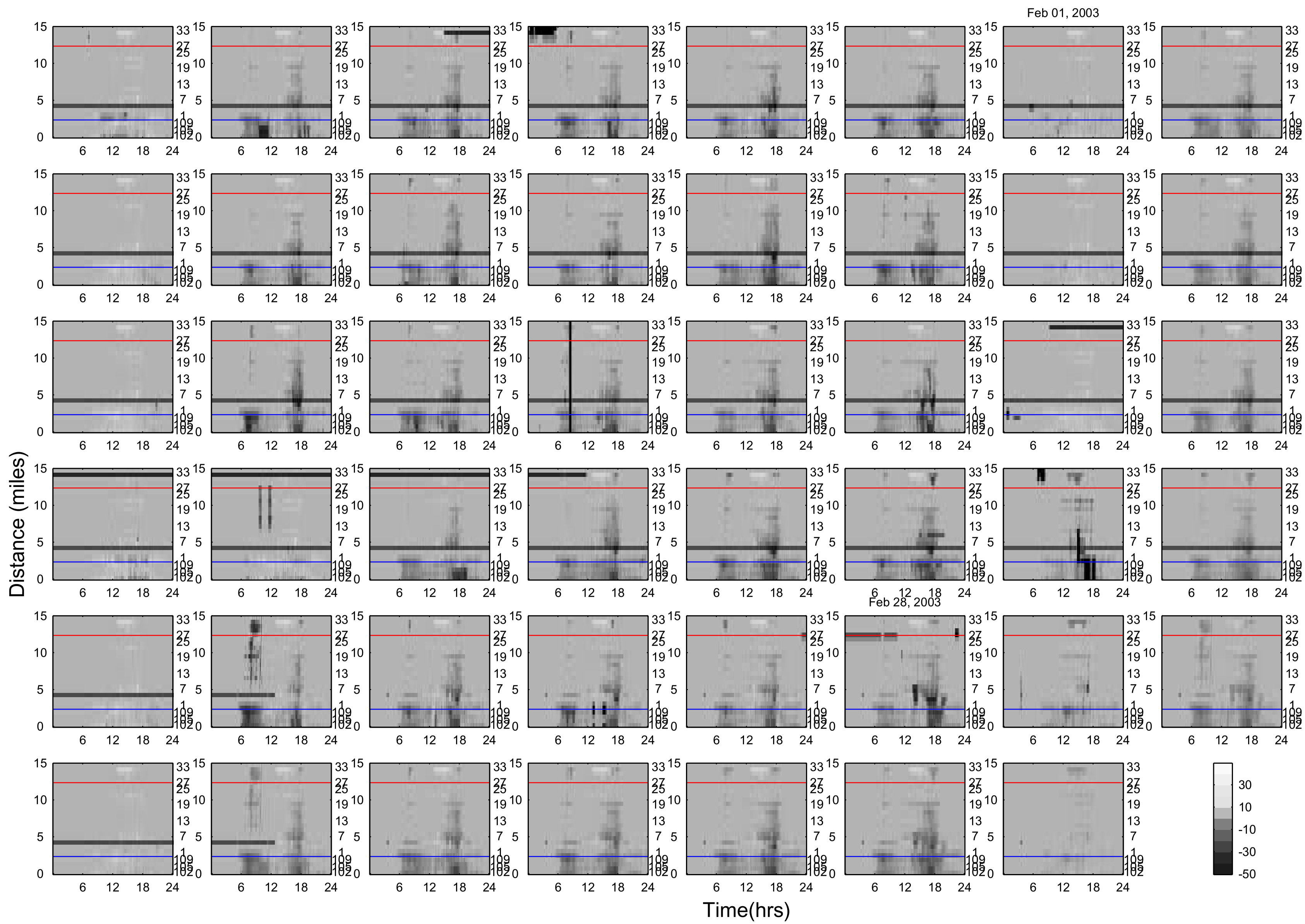
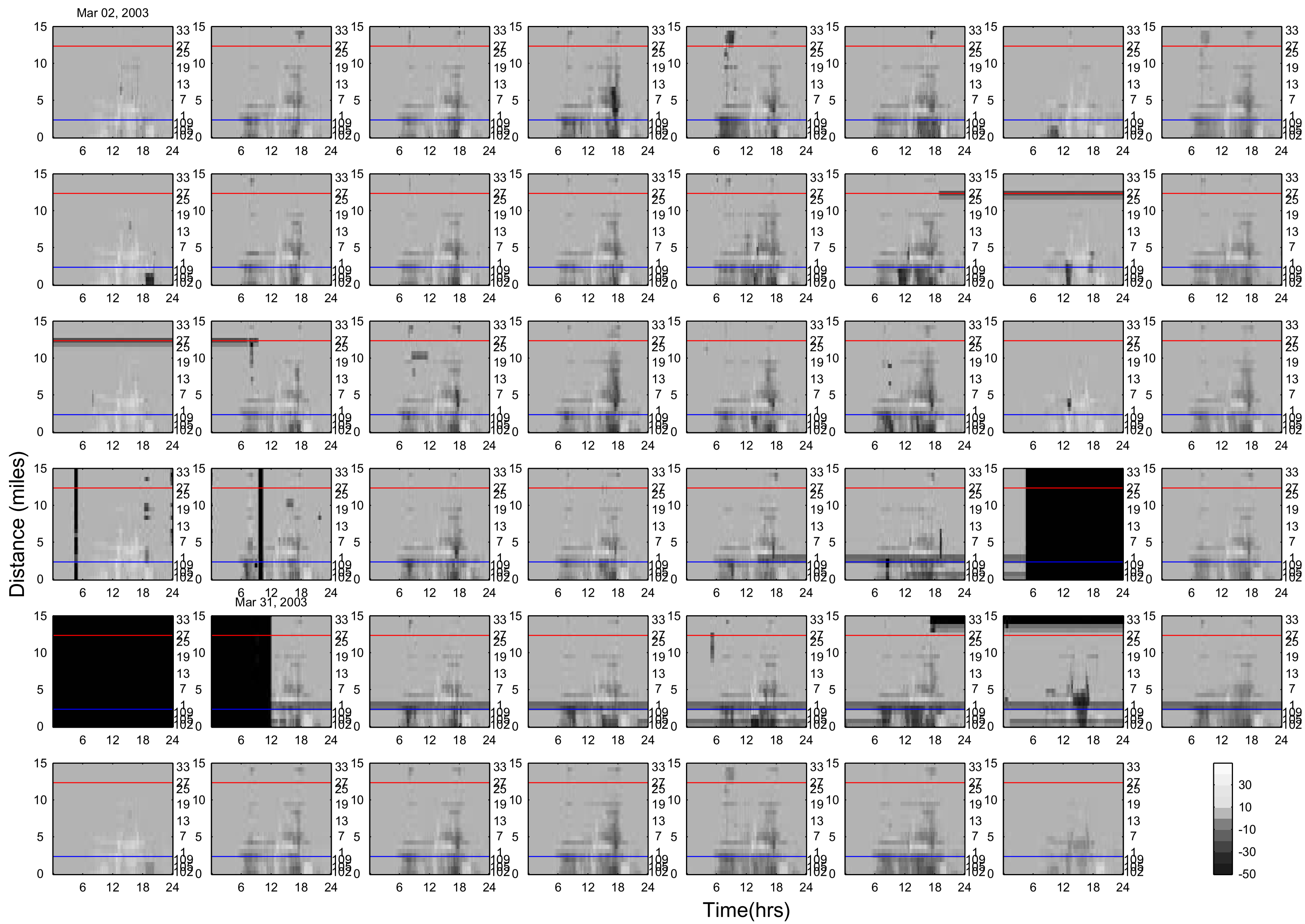
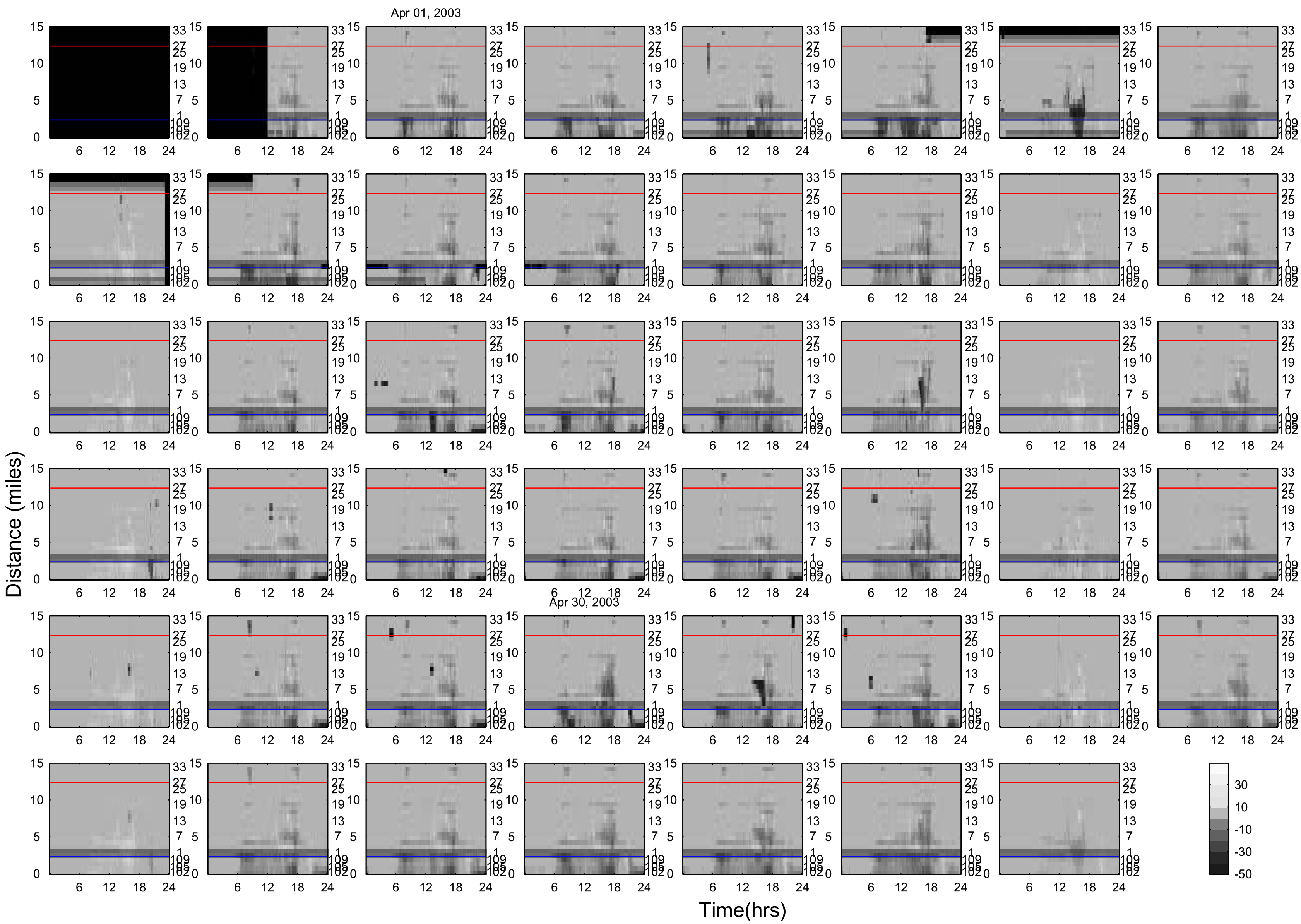
-10
-30
-50



Feb 01, 2003
Feb 28, 2003
Distance (miles)
Time(hrs)
30
10
-10
-30
-50



Mar 02, 2003
Mar 31, 2003
Distance (miles)
Time(hrs)
30
10
-10
-30
-50


Apr 01, 2003
Apr 30, 2003
Distance (miles)
Time(hrs)
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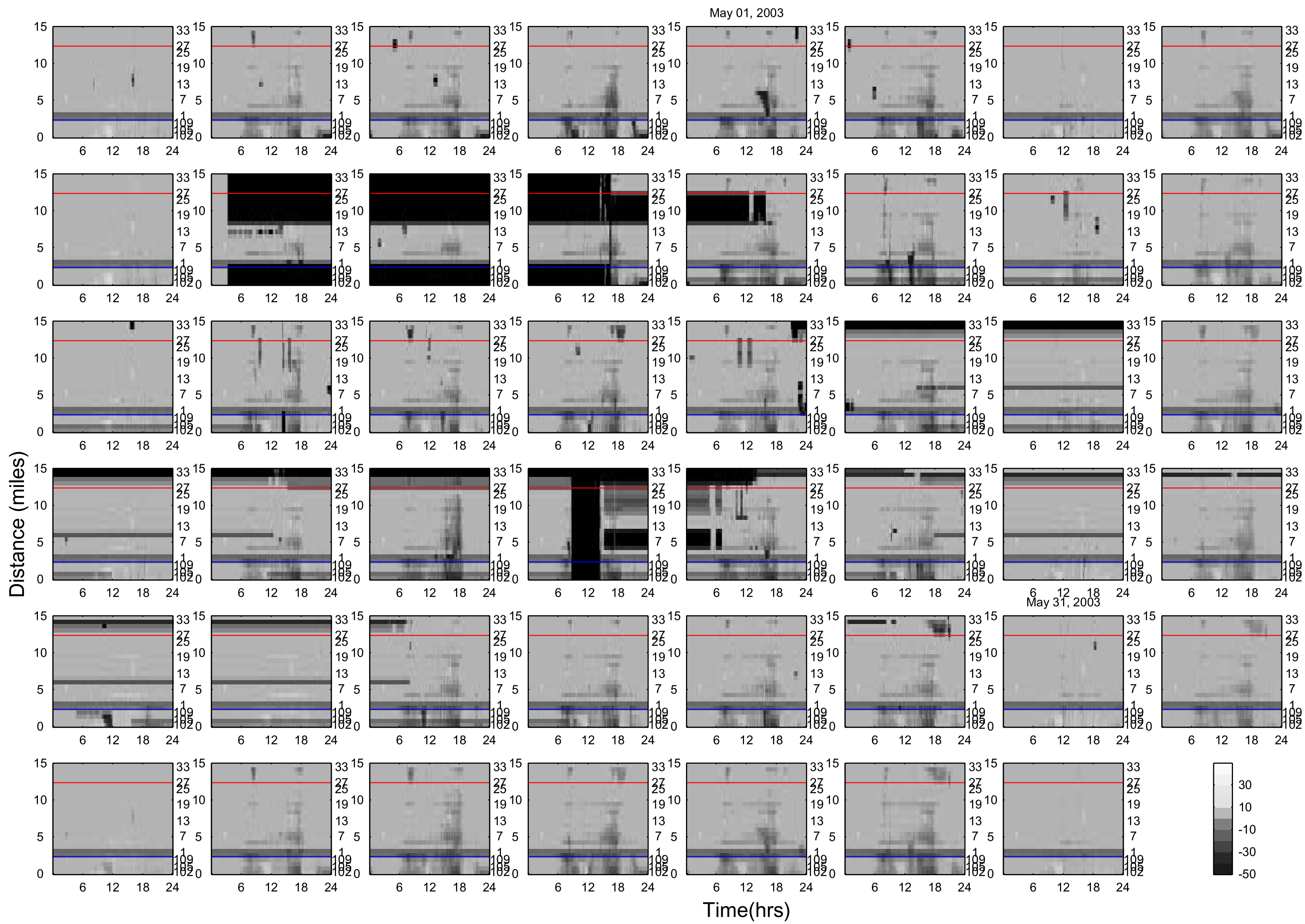
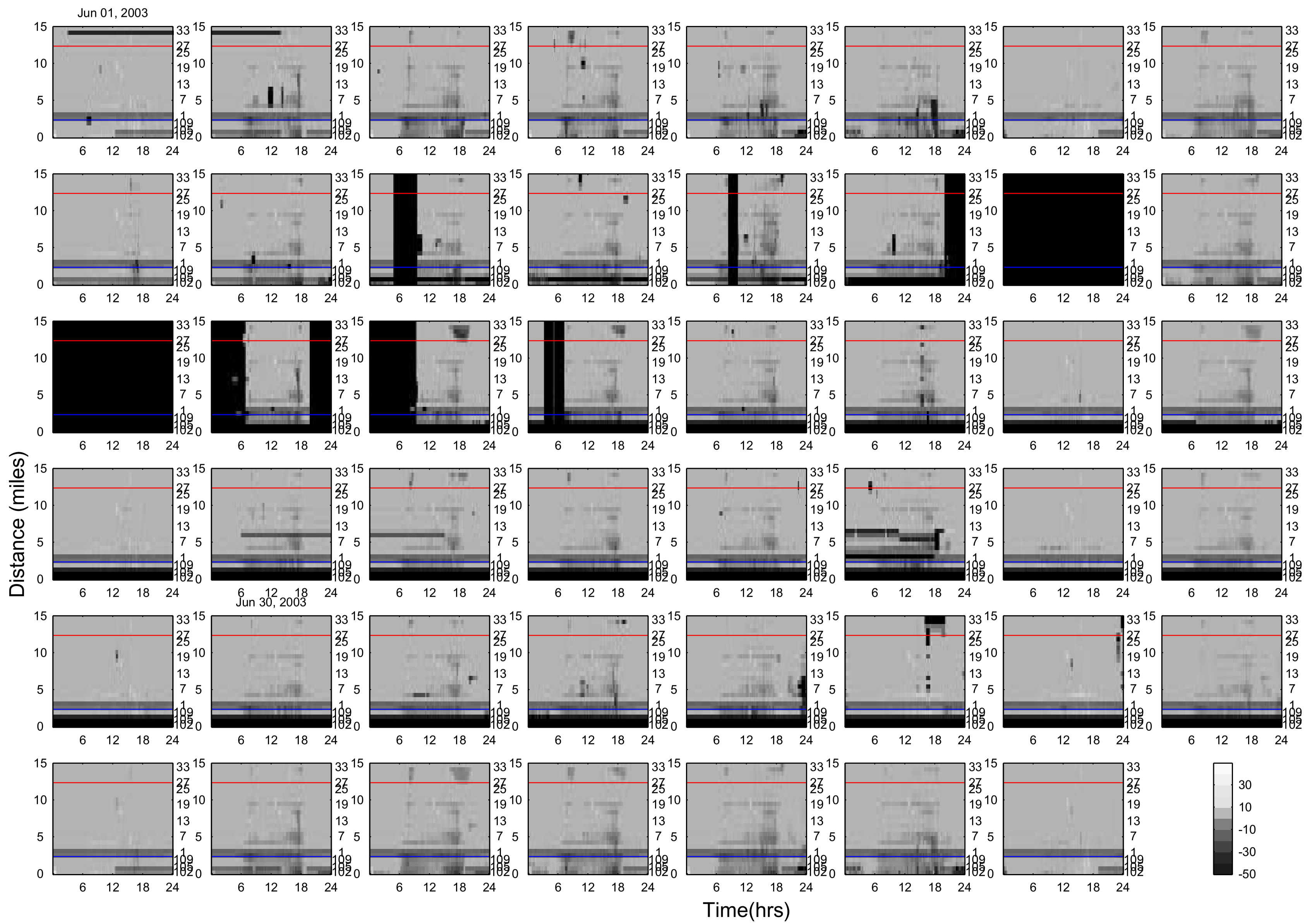
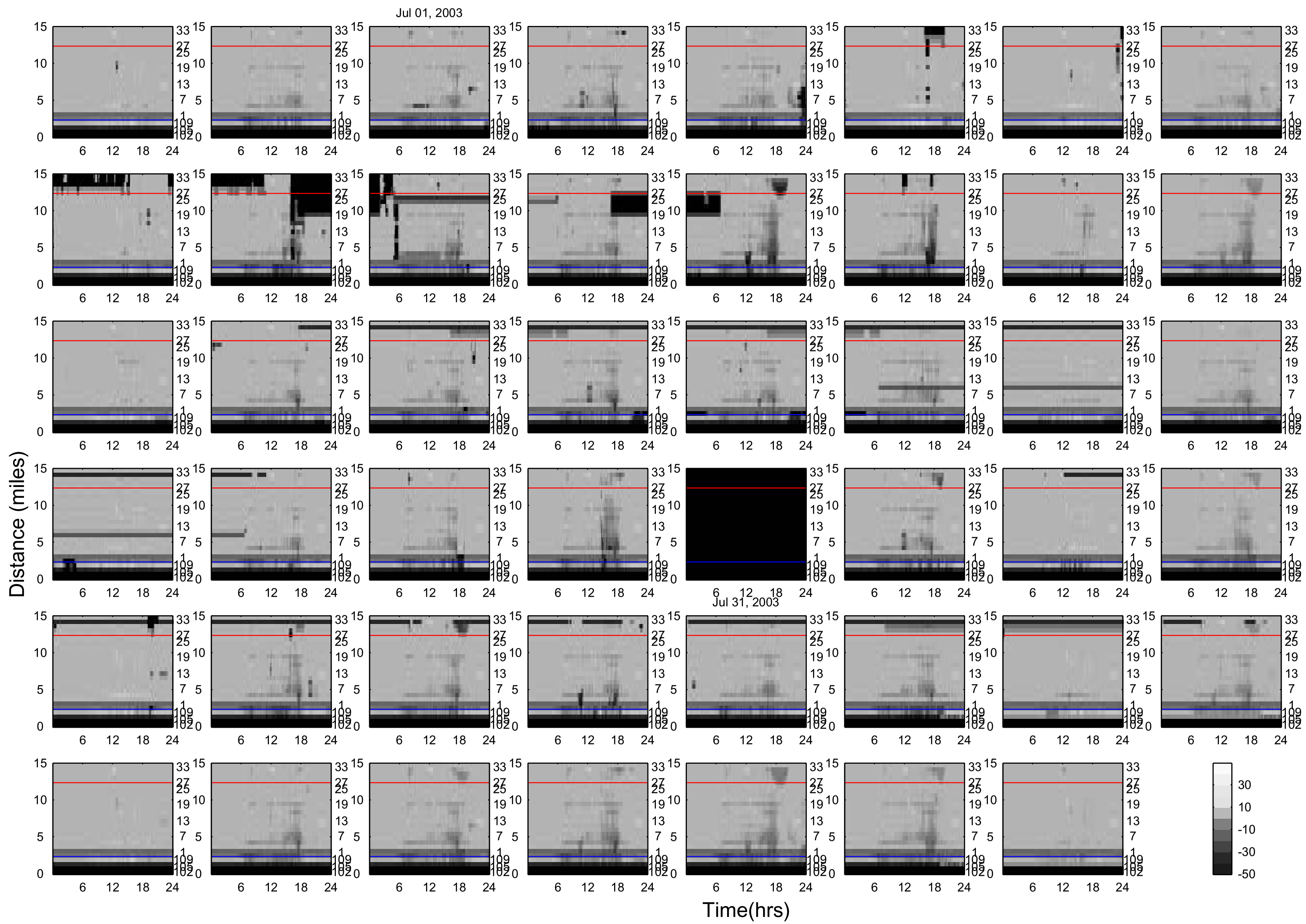
-10
-30
-50



May 01, 2003
May 31, 2003
Distance (miles)
Time(hrs)
0
5
10
15
6
12
18
24
33
27
25
19
13
7
1
109
105
102
30
10
-10
-30
-50



Jun 01, 2003
Jun 30, 2003
Distance (miles)
Time(hrs)
30
10
-10
-30
-50



Jul 01, 2003
Jul 31, 2003
Distance (miles)
Time(hrs)
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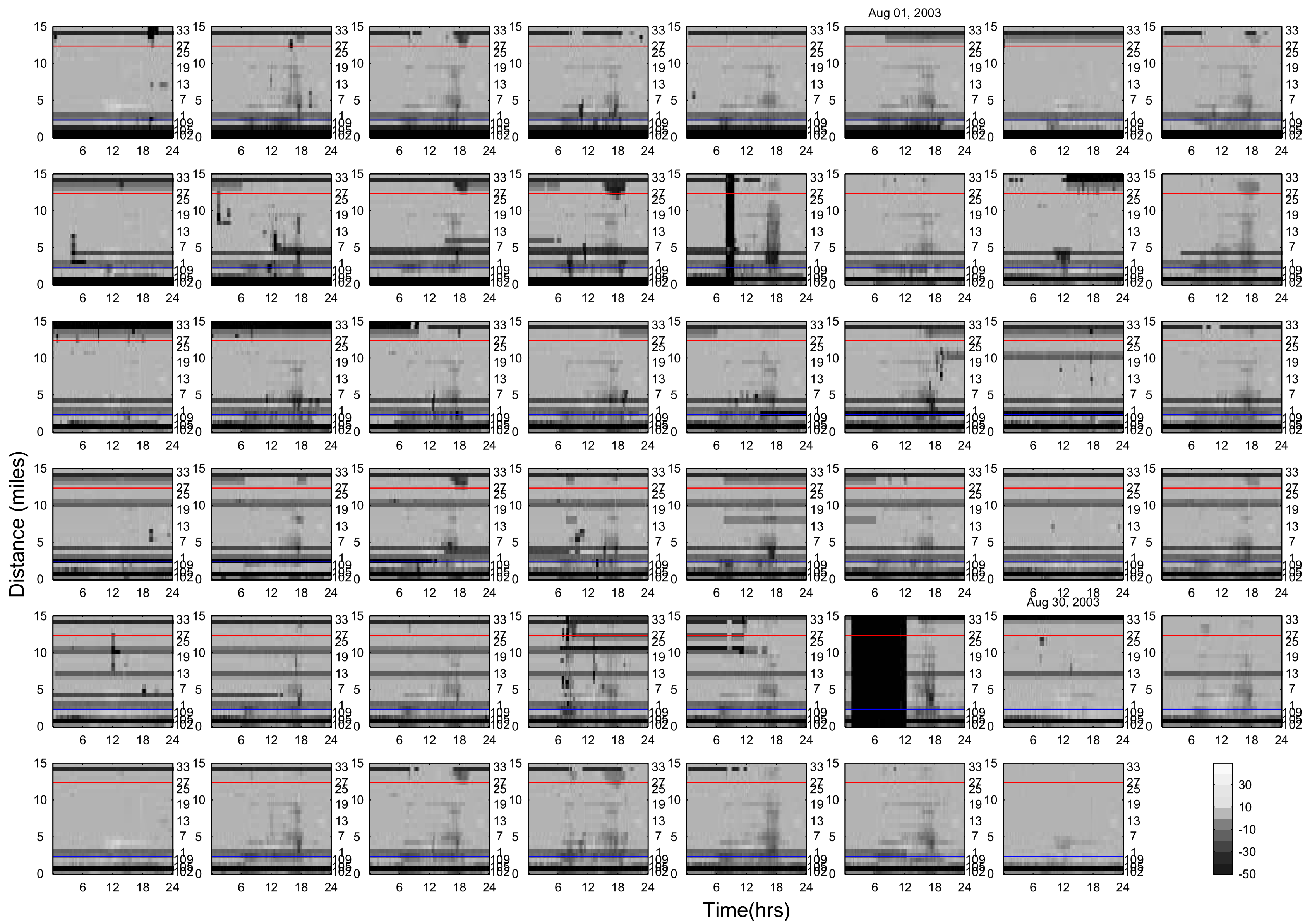
-10
-30
-50



Aug 01, 2003
Aug 30, 2003
Distance (miles)
Time(hrs)
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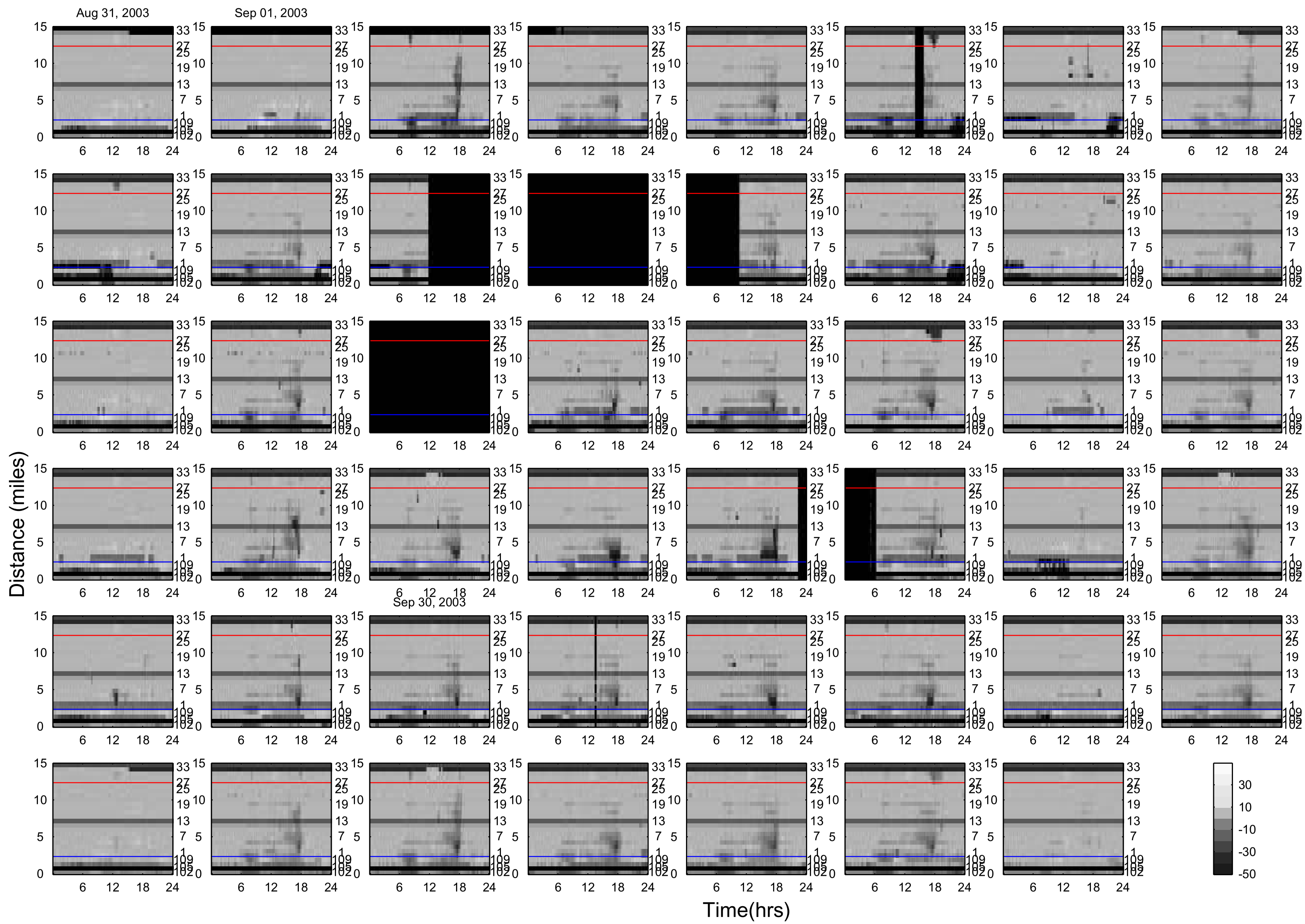
-10
-30
-50



Aug 31, 2003
Sep 01, 2003
Sep 30, 2003
Distance (miles)
Time(hrs)
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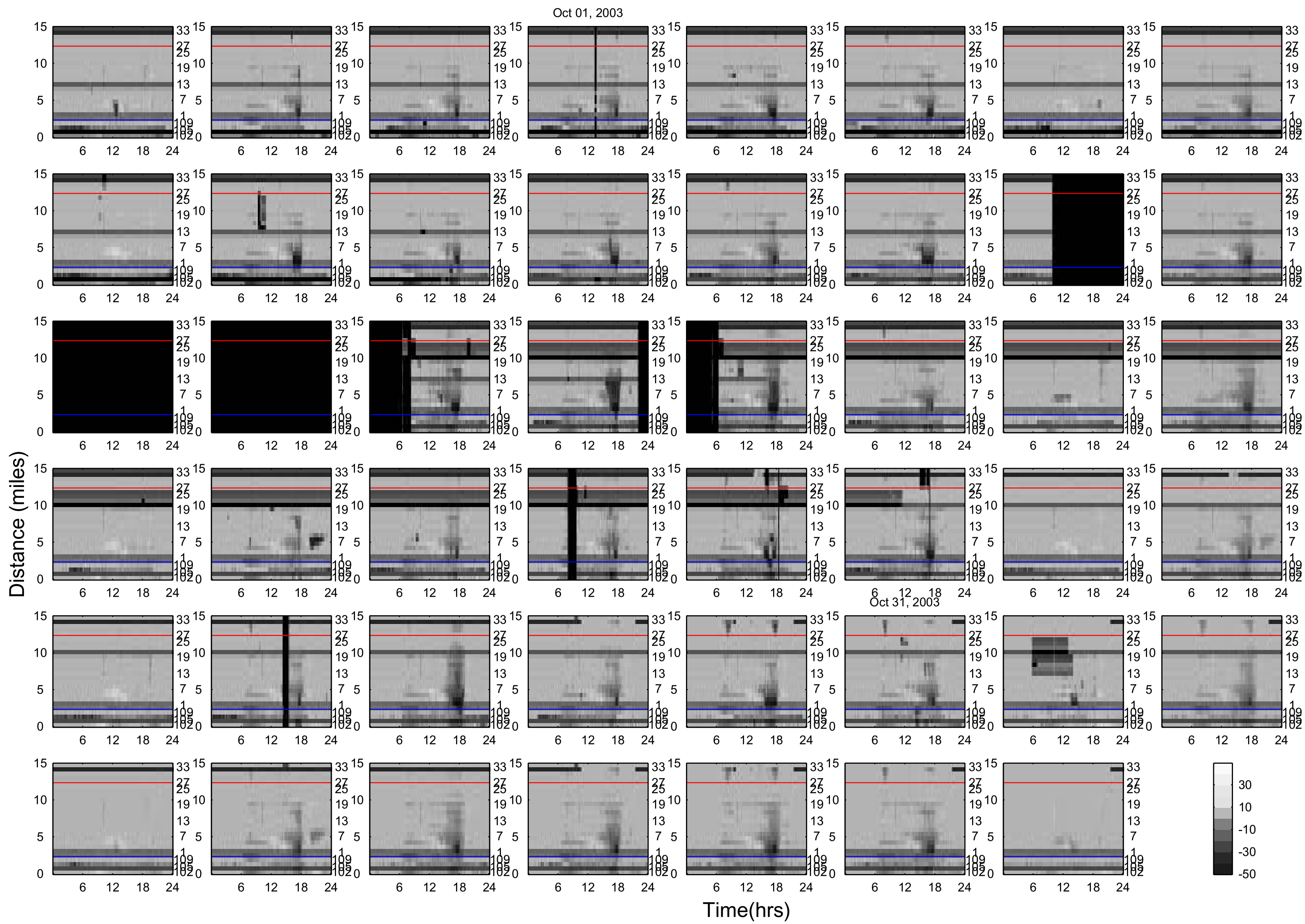
-10
-30
-50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Oct 31, 2003
Distance (miles)
Time(hrs)
30
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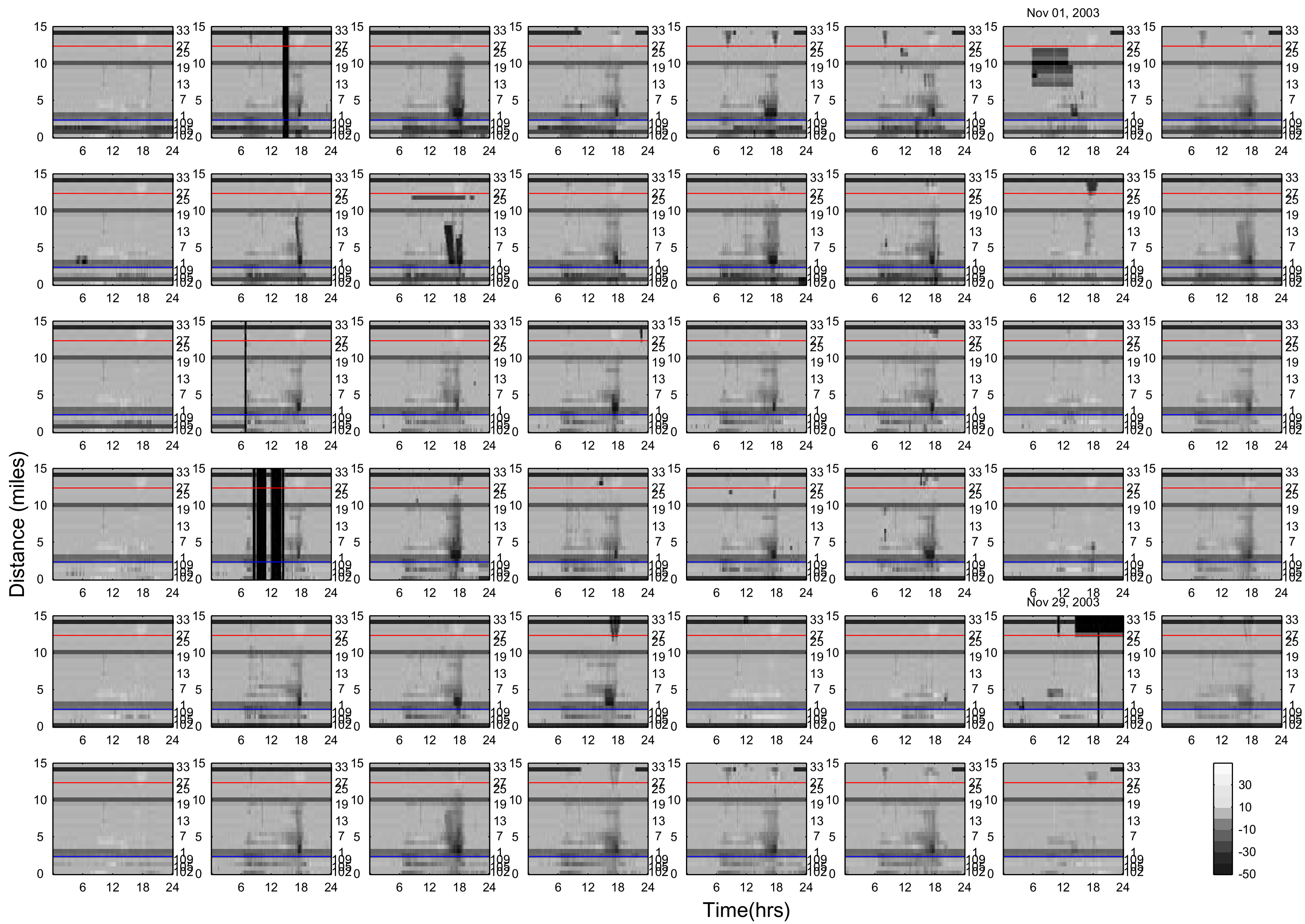
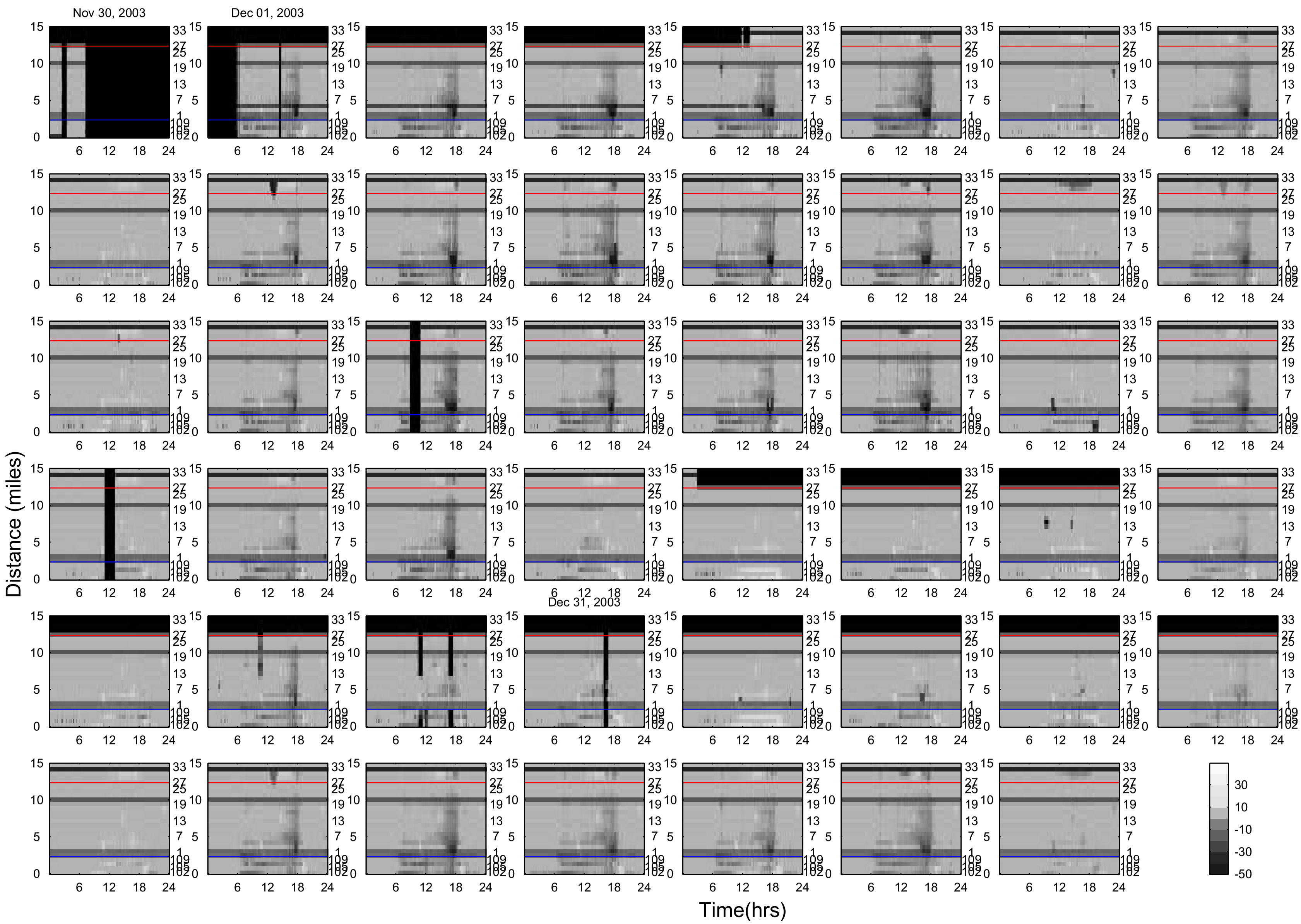
-10
-30
-50


Nov 01, 2003
Nov 29, 2003
Distance (miles)
Time(hrs)



Nov 30, 2003
Dec 01, 2003
Dec 31, 2003
Distance (miles)
Time(hrs)
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-10
-30
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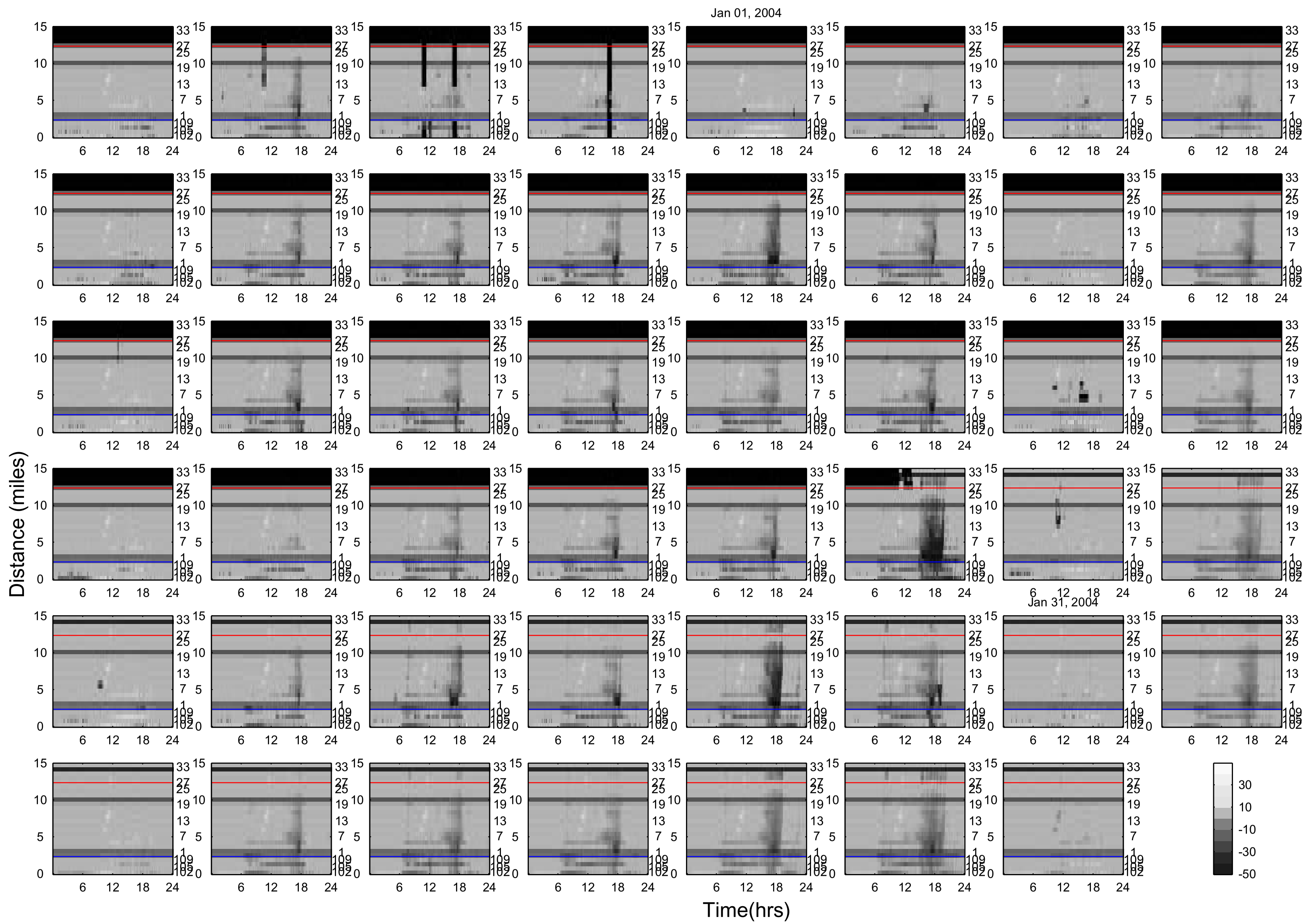
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Jan 31, 2004
Distance (miles)
Time(hrs)
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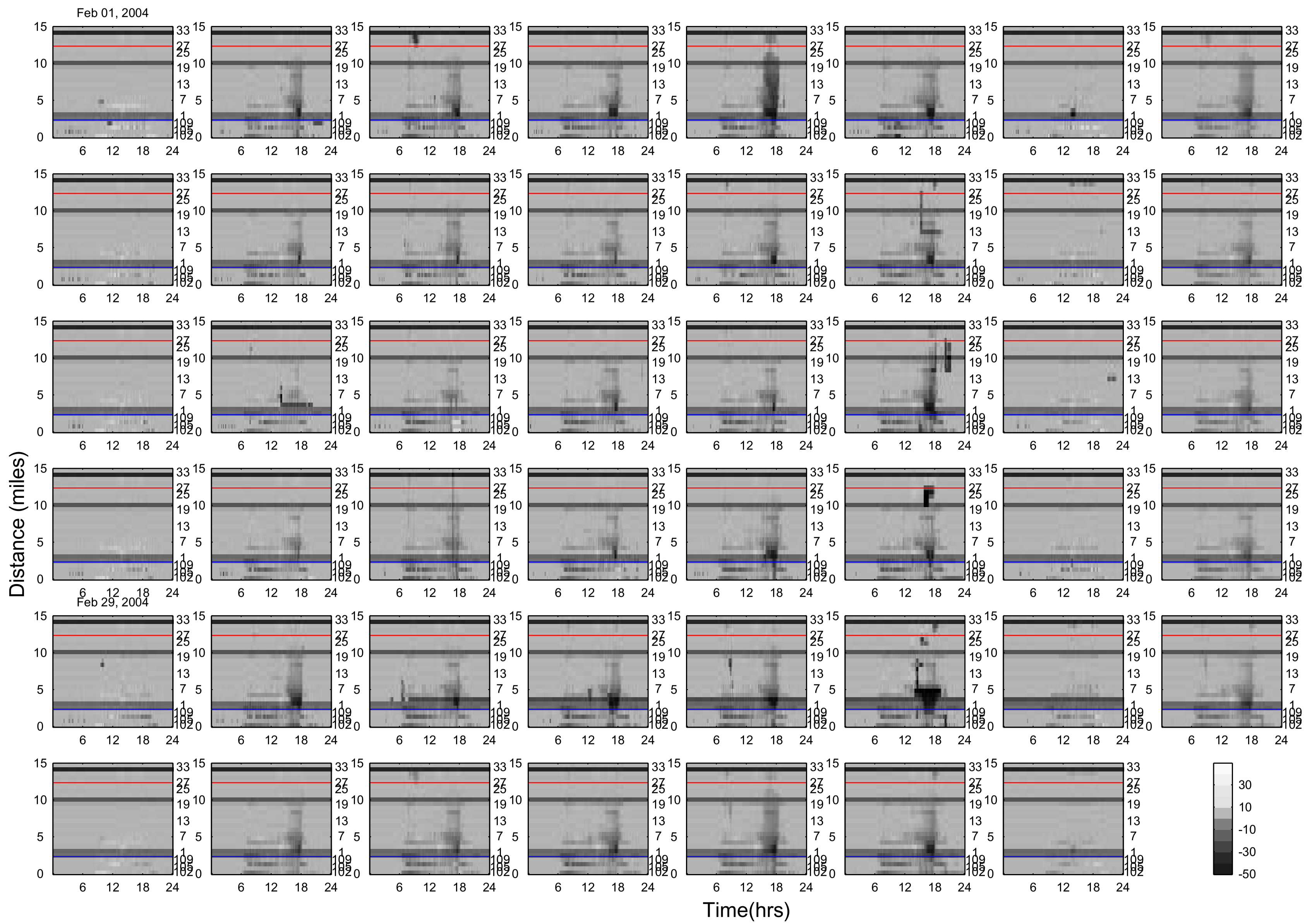

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Feb 29, 2004
Distance (miles)
Time(hrs)
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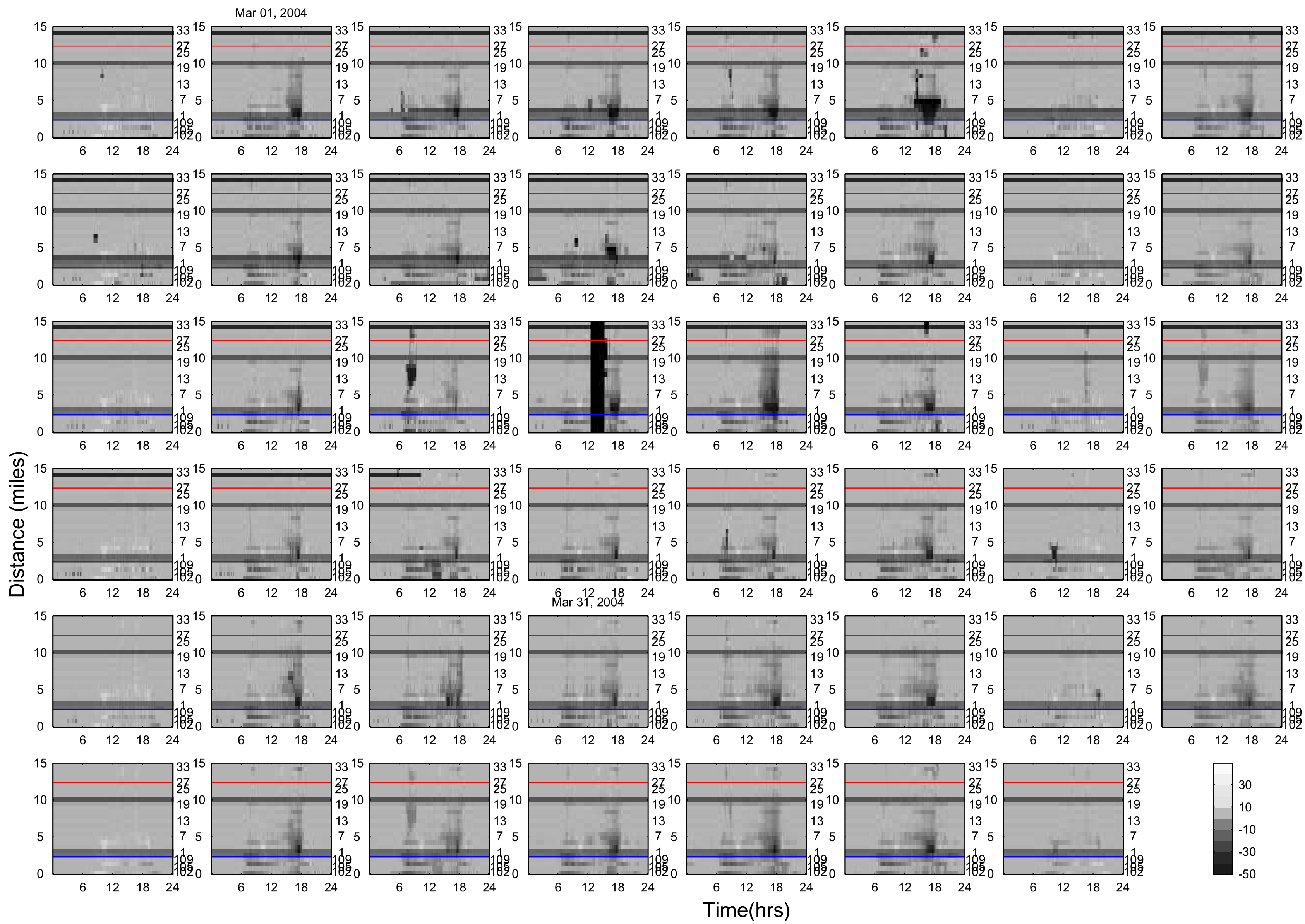
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Mar 31, 2004
Distance (miles)
Time(hrs)
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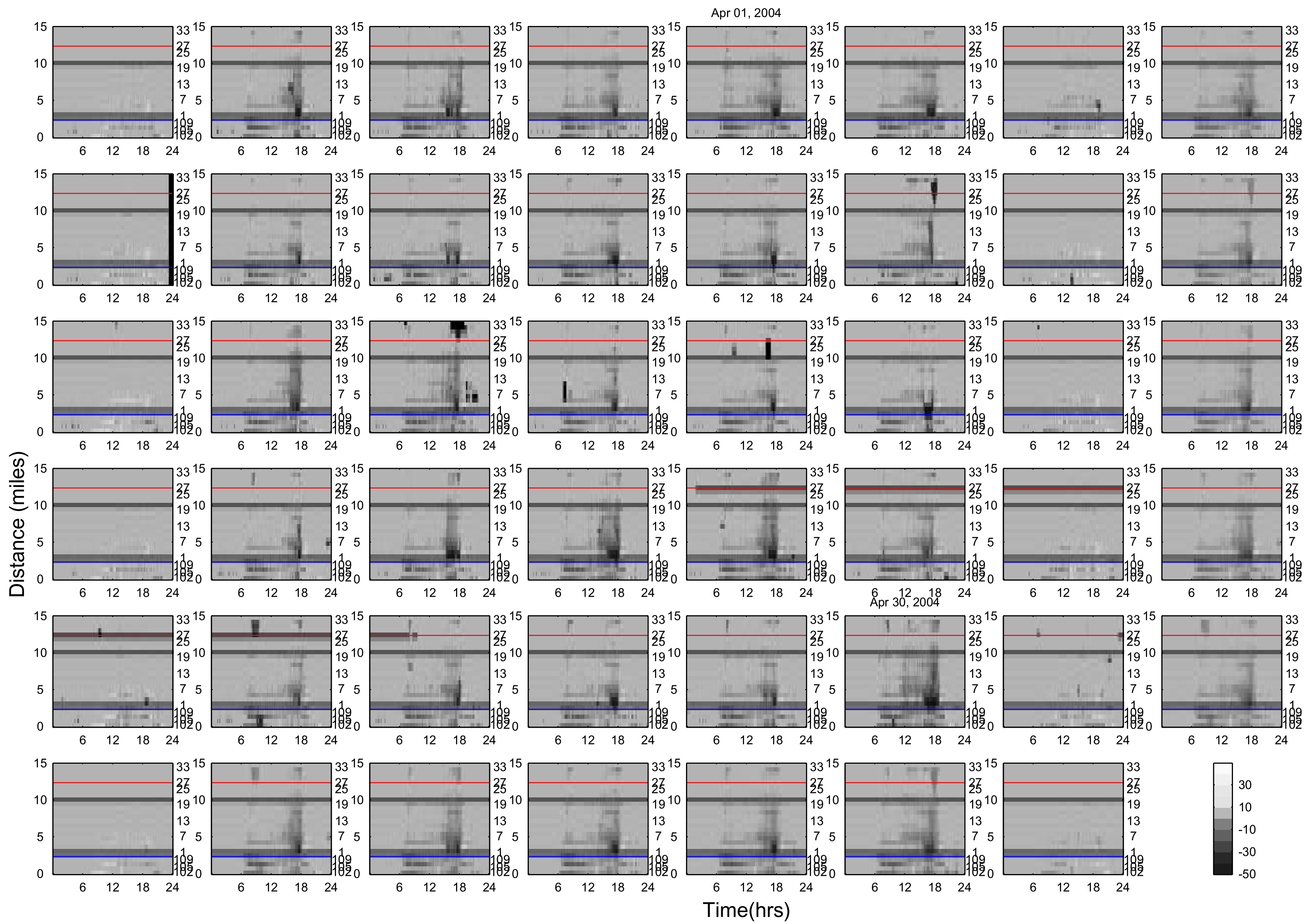
-30
-50



Apr 01, 2004
Apr 30, 2004
Distance (miles)
Time(hrs)
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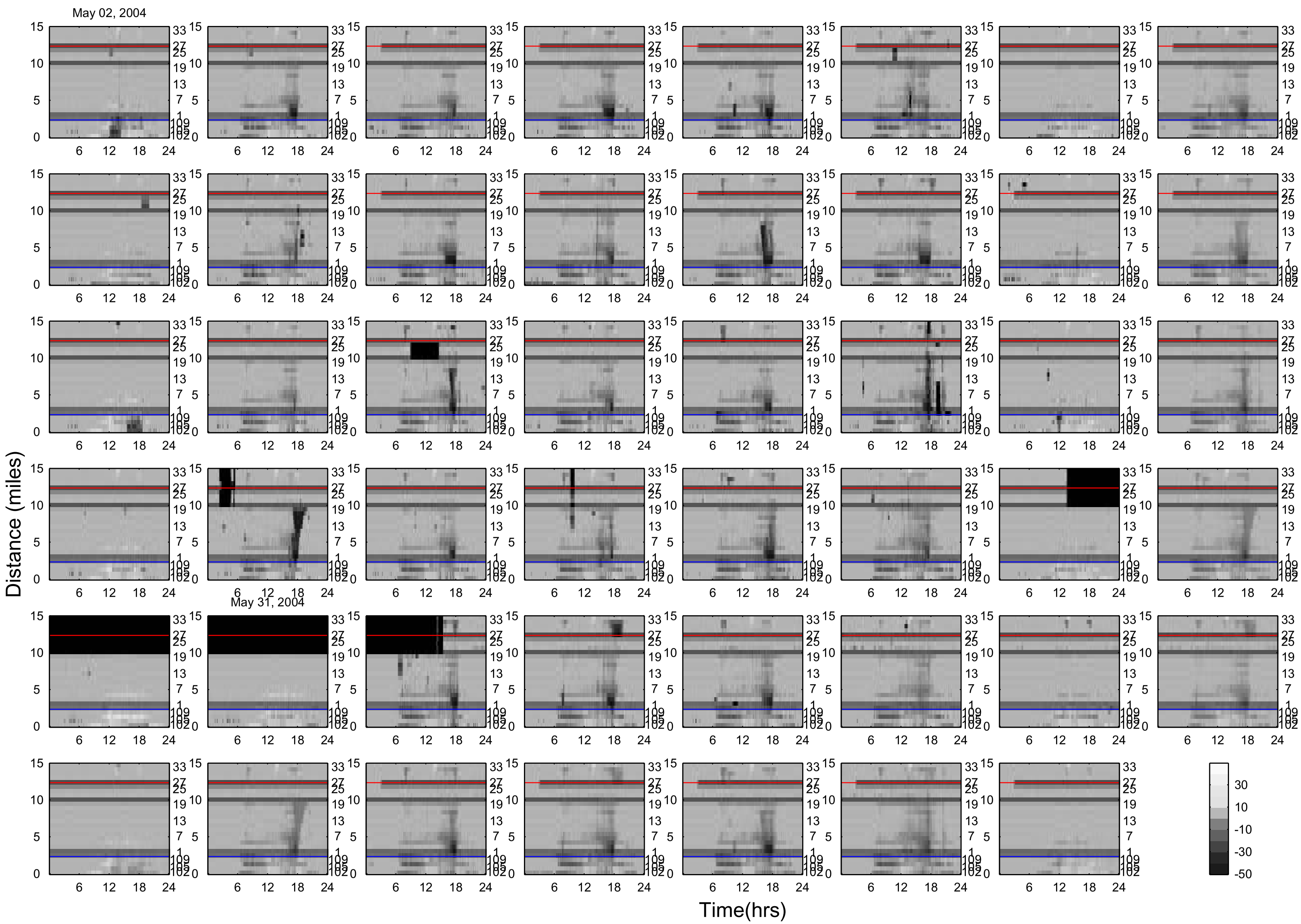
10
-10
-30
-50



May 02, 2004
May 31, 2004
Distance (miles)
Time(hrs)
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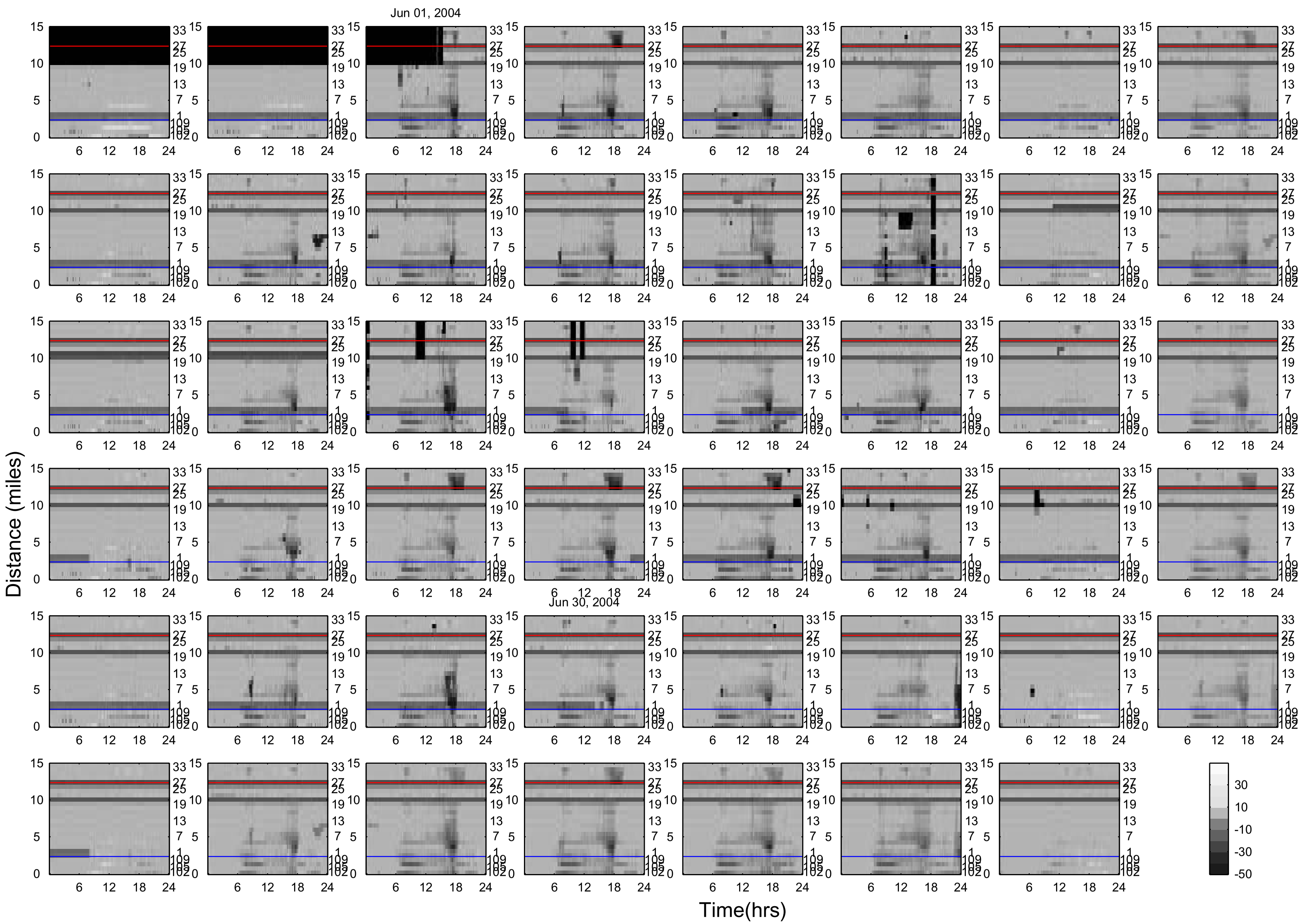
10
-10
-30
-50



Jun 01, 2004
Jun 30, 2004
Distance (miles)
Time(hrs)
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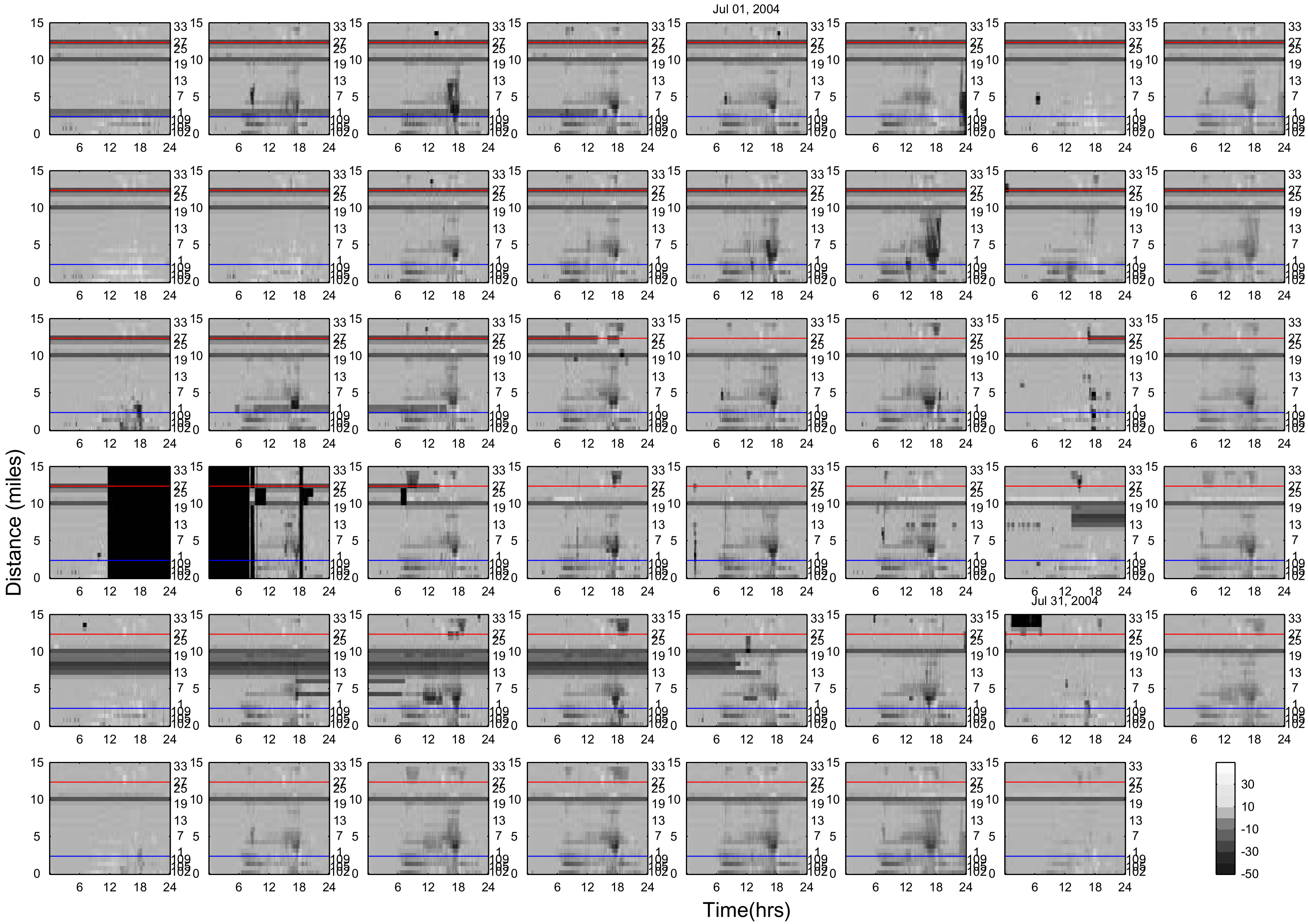
-10
-30
-50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Jul 31, 2004
Distance (miles)
Time(hrs)
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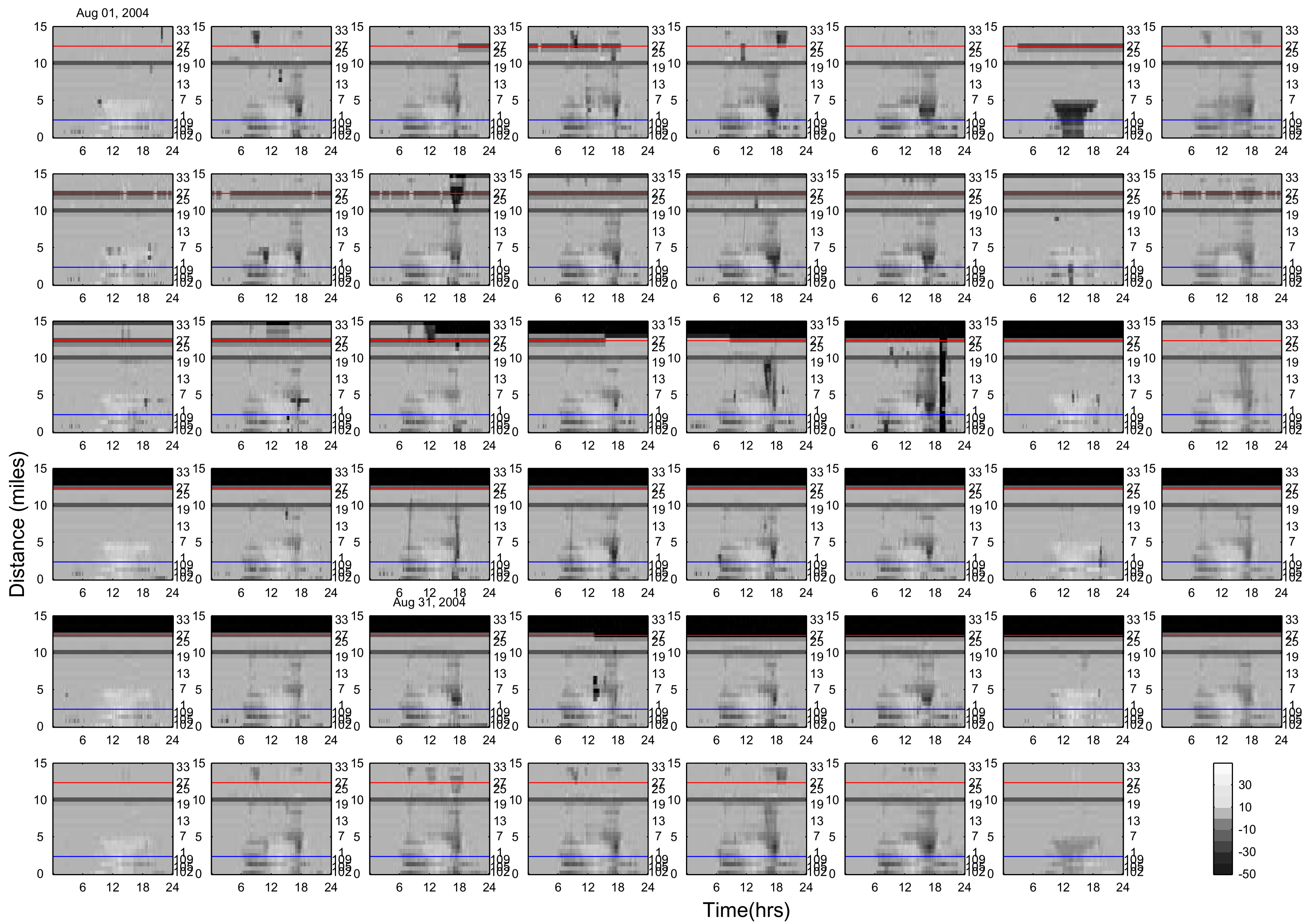
-10
-30
-50



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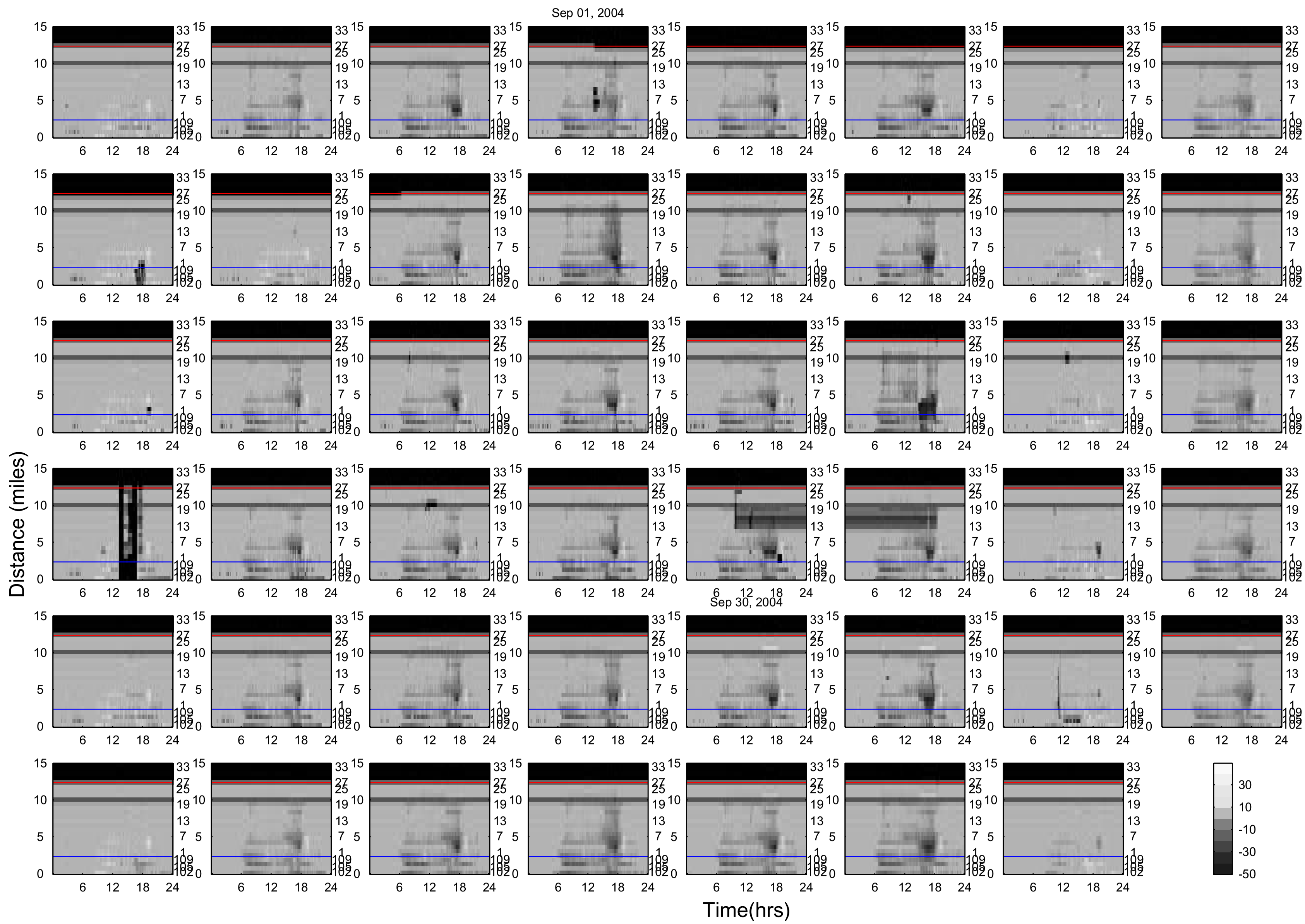
Aug 31, 2004
Distance (miles)
Time(hrs)



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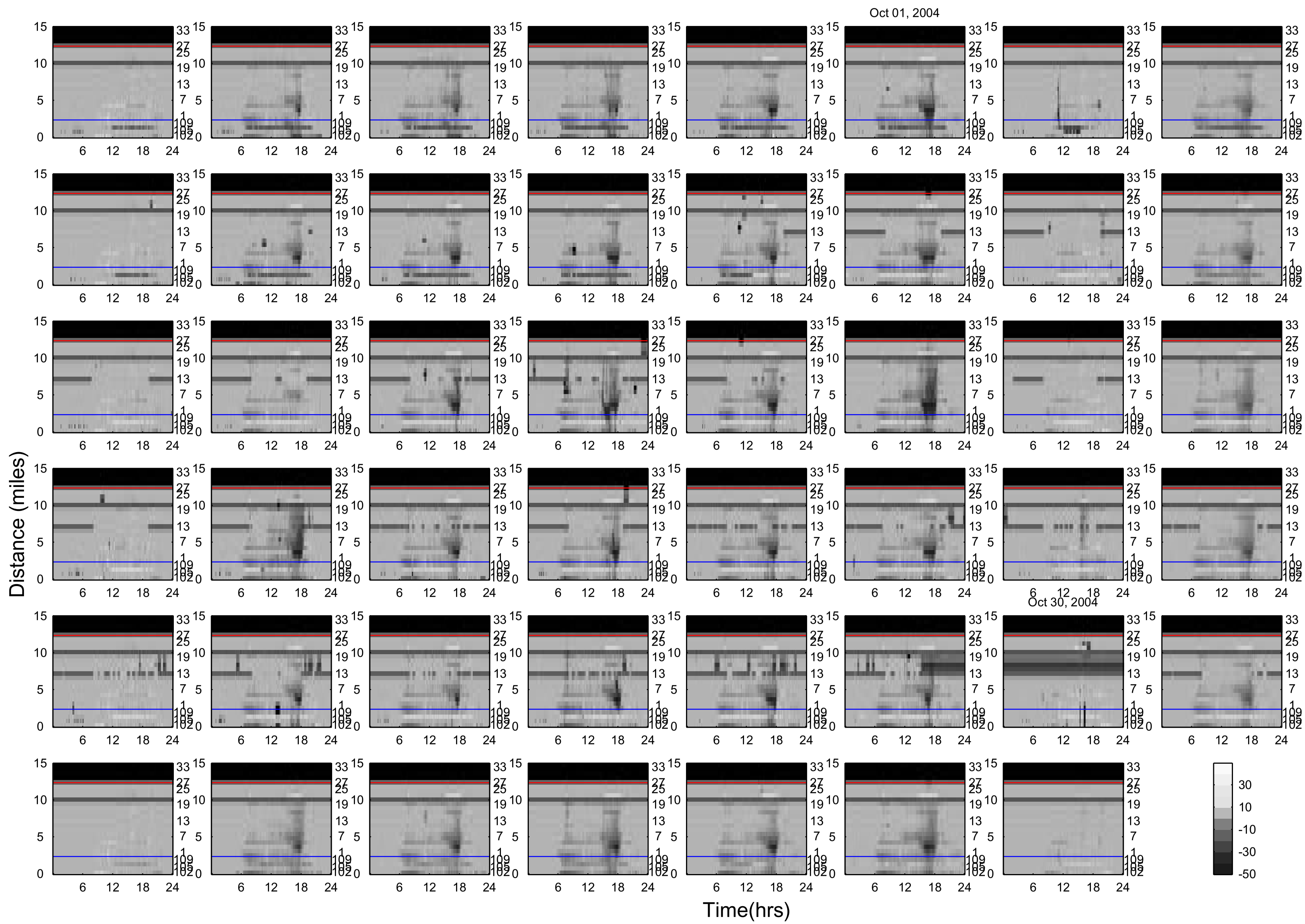
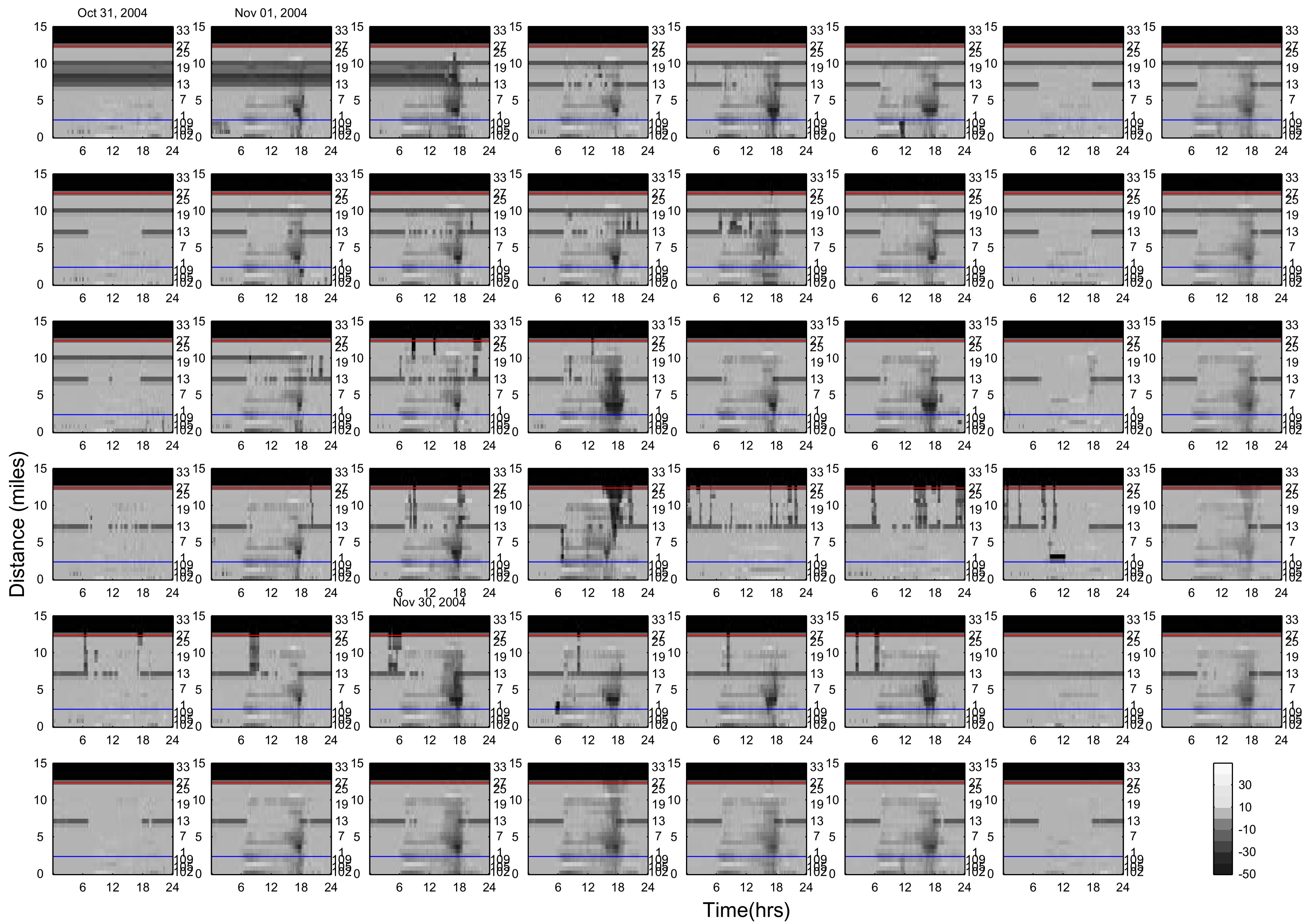
Sep 30, 2004
Distance (miles)
Time(hrs)



Oct 01, 2004
Oct 30, 2004
Distance (miles)
Time(hrs)



Oct 31, 2004
Nov 01, 2004
Nov 30, 2004
Distance (miles)
Time(hrs)
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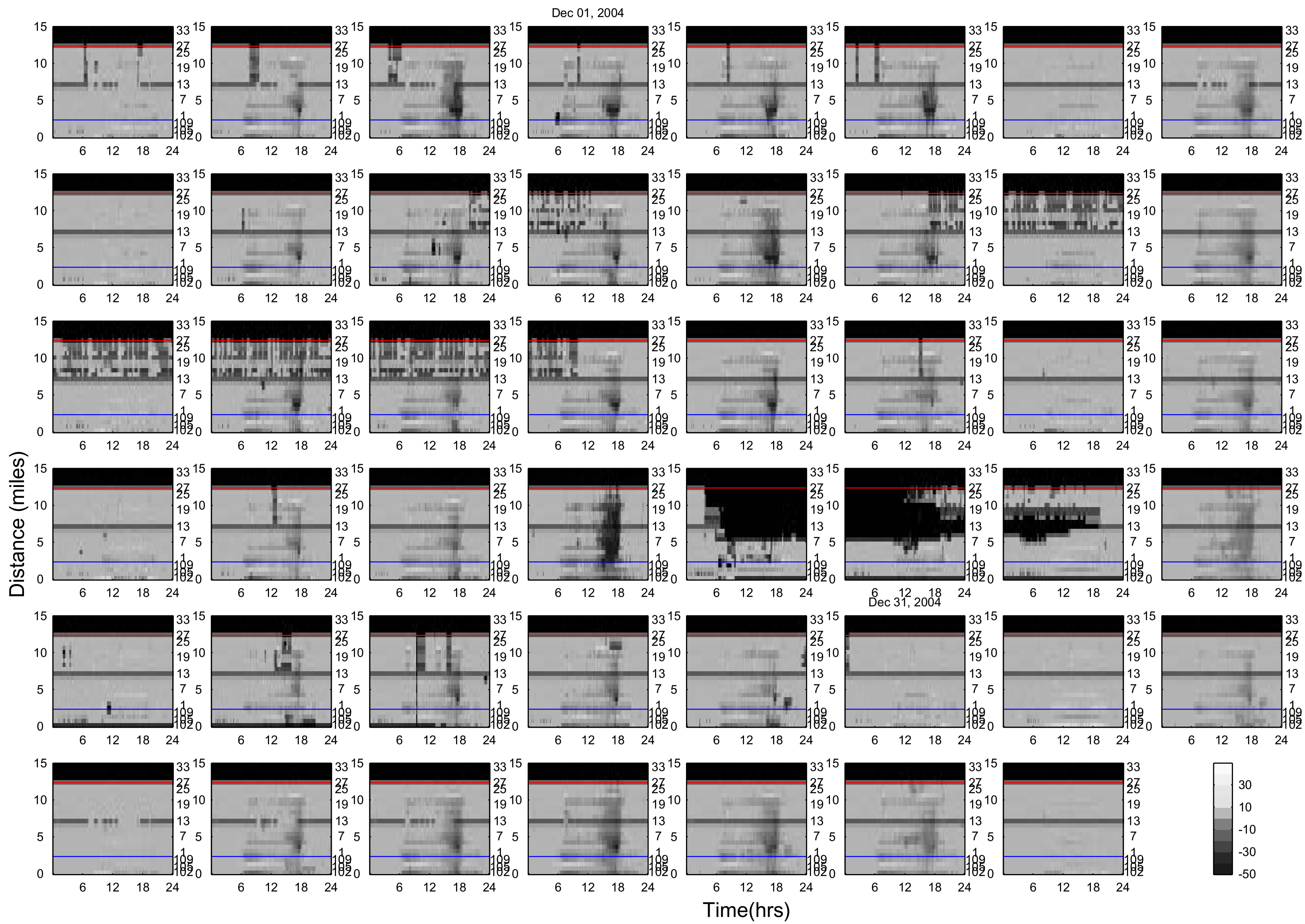
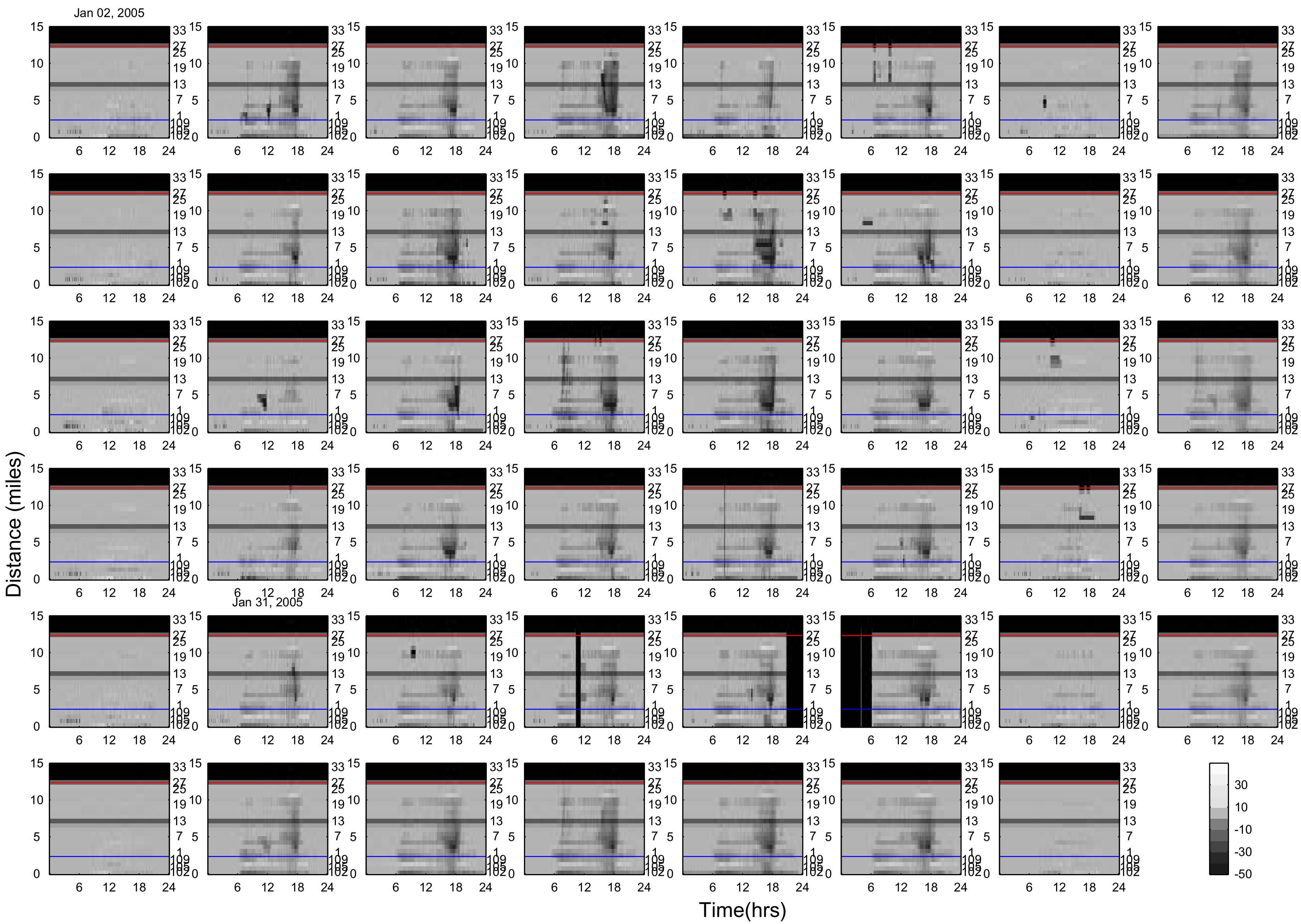
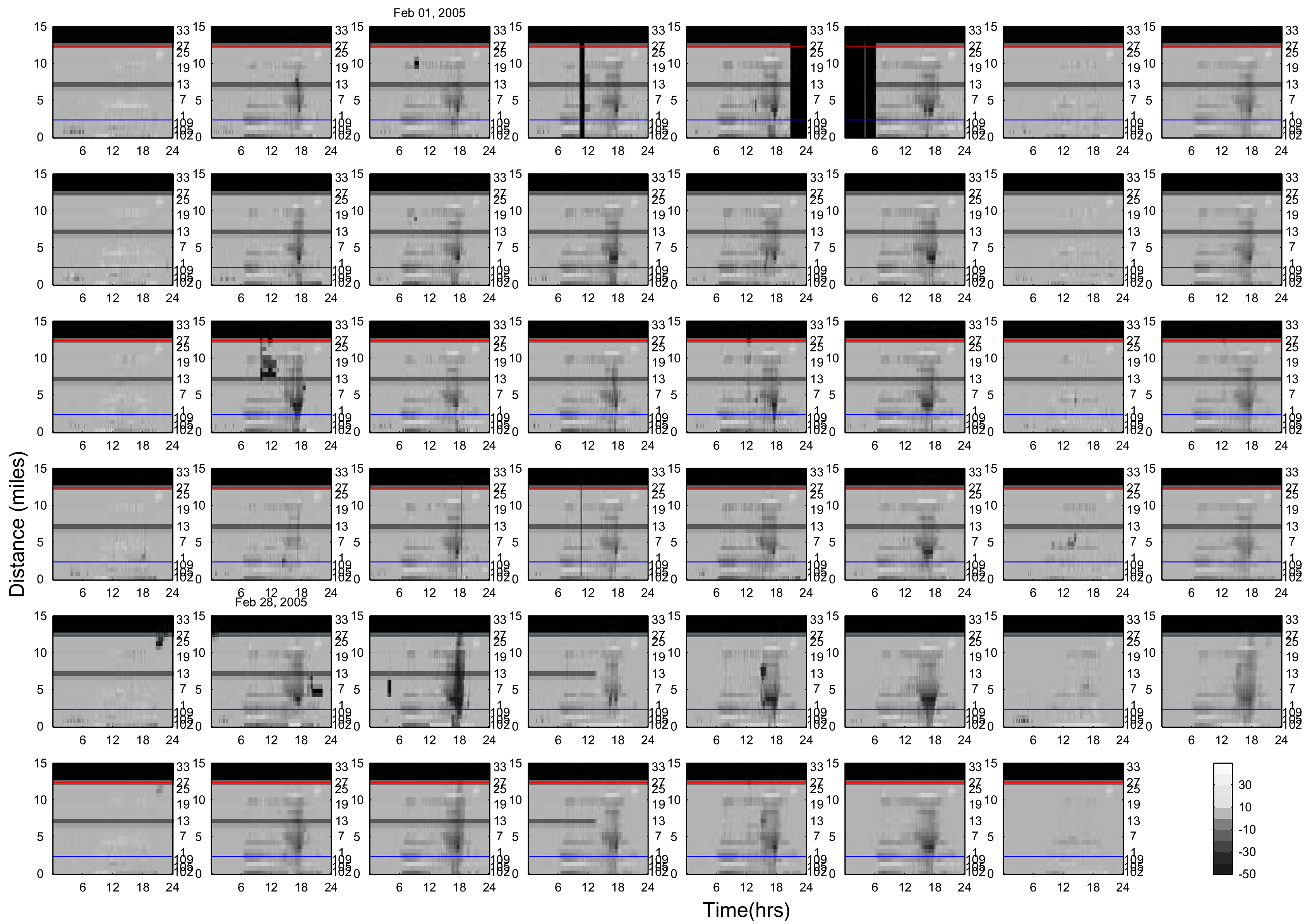
-10
-30
-50



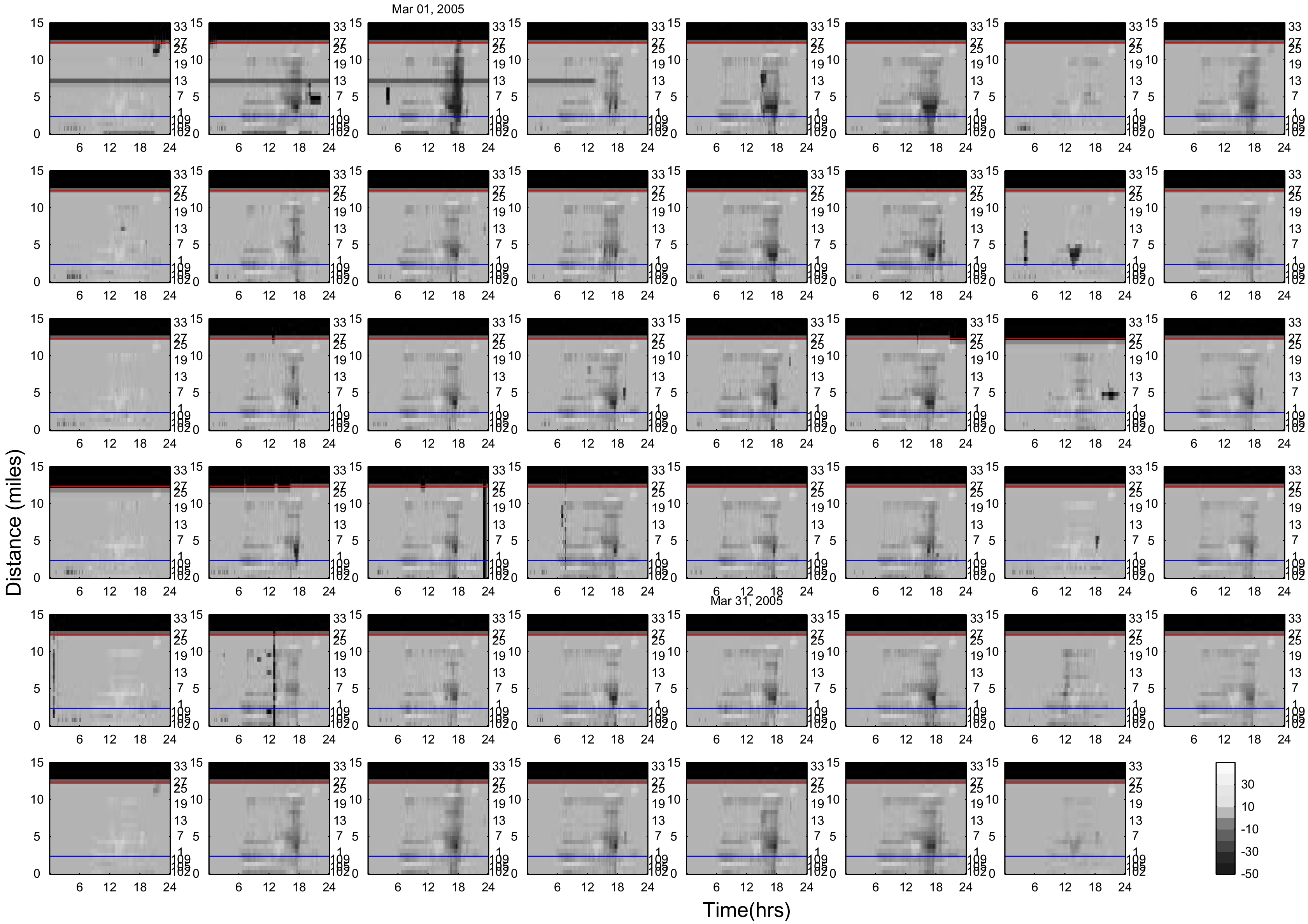
Dec 01, 2004
Dec 31, 2004
Distance (miles)
Time(hrs)



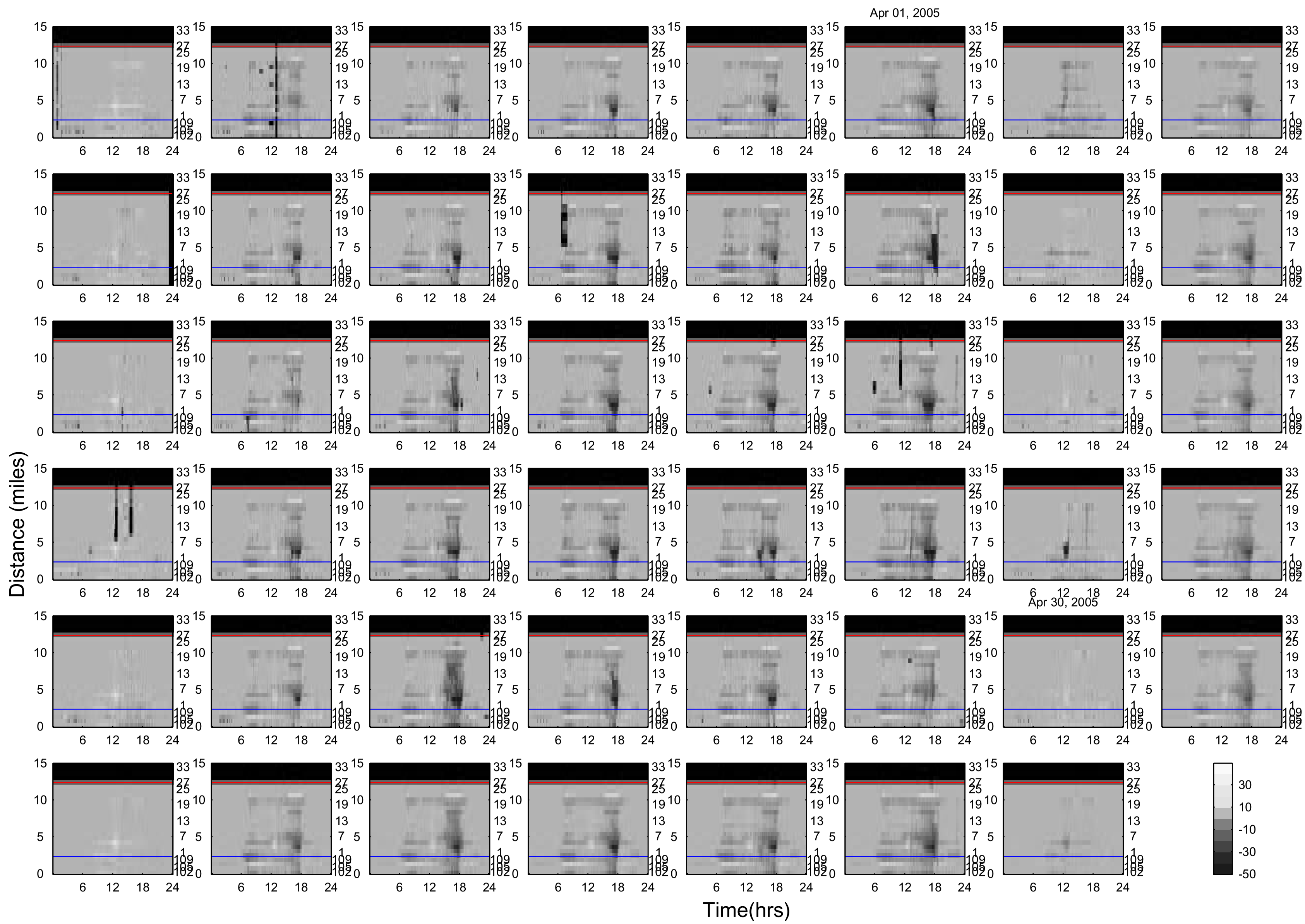
Jan 02, 2005
Jan 31, 2005
Distance (miles)
Time(hrs)



Feb 01, 2005
Feb 28, 2005
Distance (miles)
Time(hrs)
30
10
-10
-30
-50



Mar 01, 2005
Mar 31, 2005
Distance (miles)
Time(hrs)
30
10
-10
-30
-50



Apr 01, 2005
Apr 30, 2005
Distance (miles)
Time(hrs)
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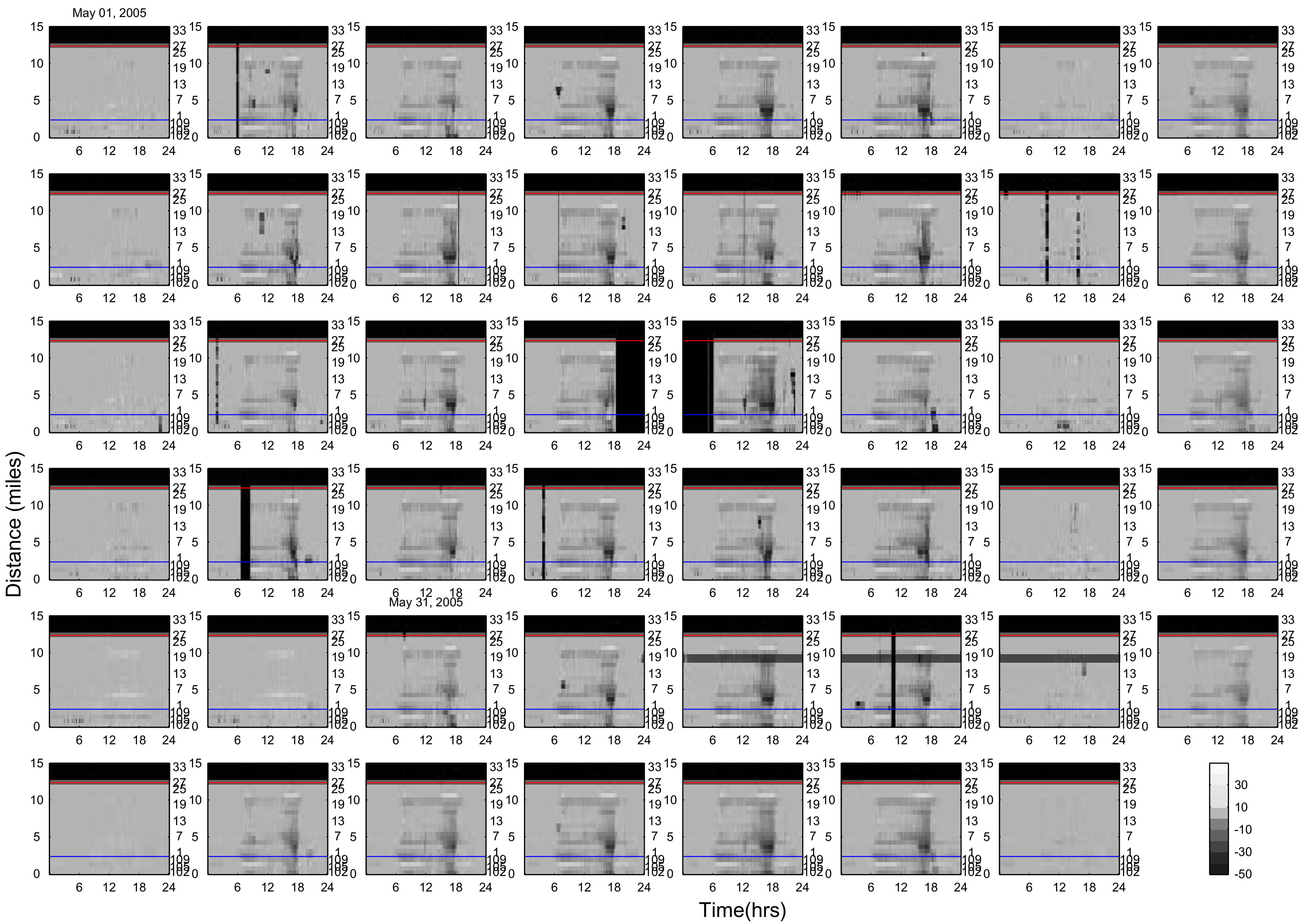
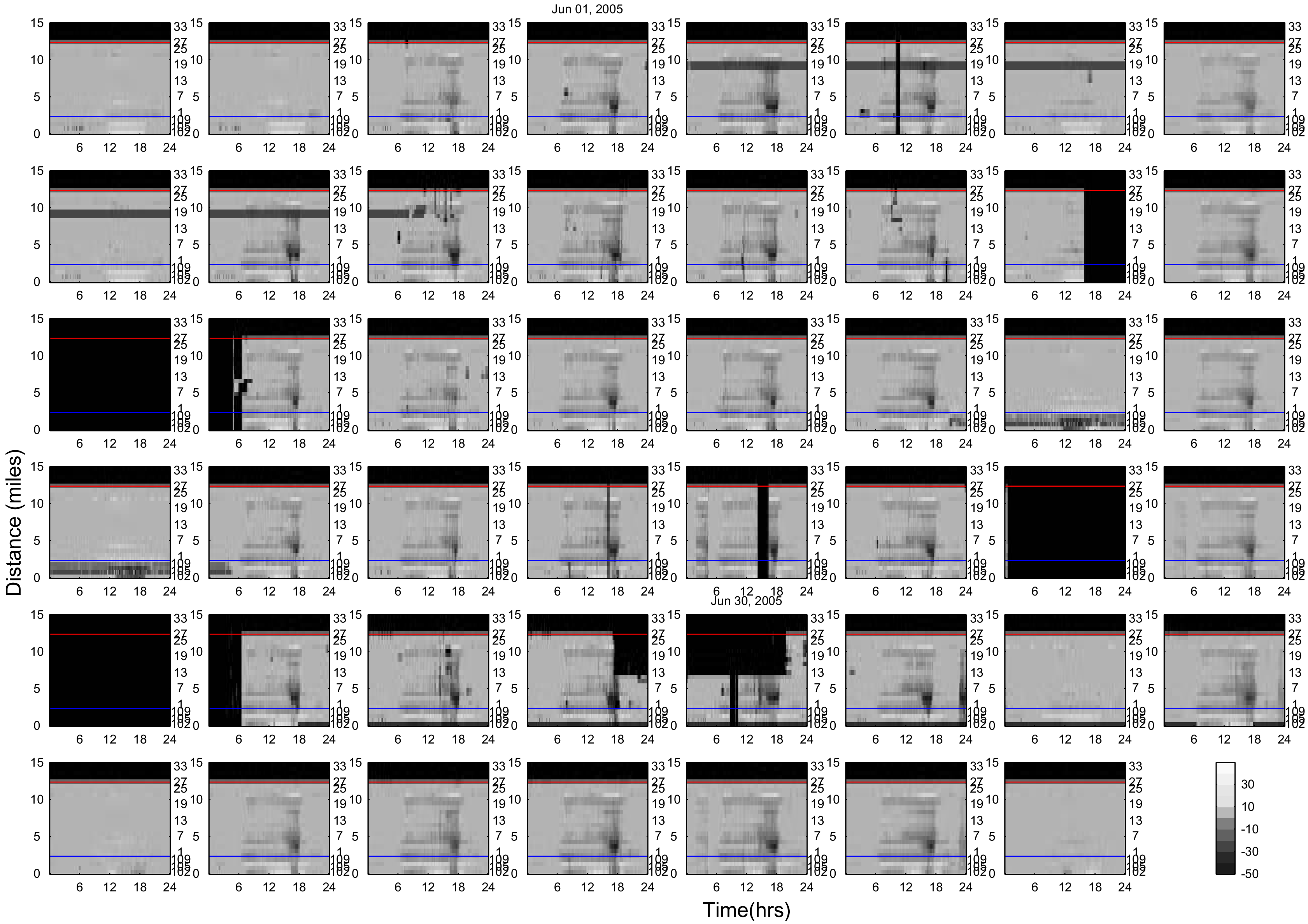
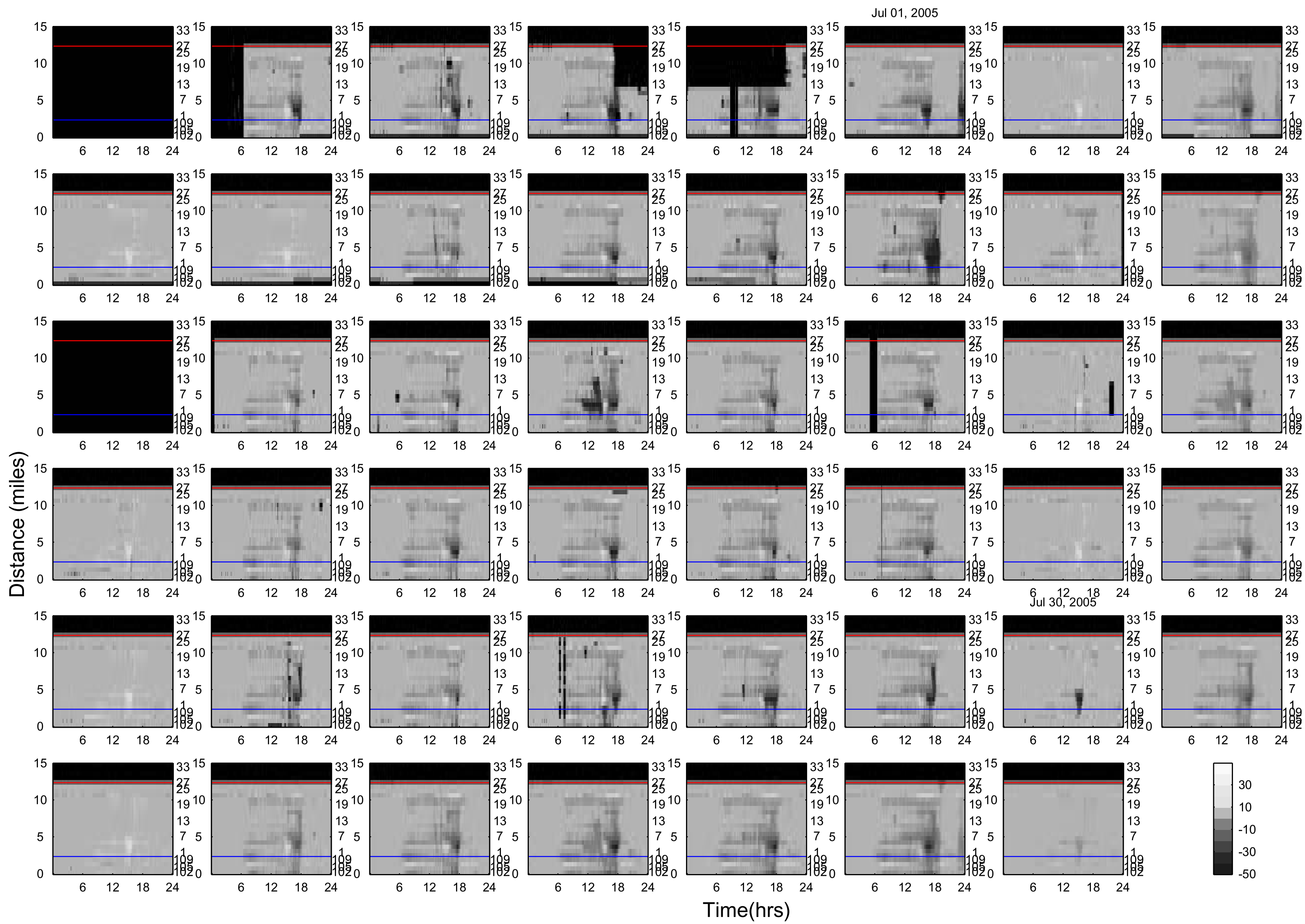
-10
-30
-50

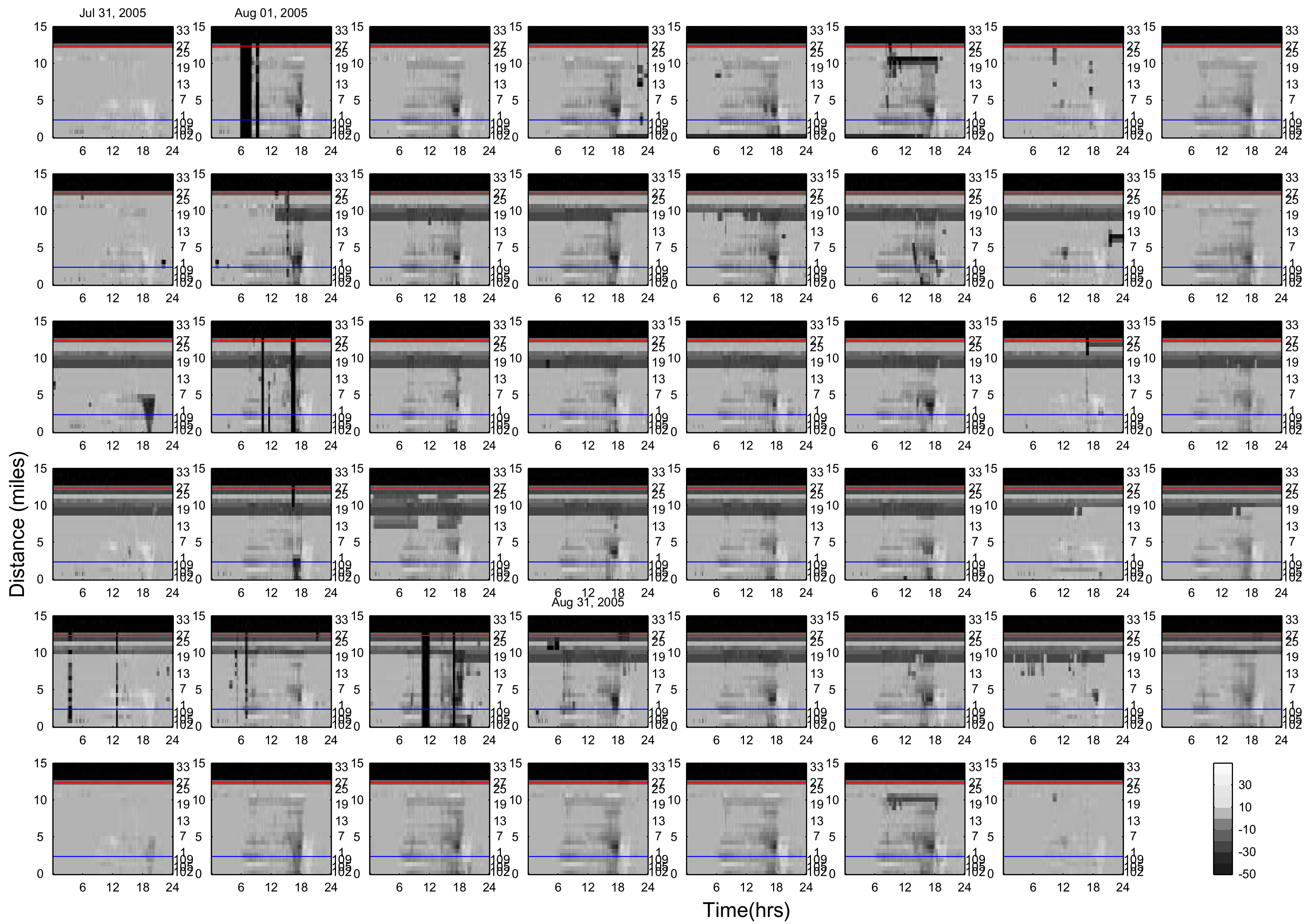

May 01, 2005
May 31, 2005
Distance (miles)
Time(hrs)
30
10
-10
-30
-50



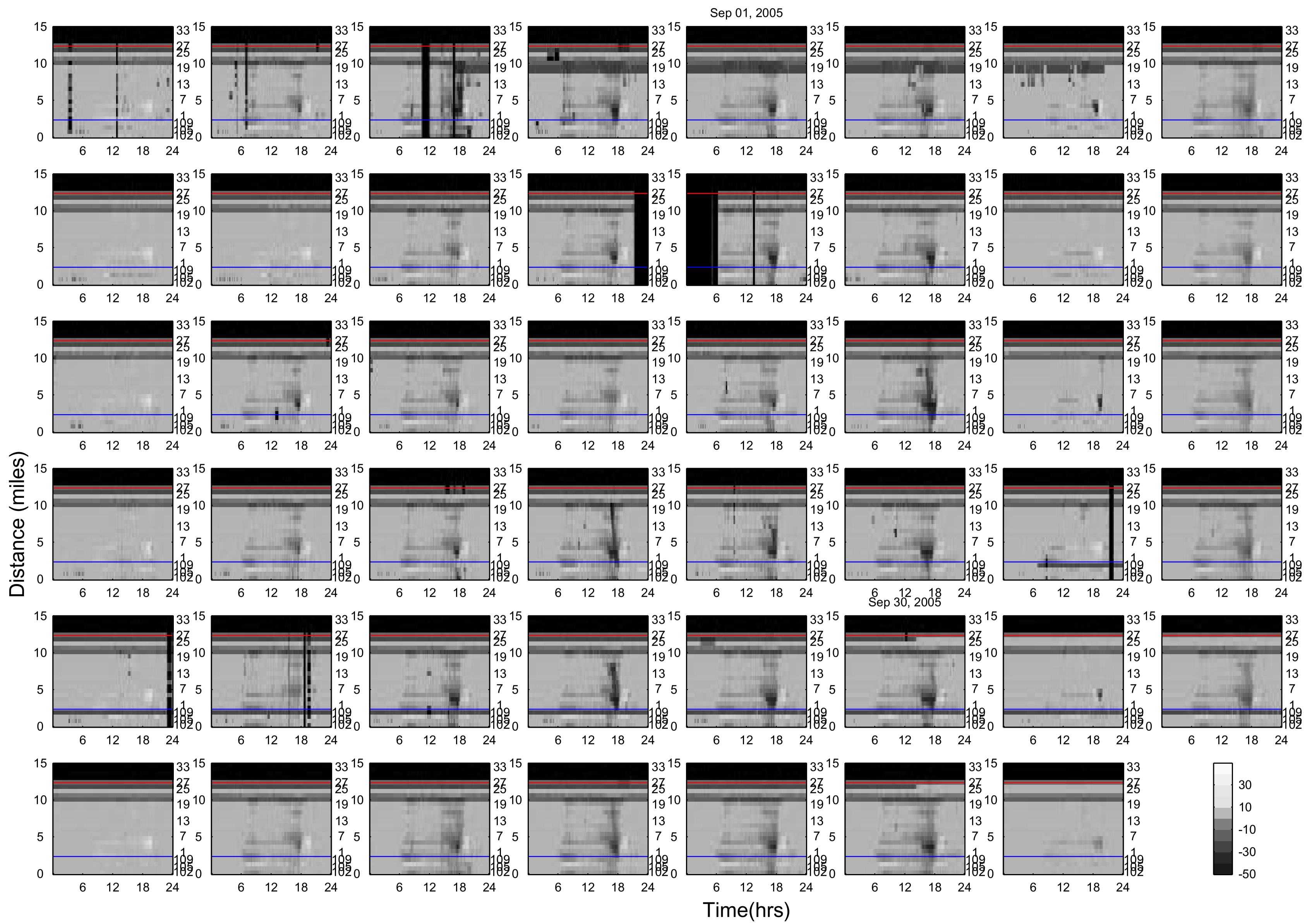
Jun 01, 2005
Jun 30, 2005
Distance (miles)
Time(hrs)



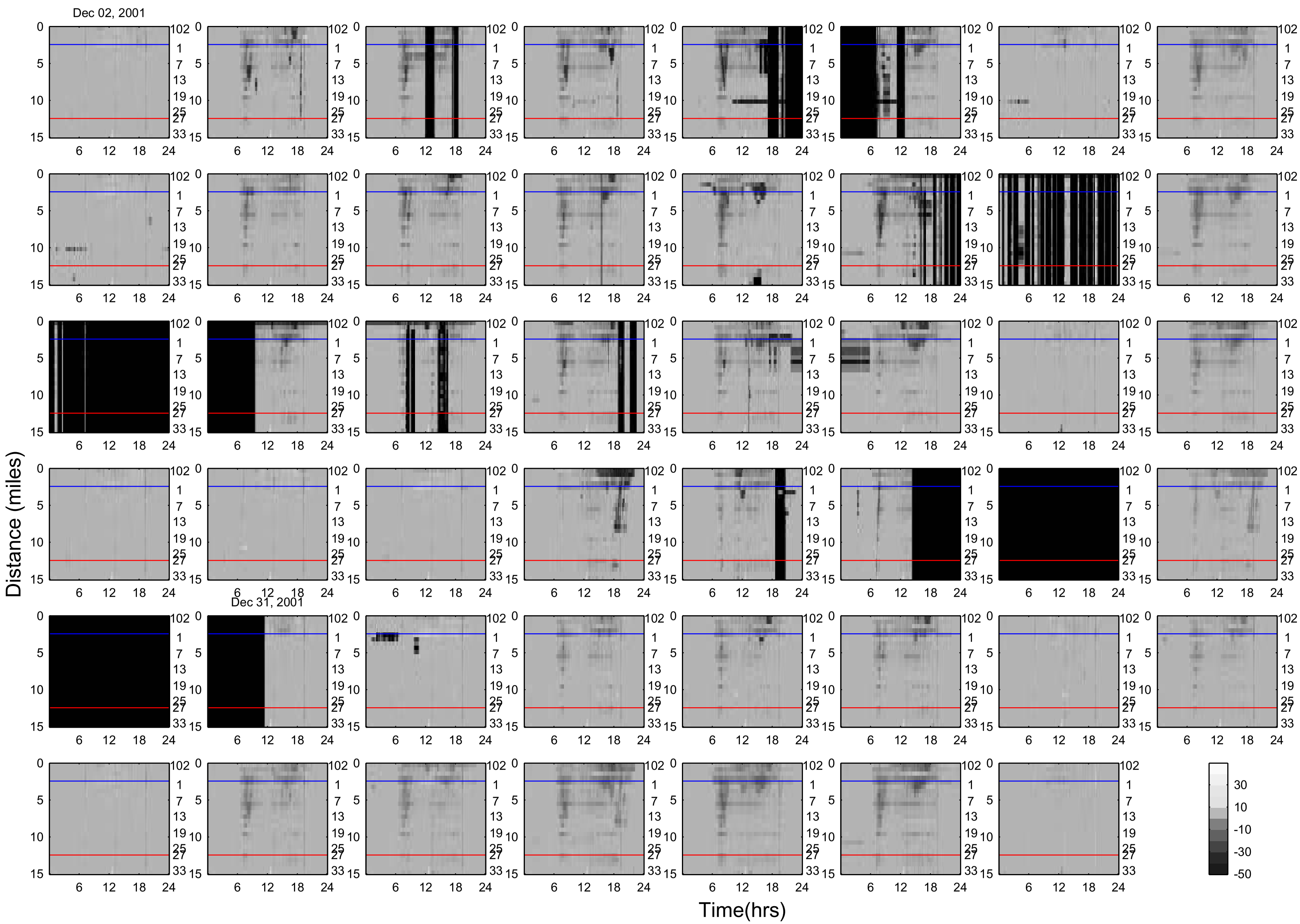
Jul 01, 2005
Jul 30, 2005
Distance (miles)
Time(hrs)
30
10
-10
-30
-50



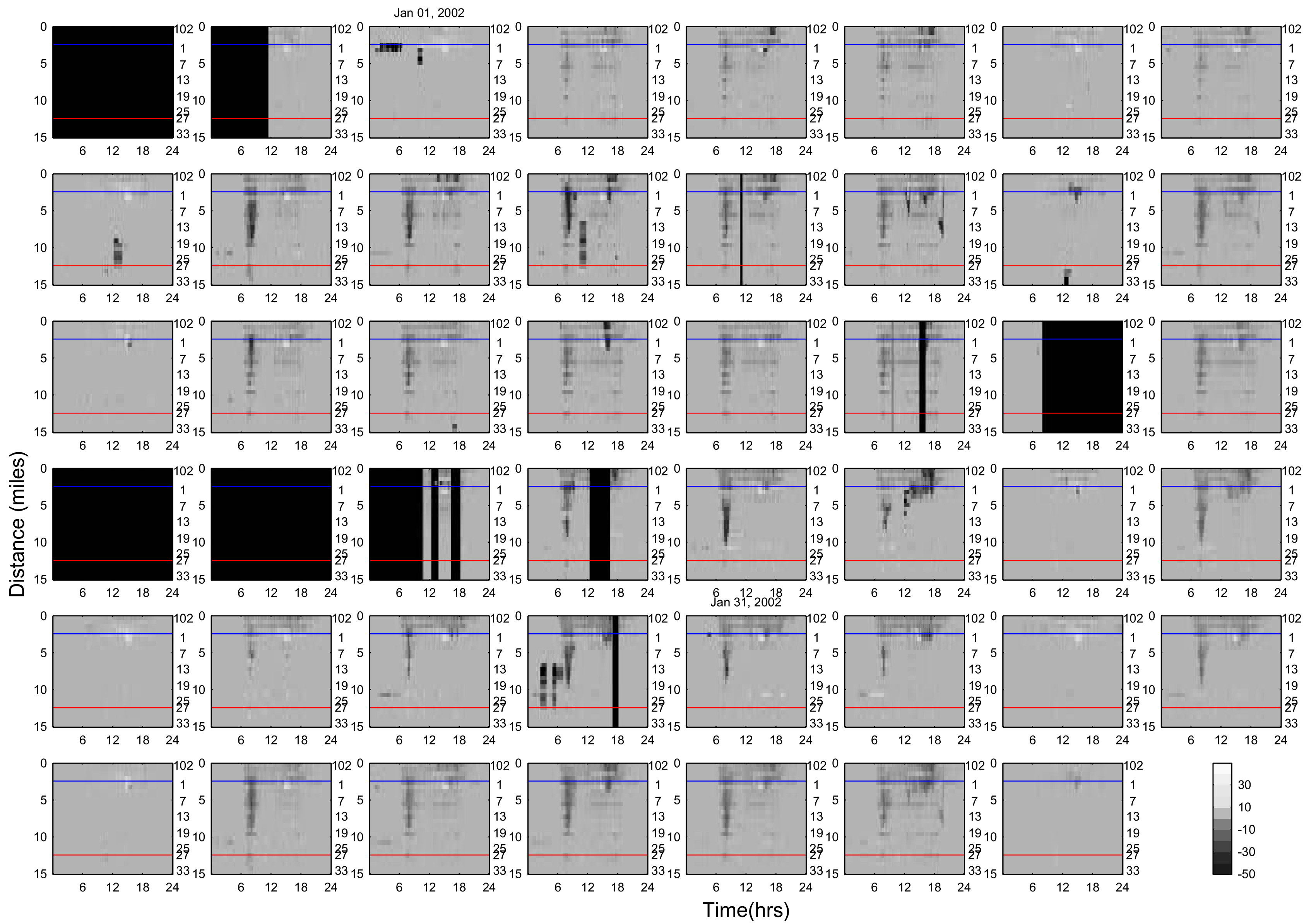
Jul 31, 2005
Aug 01, 2005
Aug 31, 2005
Distance (miles)
Time(hrs)


Sep 01, 2005
Sep 30, 2005
Distance (miles)
Time(hrs)
30
10
-10
-30
-50

SOUTHBOUND



Dec 02, 2001
Dec 31, 2001
Distance (miles)
Time(hrs)


Jan 01, 2002
Jan 31, 2002
Distance (miles)
Time(hrs)
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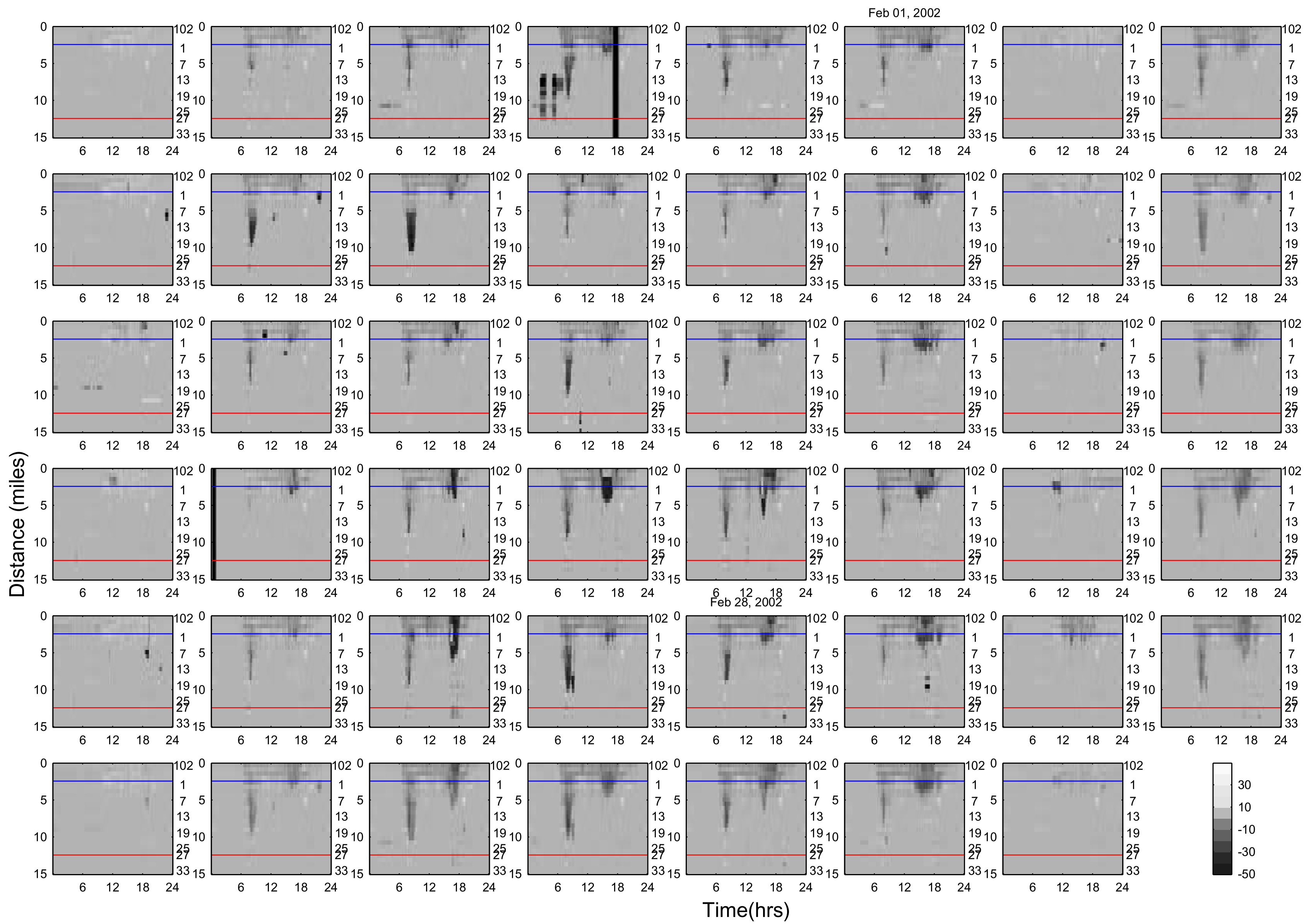
-10
-30
-50


Feb 01, 2002
Feb 28, 2002
Distance (miles)
Time(hrs)
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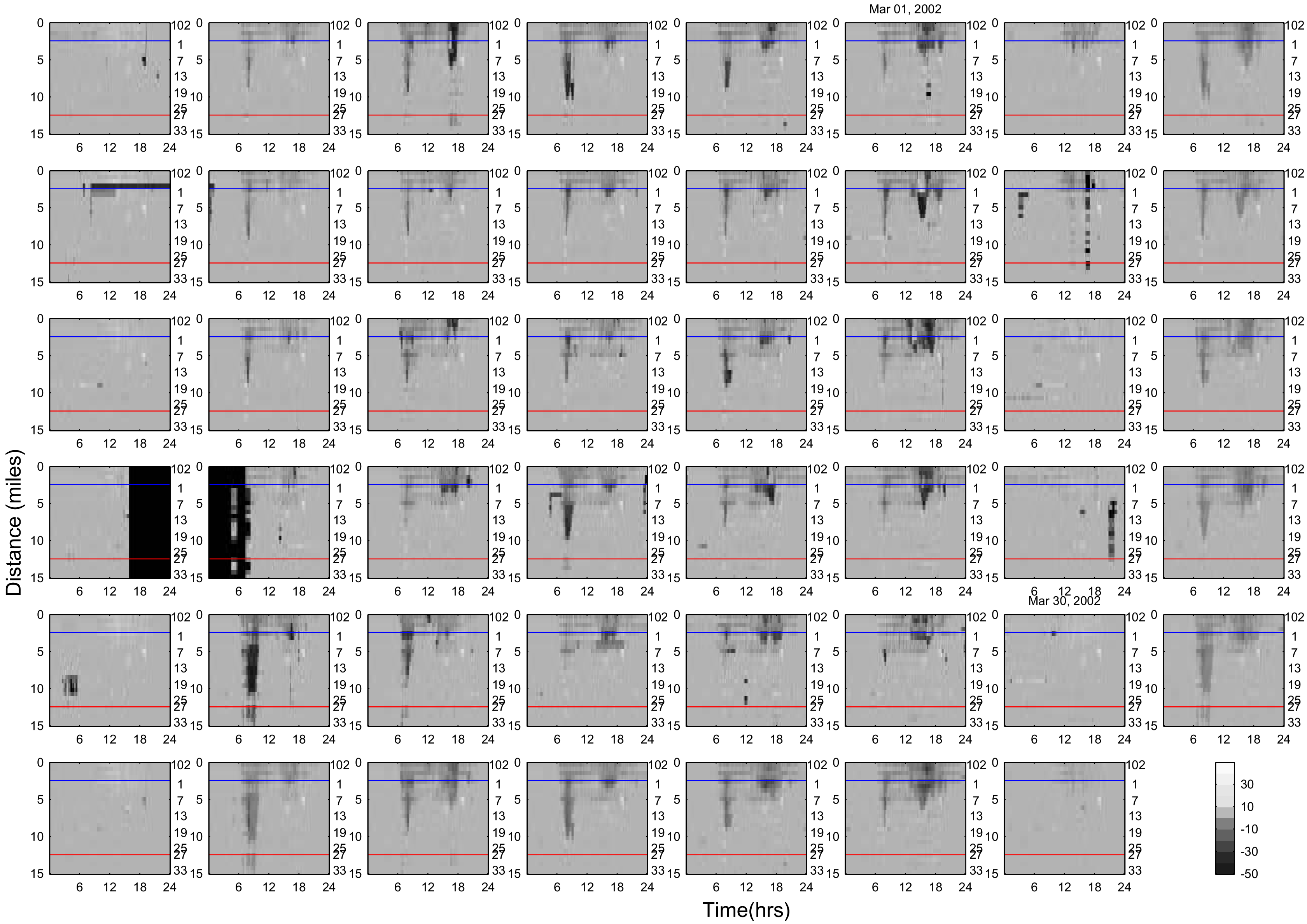
-10
-30
-50


Mar 01, 2002
Mar 30, 2002
Distance (miles)
Time(hrs)
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-30
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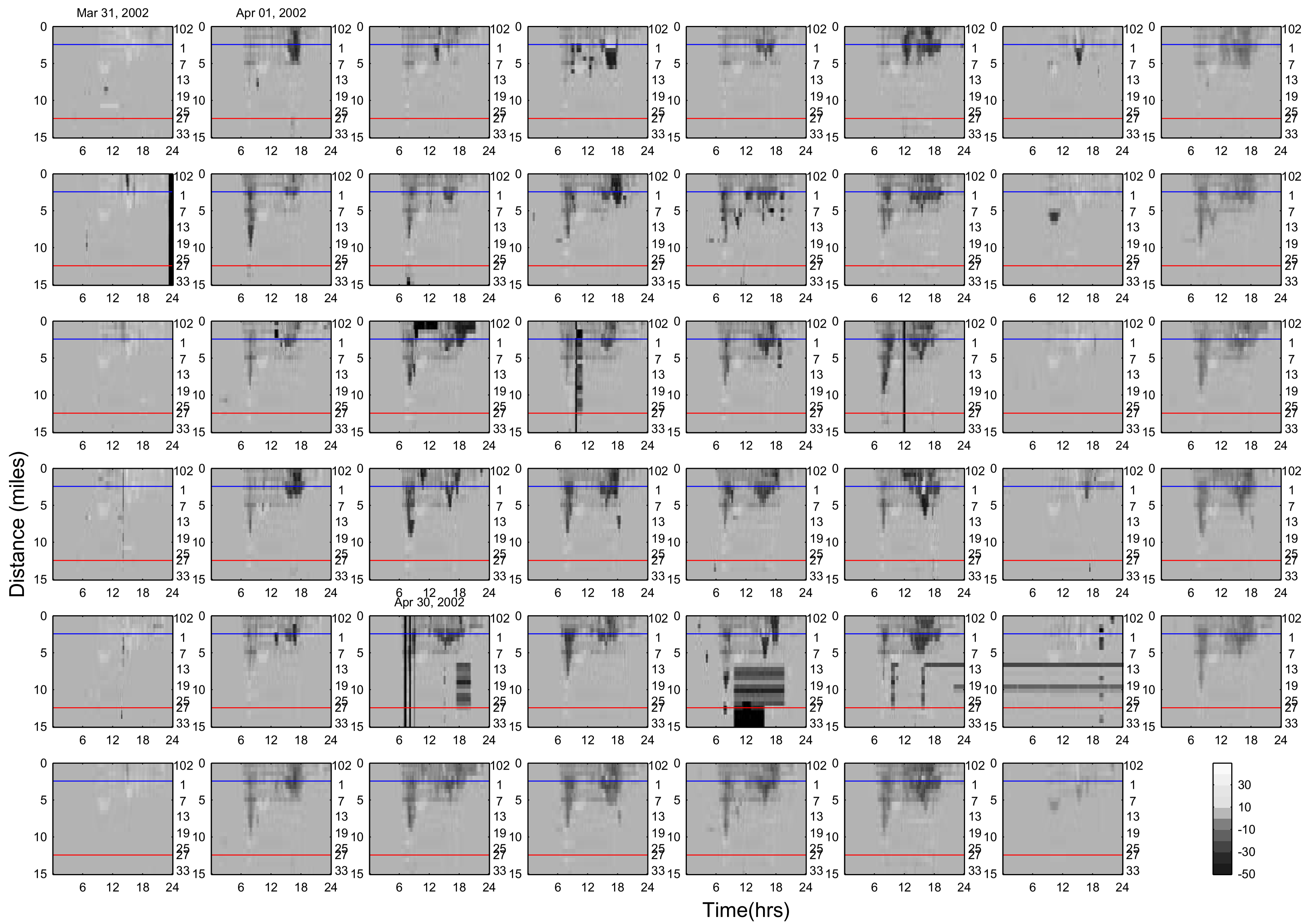
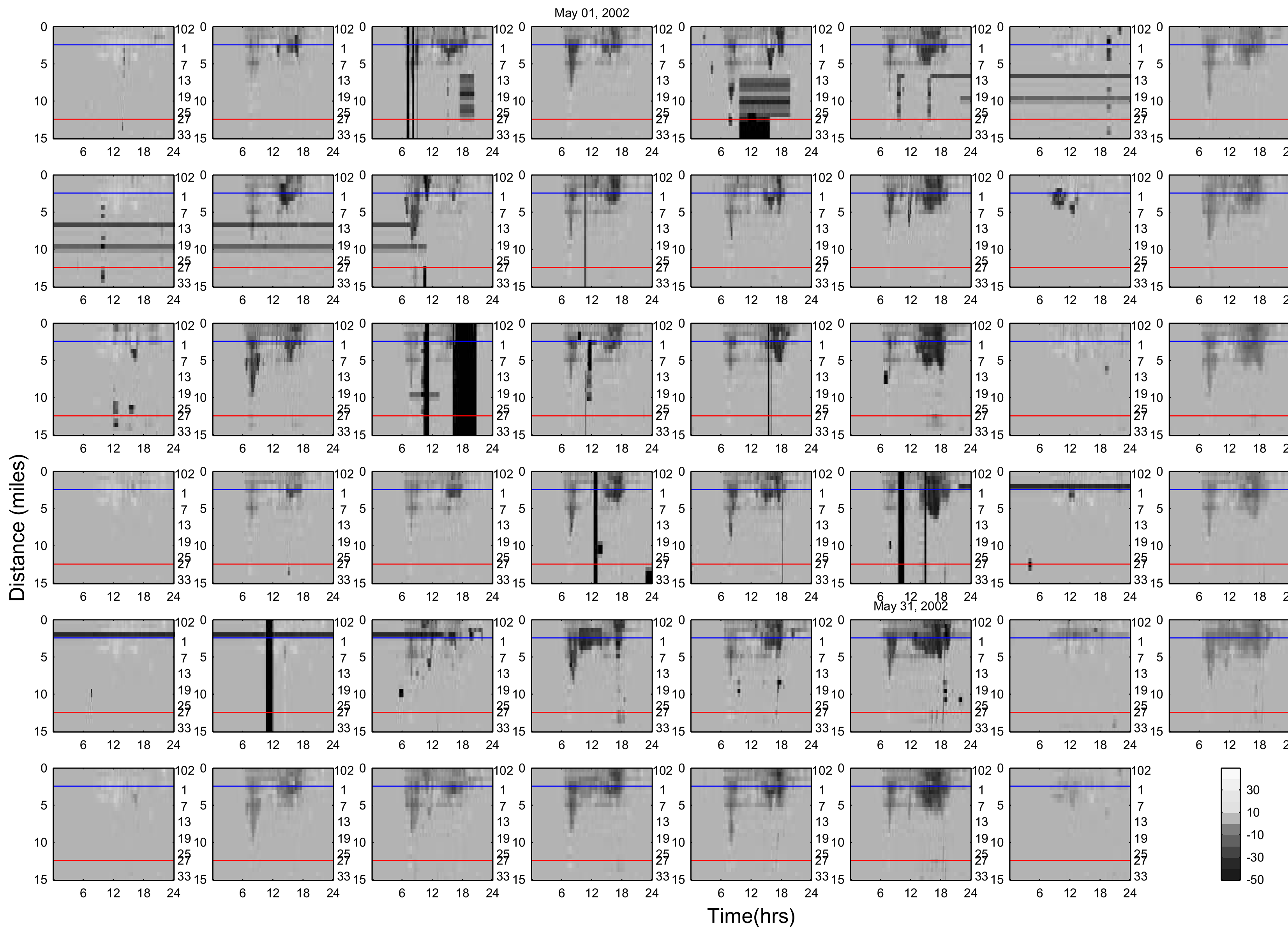


Mar 31, 2002
Apr 01, 2002
Apr 30, 2002
Distance (miles)
Time(hrs)


May 01, 2002
May 31, 2002
Distance (miles)
Time(hrs)
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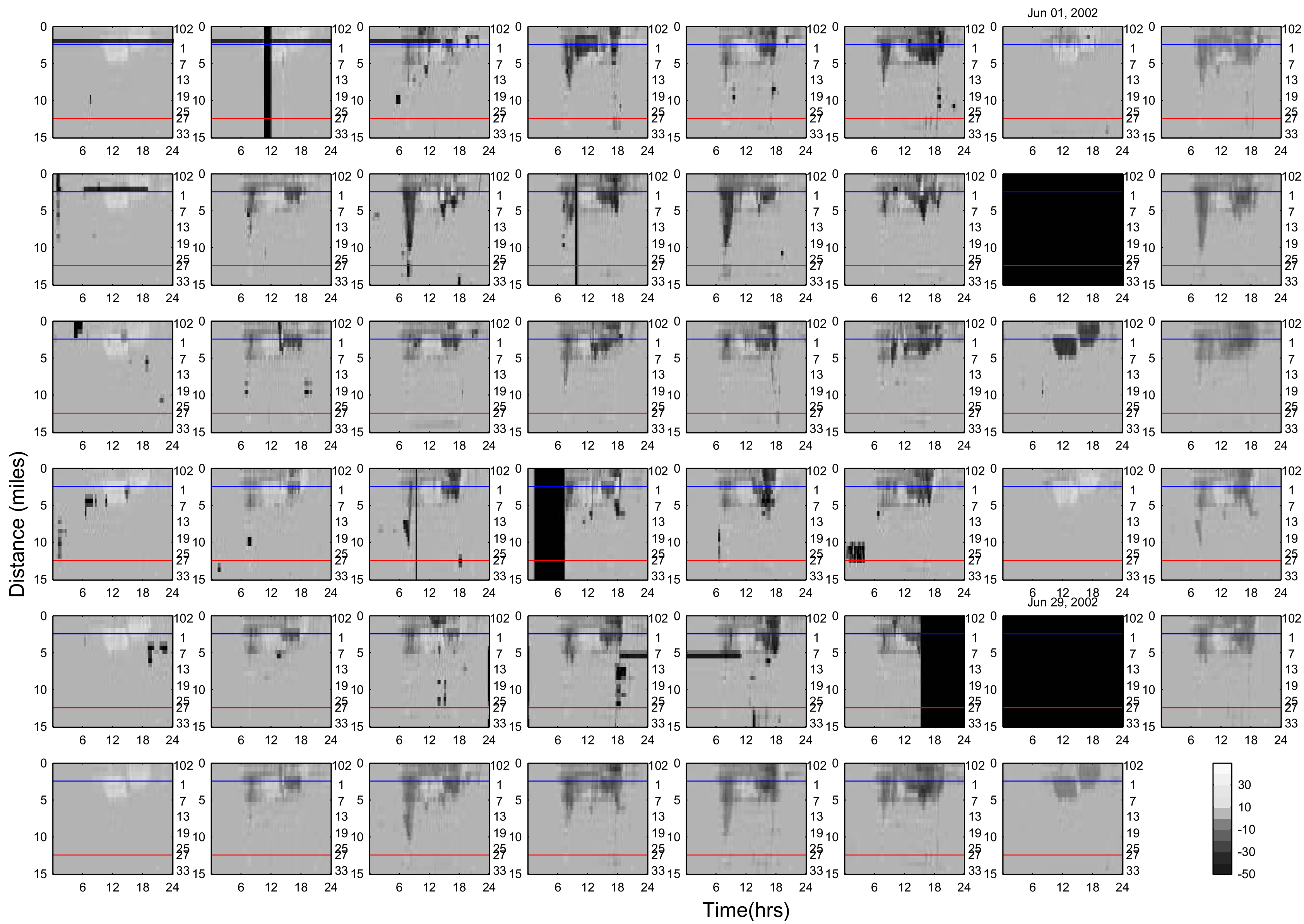
Jun 01, 2002
Jun 29, 2002
Distance (miles)
Time(hrs)
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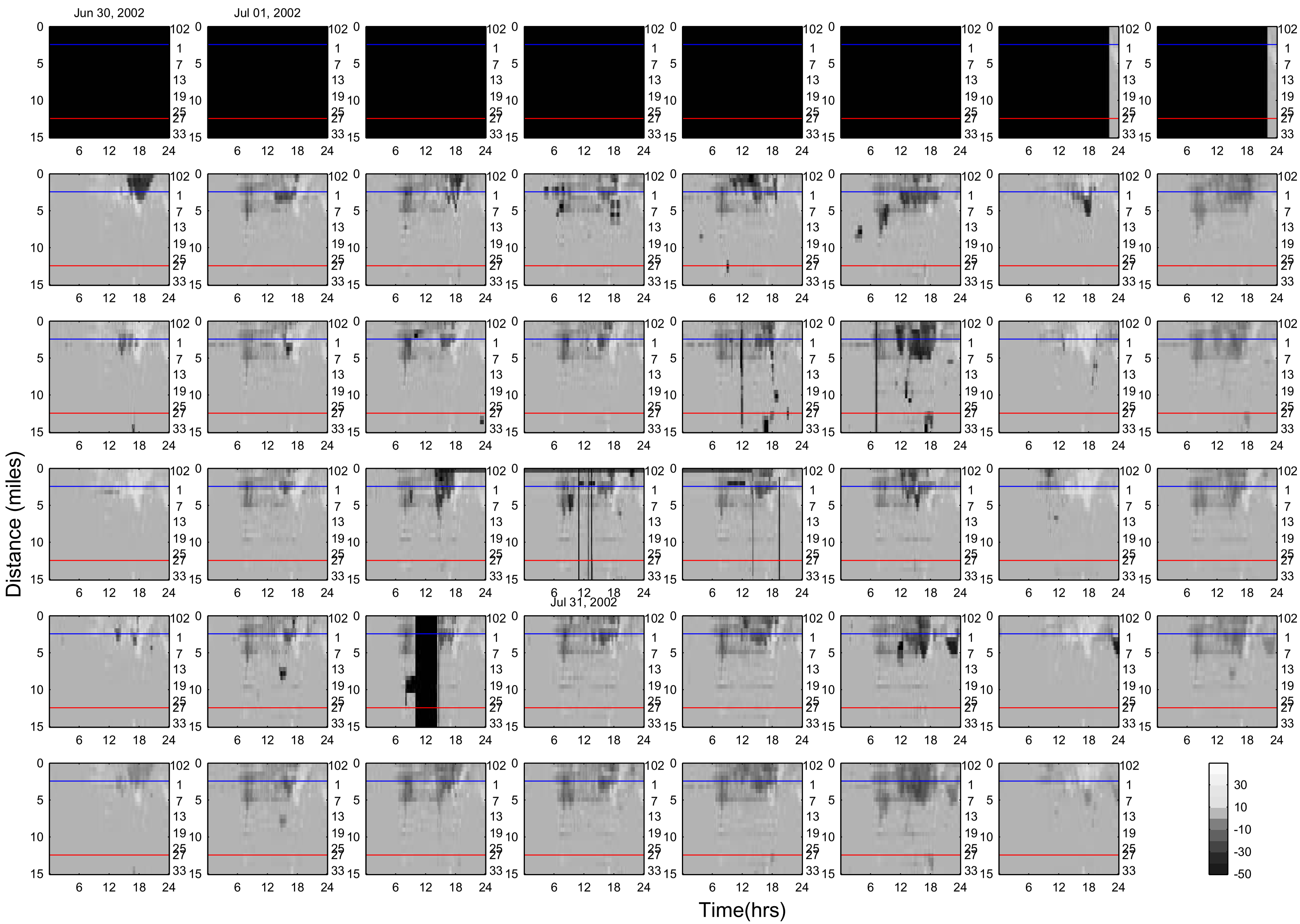
Jun 30, 2002
Jul 01, 2002
Jul 31, 2002
Distance (miles)
Time(hrs)
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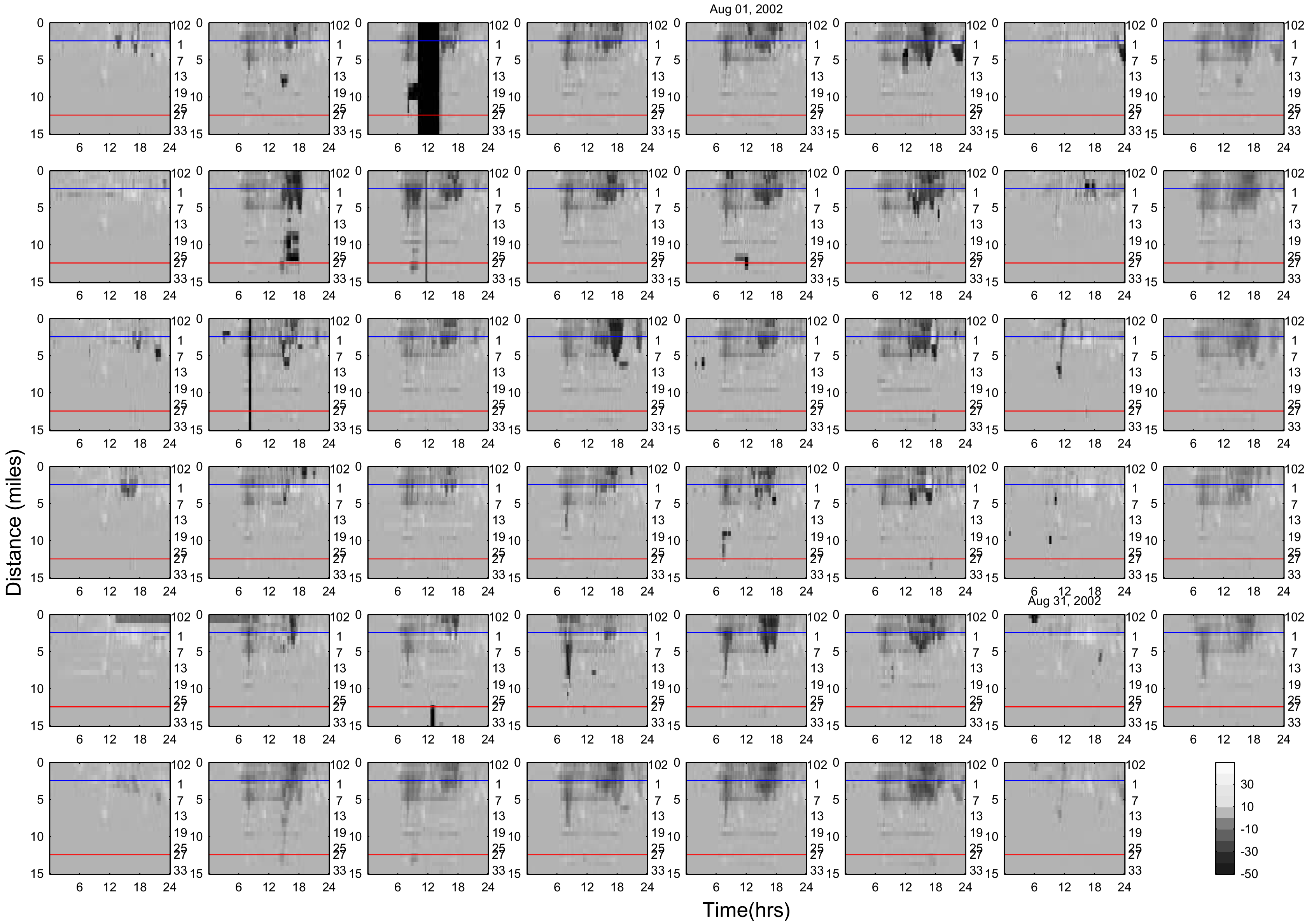
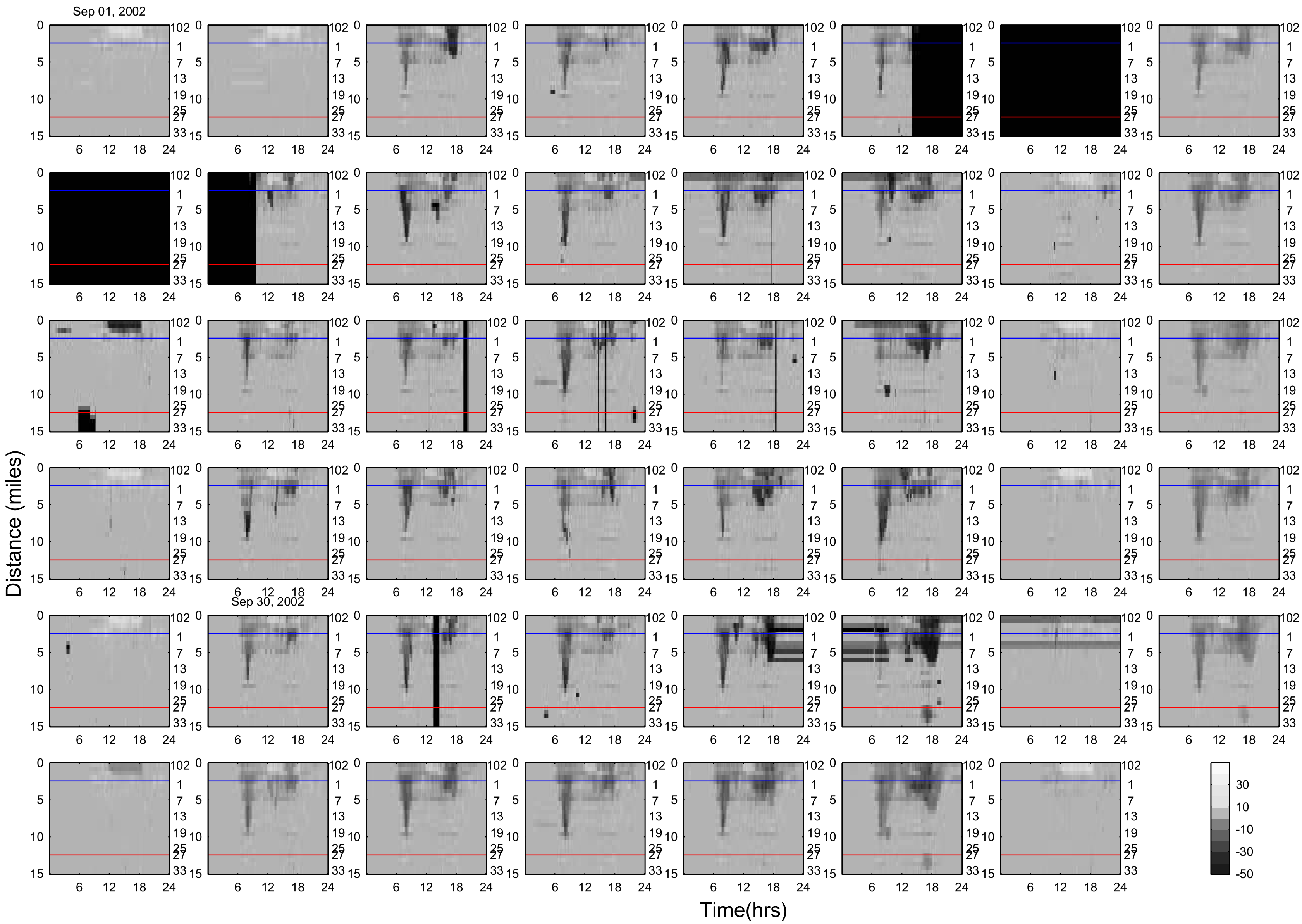
10
-10
-30
-50



Aug 01, 2002
Aug 31, 2002
Distance (miles)
Time(hrs)



Sep 01, 2002
Sep 30, 2002
Distance (miles)
Time(hrs)
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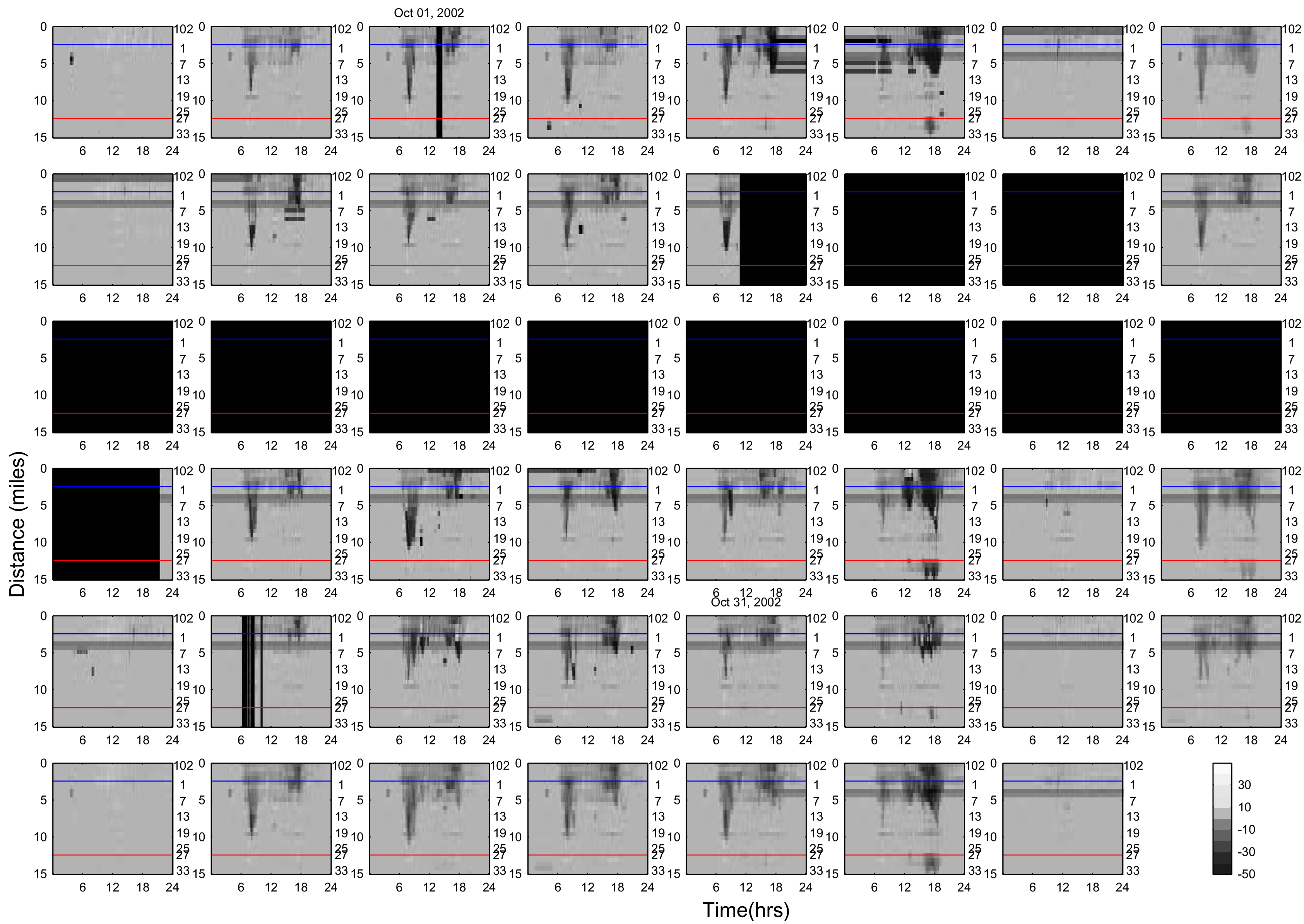
Oct 01, 2002
Oct 31, 2002
Distance (miles)
Time(hrs)
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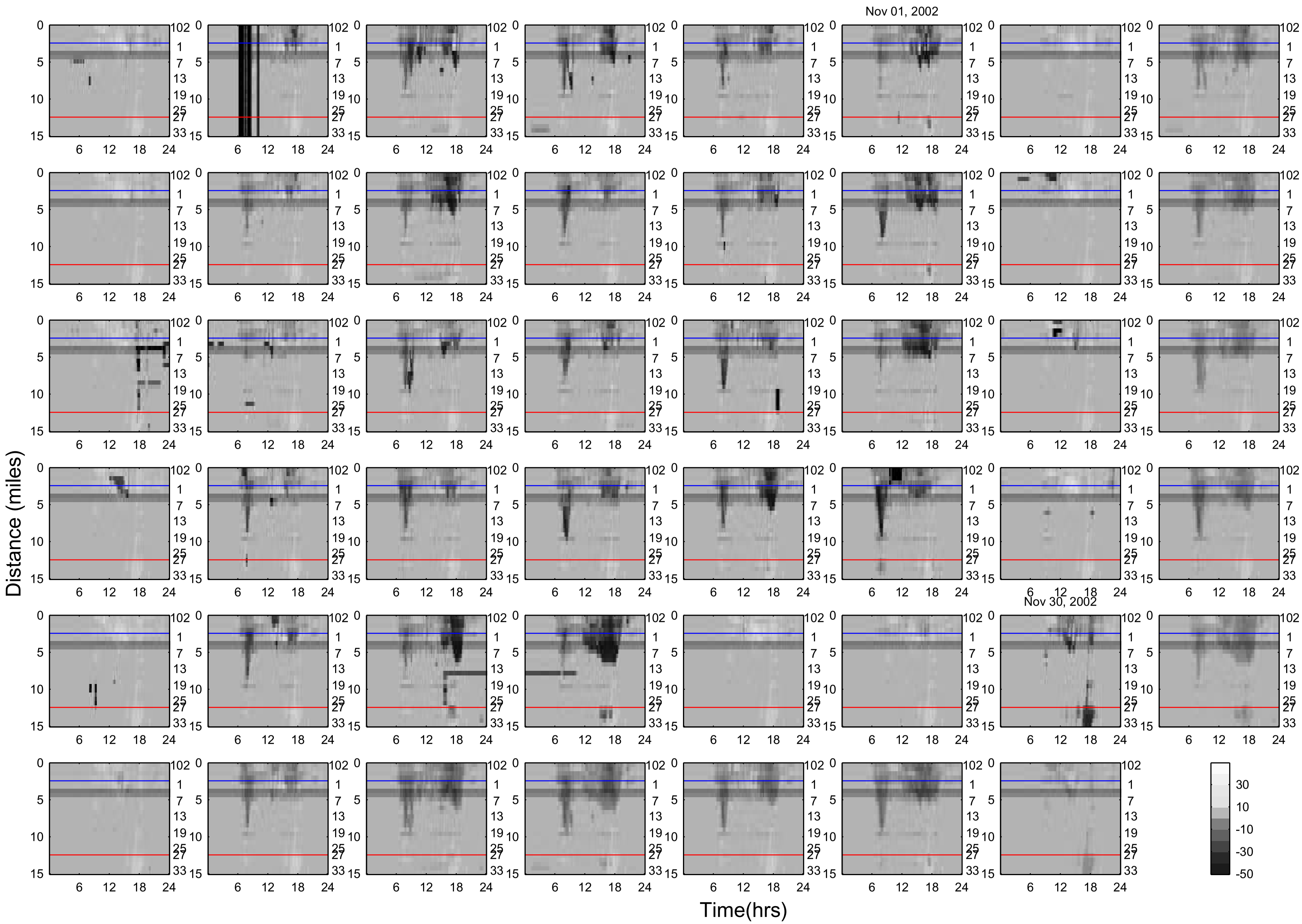

Nov 01, 2002
Nov 30, 2002
Distance (miles)
Time(hrs)
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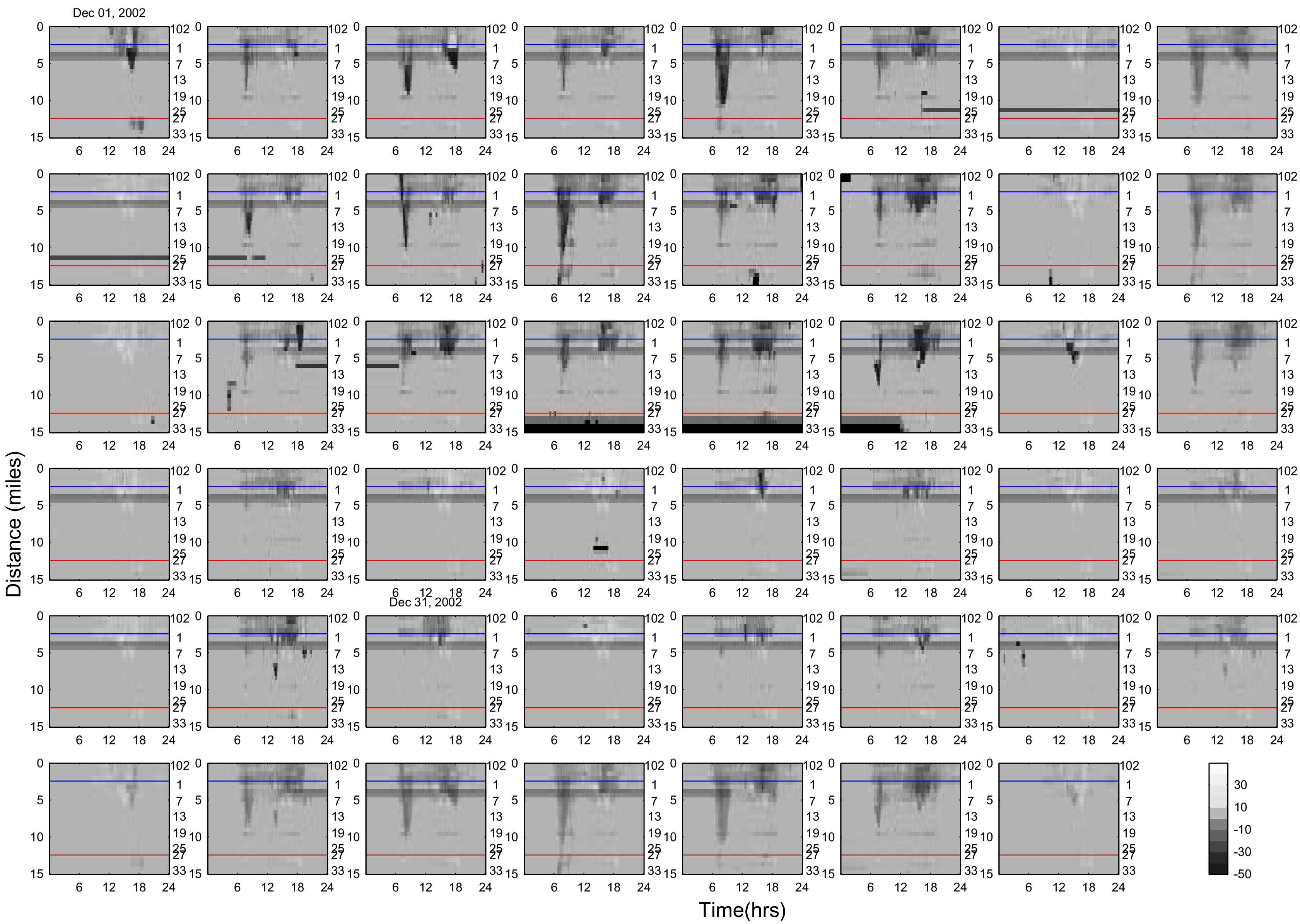
-10
-30
-50



Dec 01, 2002
Dec 31, 2002
Distance (miles)
Time(hrs)
0
5
10
15
6
12
18
24
102
1
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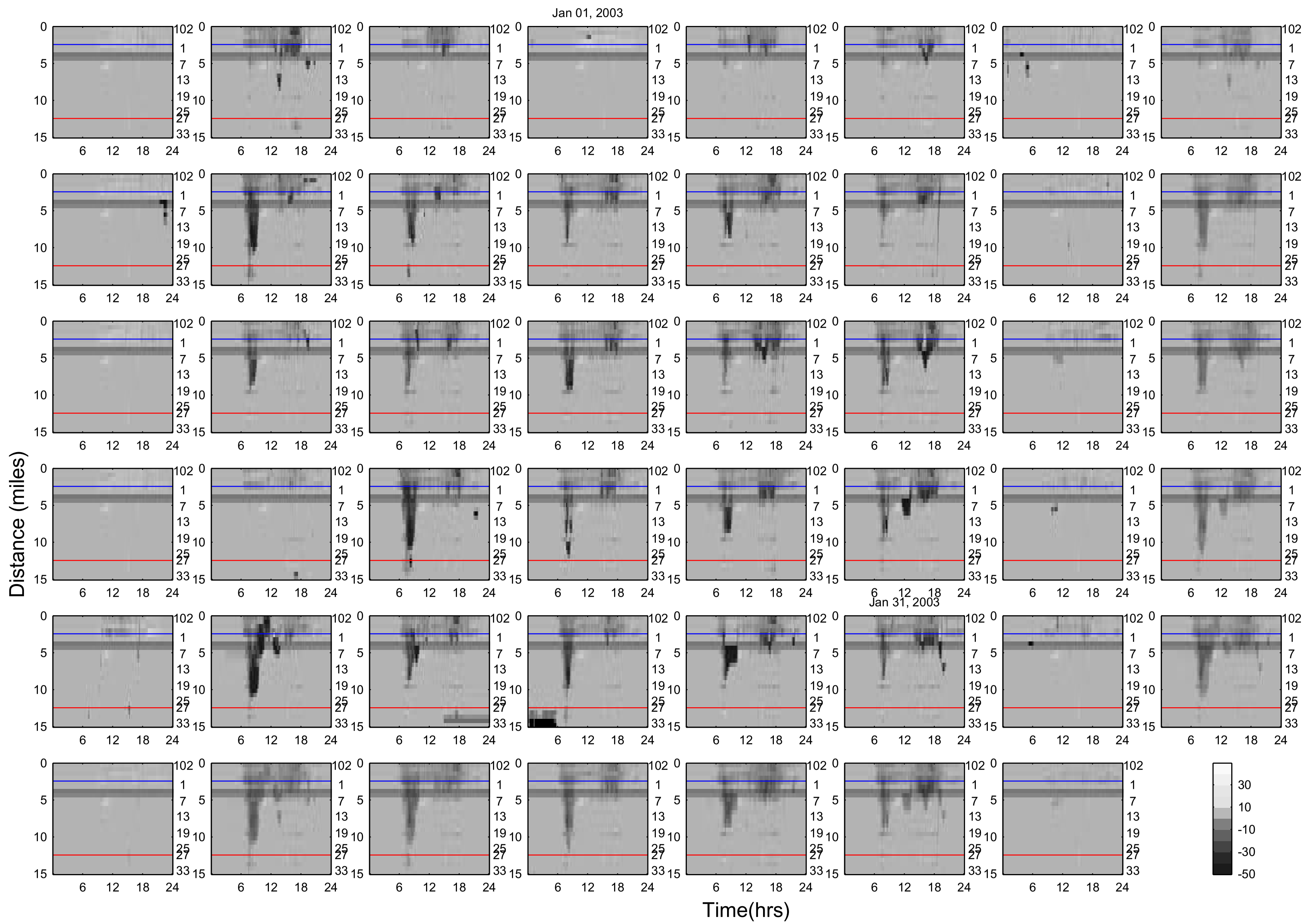
10
-10
-30
-50


Jan 01, 2003
Jan 31, 2003
Distance (miles)
Time(hrs)
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-10
-30
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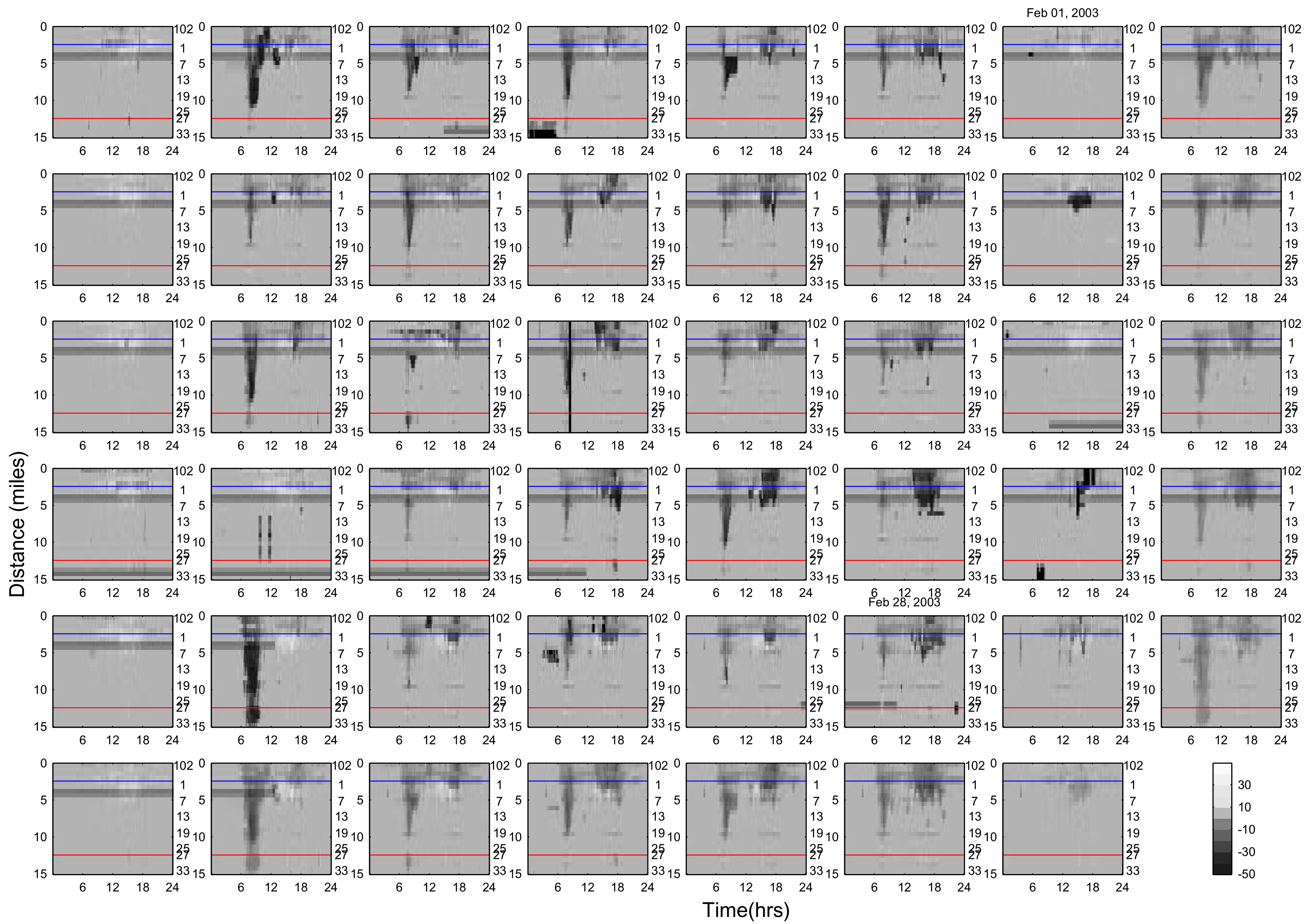

Feb 01, 2003
Feb 28, 2003
Distance (miles)
Time(hrs)
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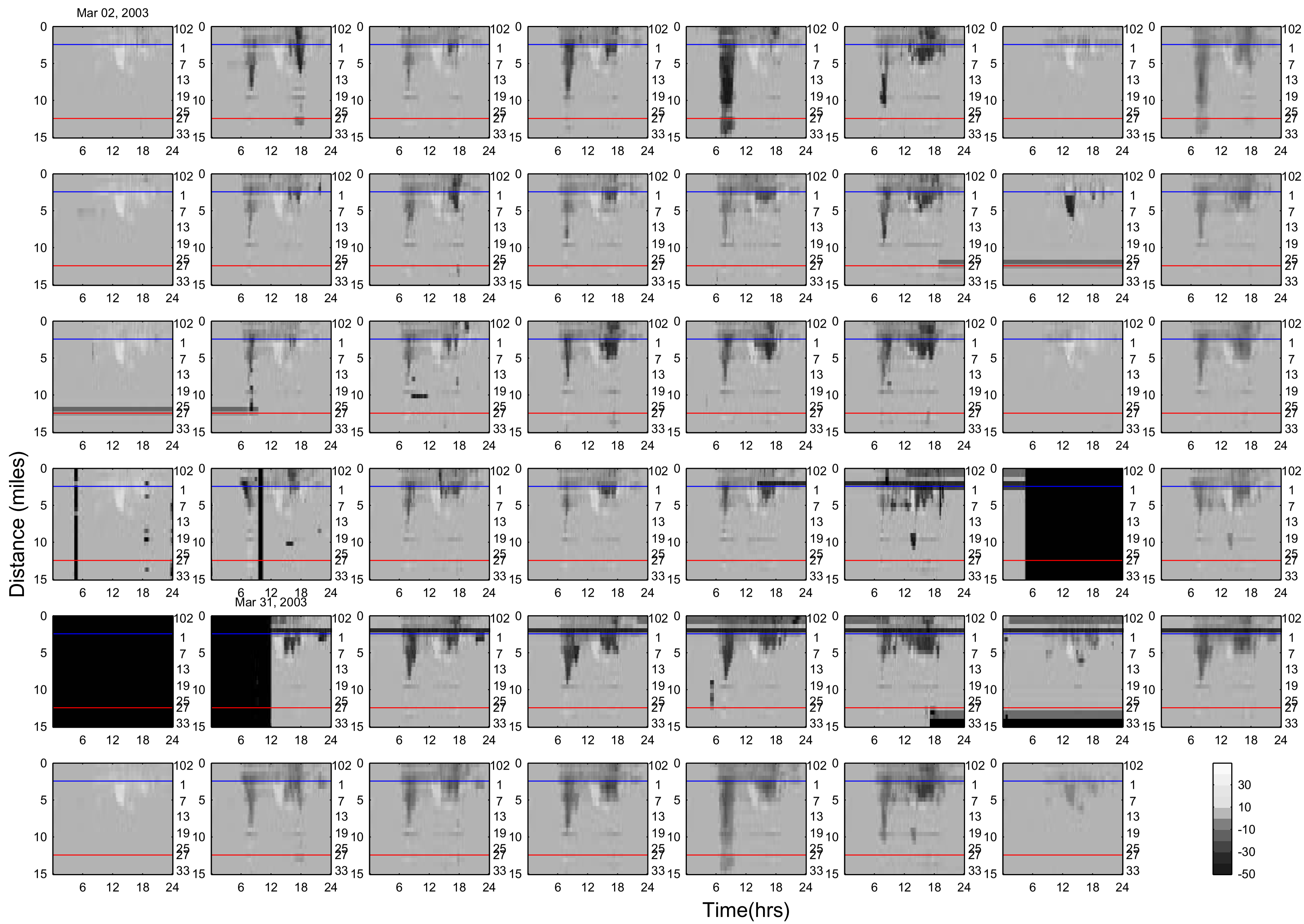
-10
-30
-50



Mar 02, 2003
Mar 31, 2003
Distance (miles)
Time(hrs)
102
1
7
13
19
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33
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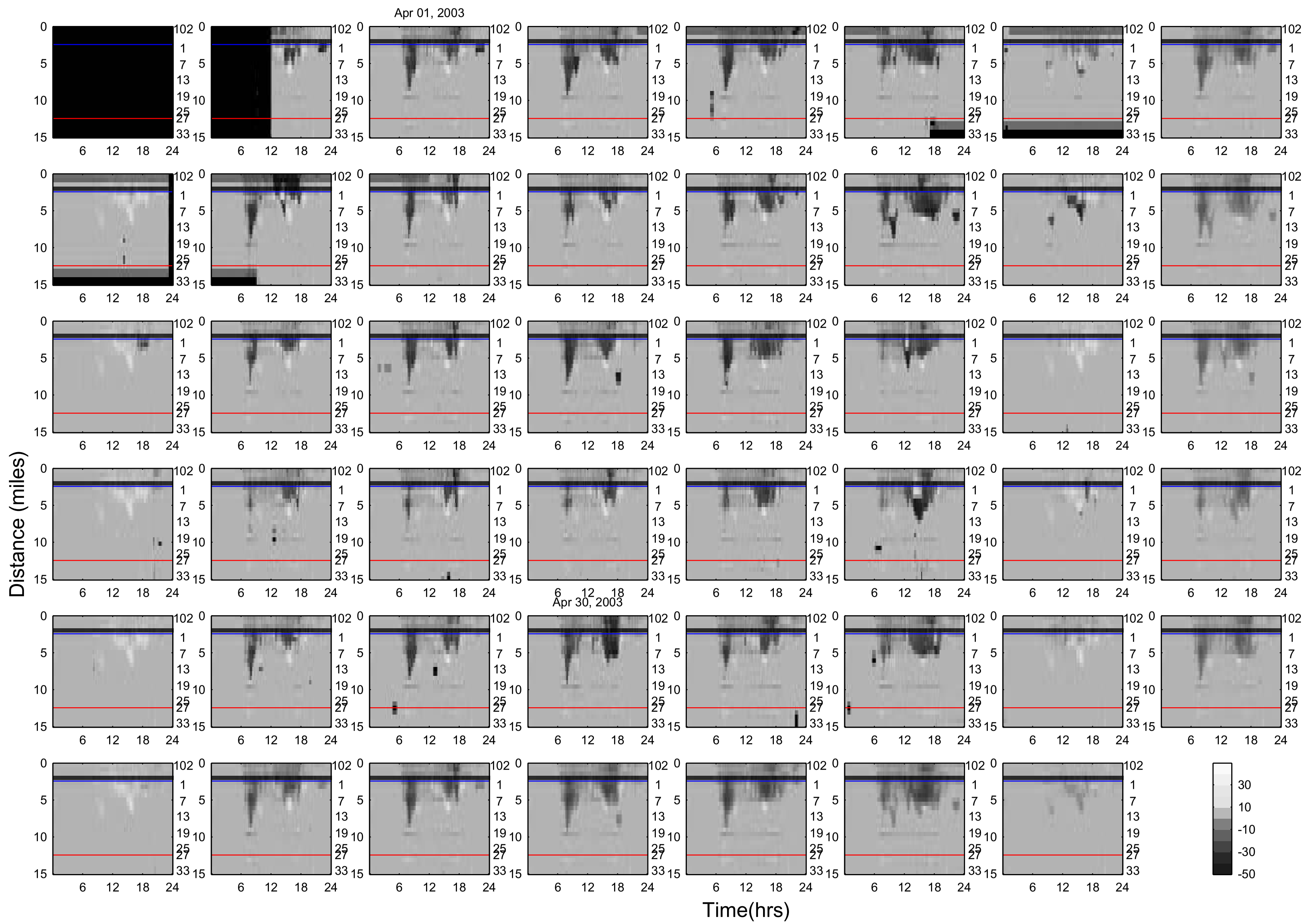
-10
-30
-50



Apr 01, 2003
Apr 30, 2003
Distance (miles)
Time(hrs)
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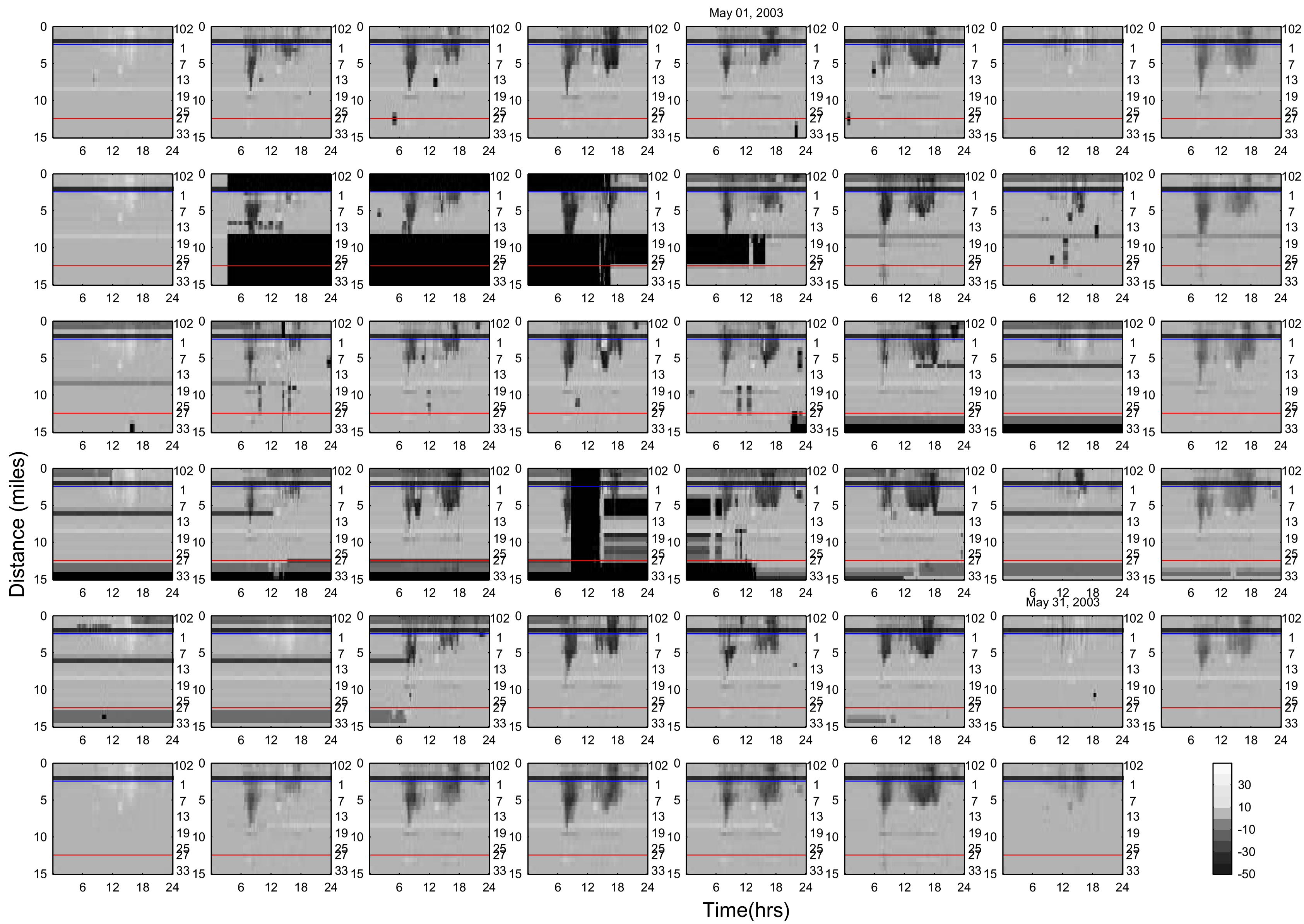

May 01, 2003
May 31, 2003
Distance (miles)
Time(hrs)
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-30
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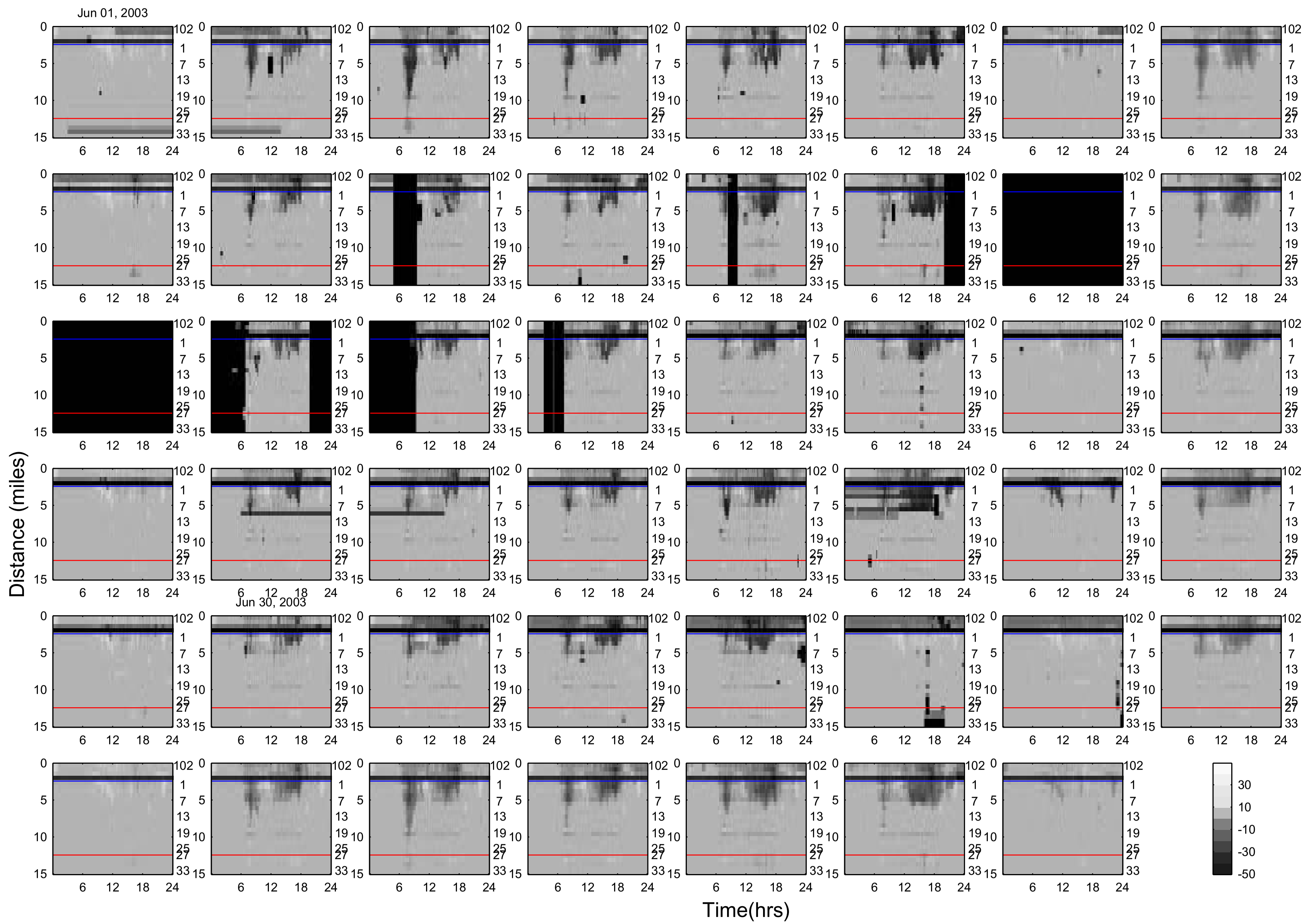

Jun 01, 2003
Jun 30, 2003
Distance (miles)
Time(hrs)
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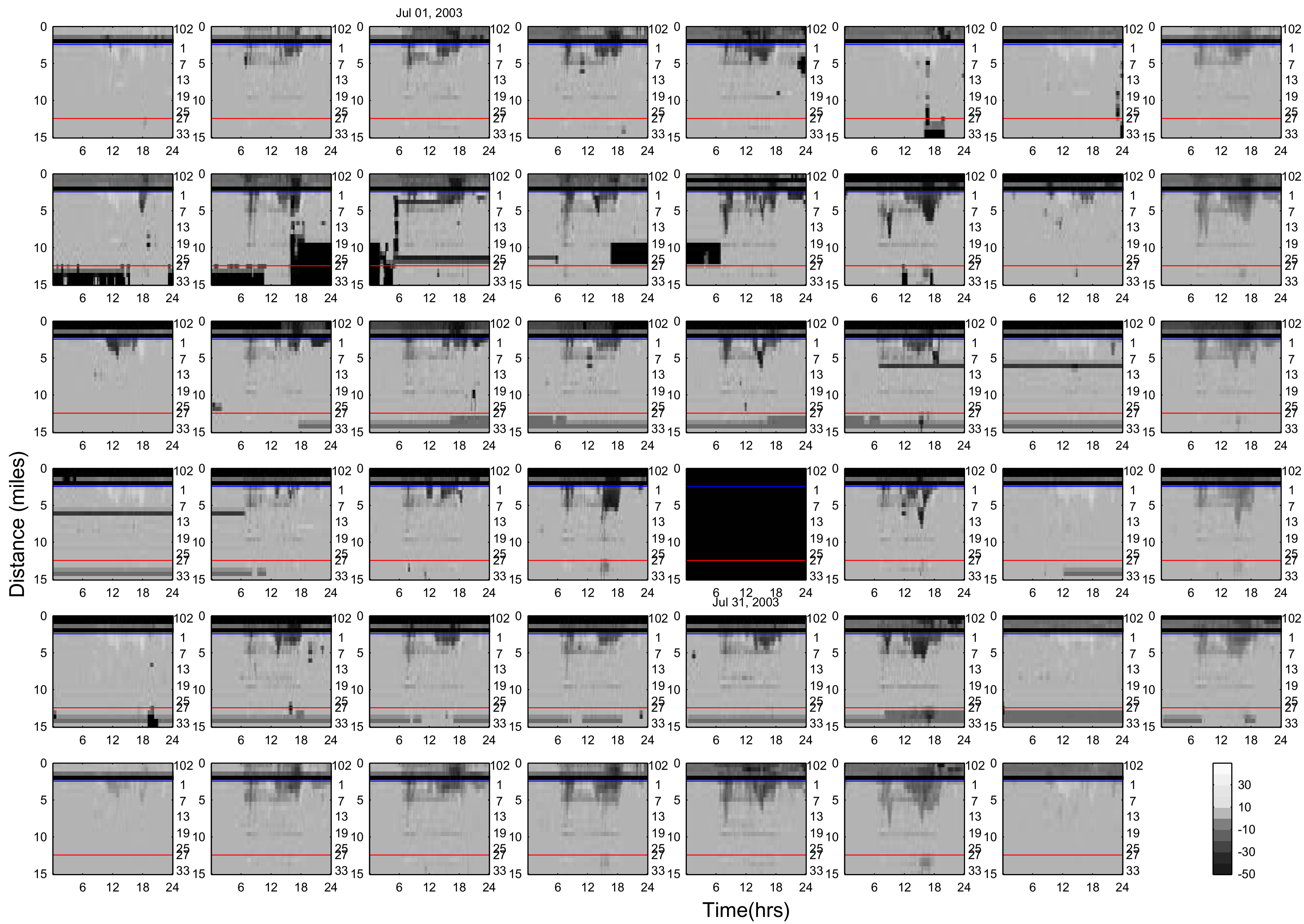
-10
-30
-50


Jul 01, 2003
Jul 31, 2003
Distance (miles)
Time(hrs)
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-30
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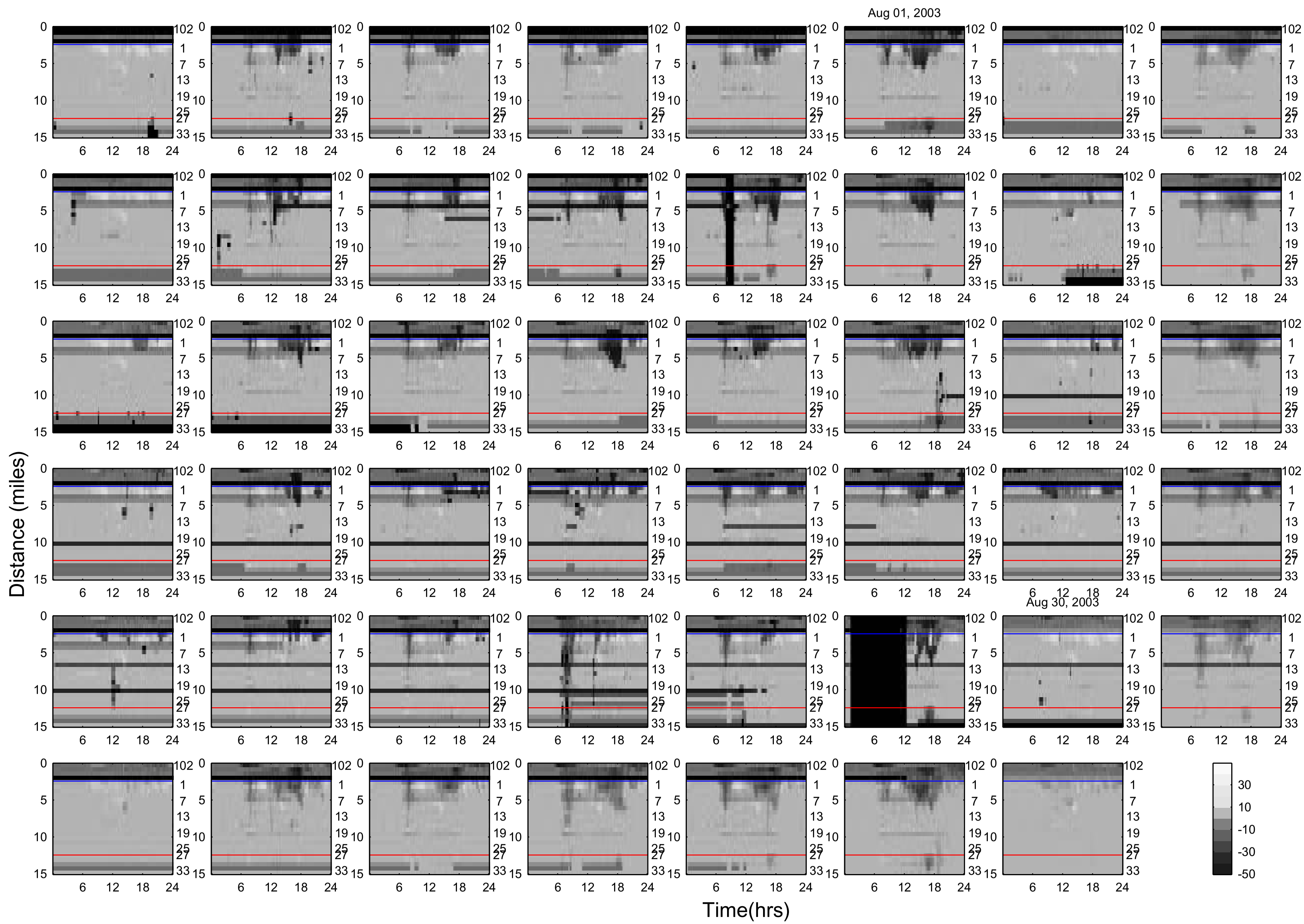

Aug 01, 2003
Aug 30, 2003
Distance (miles)
Time(hrs)
30
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-10
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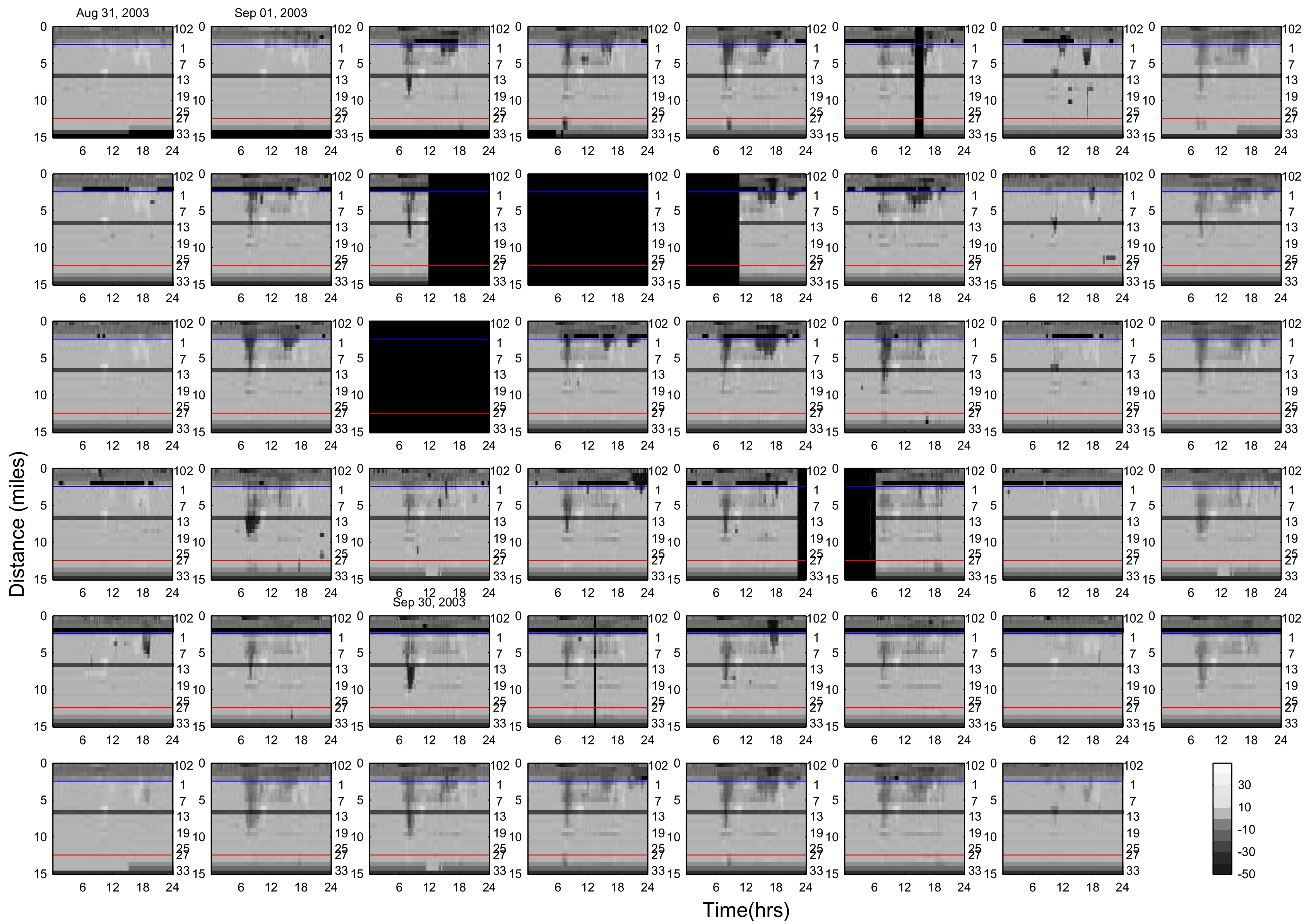
-50



Aug 31, 2003
Sep 01, 2003
Sep 30, 2003
Distance (miles)
Time(hrs)
0
5
10
15
6
12
18
24
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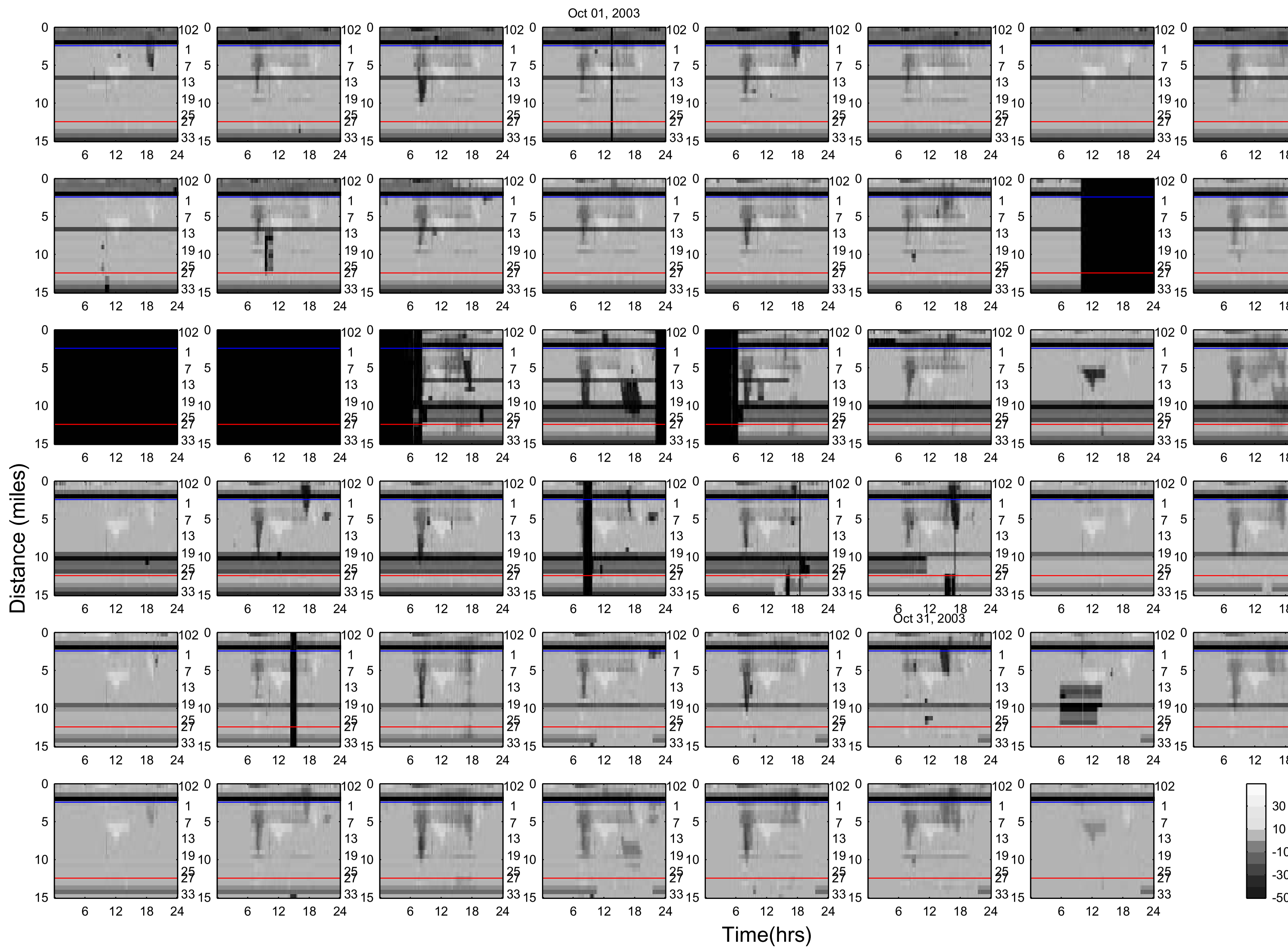
-10
-30
-50



Oct 01, 2003
Oct 31, 2003
Distance (miles)
Time(hrs)
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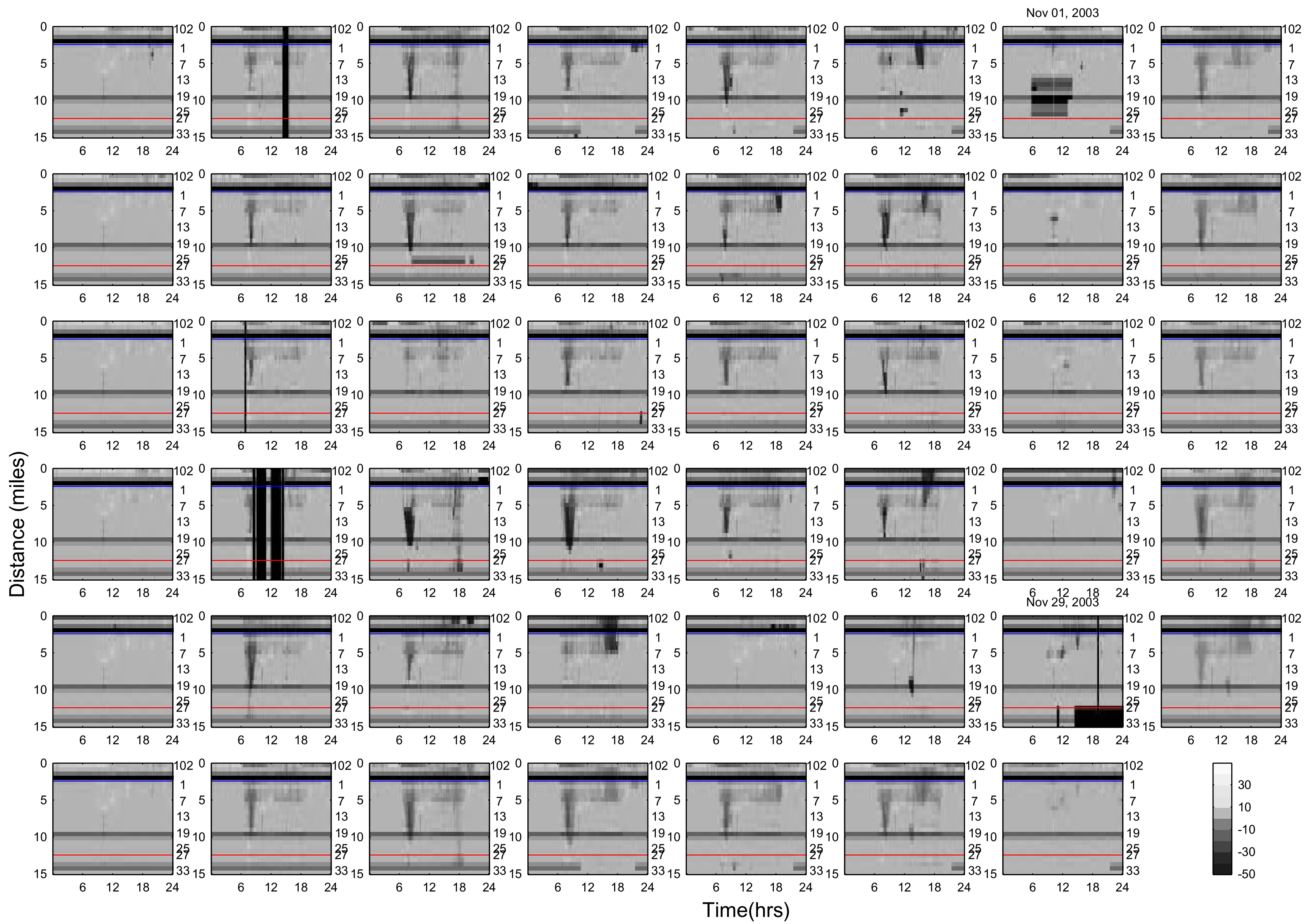

Nov 01, 2003
Nov 29, 2003
Distance (miles)
Time(hrs)
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-10
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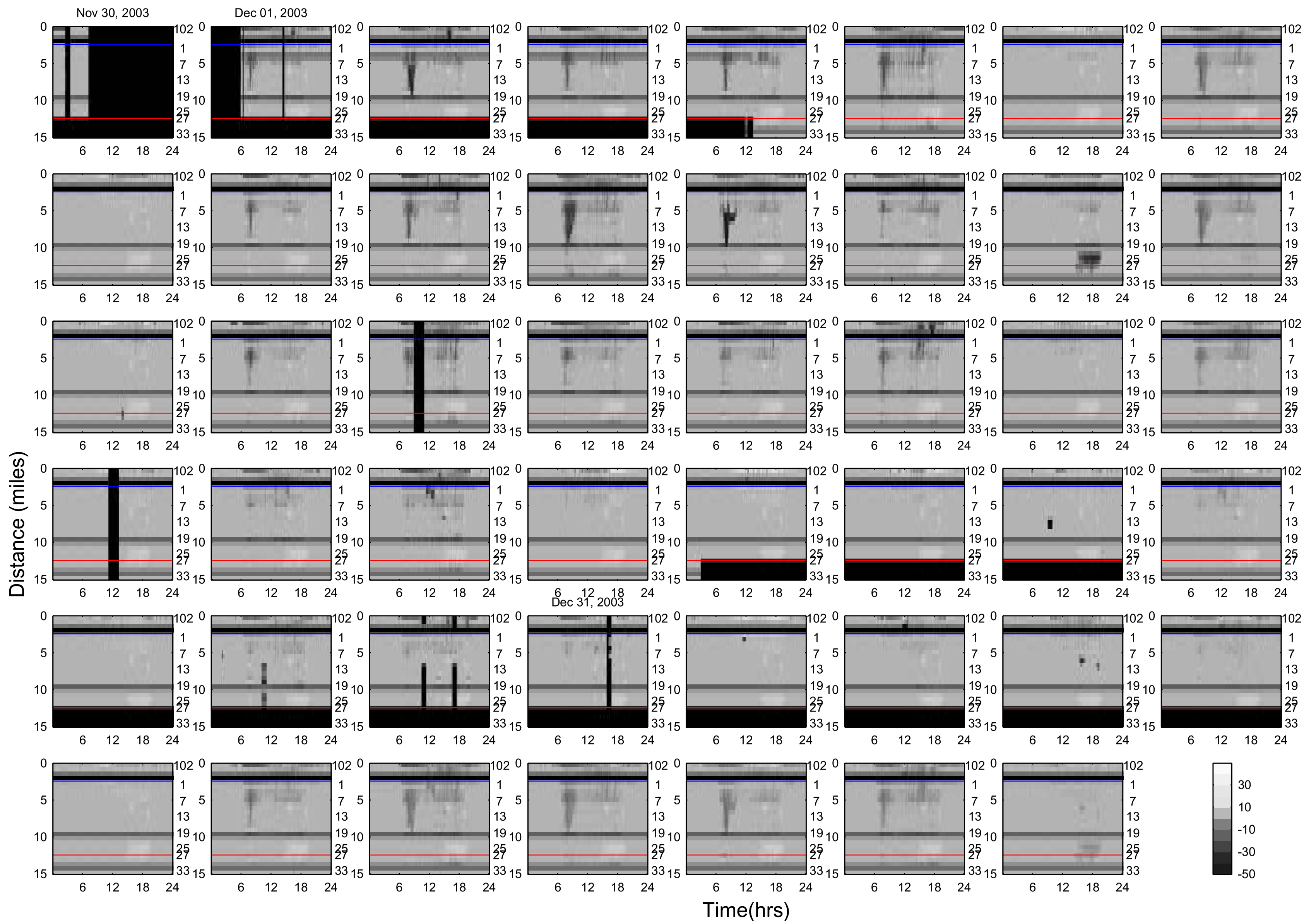
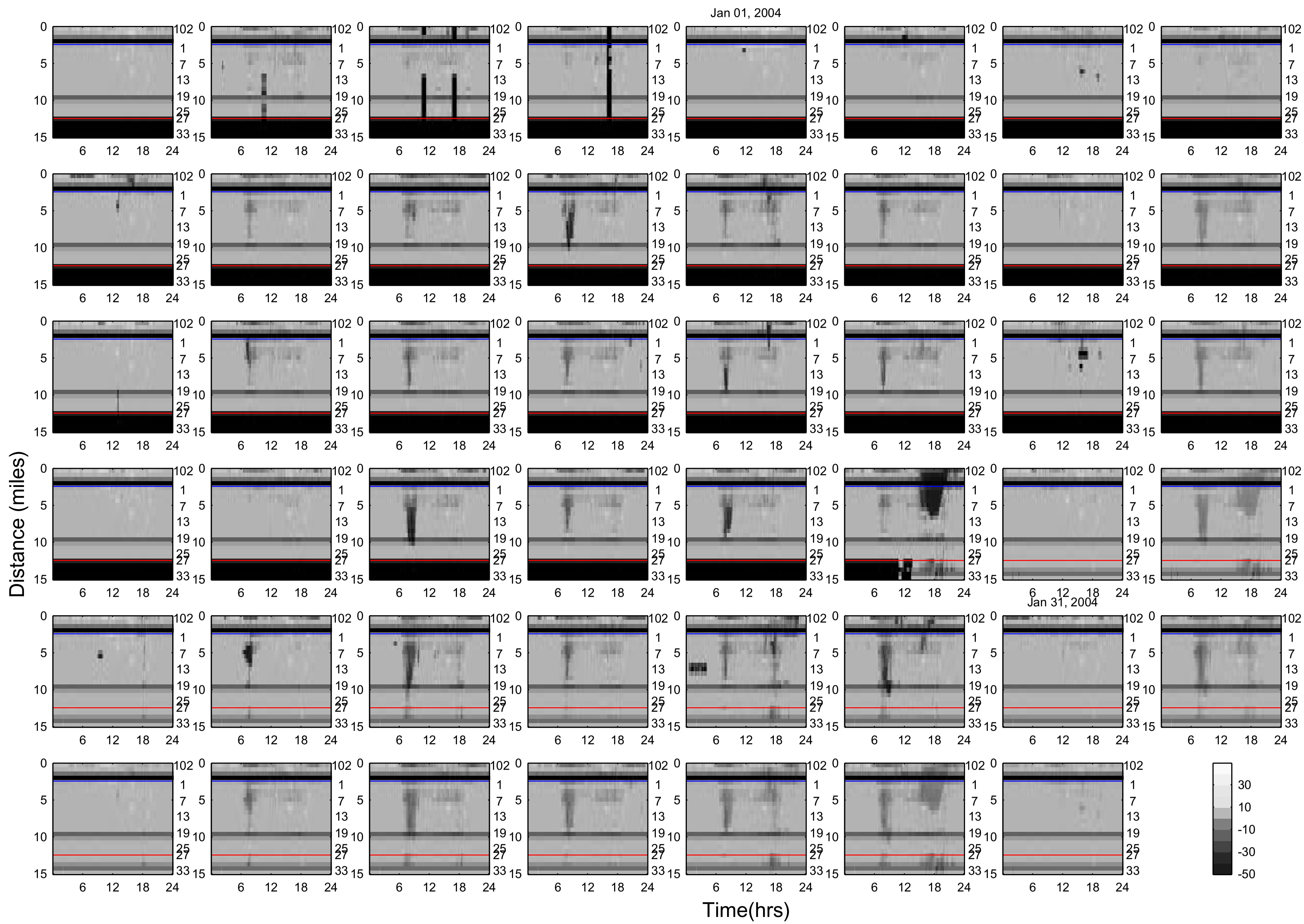


Nov 30, 2003
Dec 01, 2003
Dec 31, 2003
Distance (miles)
Time(hrs)



Jan 01, 2004
Jan 31, 2004
Distance (miles)
Time(hrs)
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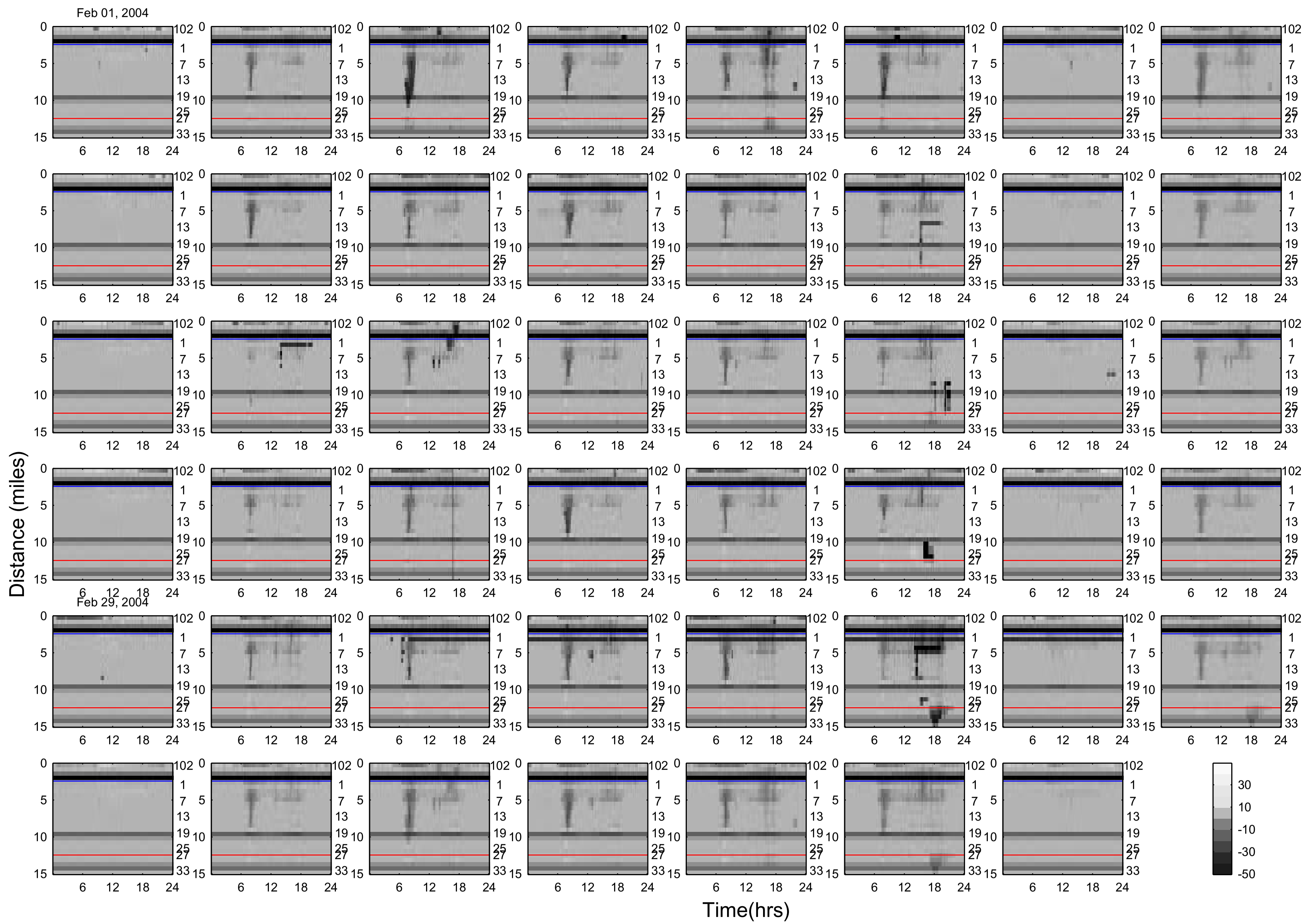
Feb 01, 2004
Feb 29, 2004
Distance (miles)
Time(hrs)
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-10
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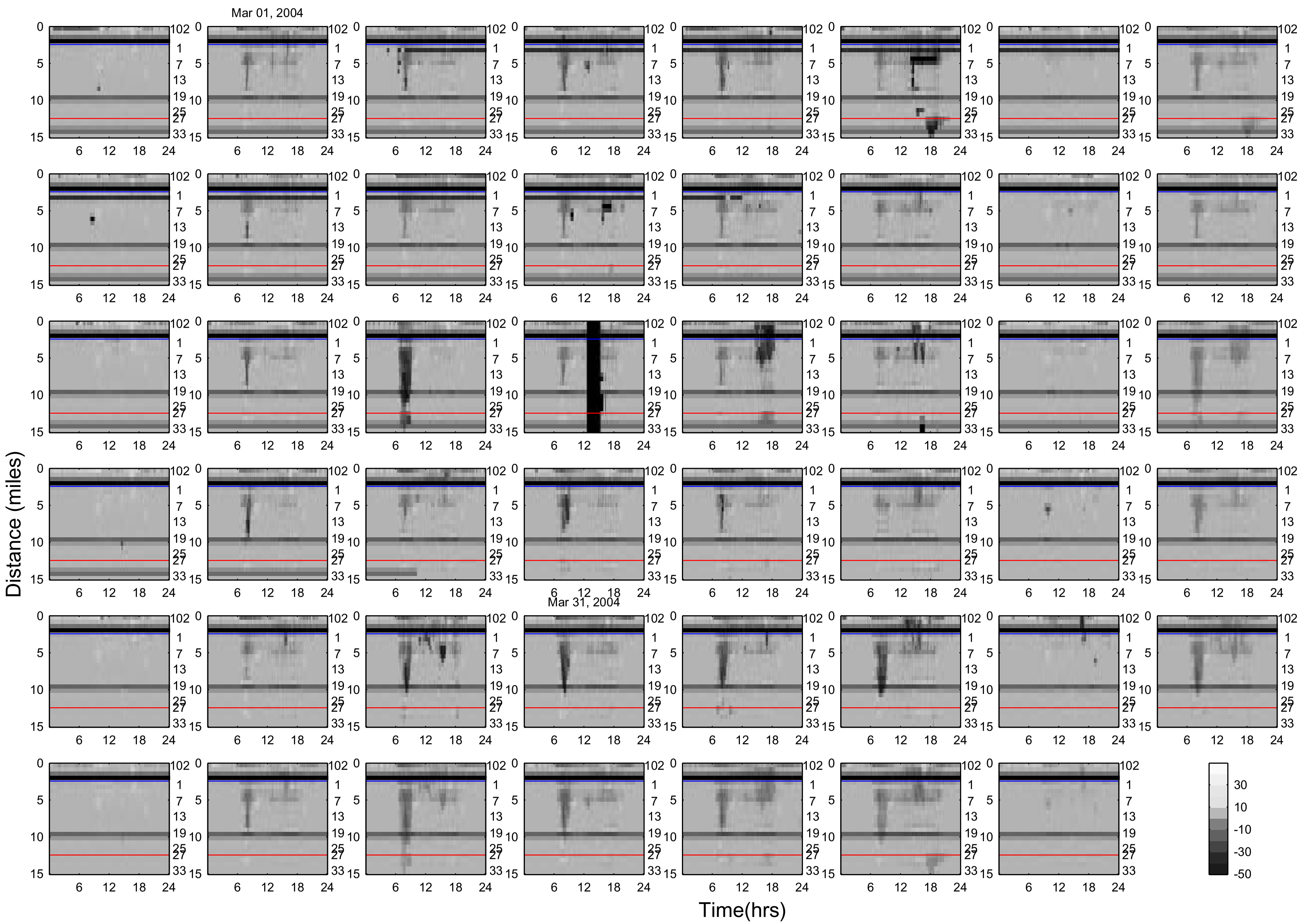
Mar 01, 2004
Mar 31, 2004
Distance (miles)
Time(hrs)
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-30
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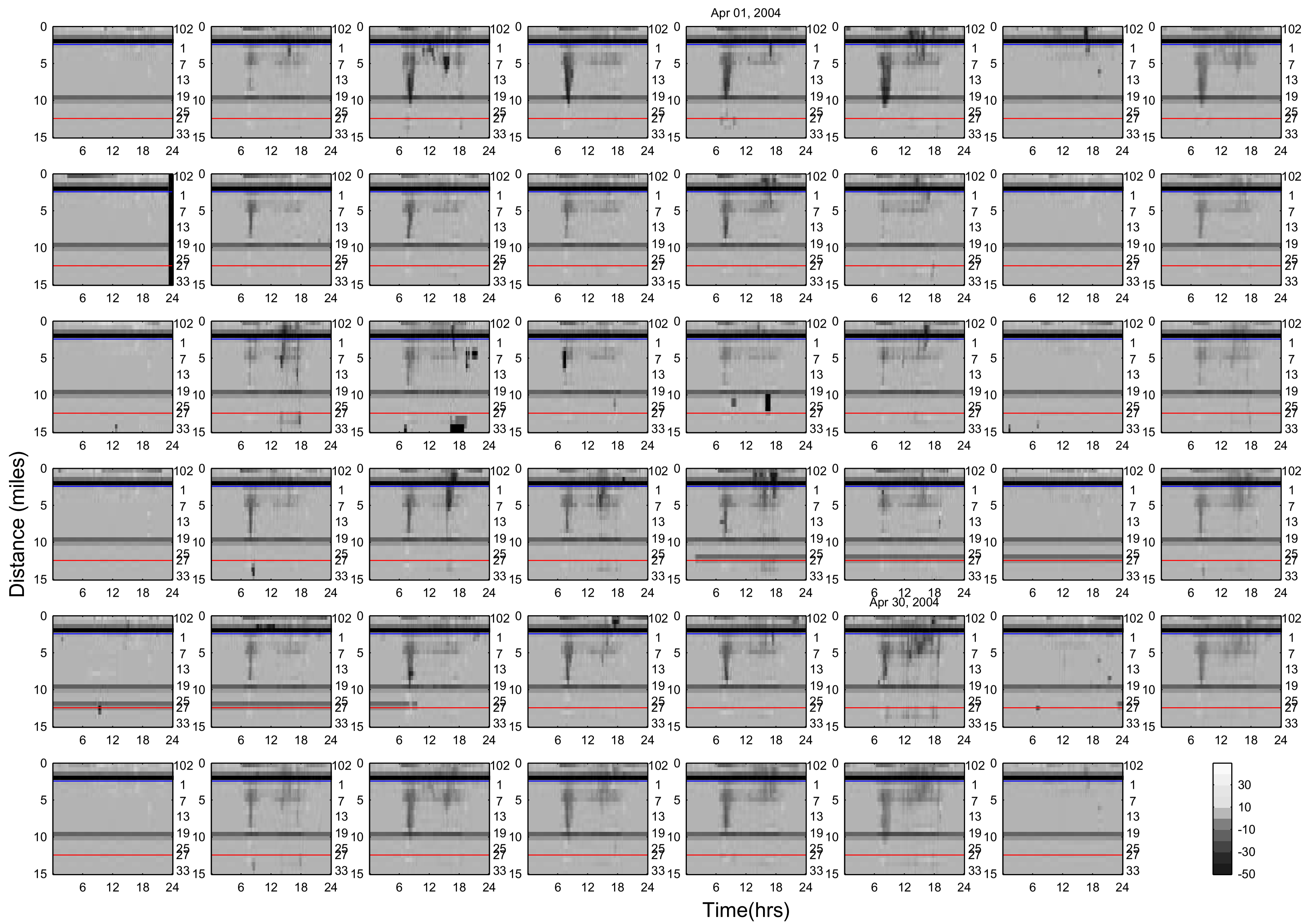

Apr 01, 2004
Apr 30, 2004
Distance (miles)
Time(hrs)
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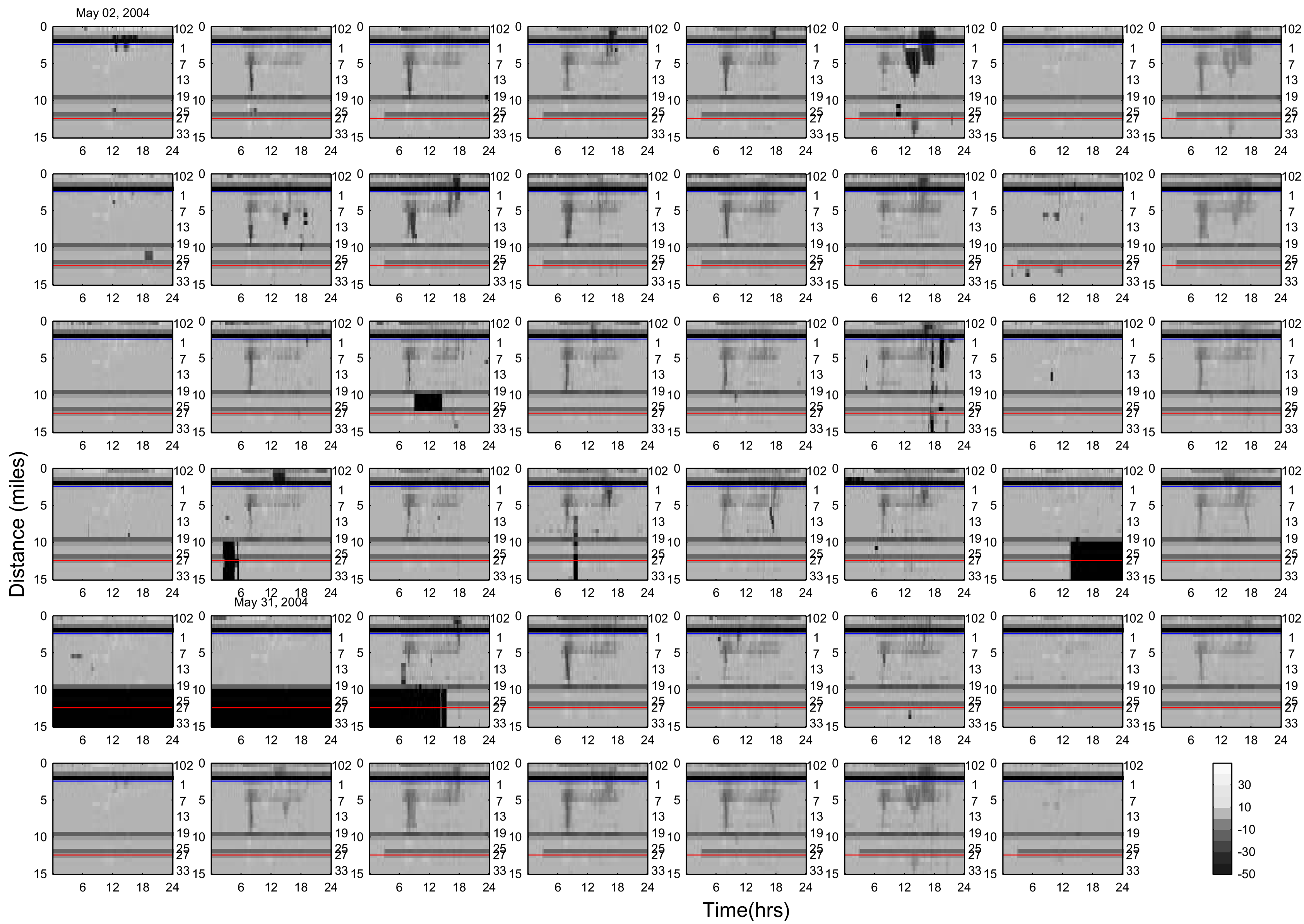
May 02, 2004
May 31, 2004
Distance (miles)
Time(hrs)
0
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102
1
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27
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-10
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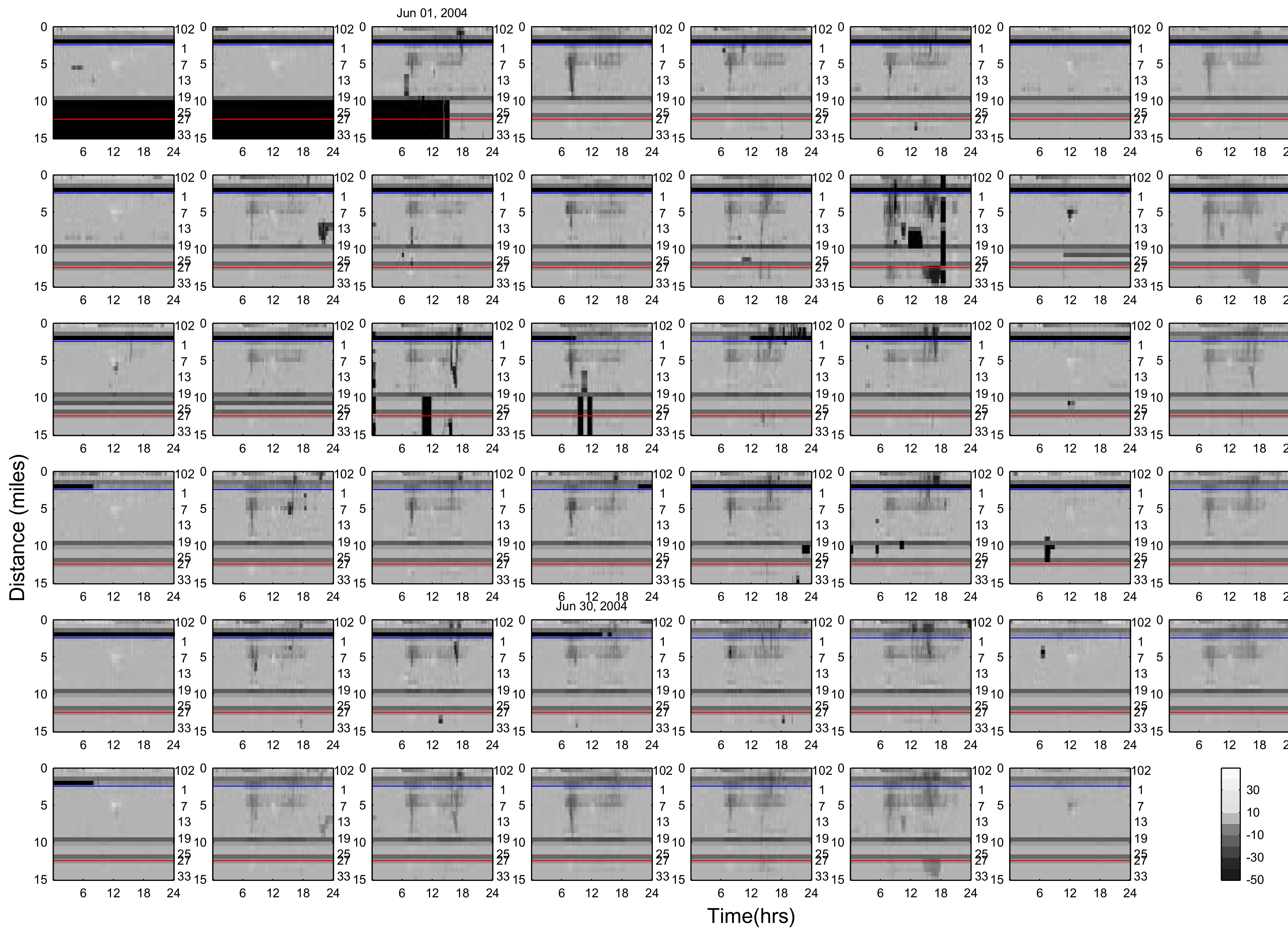
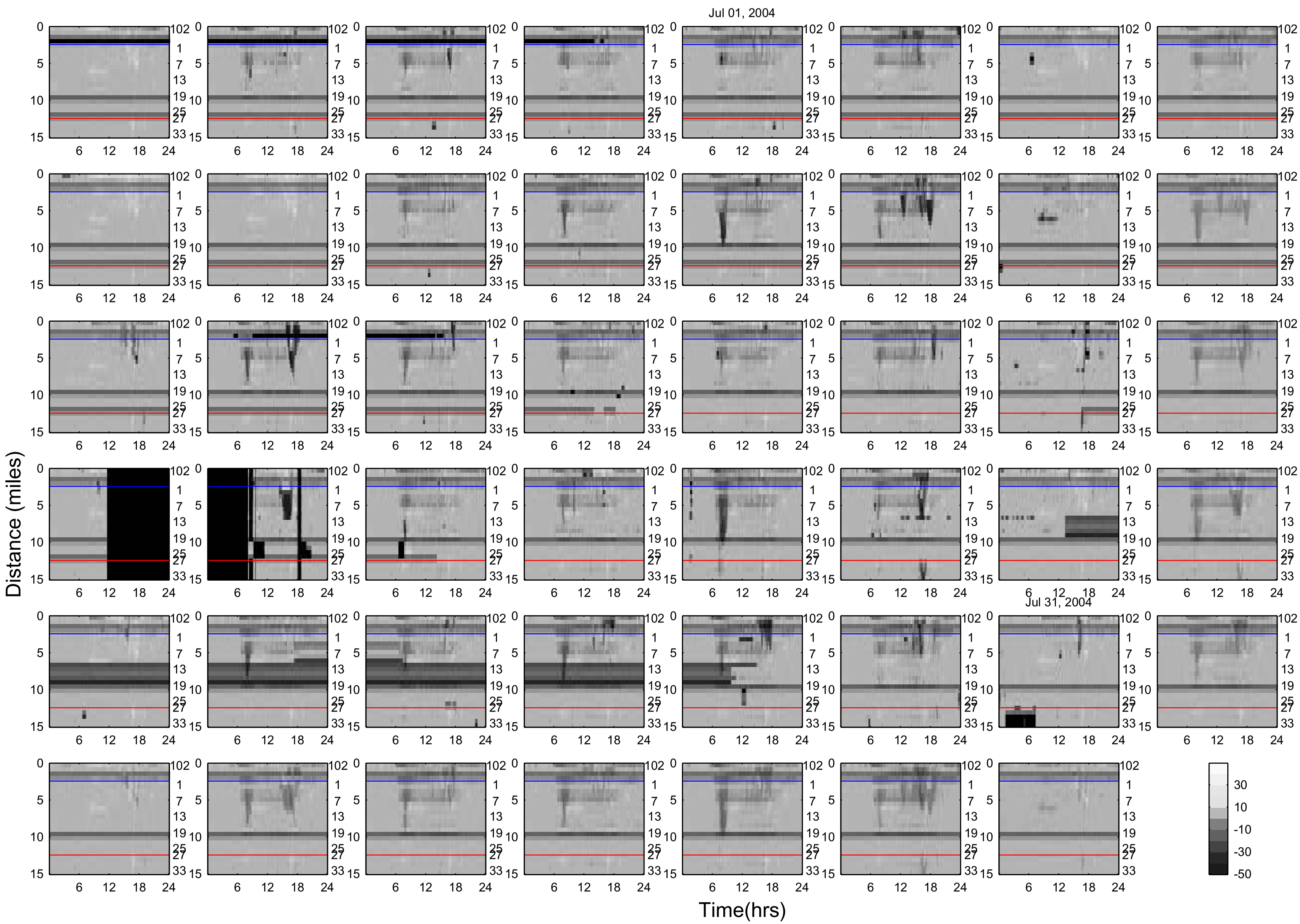


Jun 01, 2004
Jun 30, 2004
Distance (miles)
Time(hrs)



Jul 01, 2004
Jul 31, 2004
Distance (miles)
Time(hrs)
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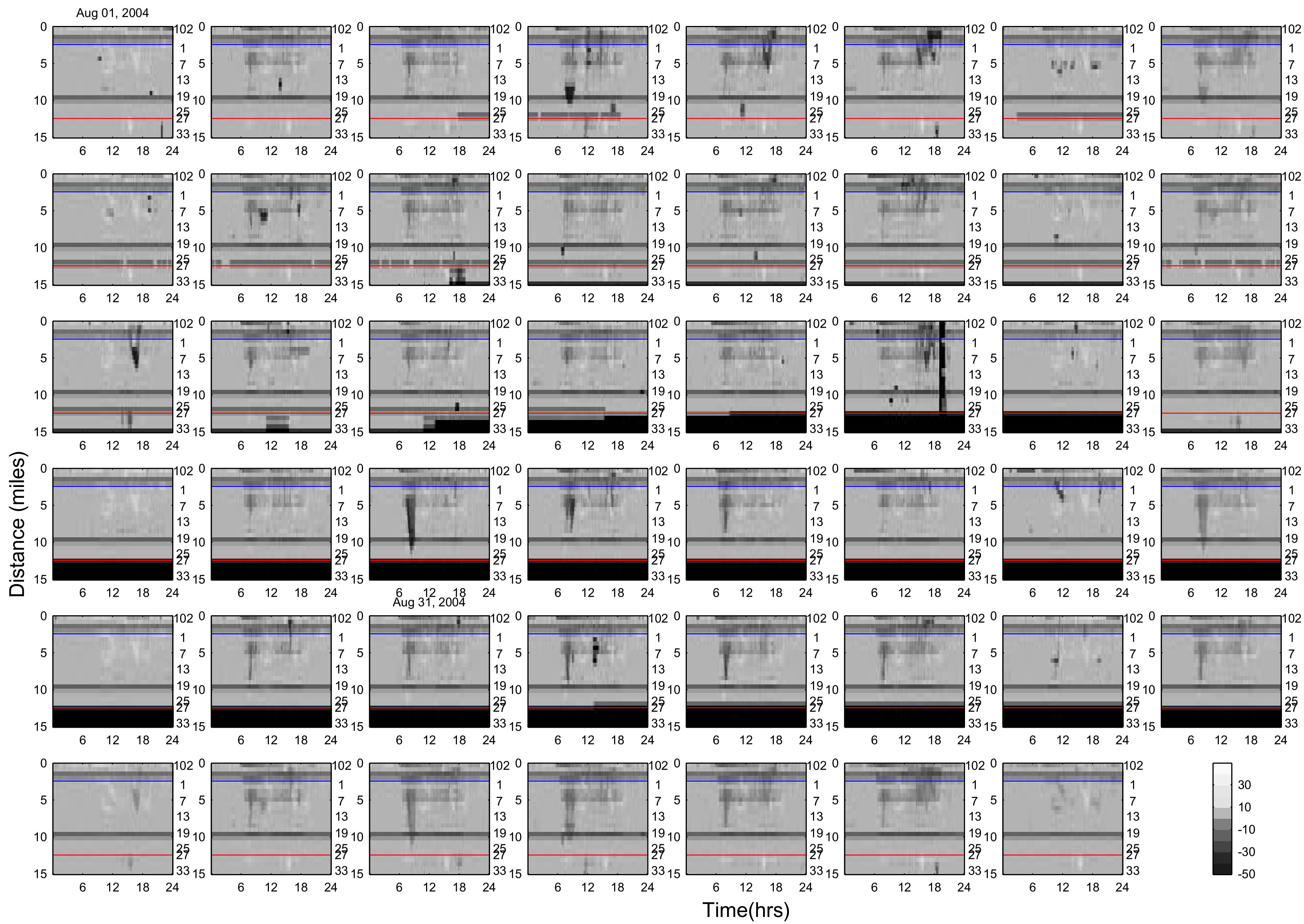

Aug 01, 2004
Aug 31, 2004
Distance (miles)
Time(hrs)
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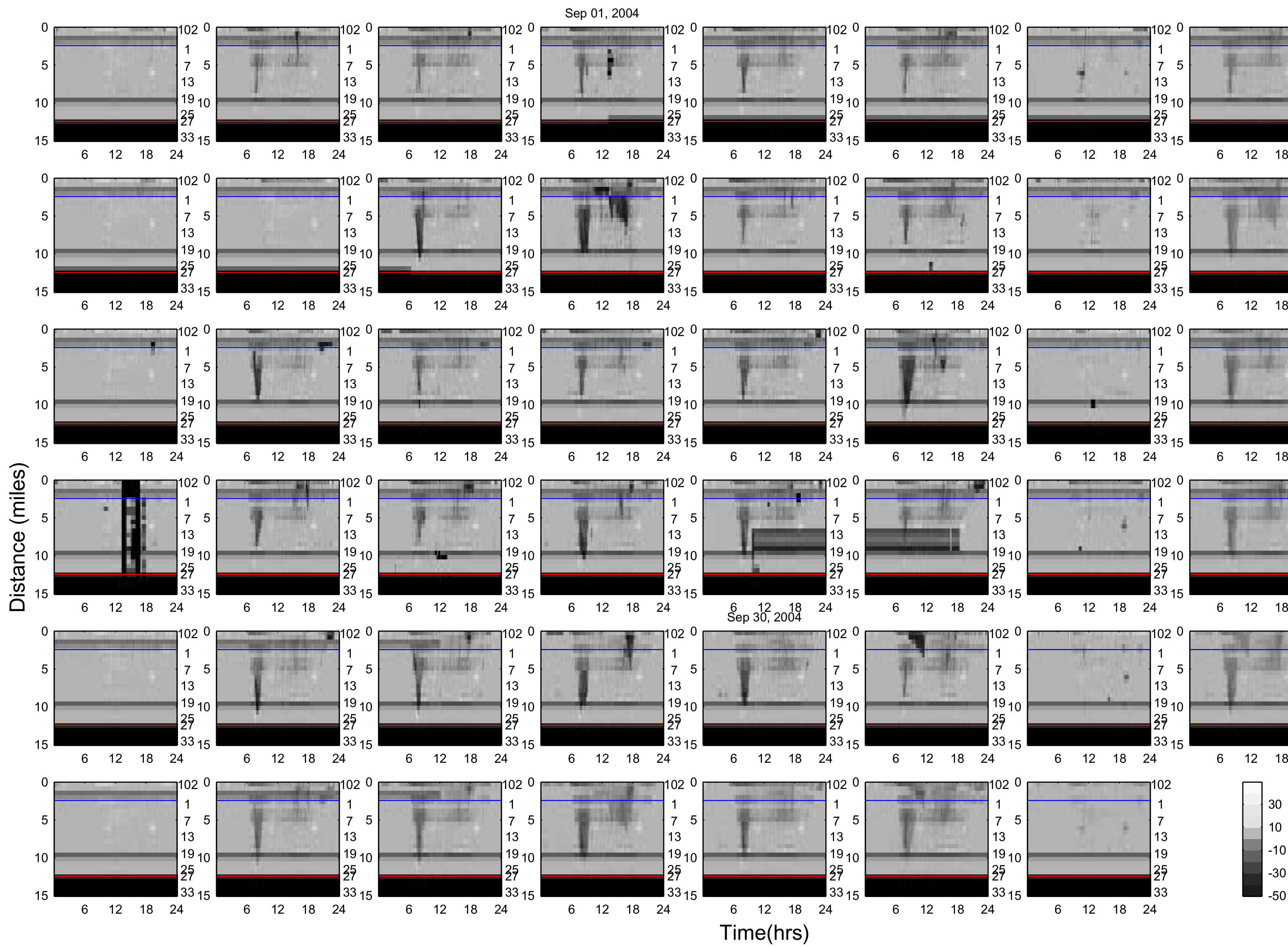
Sep 01, 2004
Sep 30, 2004
Distance (miles)
Time(hrs)
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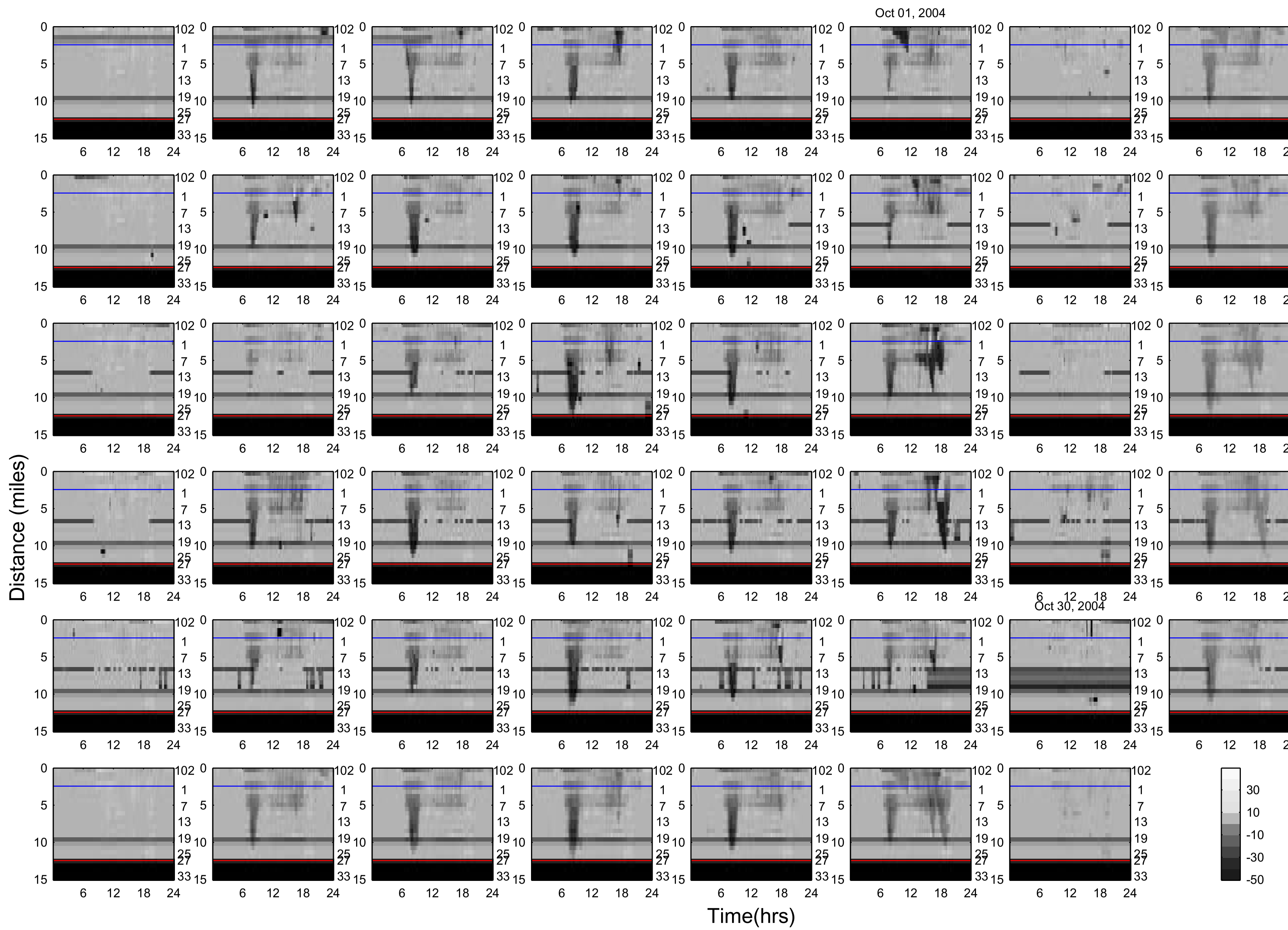

Oct 01, 2004
Oct 30, 2004
Distance (miles)
Time(hrs)
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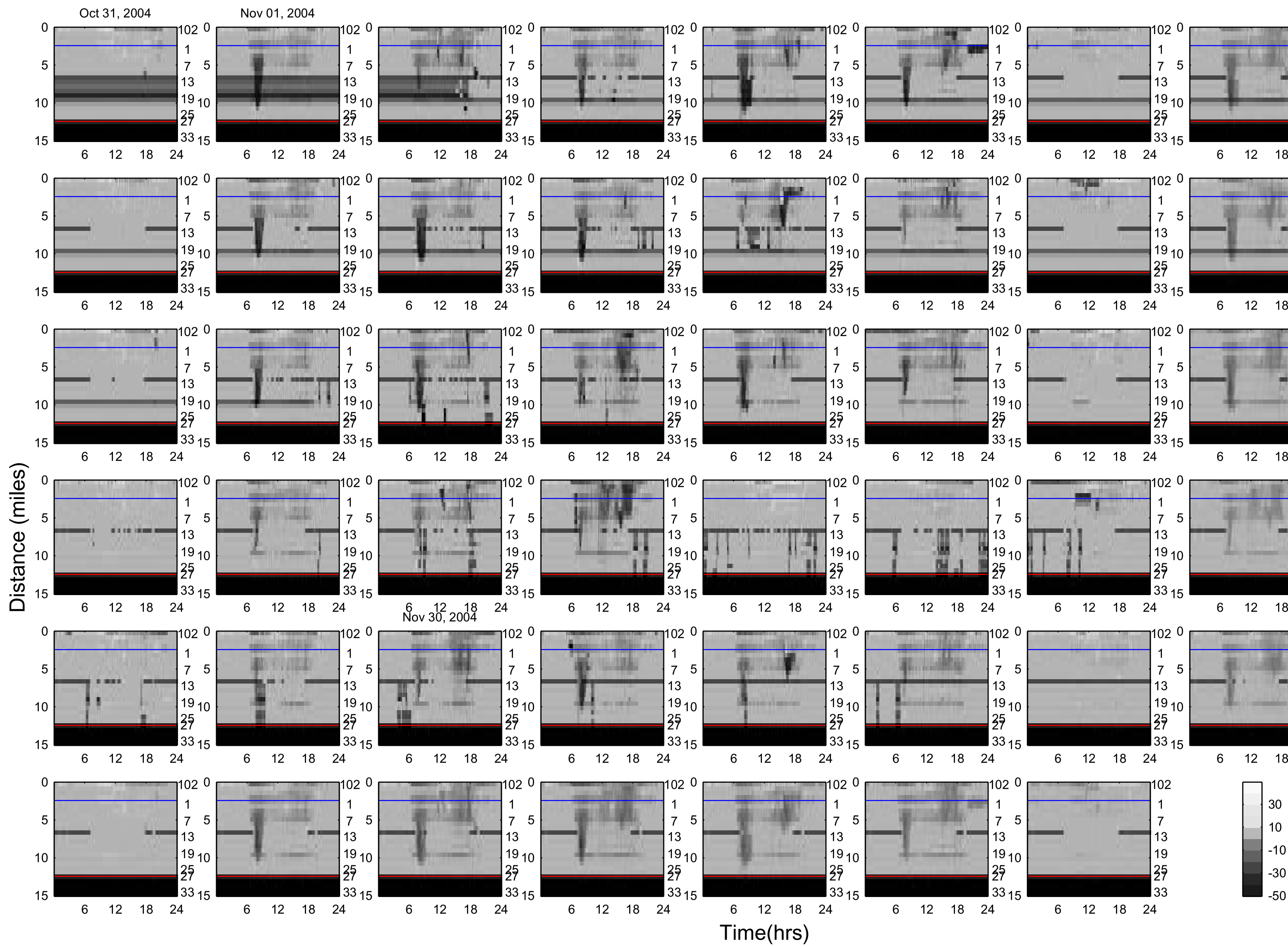
Oct 31, 2004
Nov 01, 2004
Nov 30, 2004
Distance (miles)
Time(hrs)
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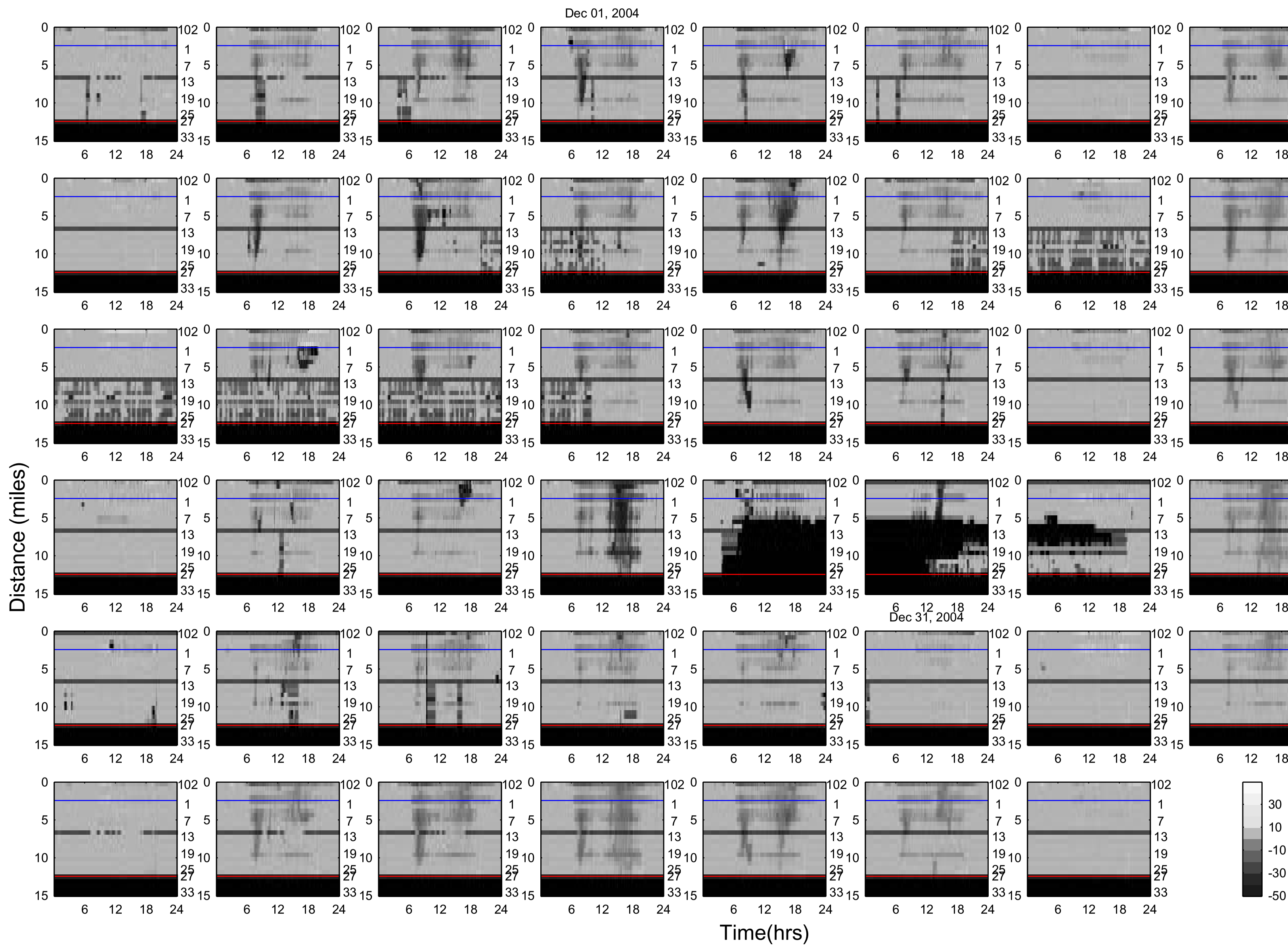

Dec 01, 2004
Dec 31, 2004
Distance (miles)
Time(hrs)
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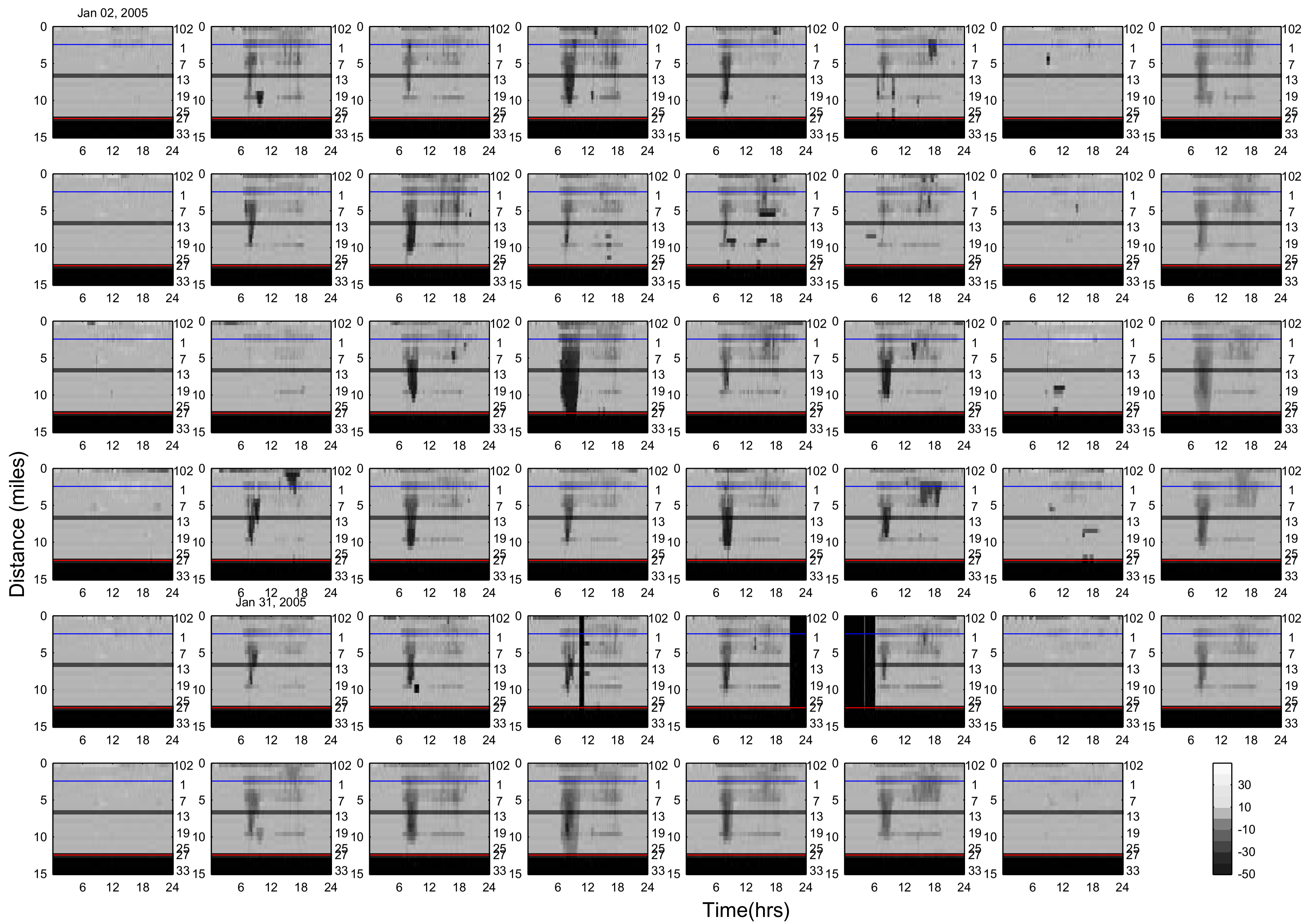
Jan 02, 2005
Jan 31, 2005
Distance (miles)
Time(hrs)
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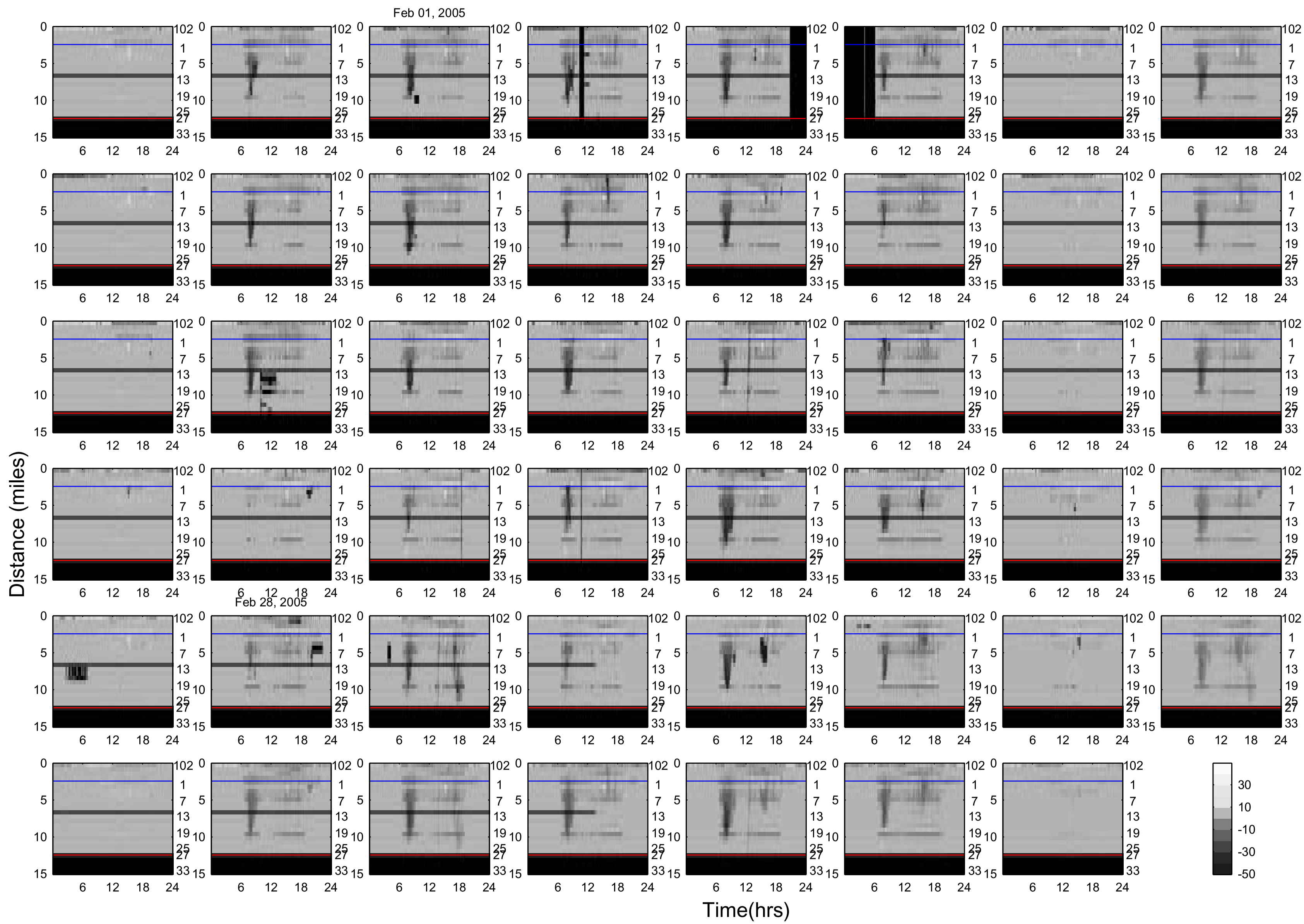

Feb 01, 2005
Feb 28, 2005
Distance (miles)
Time(hrs)
0
5
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15
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18
24
102
1
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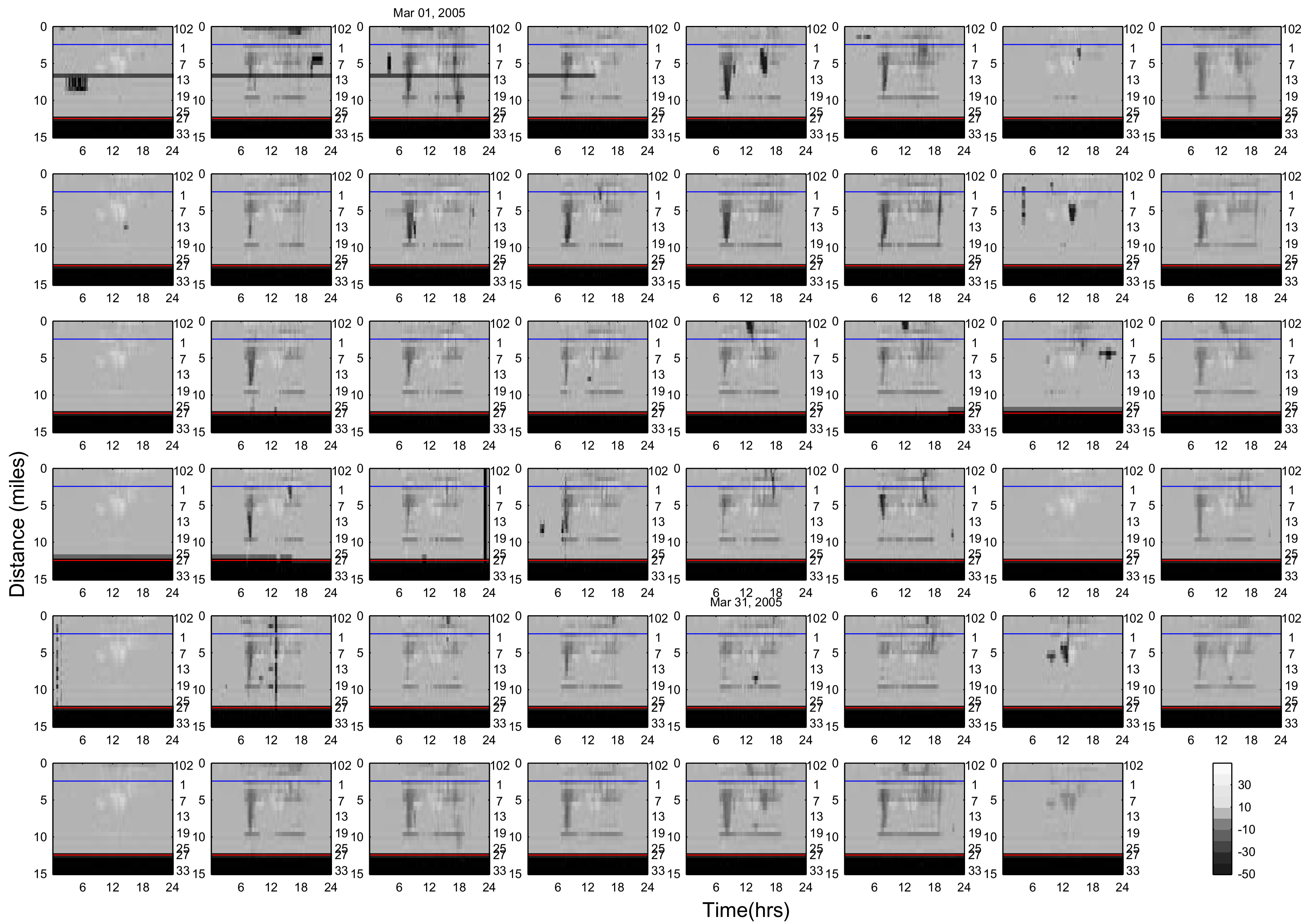
-10
-30
-50


Mar 01, 2005
Mar 31, 2005
Distance (miles)
Time(hrs)
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-10
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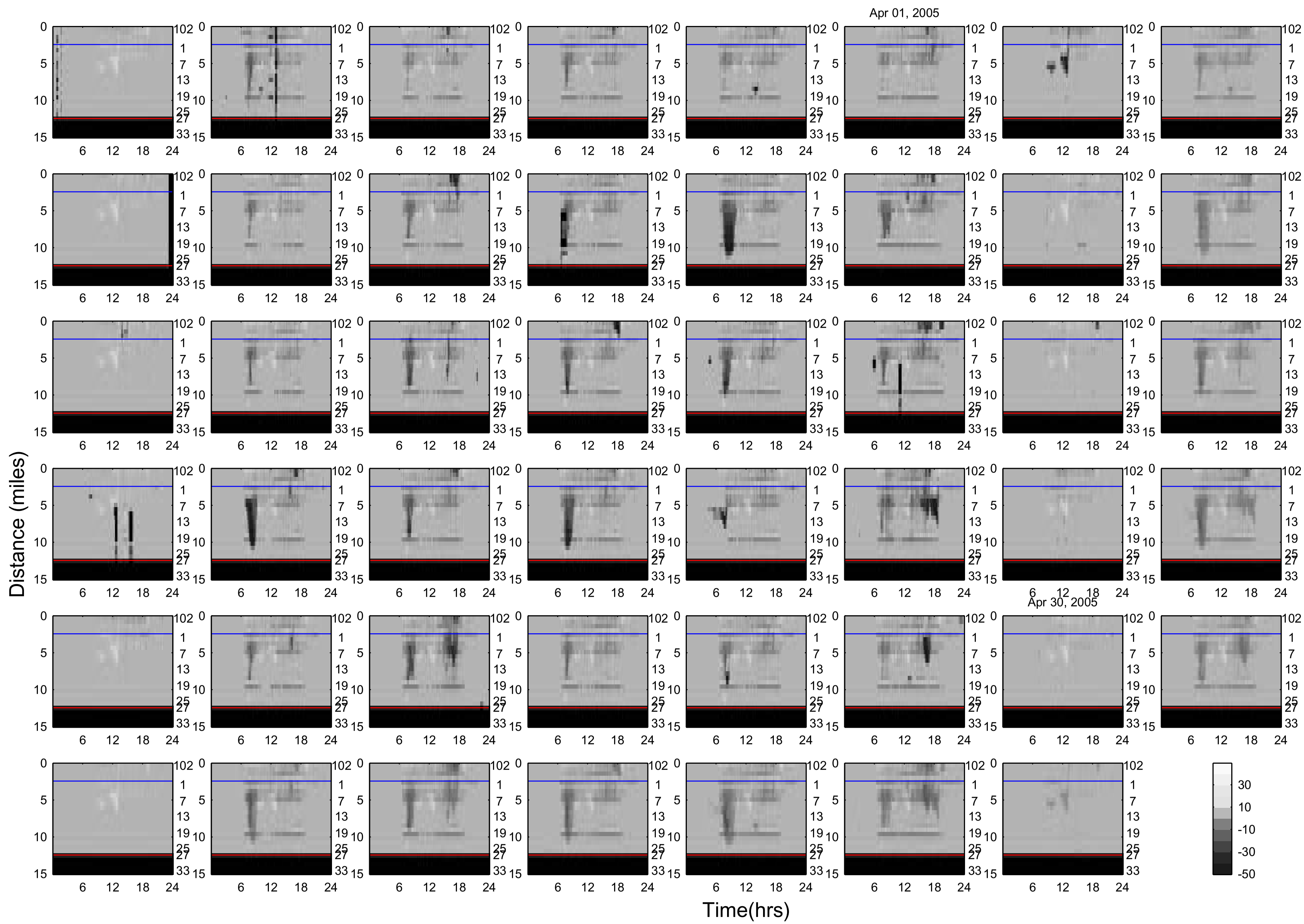

Apr 01, 2005
Apr 30, 2005
Distance (miles)
Time(hrs)
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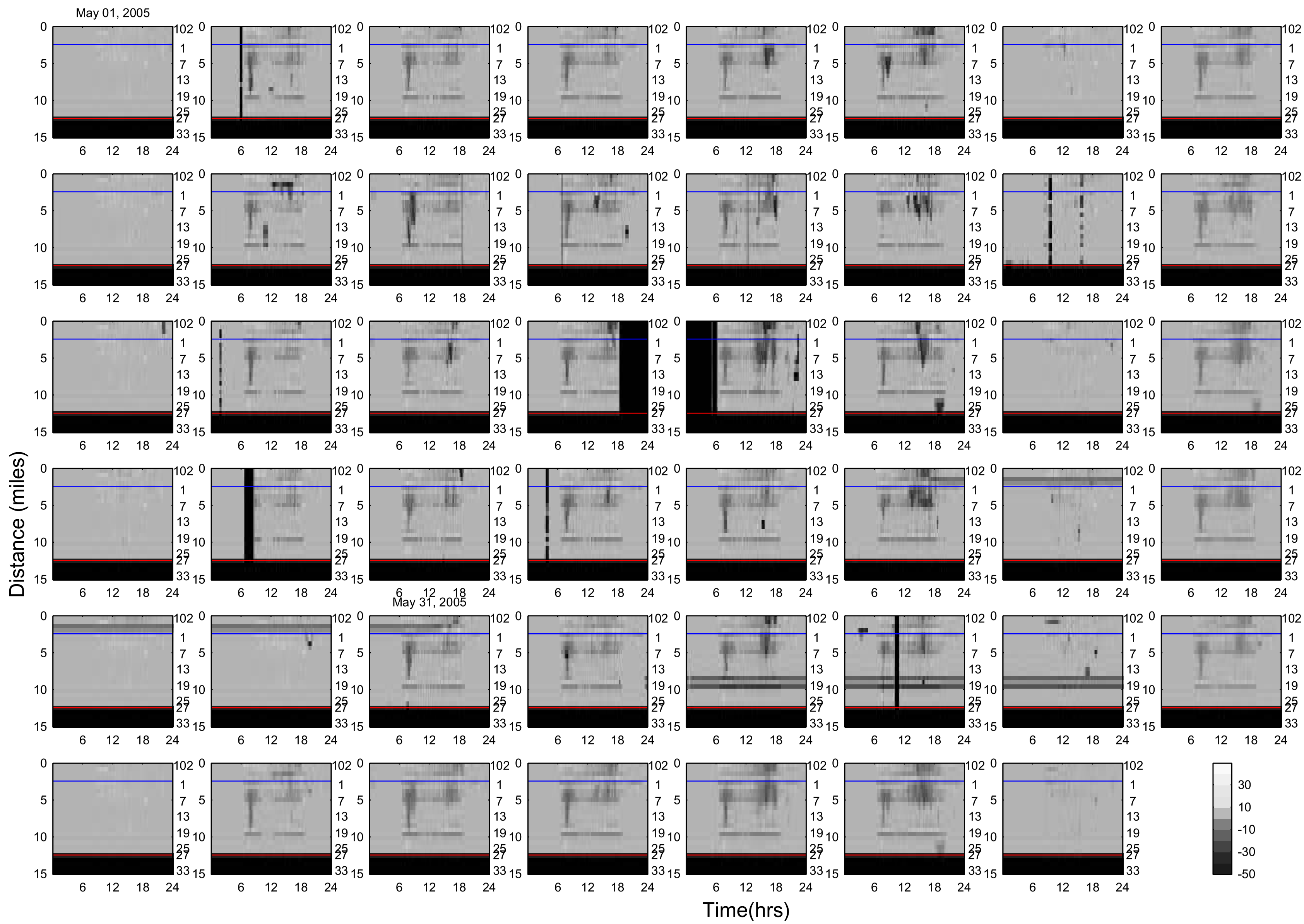
-10
-30
-50



May 01, 2005
May 31, 2005
Distance (miles)
Time(hrs)
30
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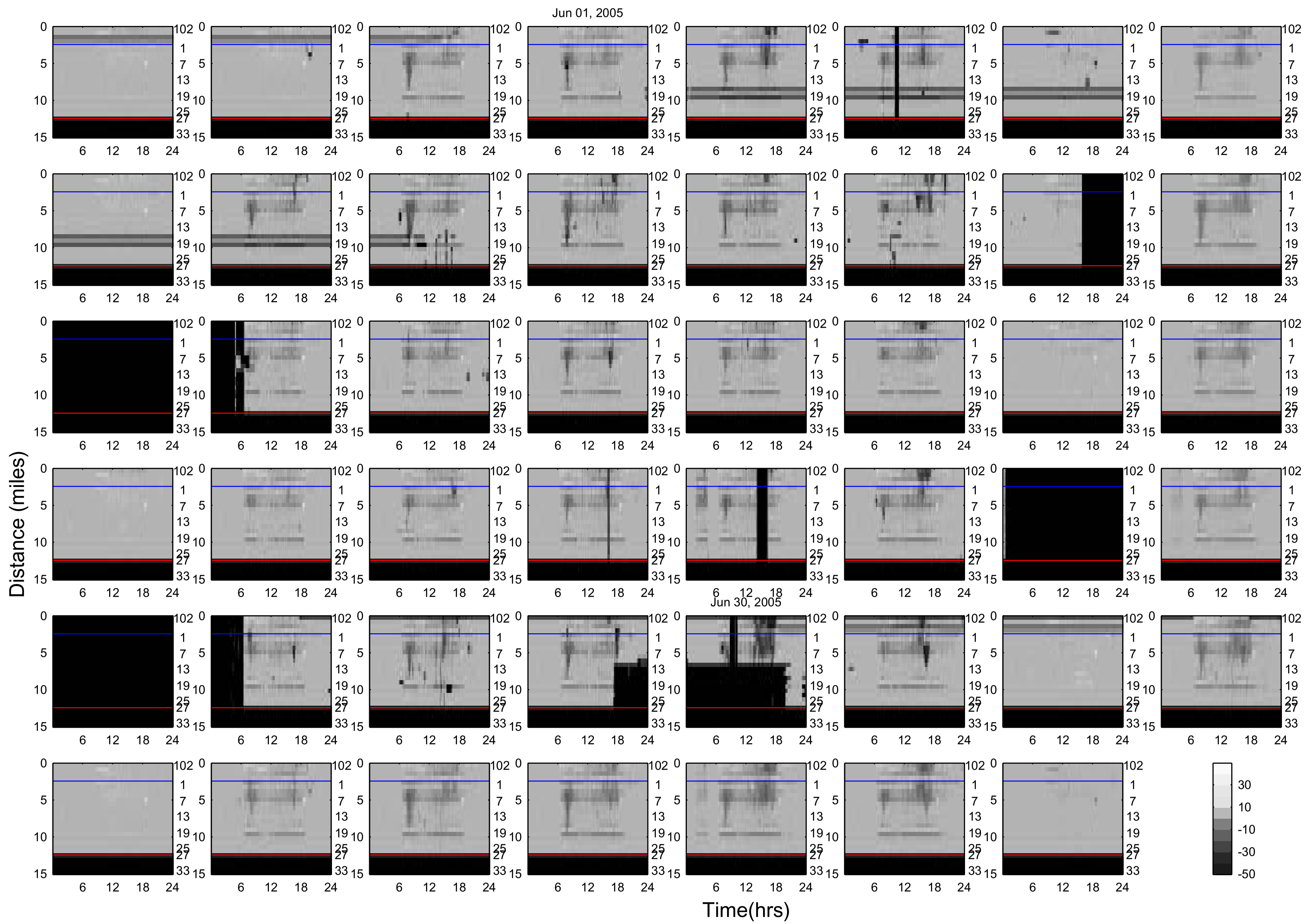
-10
-30
-50



Jun 01, 2005
Jun 30, 2005
Distance (miles)
Time(hrs)
0
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24
102
1
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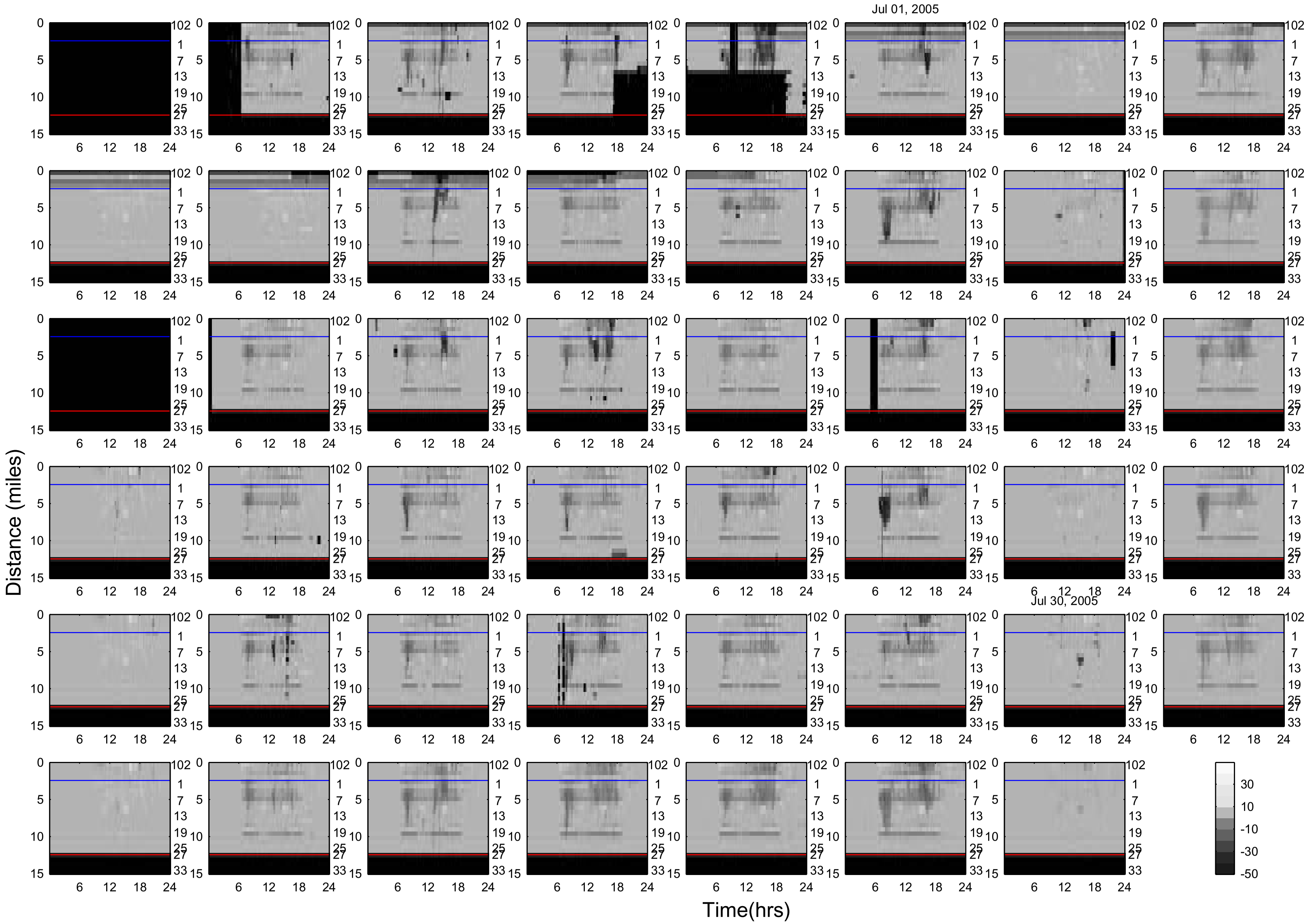
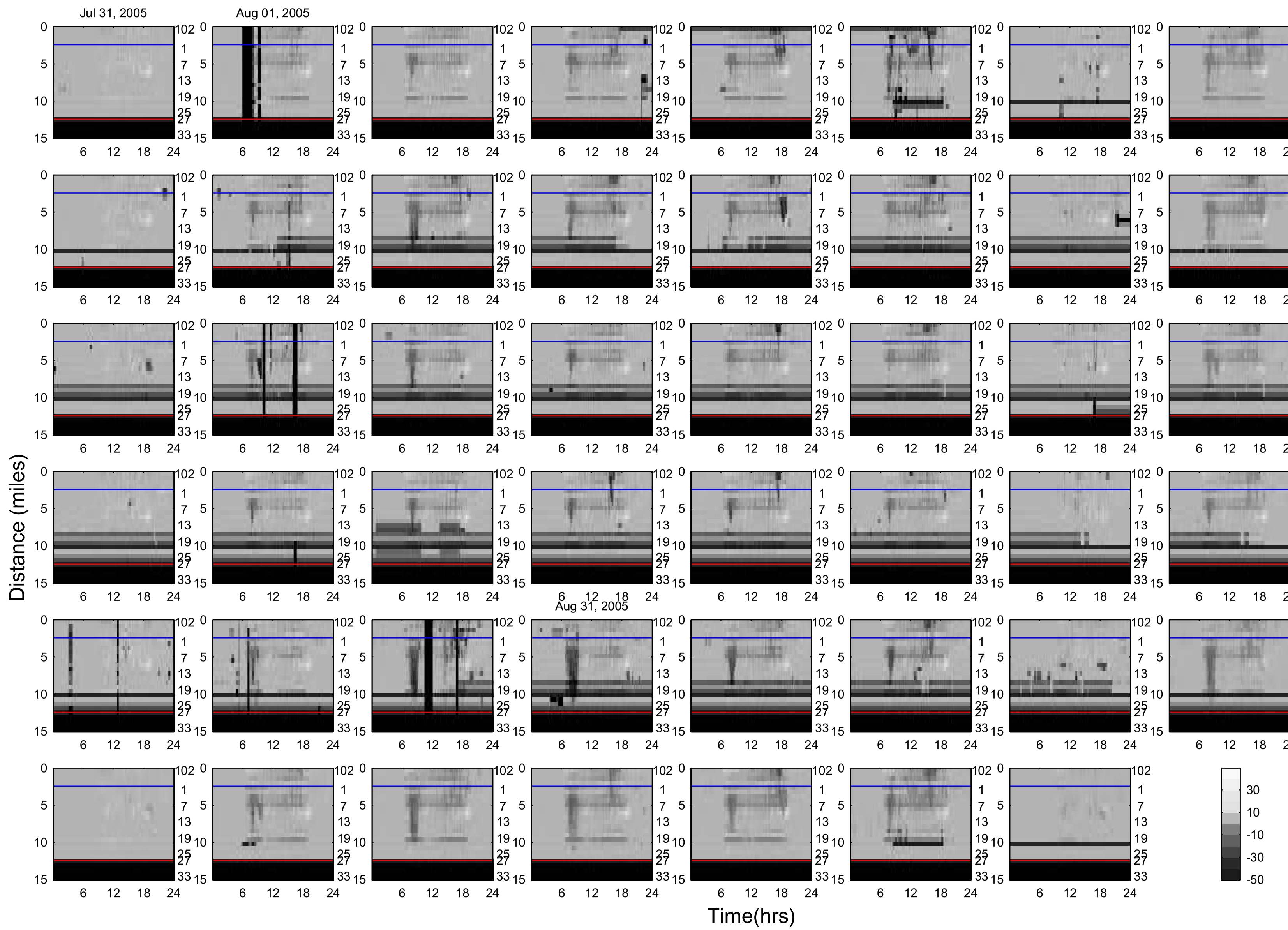
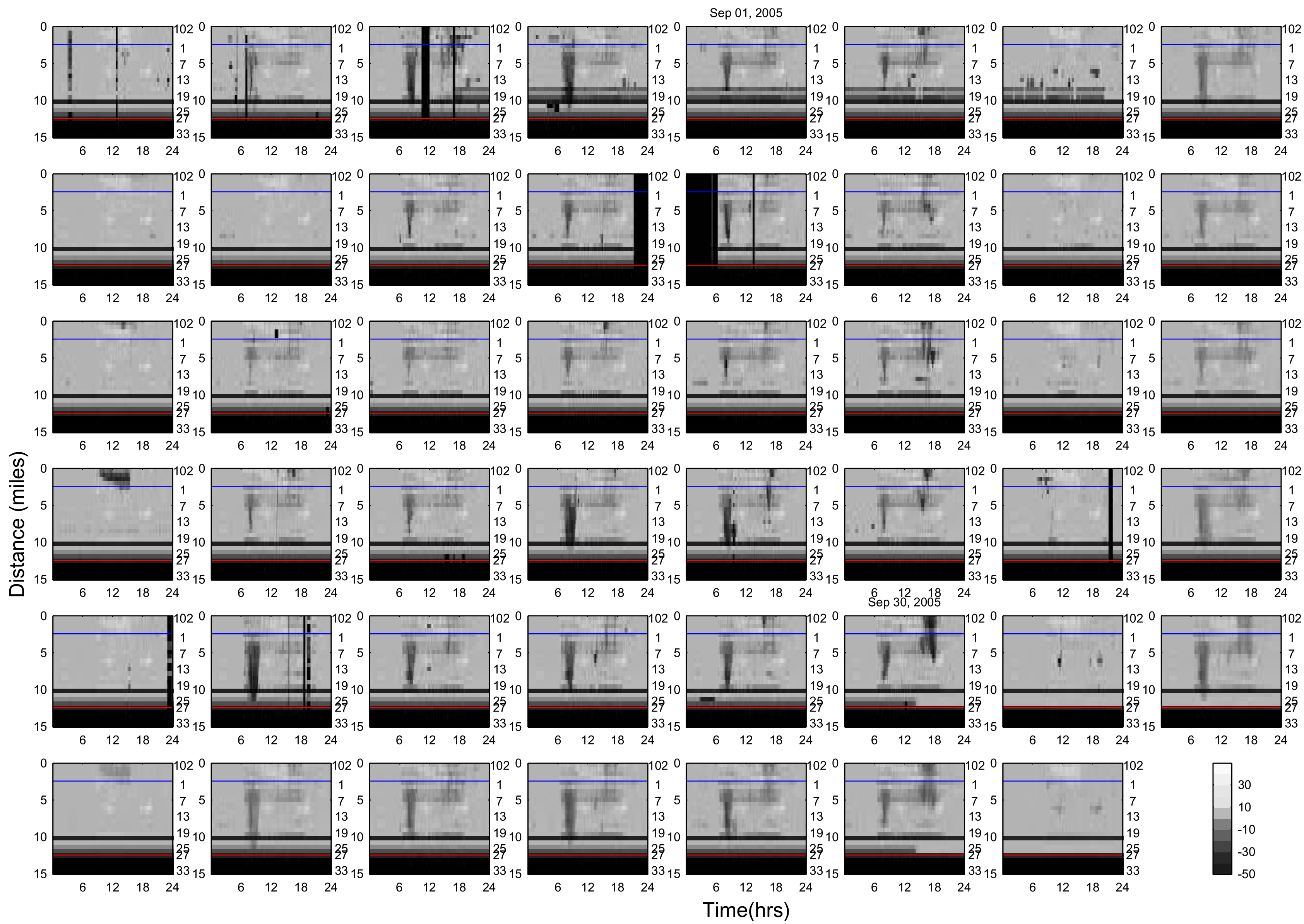
-10
-30
-50



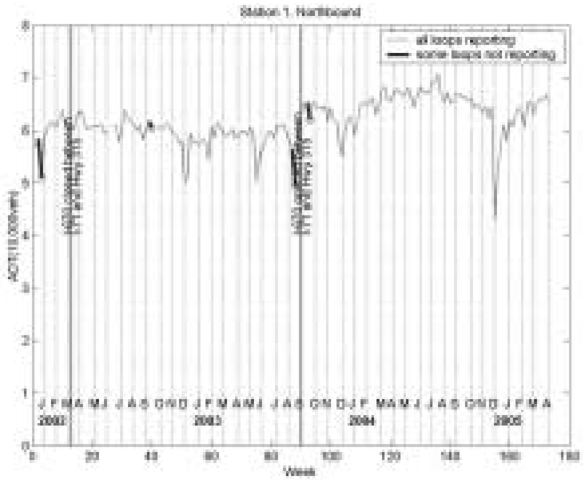
Jul 01, 2005
Jul 30, 2005
Distance (miles)
Time(hrs)

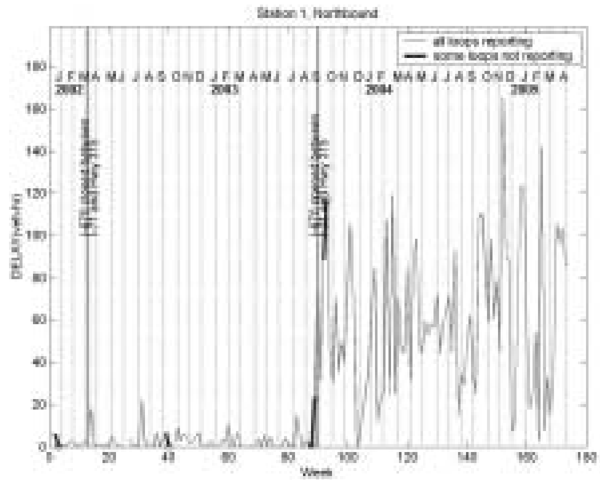

Jul 31, 2005
Aug 01, 2005
Aug 31, 2005
Distance (miles)
Time(hrs)
30
10
-10
-30
-50

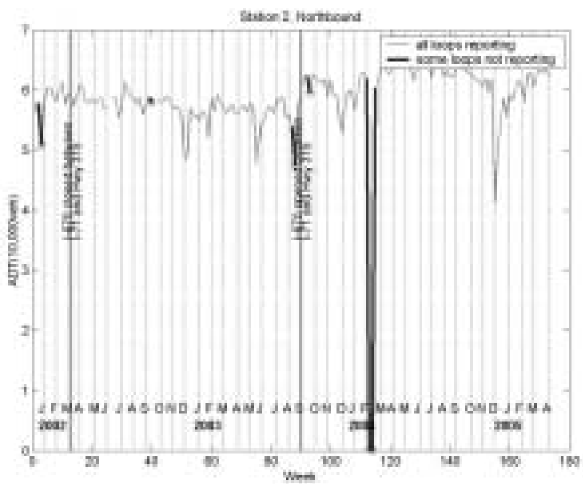

Sep 01, 2005
Sep 30, 2005
Distance (miles)
Time(hrs)
30
10
-10
-30
-50

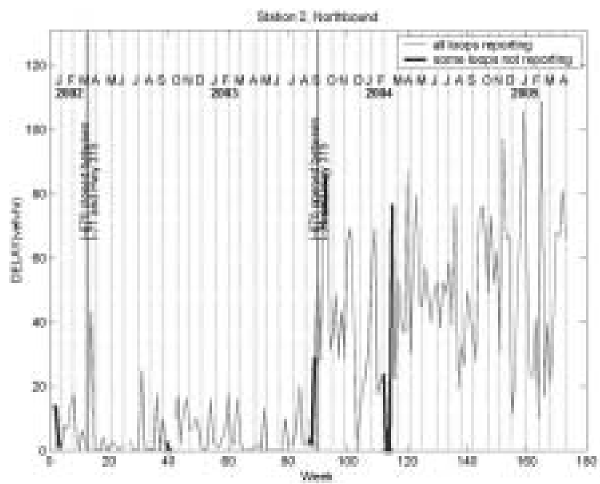
APPENDIX F: EVOLUTION OF WEEKLY MEDIAN ADT AND DELAY

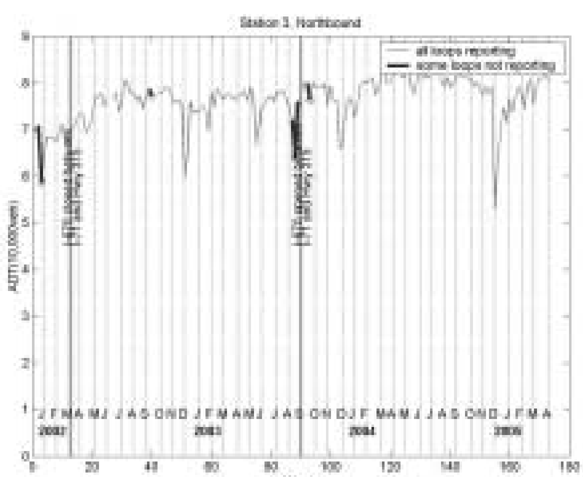
NORTHBOUND- 24 HRS

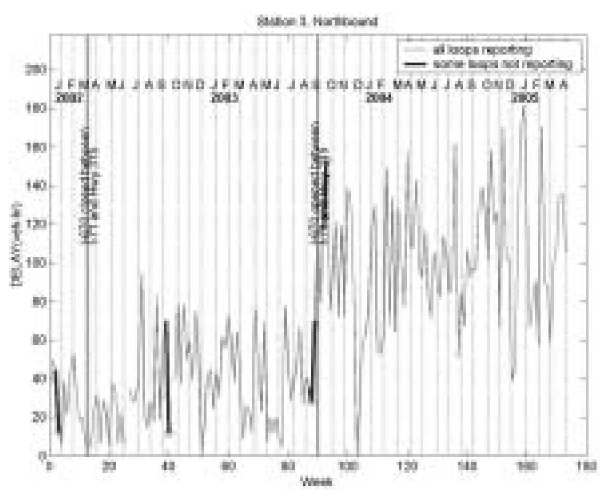


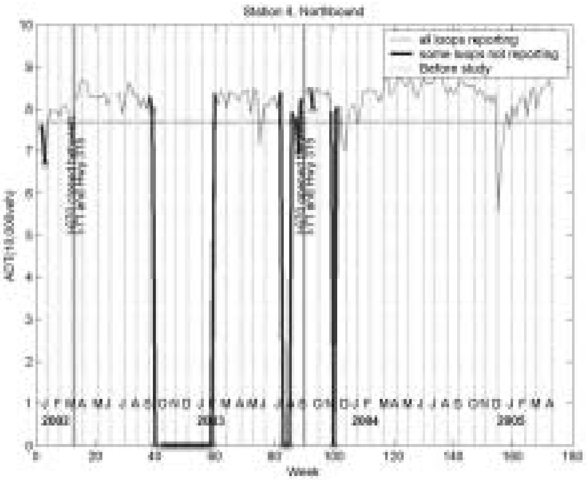


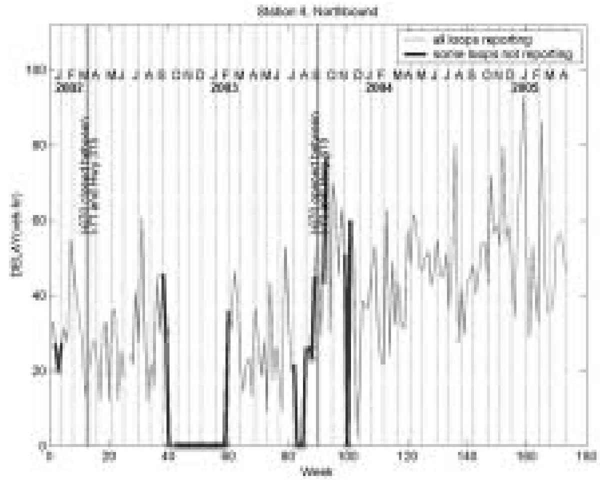


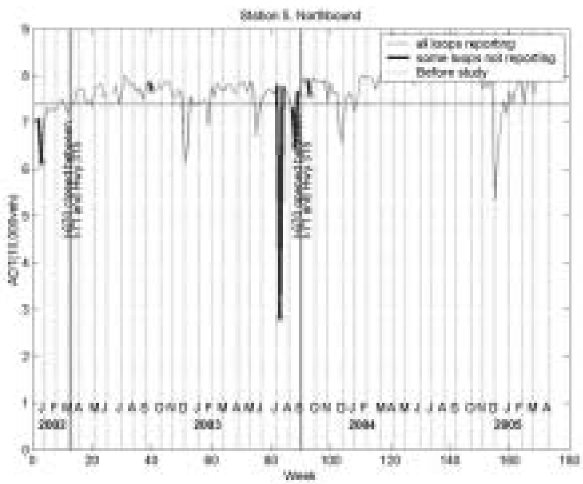


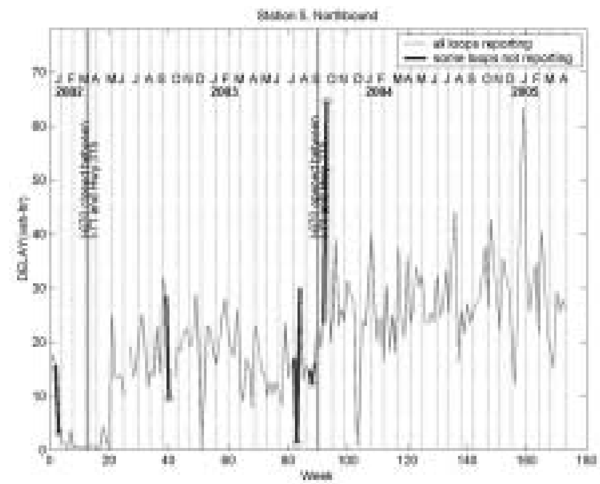


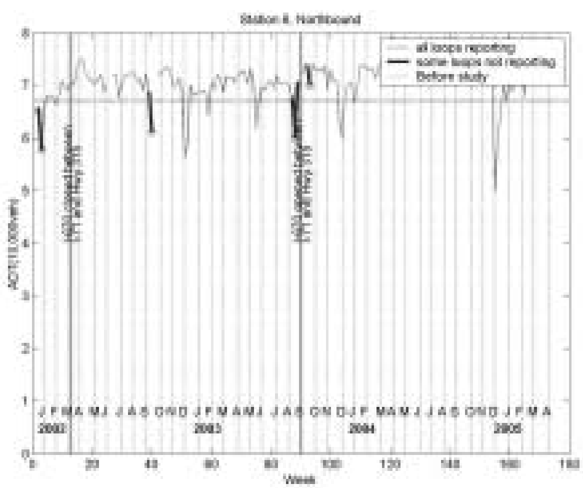


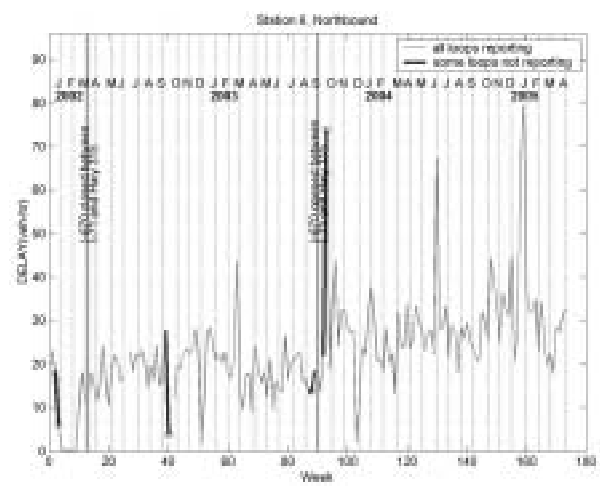

Station 4, Northbound
all loops reporting
some loops not reporting
Before study
ACT(10,000veh)
Week

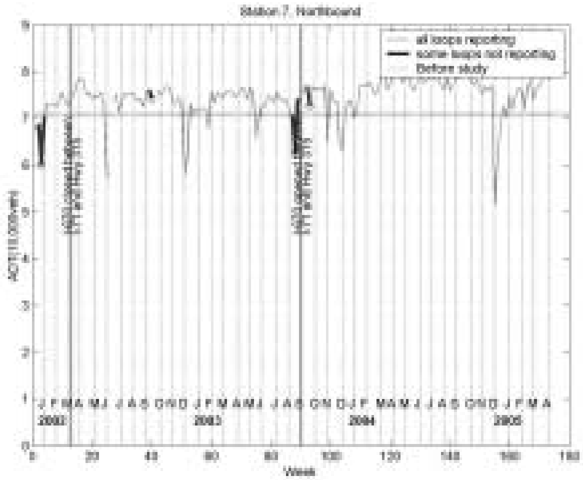

Station 4, Northbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

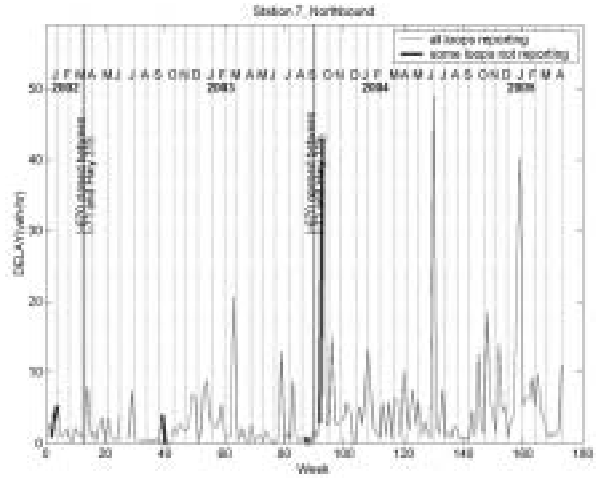

Station 5, Northbound
all loops reporting
some loops not reporting
Before study
ACT(10,000veh)
Week

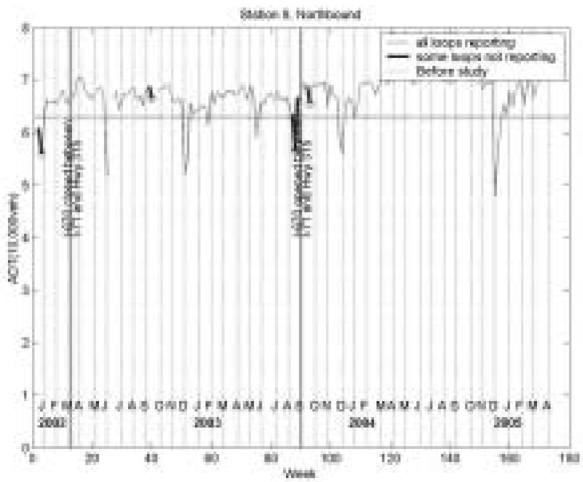

Station 5, Northbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

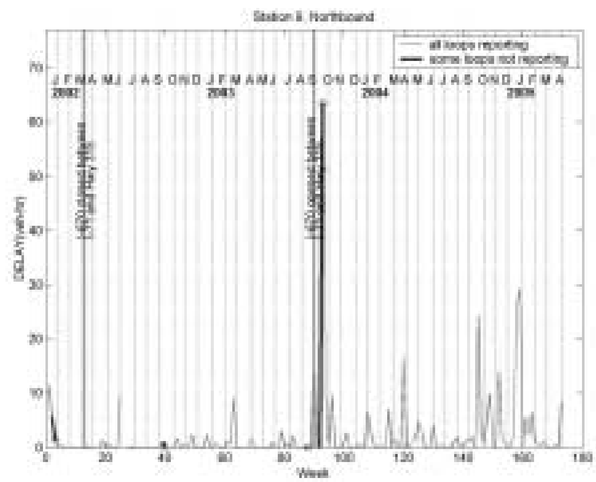

Station 6, Northbound
all loops reporting
some loops not reporting
Before study
ACT(10,000veh)
Week

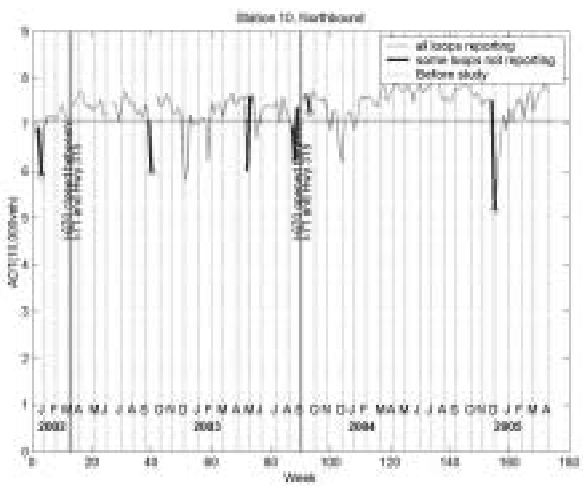

Station 6, Northbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

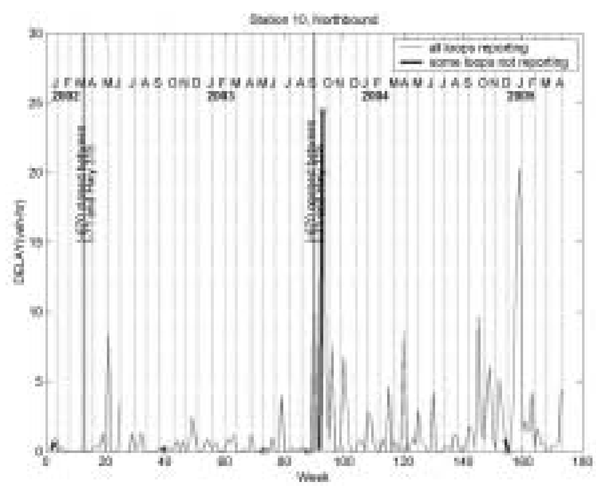

Station 7, Northbound
all loops reporting
some loops not reporting
Before study
ACT(1,000veh)
Week

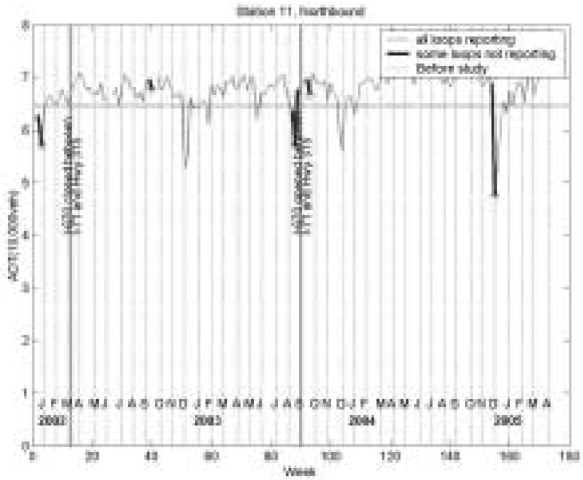

Station 7, Northbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

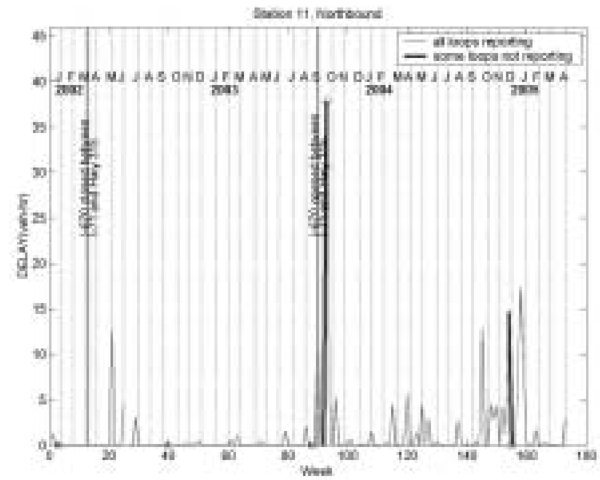

Station 8, Northbound
all loops reporting
some loops not reporting
Before study
ACT(1,000veh)
Week

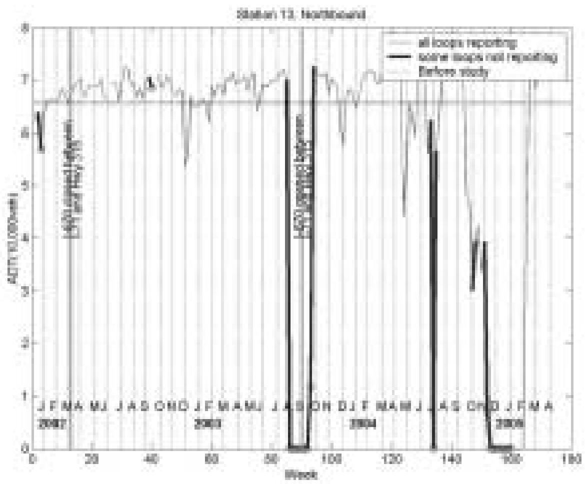

Station 8, Northbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

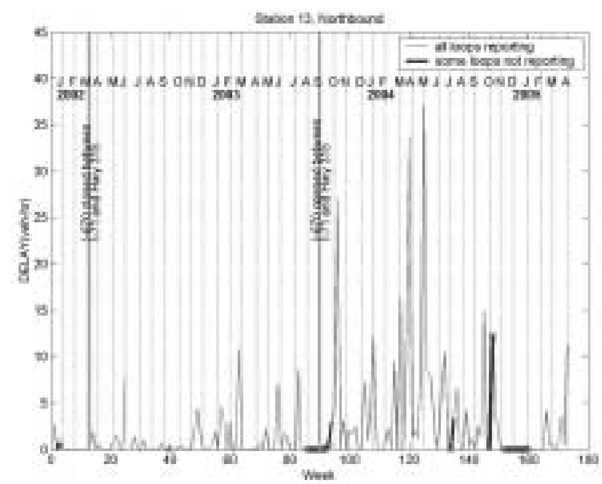

Station 10, Northbound
all loops reporting
some loops not reporting
Before study
ACT(1,000veh)
Week

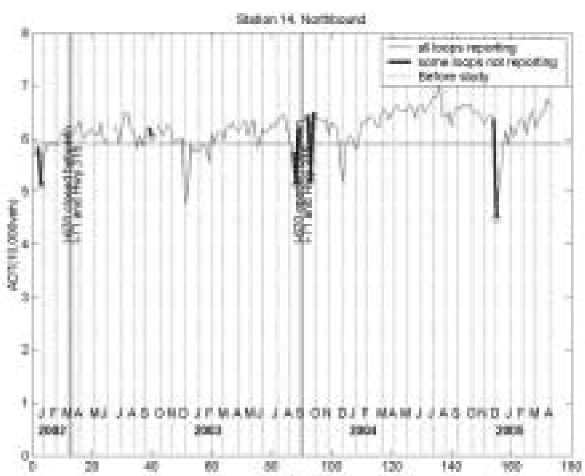

Station 10, Northbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

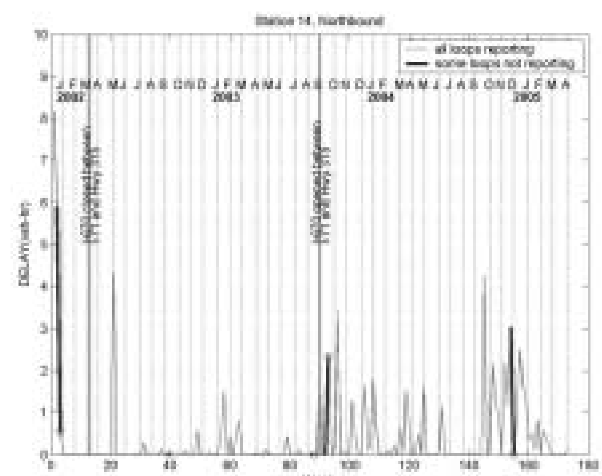

Station 11, Northbound
all loops reporting
some loops not reporting
Before study
Week

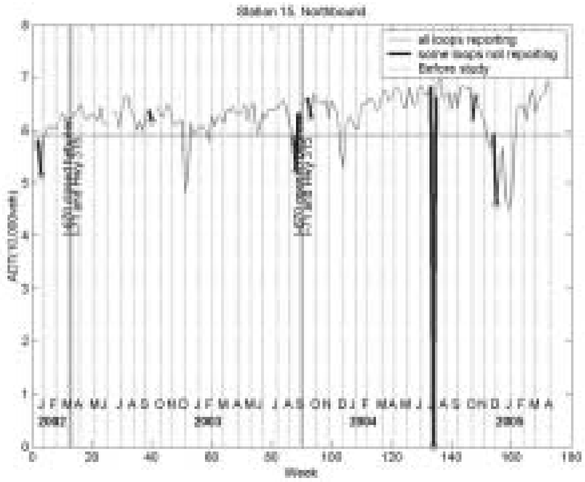

Station 11, Northbound
all loops reporting
some loops not reporting
Week

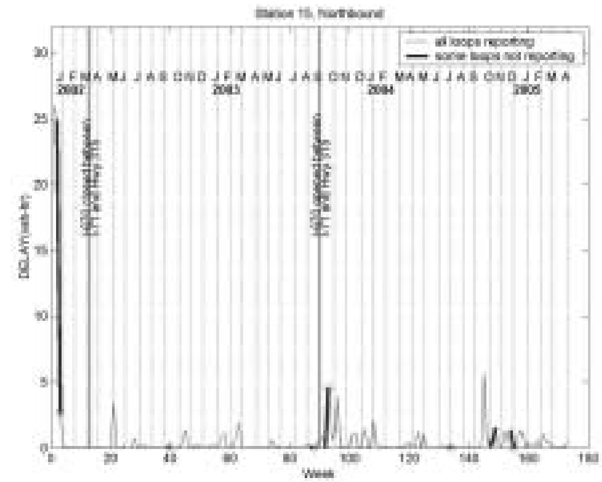

Station 13, Northbound
all loops reporting
some loops not reporting
Before study
Week

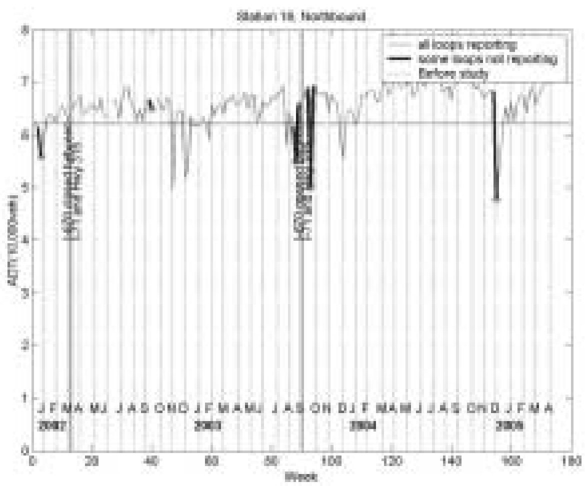

Station 13, Northbound
all loops reporting
some loops not reporting
Week

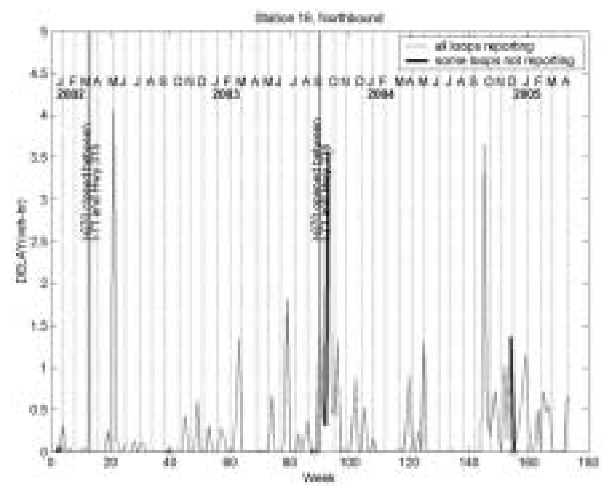

Station 14, Northbound
all loops reporting
some loops not reporting
Before study
Week

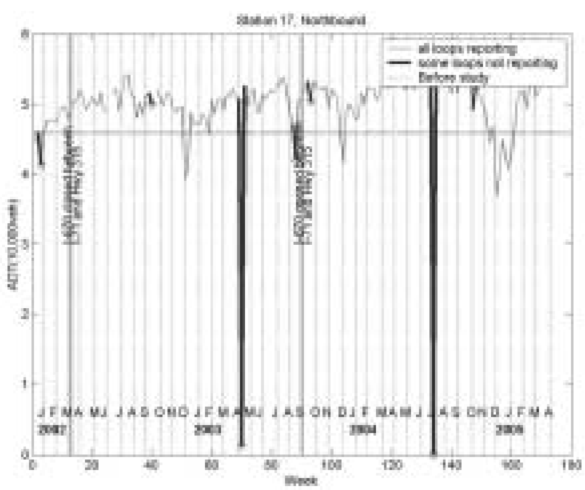

Station 14, Northbound
all loops reporting
some loops not reporting
Week

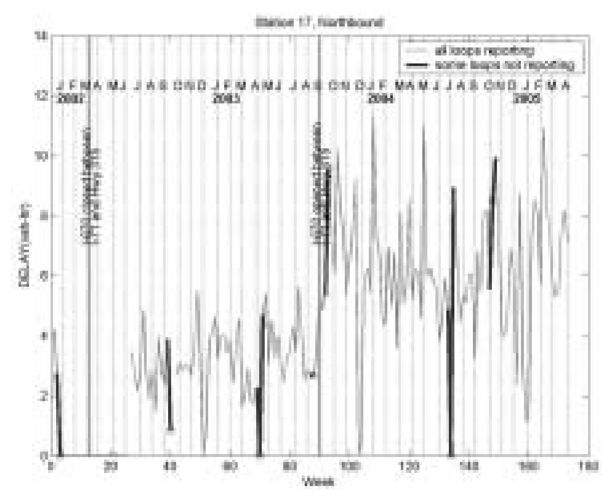

Station 15, Northbound
all loops reporting
some loops not reporting
Before study
Week

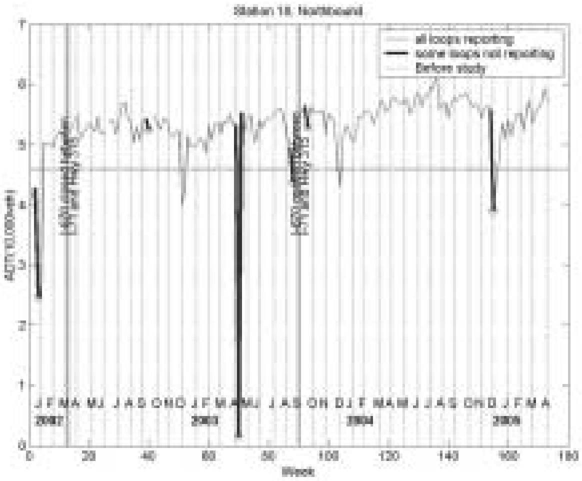

Station 15, Northbound
all loops reporting
some loops not reporting
Week

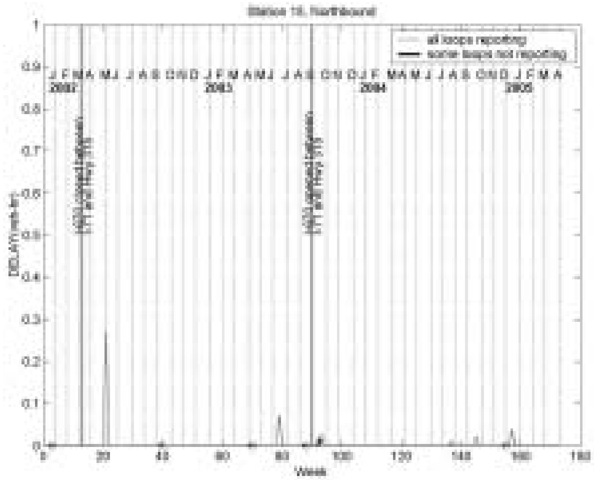

Station 16, Northbound
all loops reporting
some loops not reporting
Before study
Week

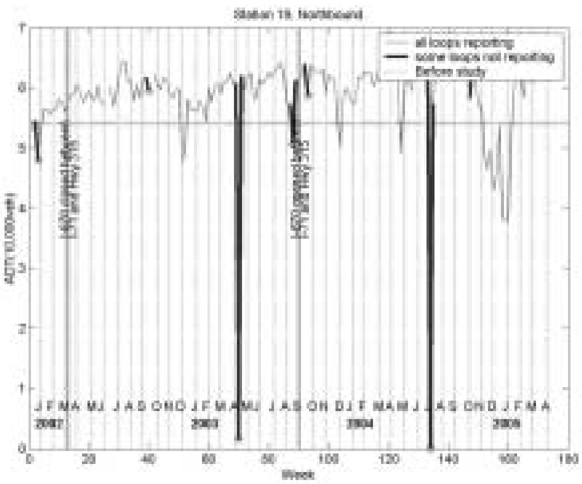

Station 16, Northbound
all loops reporting
some loops not reporting
Week

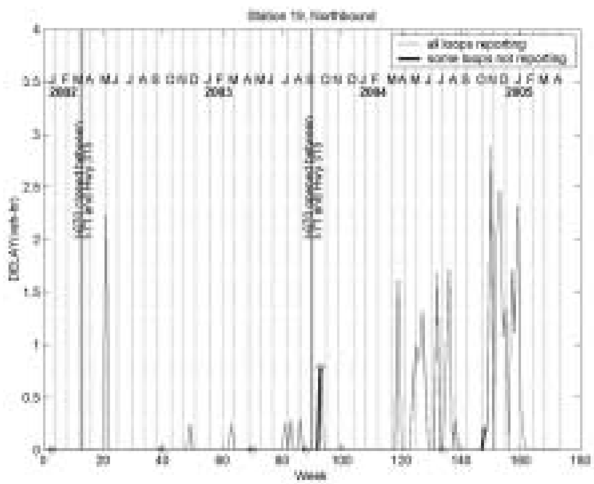

Station 17, Northbound
all loops reporting
some loops not reporting
Before study
Week

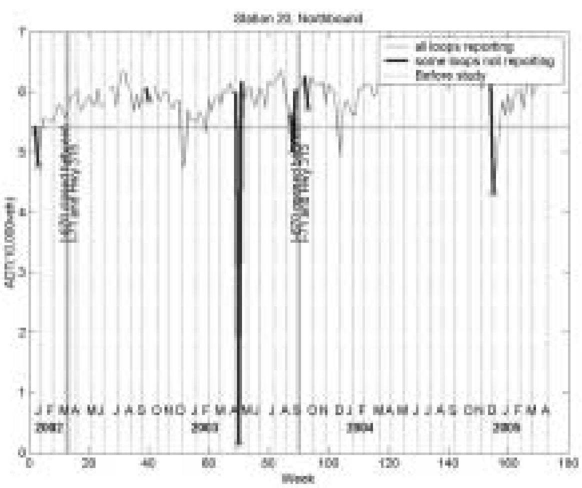

Station 17, Northbound
all loops reporting
some loops not reporting
Week

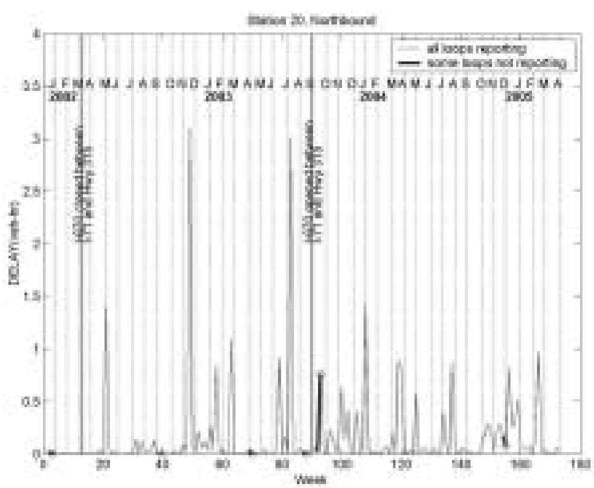

Station 18, Northbound
all loops reporting
some loops not reporting
Before study
Week

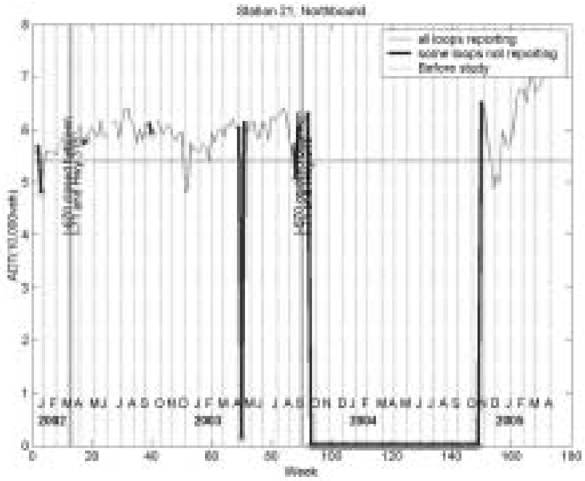

Station 18, Northbound
all loops reporting
some loops not reporting
Week

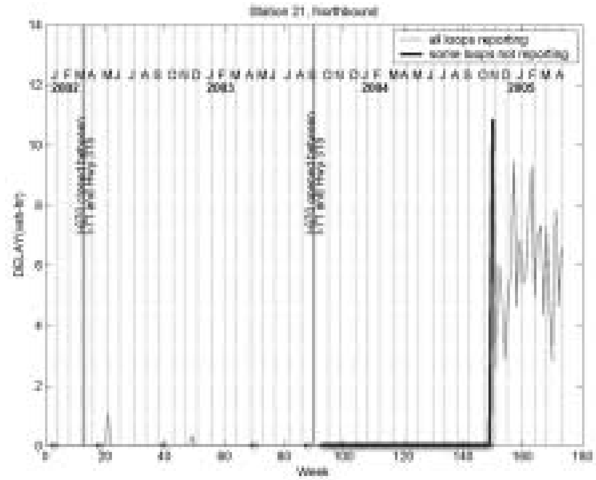

Station 19, Northbound
all loops reporting
some loops not reporting
Before study
Week

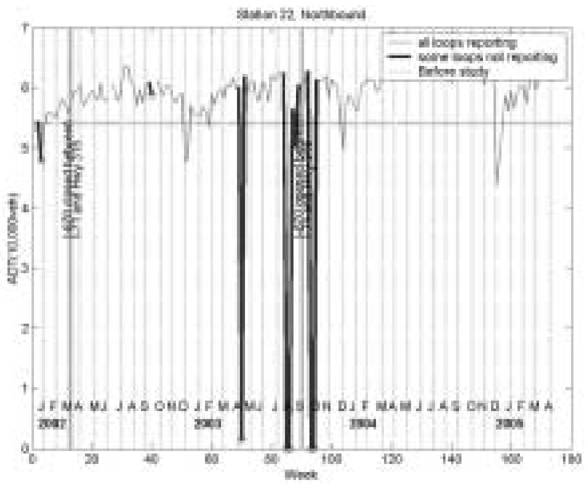

Station 19, Northbound
all loops reporting
some loops not reporting
Week

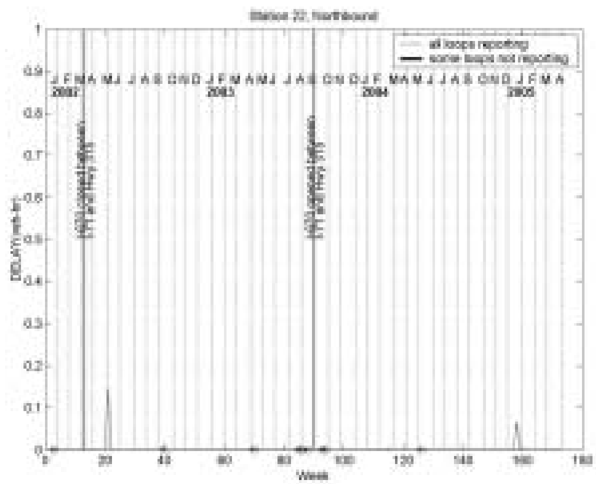

Station 20, Northbound
all loops reporting
some loops not reporting
Before study
Week

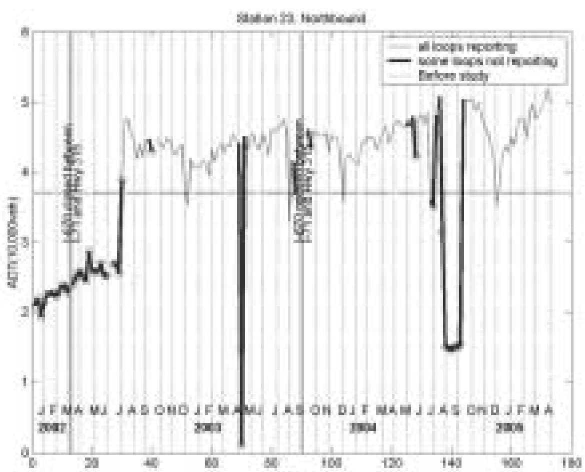

Station 20, Northbound
all loops reporting
some loops not reporting
Week

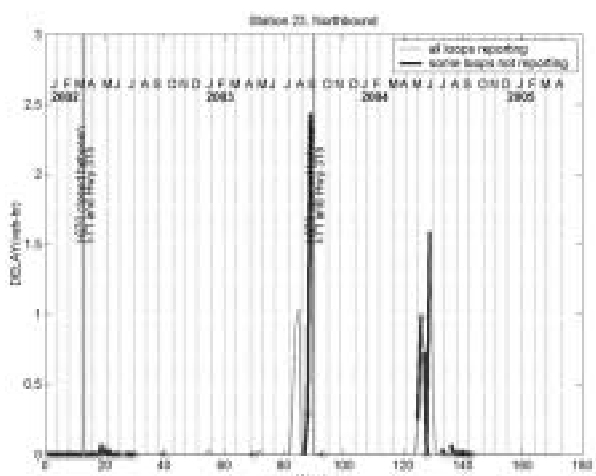

Station 21, Northbound
all loops reporting
some loops not reporting
Before study
ADT(10,000veh)
Week

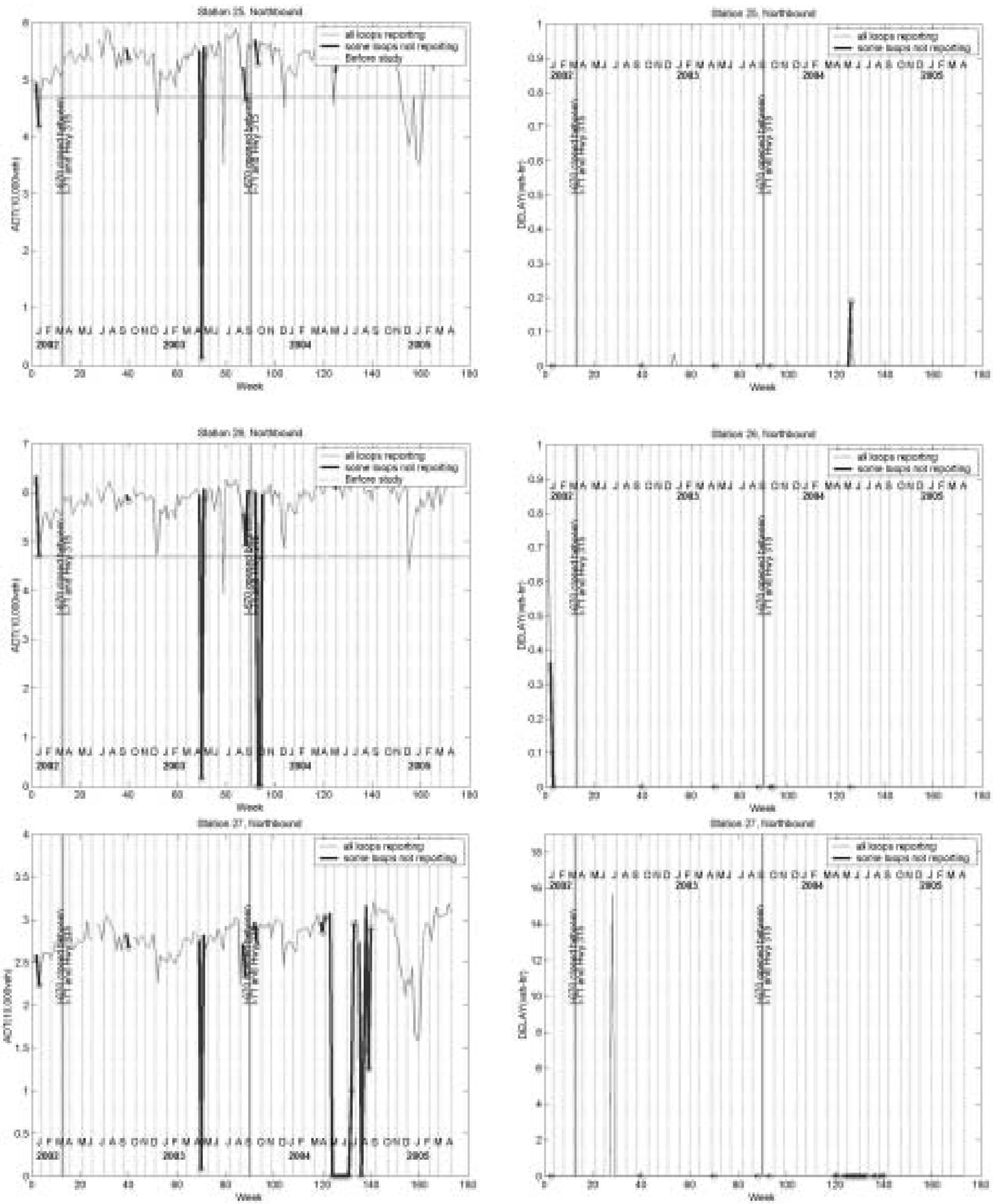

Station 21, Northbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week


Station 22, Northbound
all loops reporting
some loops not reporting
Before study
ADT(10,000veh)
Week

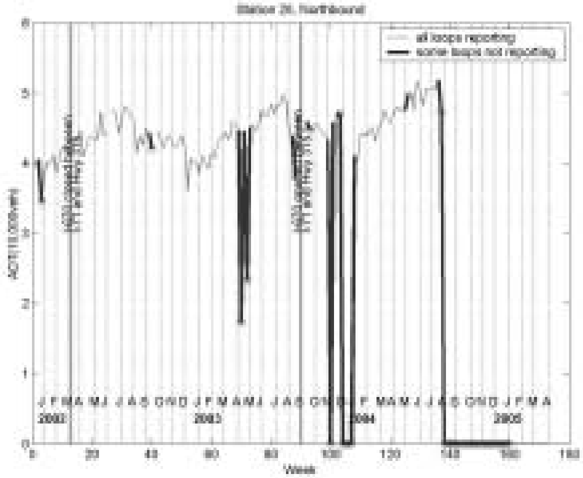

Station 22, Northbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

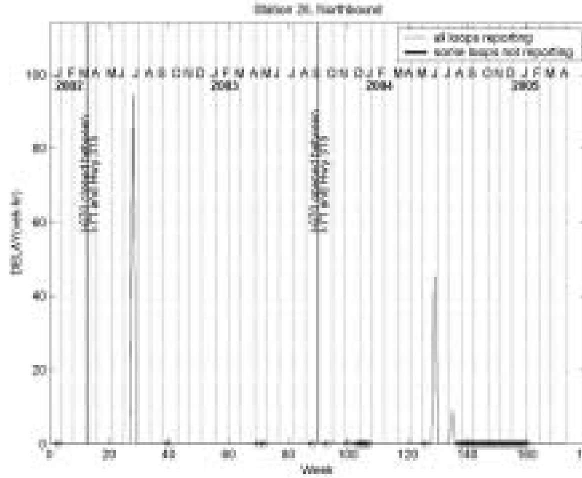

Station 23, Northbound
all loops reporting
some loops not reporting
Before study
ADT(10,000veh)
Week

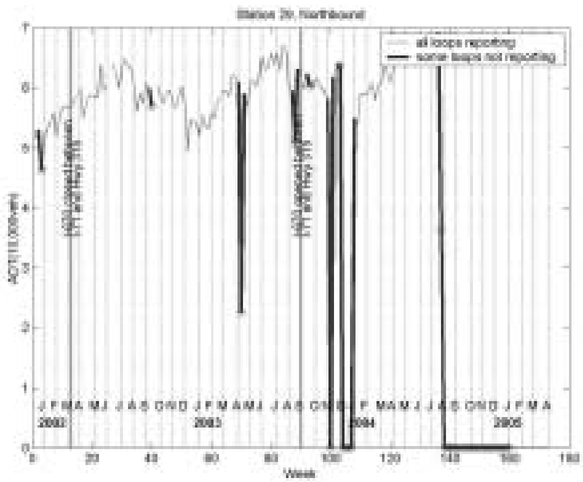

Station 23, Northbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

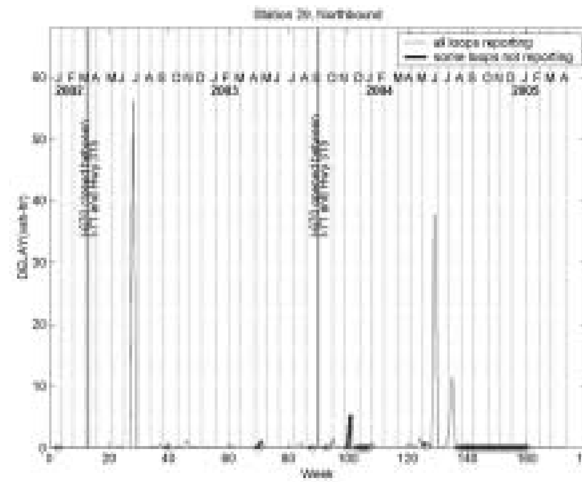


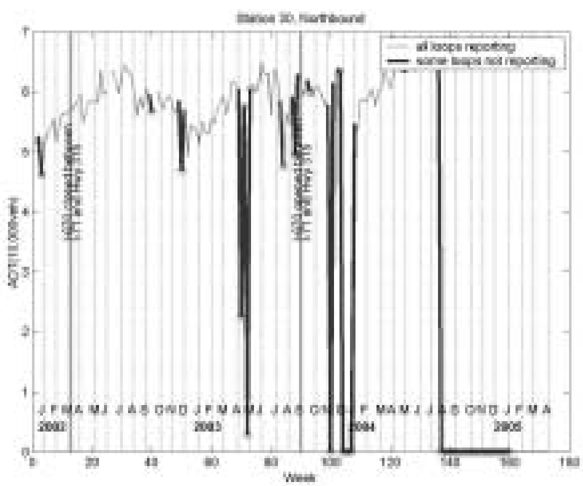
Station 25, Northbound
all loops reporting
some loops not reporting
Before study
ADT(10,000veh)
DELAY(veh-hr)
Week
Station 26, Northbound
Station 27, Northbound

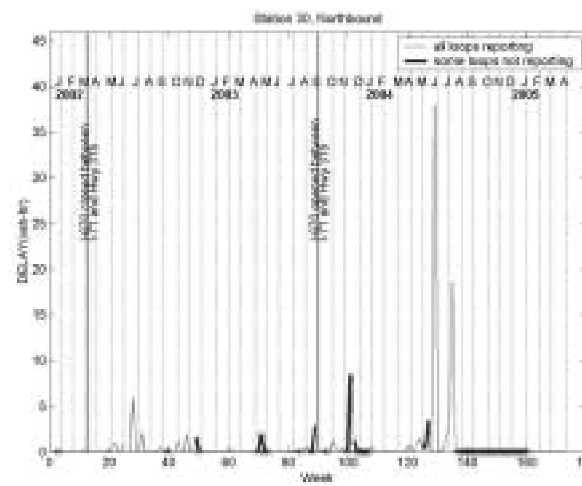

Station 28, Northbound
all loops reporting
some loops not reporting
Week

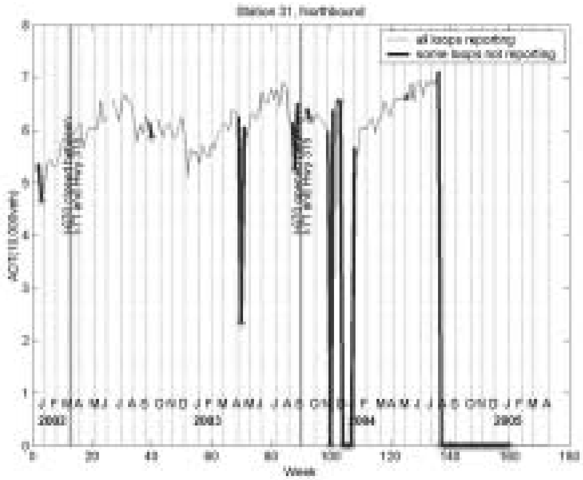

Station 28, Northbound
all loops reporting
some loops not reporting
Week

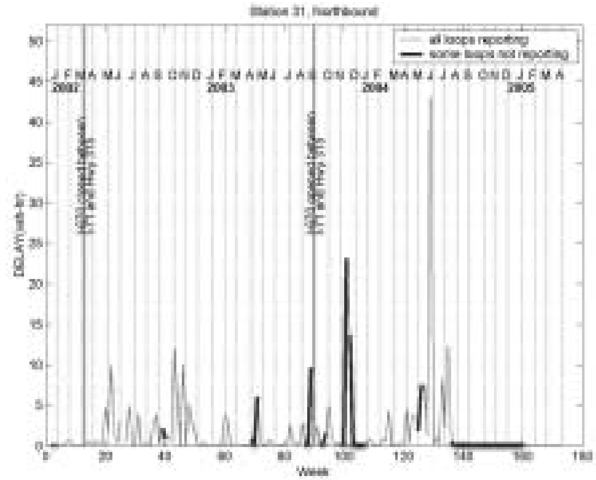

Station 29, Northbound
all loops reporting
some loops not reporting
Week

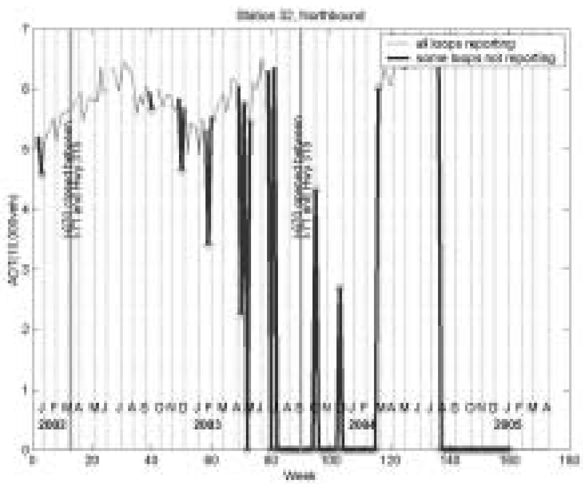

Station 29, Northbound
all loops reporting
some loops not reporting
Week

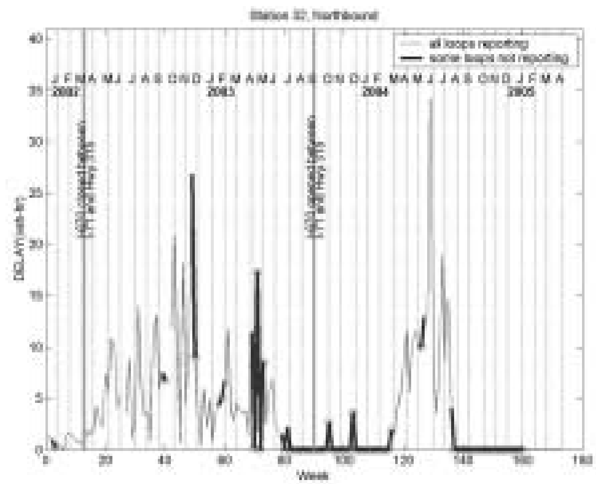

Station 30, Northbound
all loops reporting
some loops not reporting
Week

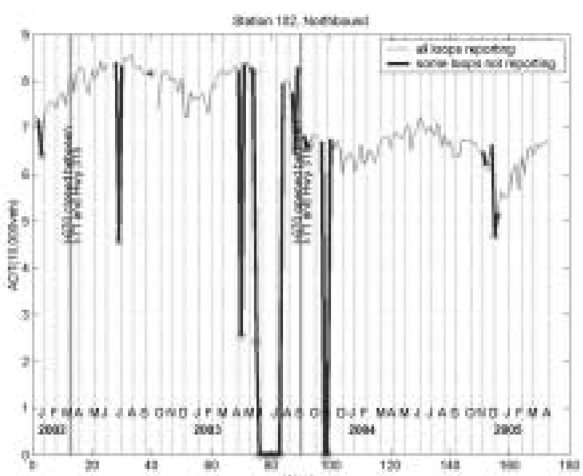

Station 30, Northbound
all loops reporting
some loops not reporting
Week

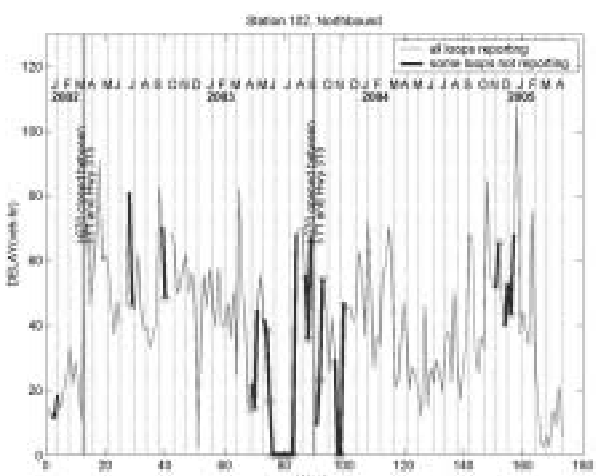

Station 31, Northbound
all loops reporting
some loops not reporting
Week

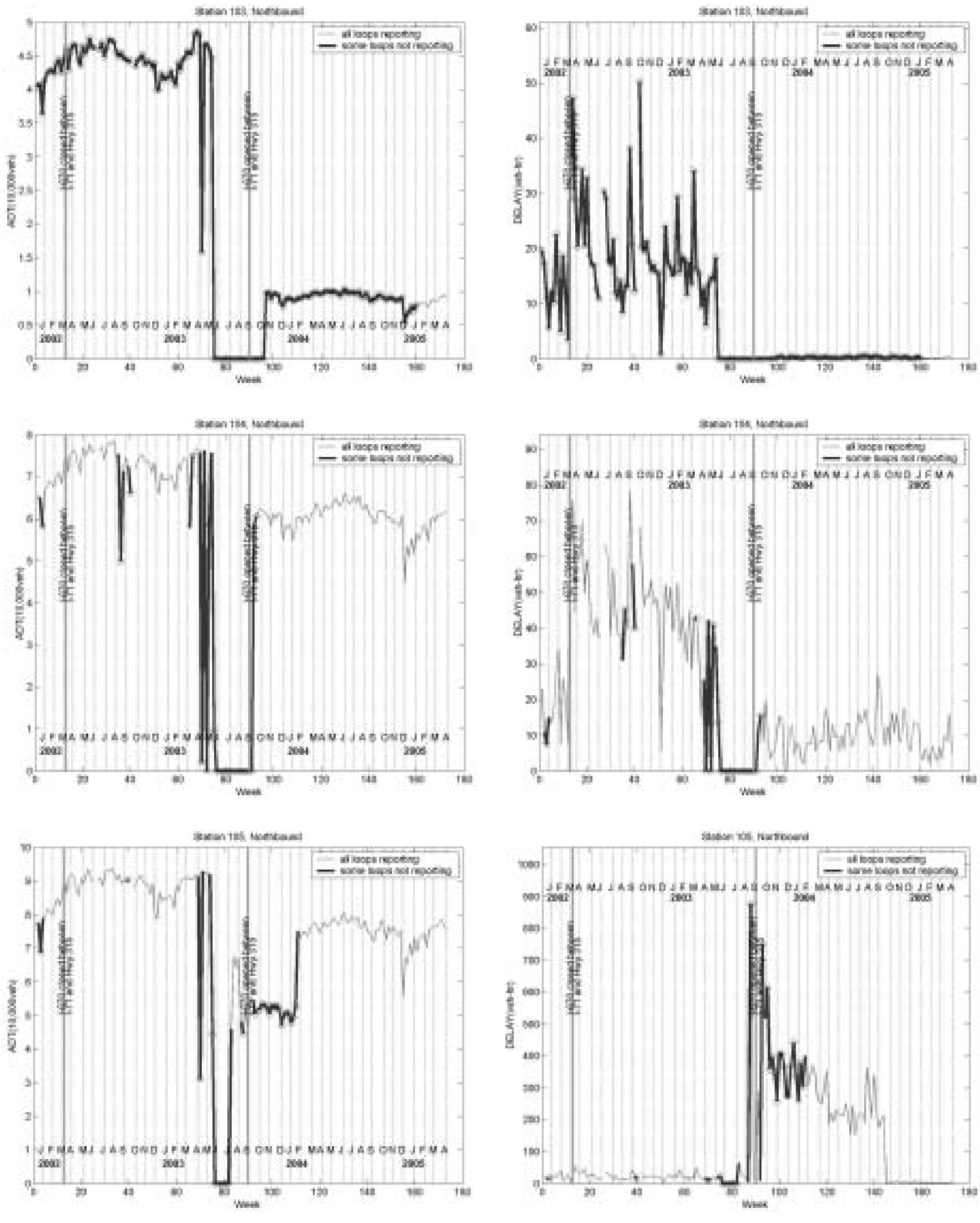

Station 31, Northbound
all loops reporting
some loops not reporting
Week

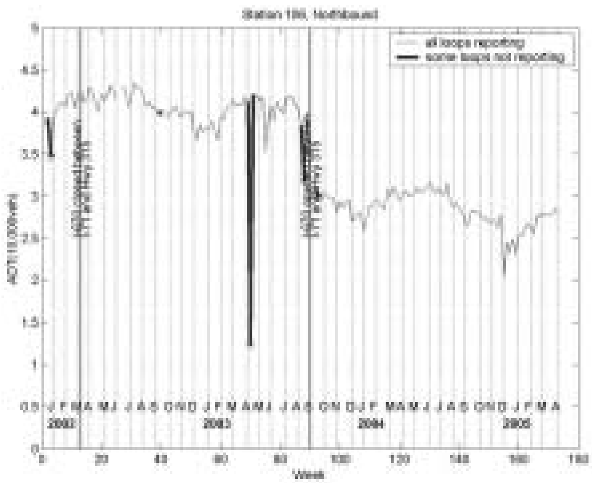

Station 32, Northbound
all loops reporting
some loops not reporting
Week

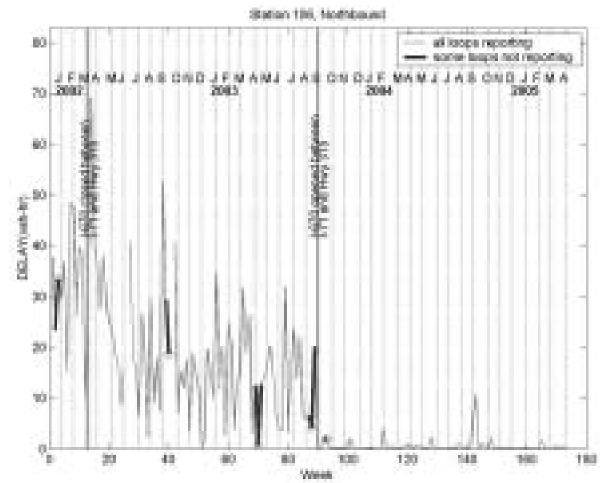

Station 32, Northbound
all loops reporting
some loops not reporting
Week

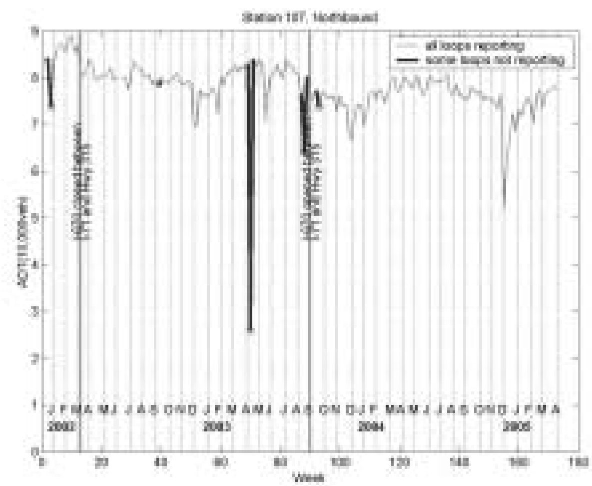

Station 182, Northbound
all loops reporting
some loops not reporting
Week

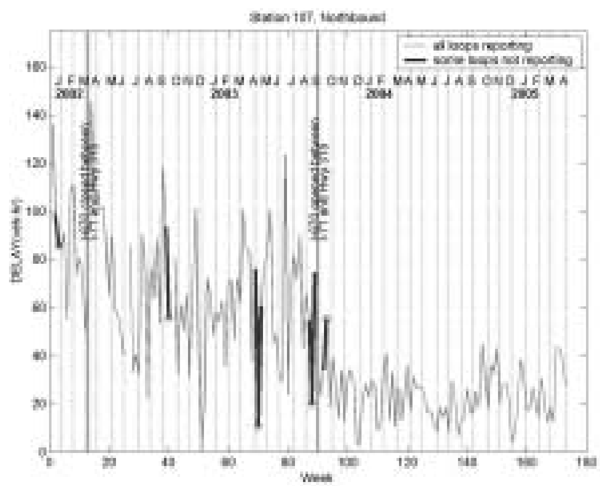

Station 182, Northbound
all loops reporting
some loops not reporting
Week

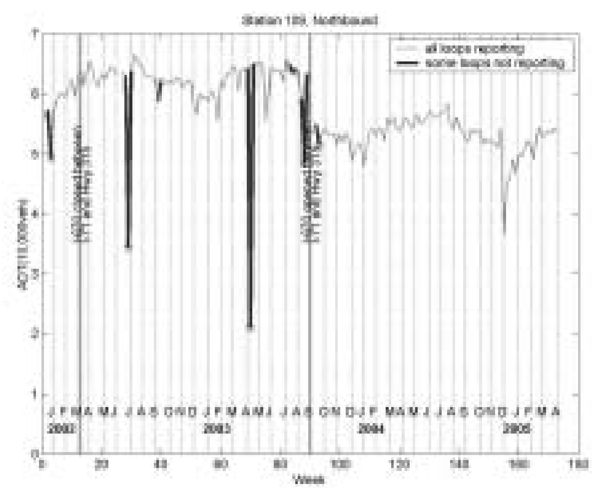

Station 103, Northbound
all loops reporting
some loops not reporting
Week
Station 104, Northbound
all loops reporting
some loops not reporting
Week
Station 105, Northbound
all loops reporting
some loops not reporting
Week

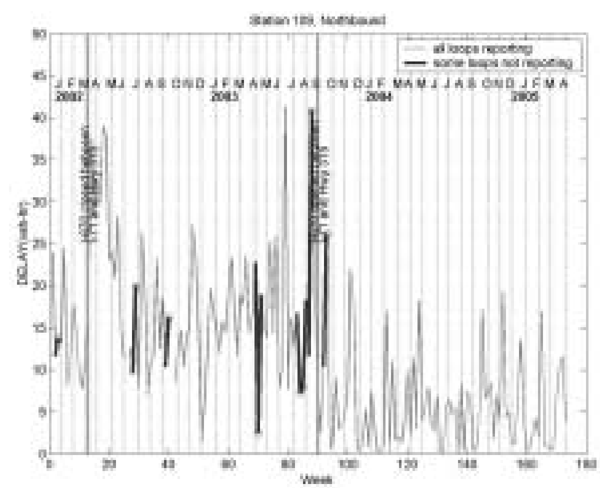

Station 106, Northbound
all loops reporting
some loops not reporting
ACT(1,000veh)
Week


Station 106, Northbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

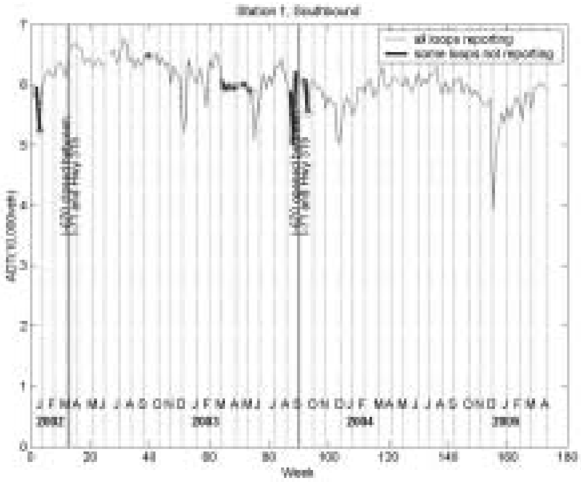

Station 107, Northbound
all loops reporting
some loops not reporting
ACT(1,000veh)
Week

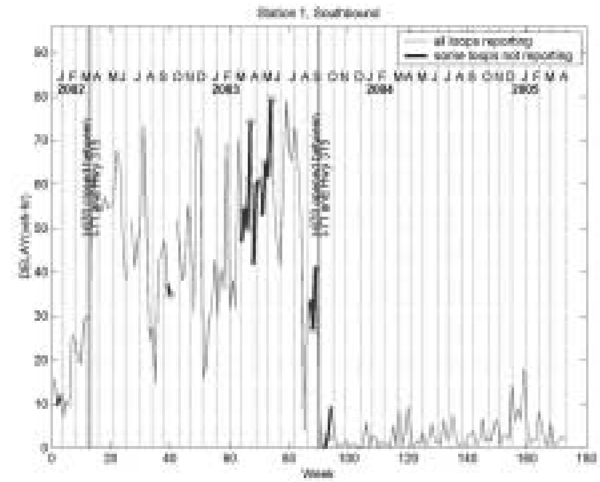

Station 107, Northbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

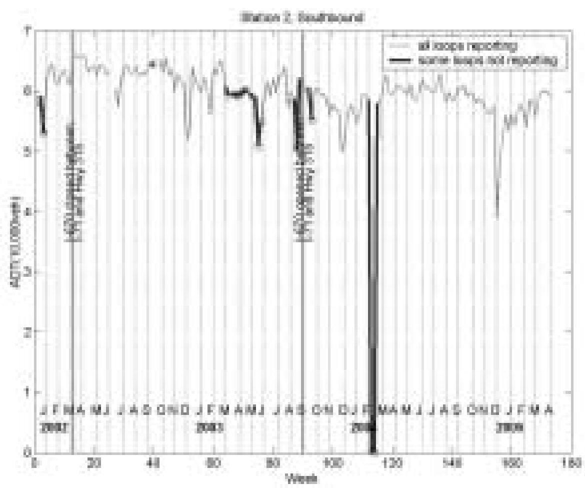

Station 109, Northbound
all loops reporting
some loops not reporting
ACT(1,000veh)
Week

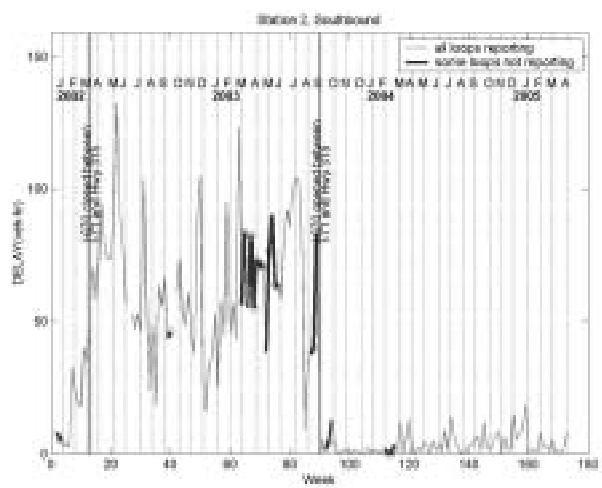

Station 109, Northbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

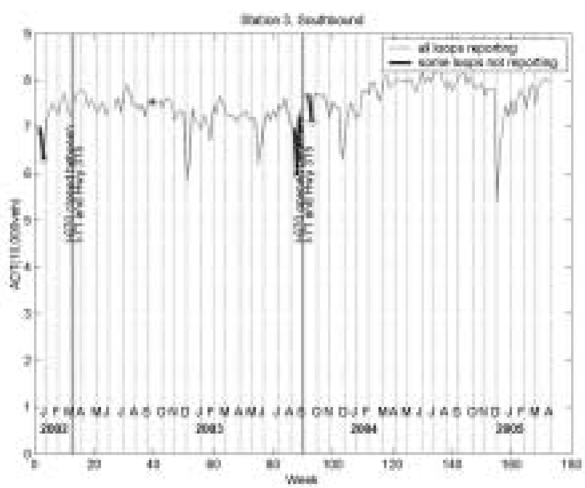
SOUTHBOUND- 24 HRS

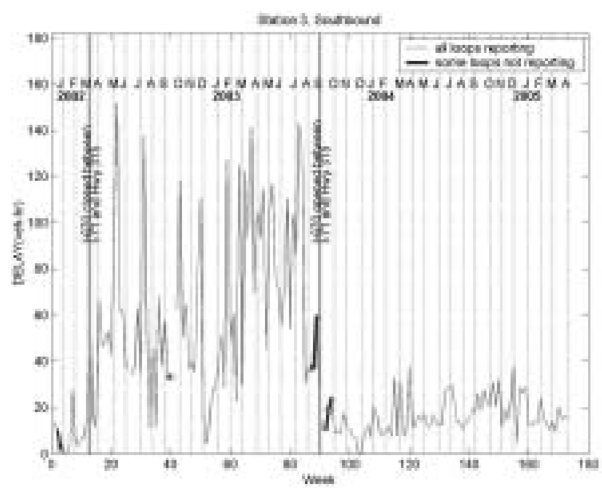


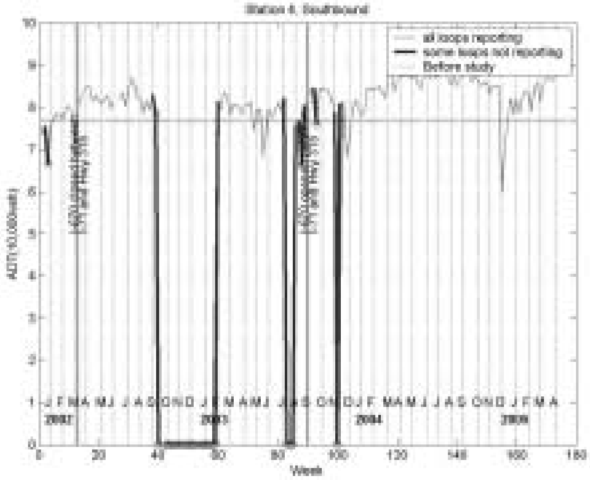


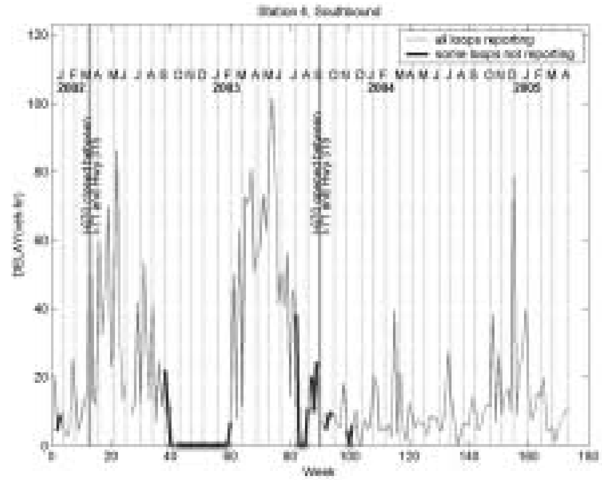


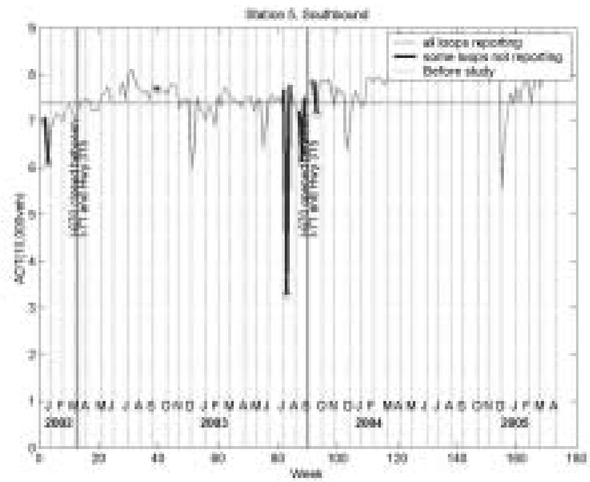


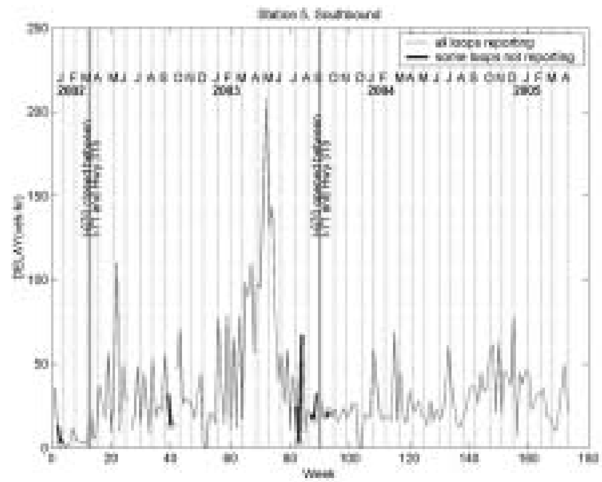


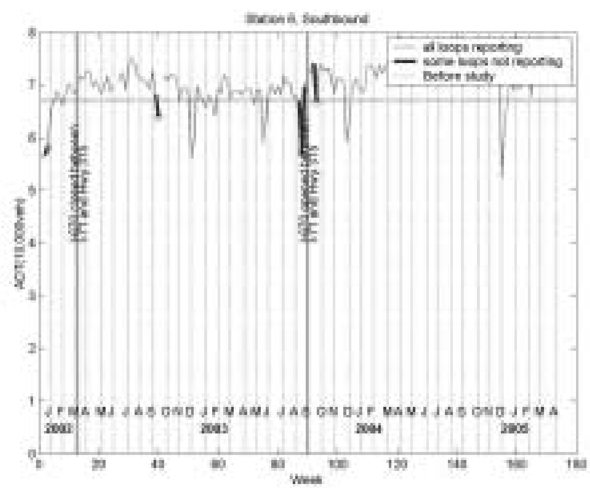


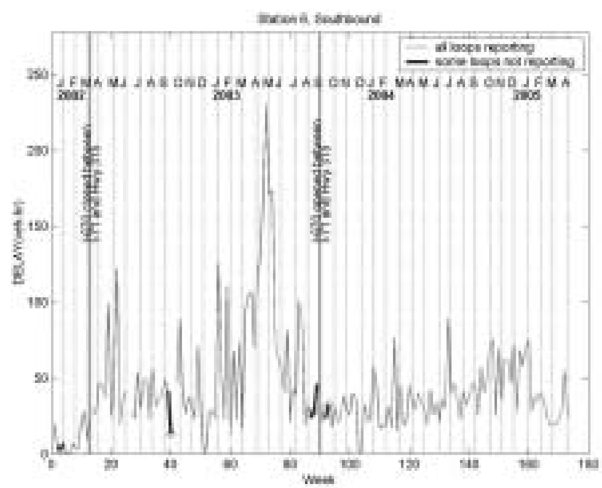

Station 4, Southbound
all loops reporting
some loops not reporting
Before study
ADT(10,000veh)
Week

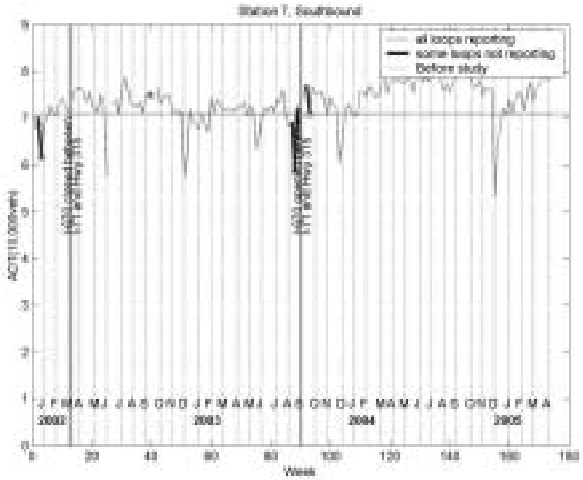

Station 4, Southbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

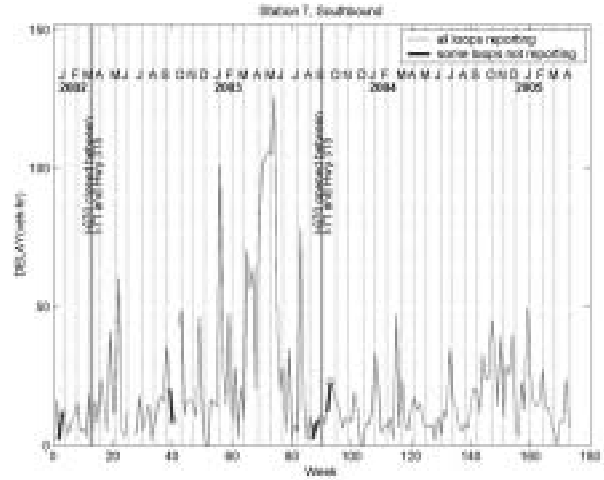

Station 5, Southbound
all loops reporting
some loops not reporting
Before study
ADT(10,000veh)
Week

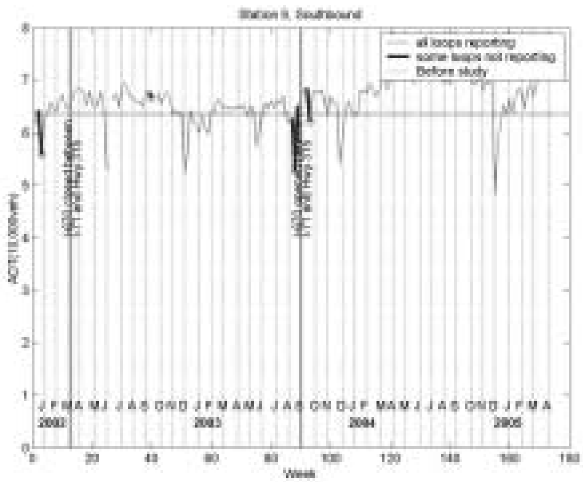

Station 5, Southbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

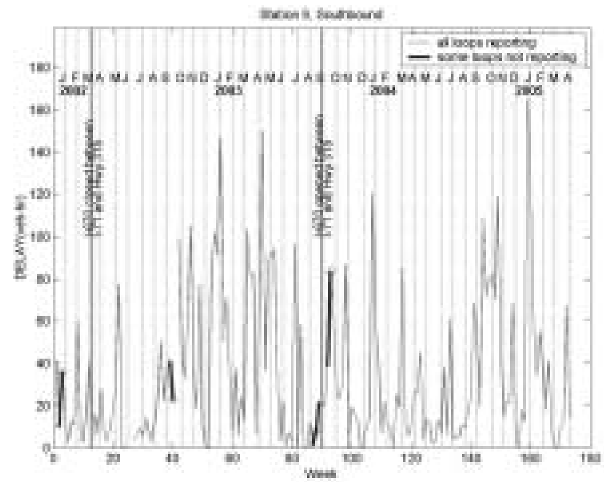

Station 6, Southbound
all loops reporting
some loops not reporting
Before study
ADT(10,000veh)
Week

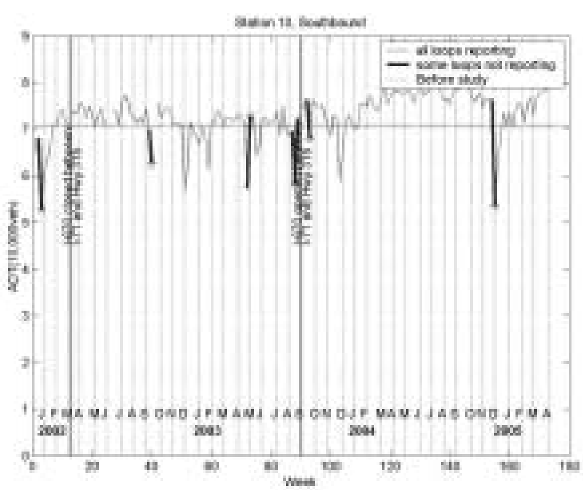

Station 6, Southbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

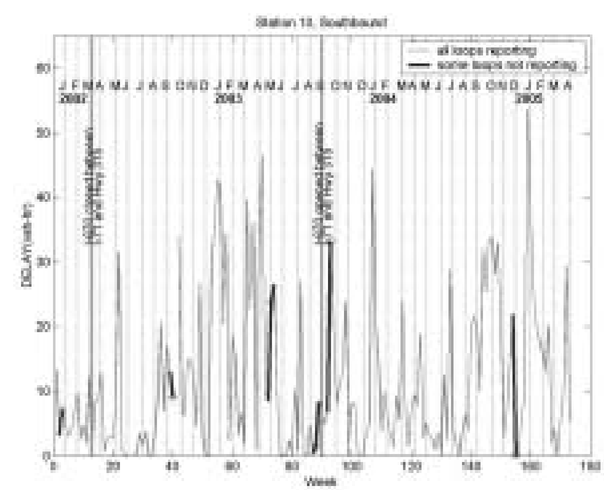

Station 7, Southbound
all loops reporting
some loops not reporting
Before study
Week

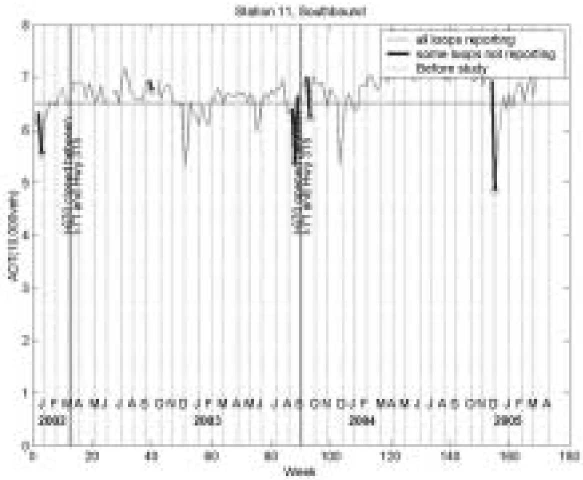

Station 7, Southbound
all loops reporting
some loops not reporting
Week

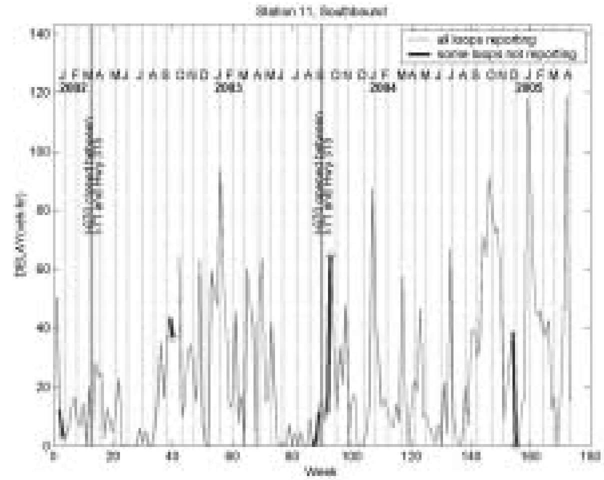

Station 9, Southbound
all loops reporting
some loops not reporting
Before study
Week

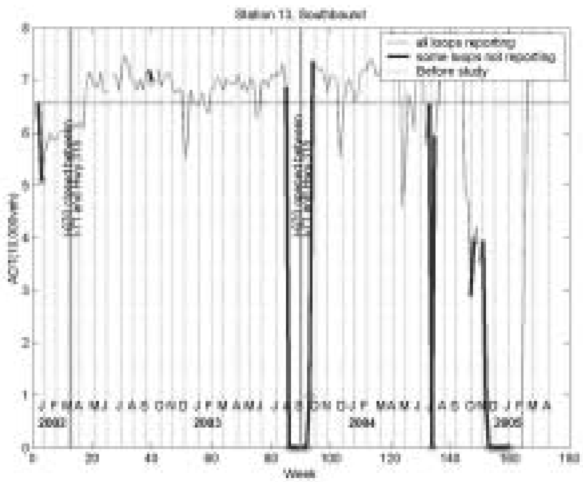

Station 9, Southbound
all loops reporting
some loops not reporting
Week

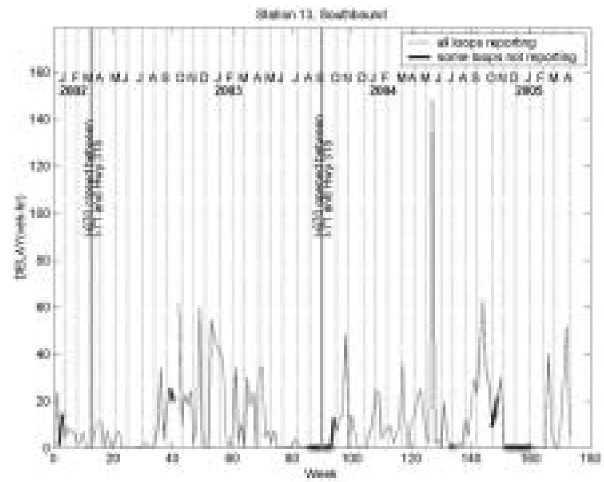

Station 10, Southbound
all loops reporting
some loops not reporting
Before study
Week

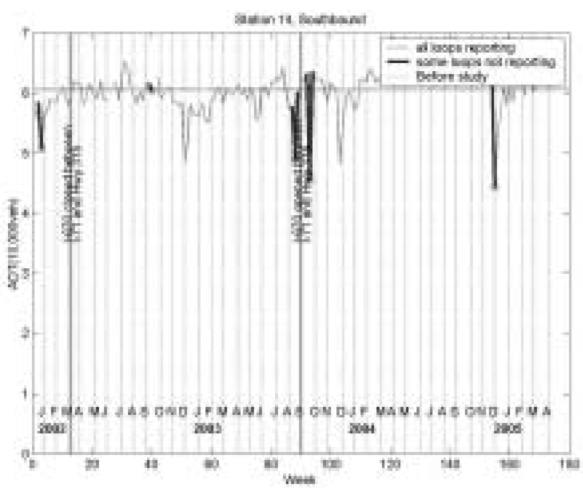

Station 10, Southbound
all loops reporting
some loops not reporting
Week

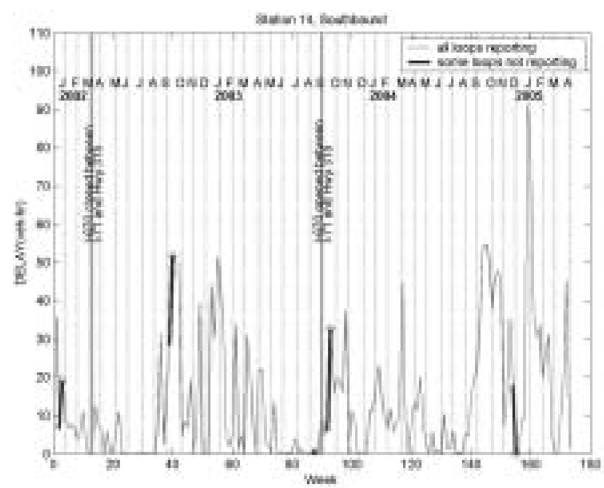

Station 11, Southbound
all loops reporting
some loops not reporting
Before study
Week

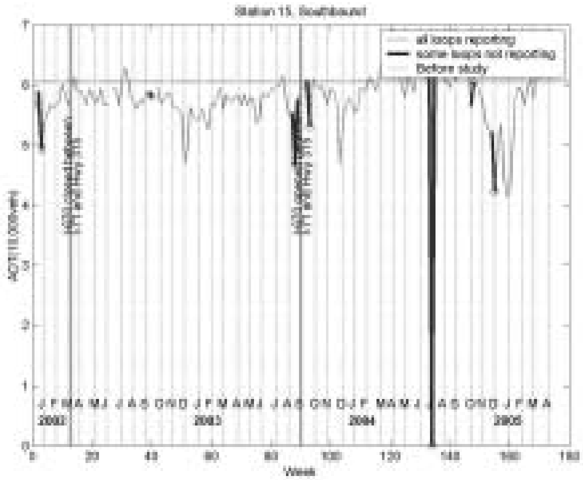

Station 11, Southbound
all loops reporting
some loops not reporting
Week

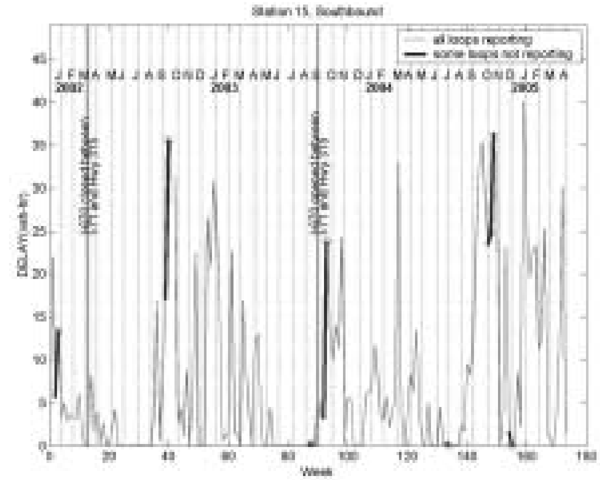

Station 13, Southbound
all loops reporting
some loops not reporting
Before study
Week

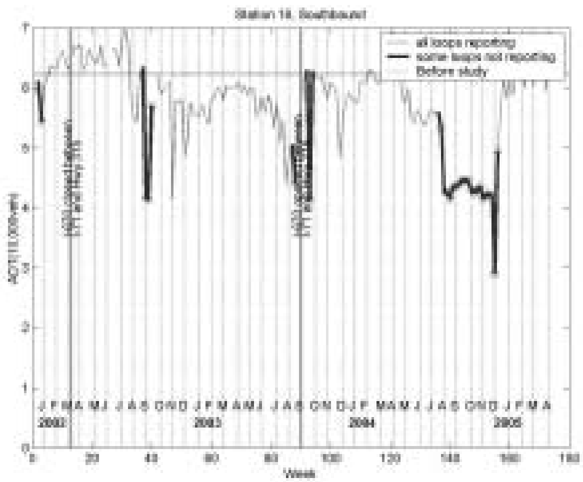

Station 13, Southbound
all loops reporting
some loops not reporting
Week

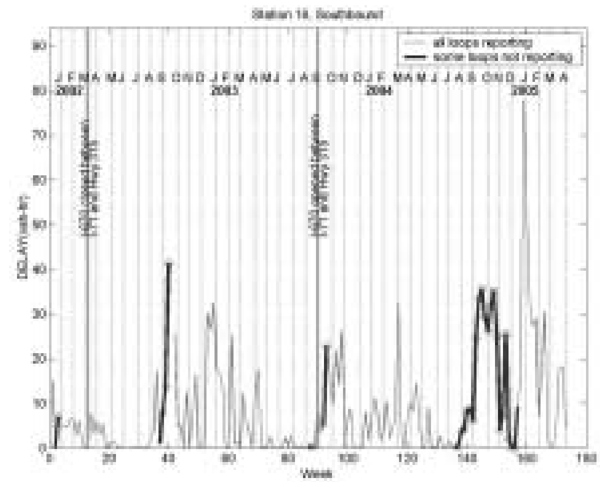

Station 14, Southbound
all loops reporting
some loops not reporting
Before study
Week

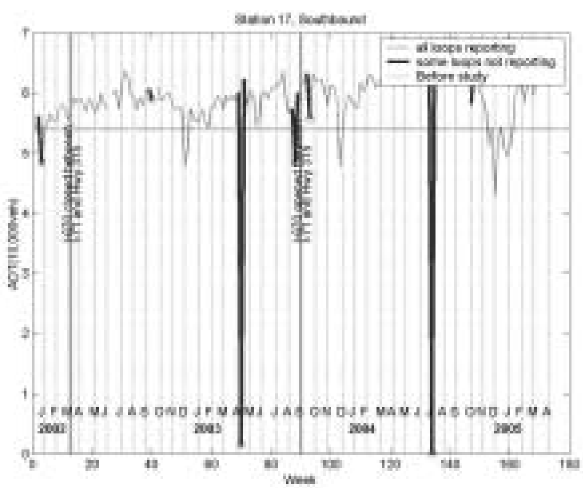

Station 14, Southbound
all loops reporting
some loops not reporting
Week

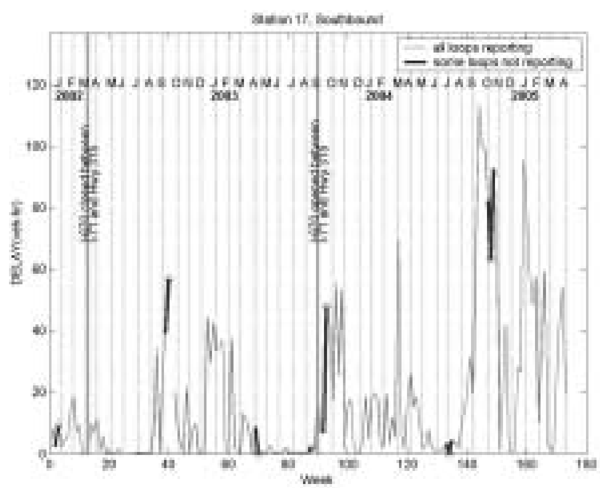

Station 15, Southbound
all loops reporting
some loops not reporting
Before study
Week

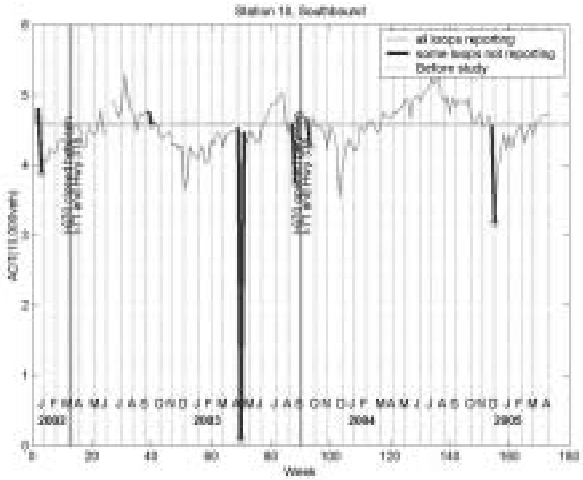

Station 15, Southbound
all loops reporting
some loops not reporting
Week

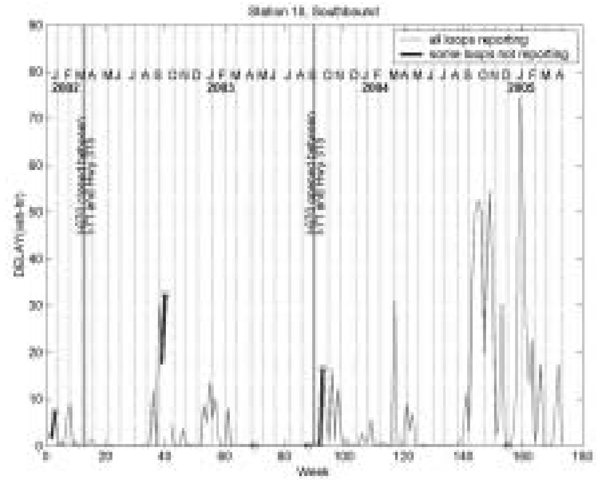

Station 16, Southbound
all loops reporting
some loops not reporting
Before study
Week

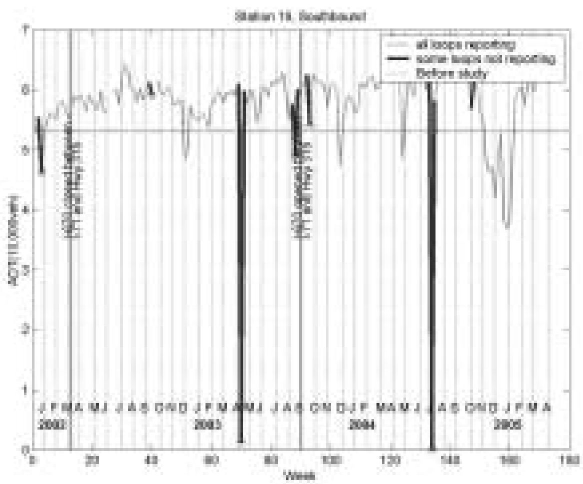

Station 16, Southbound
all loops reporting
some loops not reporting
Week

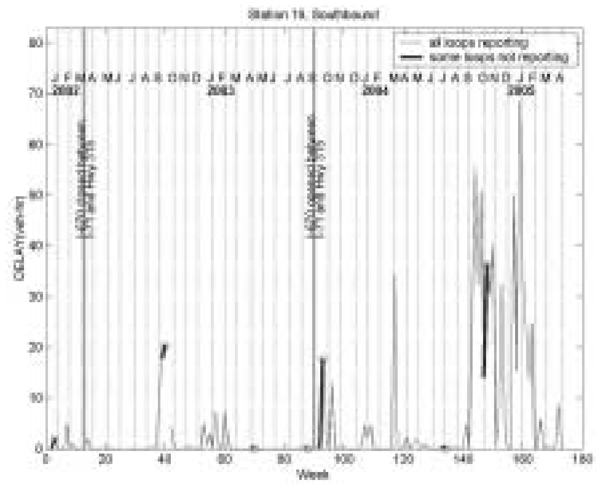

Station 17, Southbound
all loops reporting
some loops not reporting
Before study
Week

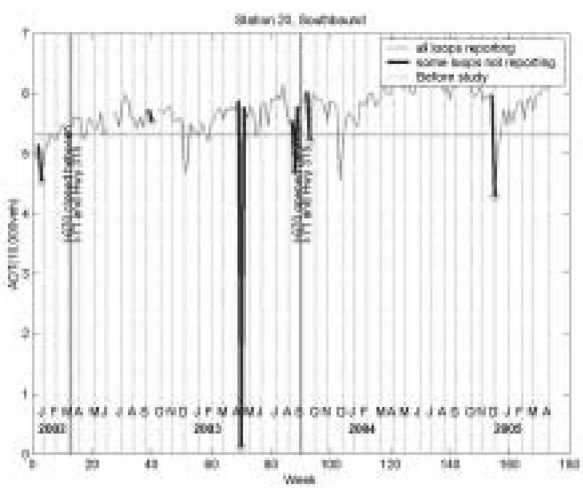

Station 17, Southbound
all loops reporting
some loops not reporting
Week

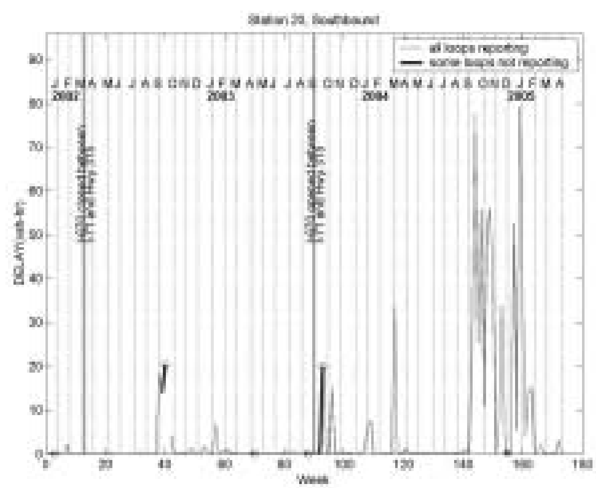

Station 18, Southbound
all loops reporting
some loops not reporting
Before study
Week

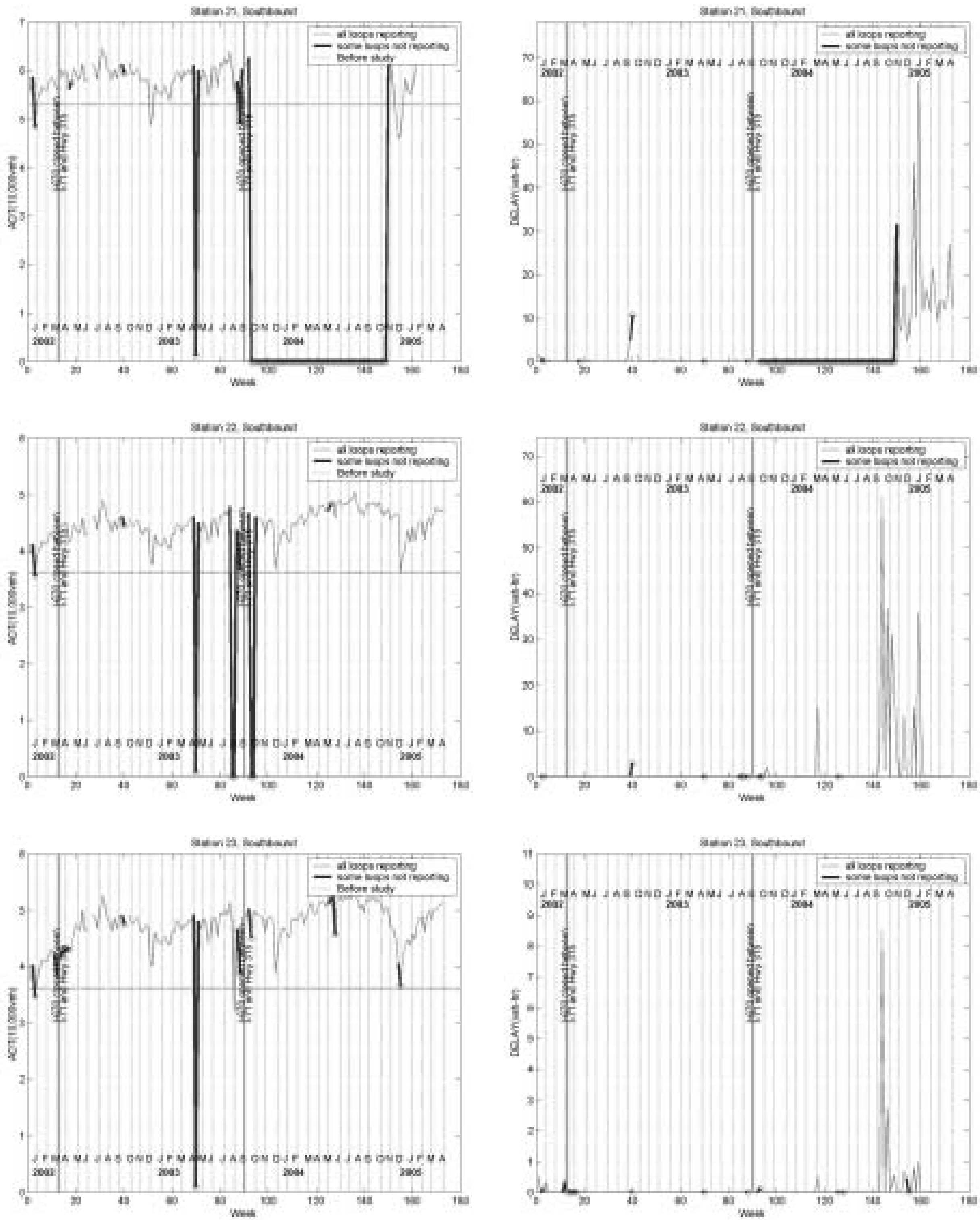

Station 18, Southbound
all loops reporting
some loops not reporting
Week

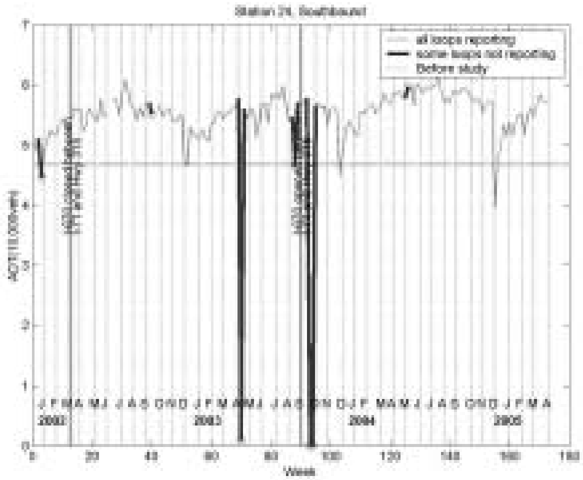
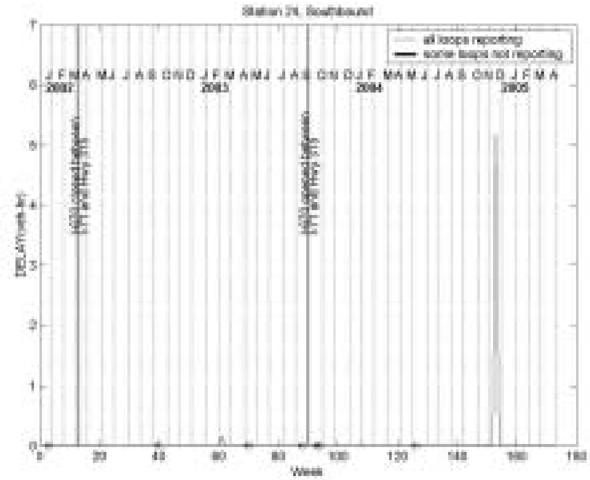
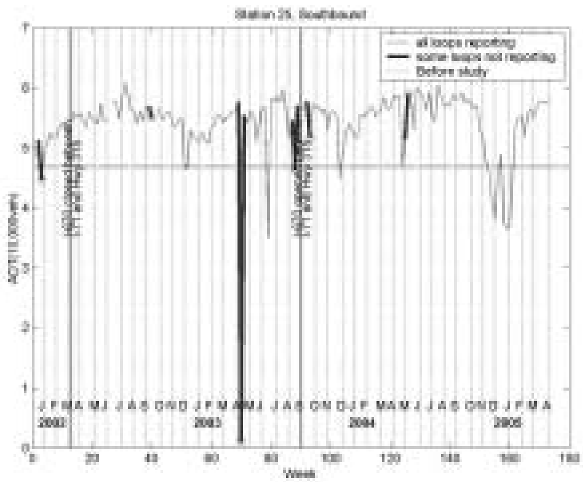
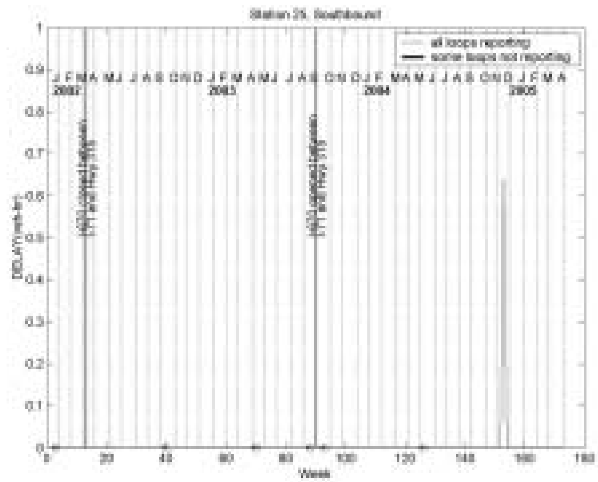
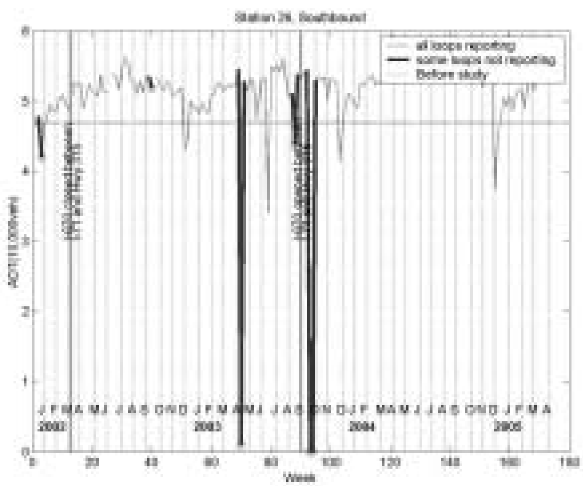
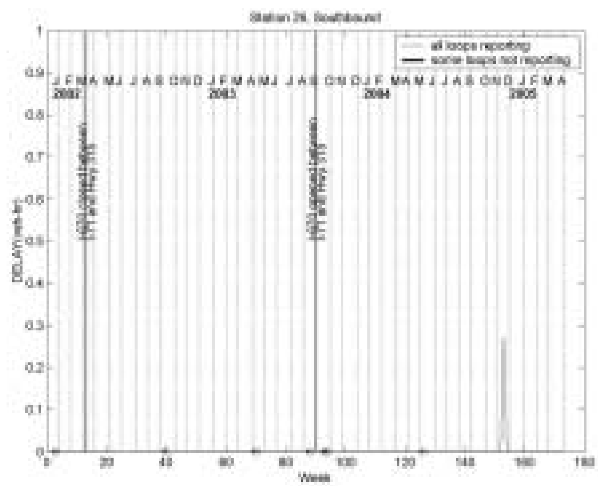

Station 19, Southbound
all loops reporting
some loops not reporting
Before study
Week

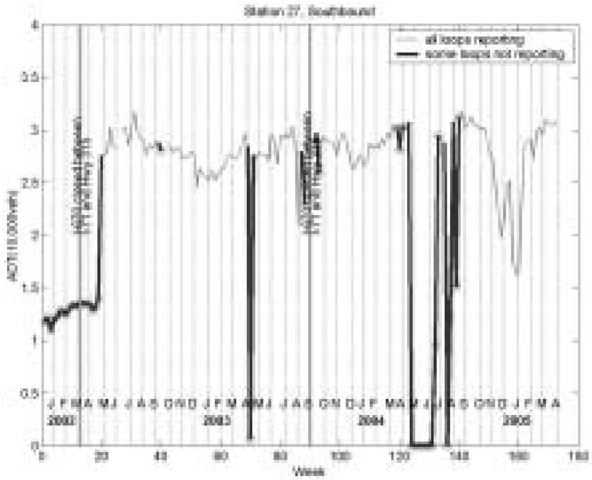

Station 19, Southbound
all loops reporting
some loops not reporting
Week

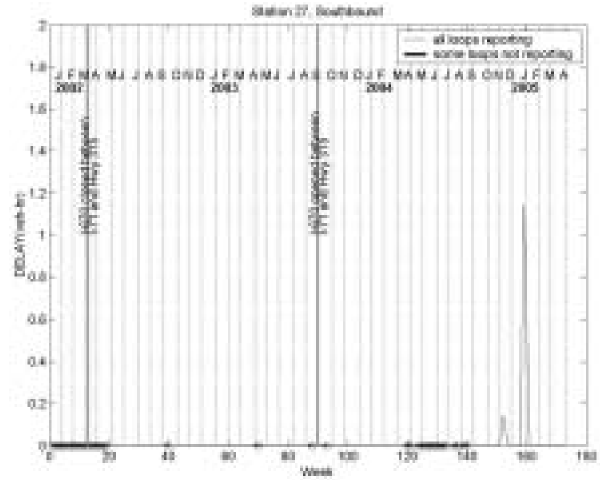

Station 20, Southbound
all loops reporting
some loops not reporting
Before study
Week

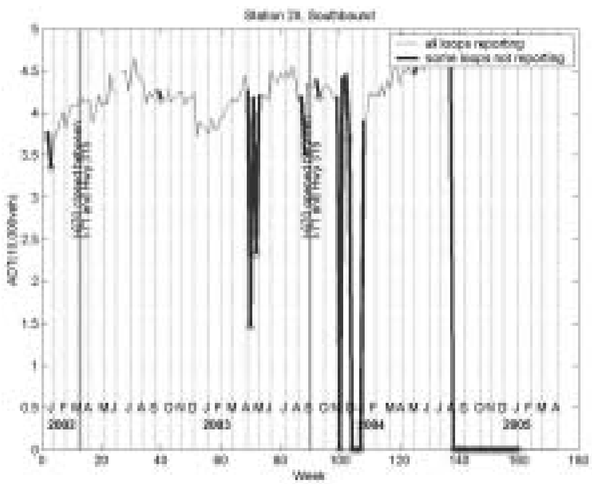

Station 20, Southbound
all loops reporting
some loops not reporting
Week

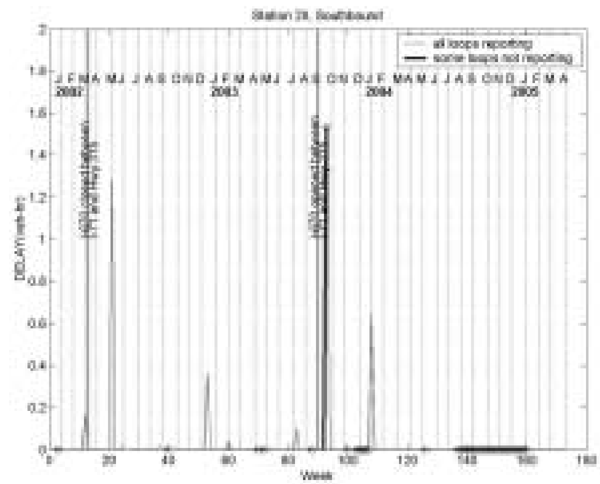

Station 21, Southbound
Station 22, Southbound
Station 23, Southbound
all loops reporting
some loops not reporting
Before study
Week

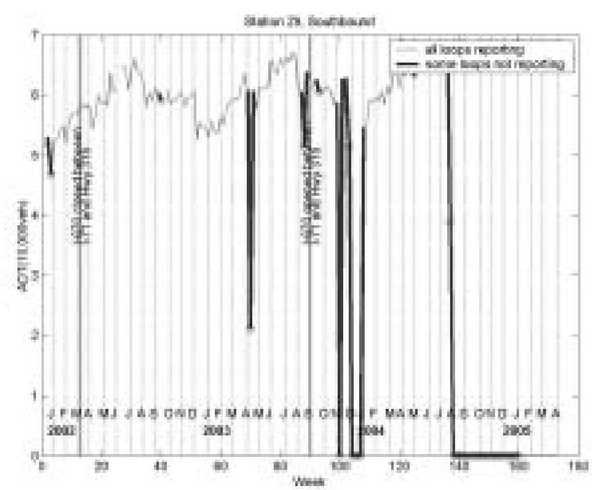

Station 24, Southbound
all loops reporting
some loops not reporting
Before study
Week

Station 24, Southbound
all loops reporting
some loops not reporting
Week

Station 25, Southbound
all loops reporting
some loops not reporting
Before study
Week

Station 25, Southbound
all loops reporting
some loops not reporting
Week

Station 26, Southbound
all loops reporting
some loops not reporting
Before study
Week

Station 26, Southbound
all loops reporting
some loops not reporting
Week

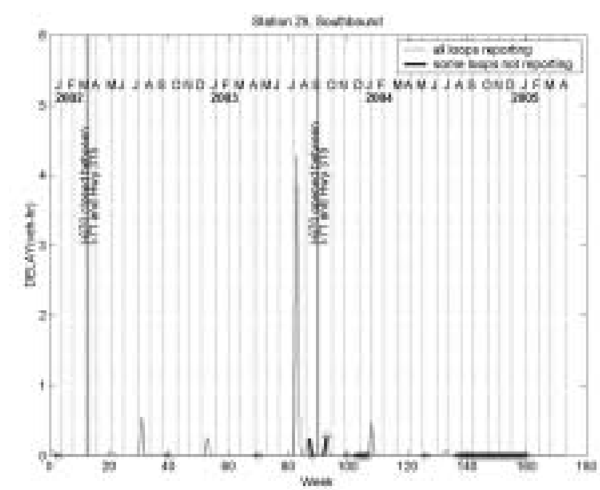

Station 27, Southbound
all loops reporting
some loops not reporting
Week

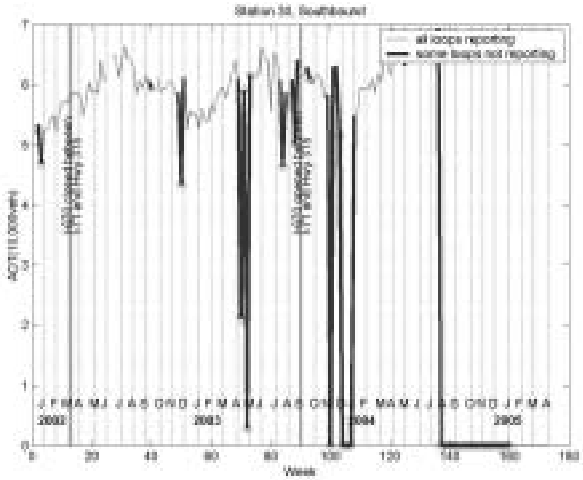

Station 27, Southbound
all loops reporting
some loops not reporting
Week

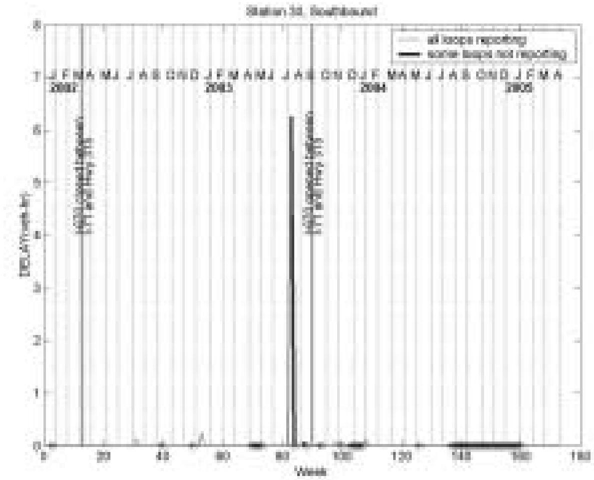

Station 28, Southbound
all loops reporting
some loops not reporting
Week

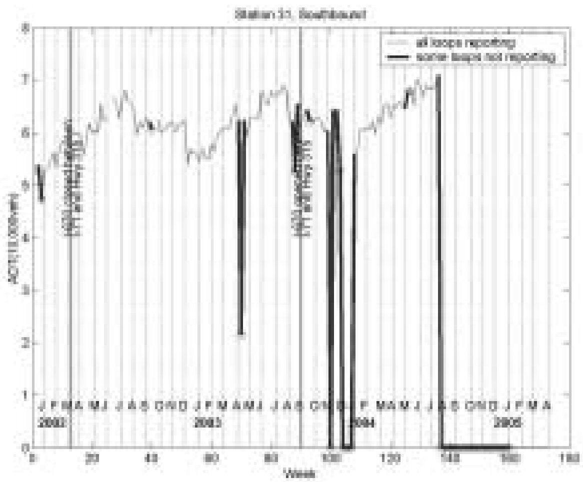

Station 28, Southbound
all loops reporting
some loops not reporting
Week

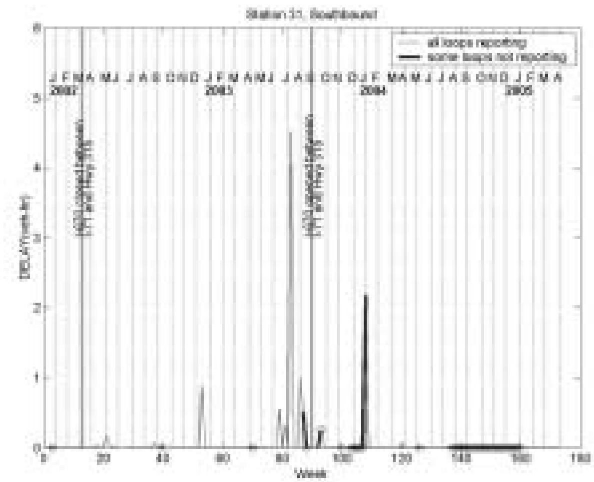

Station 29, Southbound
all loops reporting
some loops not reporting
Week

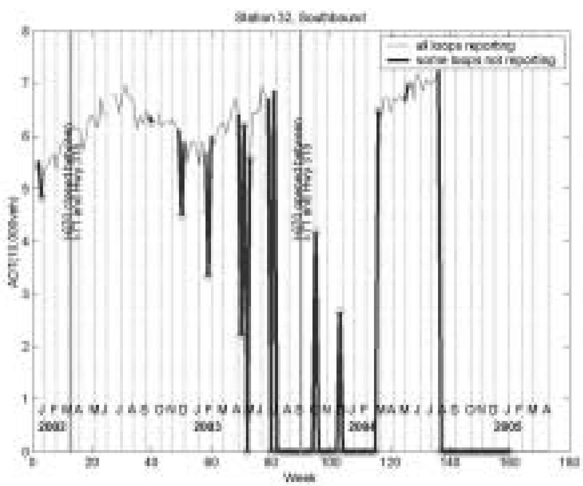

Station 29, Southbound
all loops reporting
some loops not reporting
Week

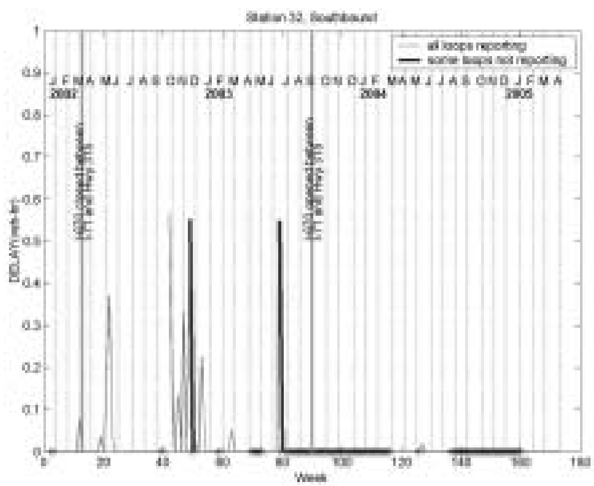

Station 30, Southbound
all loops reporting
some loops not reporting
Week

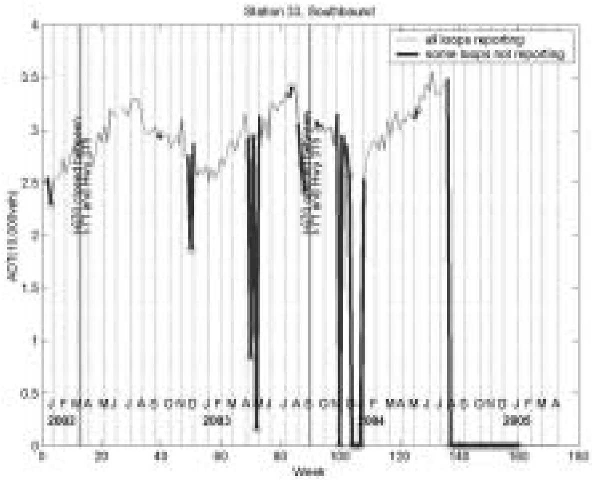

Station 30, Southbound
all loops reporting
some loops not reporting
Week

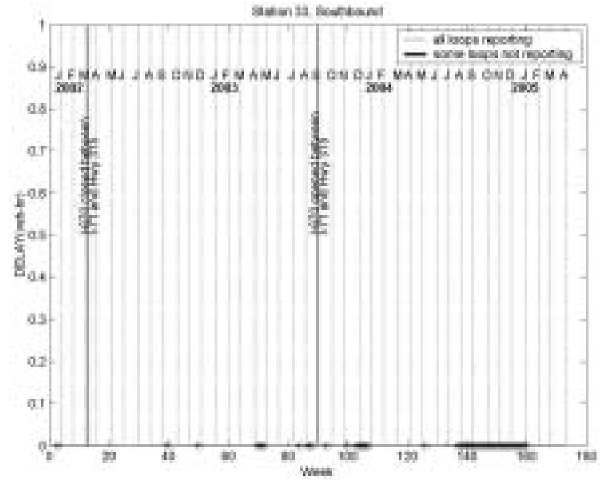

Station 31, Southbound
all loops reporting
some loops not reporting
Week

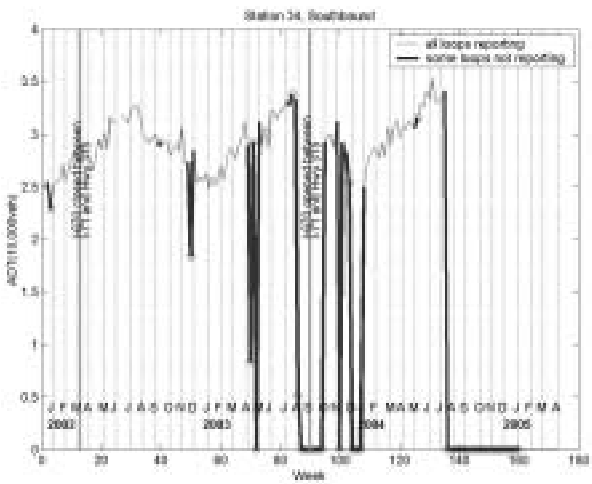

Station 31, Southbound
all loops reporting
some loops not reporting
Week

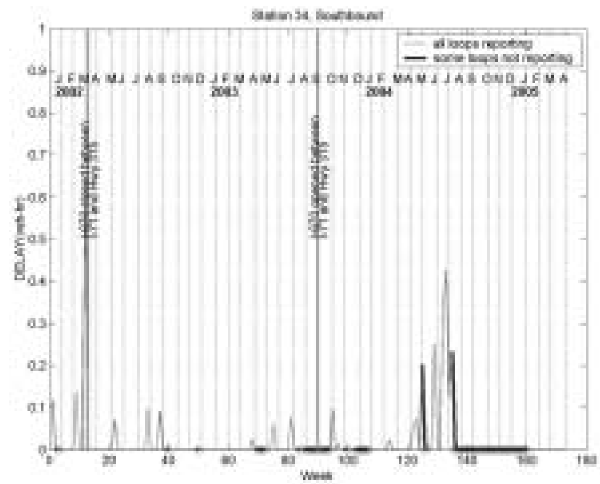

Station 32, Southbound
all loops reporting
some loops not reporting
Week

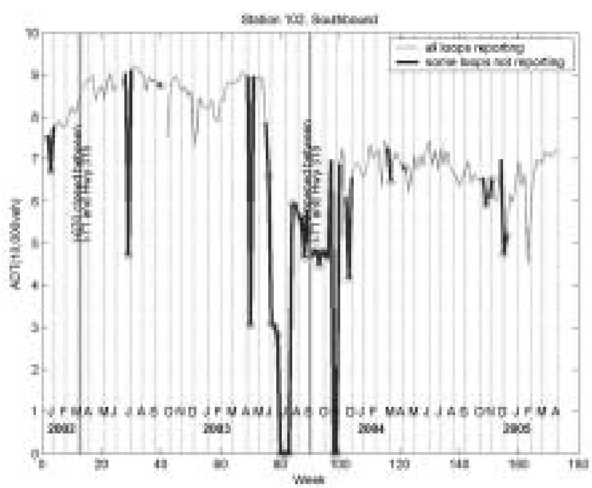

Station 32, Southbound
all loops reporting
some loops not reporting
Week

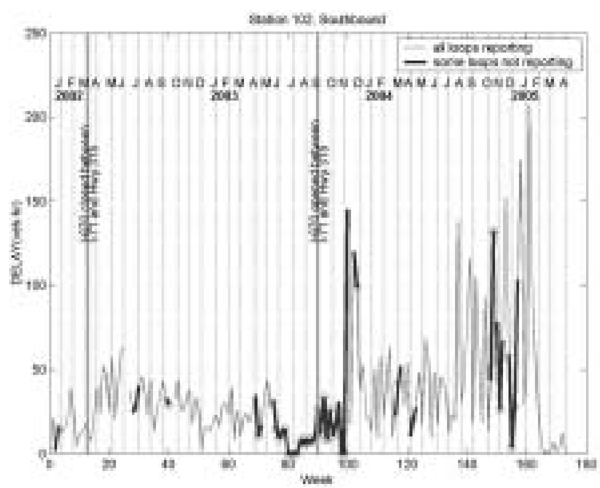

Station 33, Southbound
all loops reporting
some loops not reporting
Week

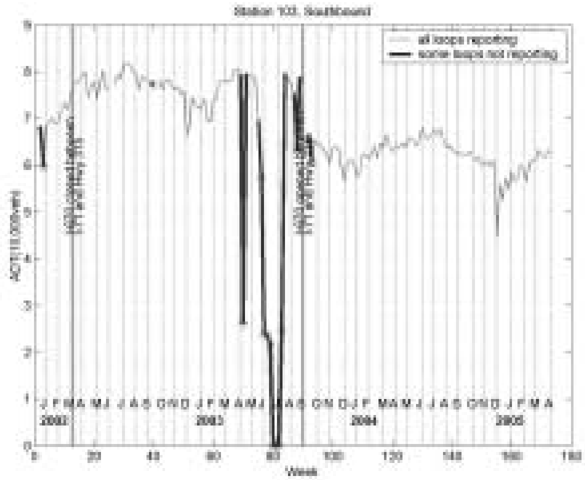

Station 33, Southbound
all loops reporting
some loops not reporting
Week

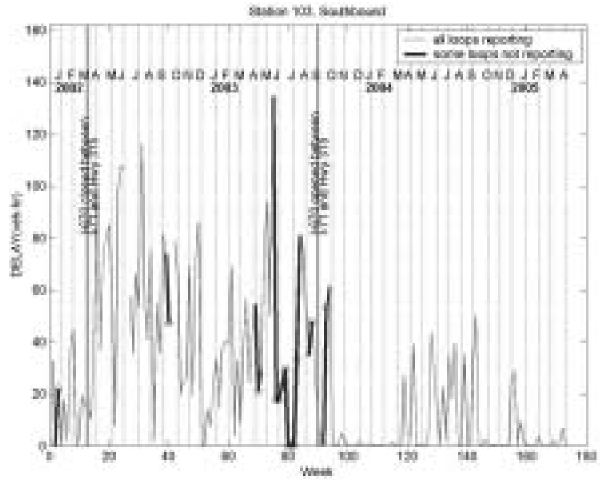

Station 34, Southbound
all loops reporting
some loops not reporting
Week

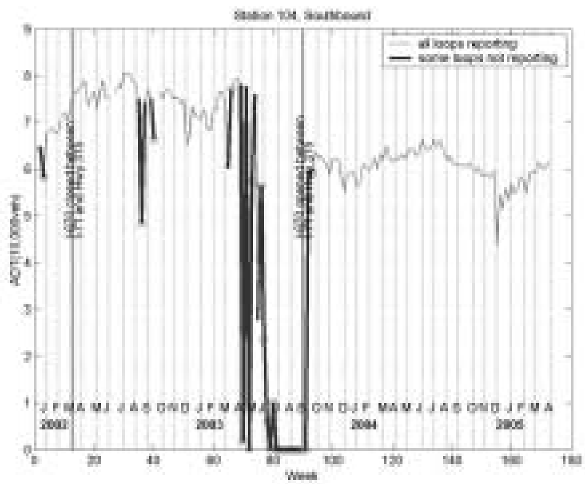

Station 34, Southbound
all loops reporting
some loops not reporting
Week

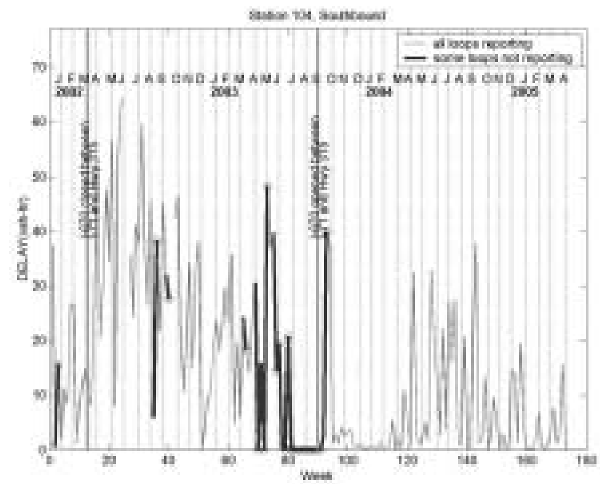

Station 102, Southbound
all loops reporting
some loops not reporting
Week

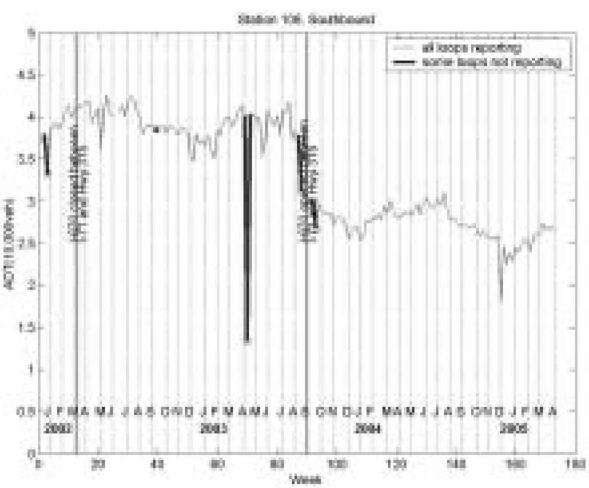

Station 102, Southbound
all loops reporting
some loops not reporting
Week

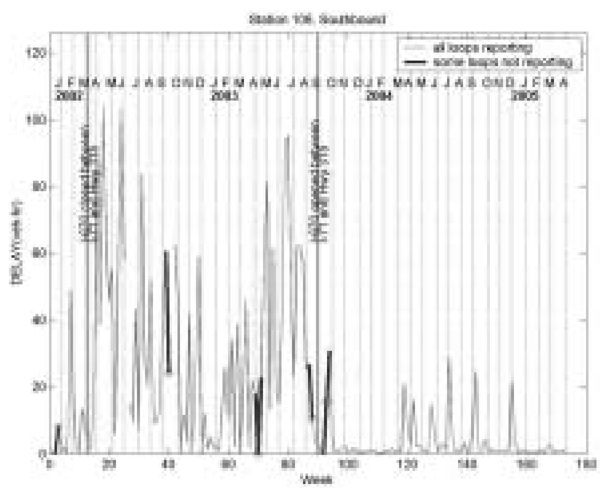

Station 103, Southbound
all loops reporting
some loops not reporting
Week

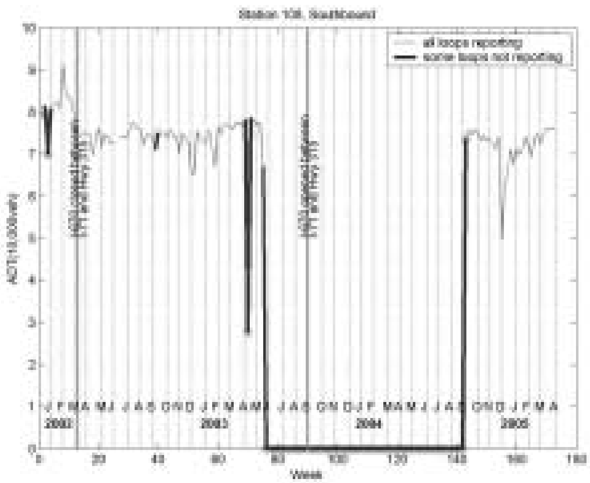

Station 103, Southbound
all loops reporting
some loops not reporting
Week

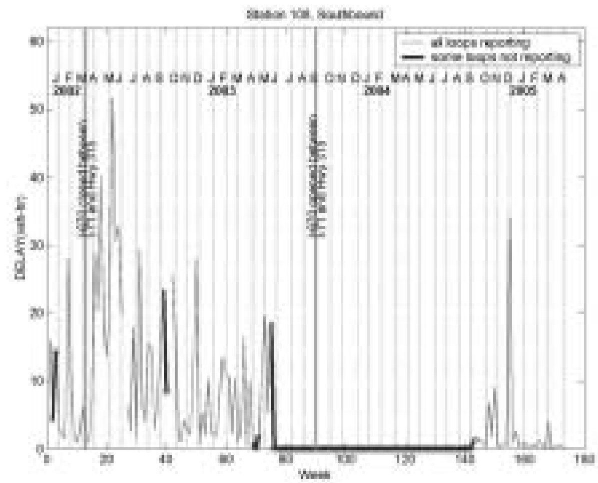

Station 104, Southbound
all loops reporting
some loops not reporting
Week

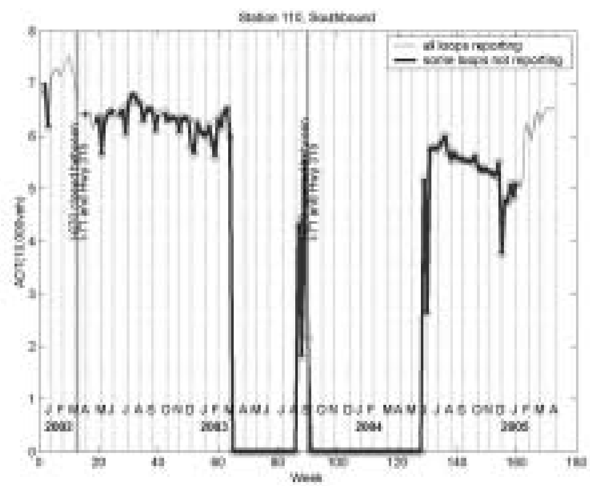

Station 104, Southbound
all loops reporting
some loops not reporting
Week

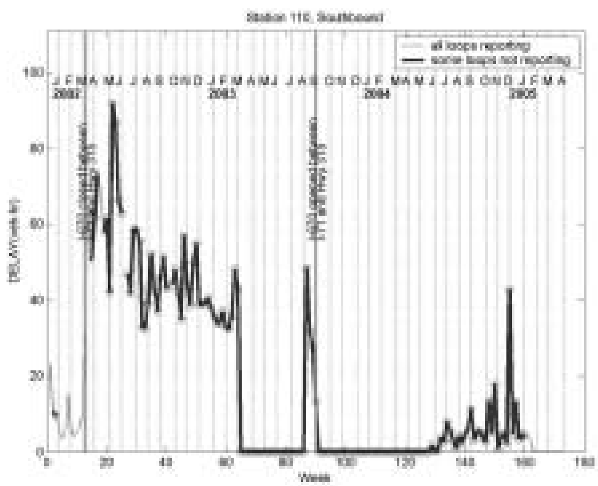

Station 106, Southbound
all loops reporting
some loops not reporting
Week

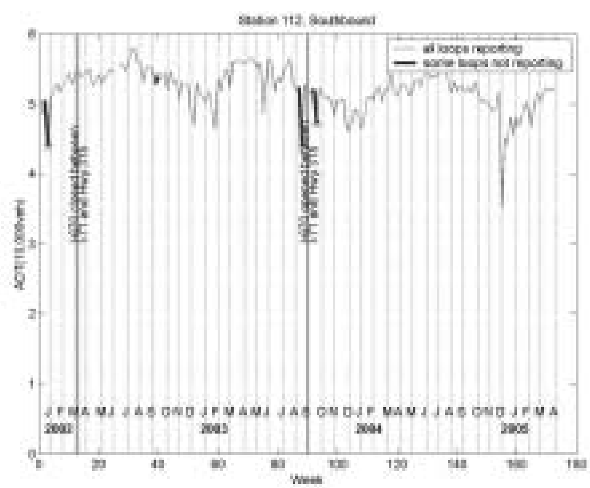

Station 106, Southbound
all loops reporting
some loops not reporting
Week

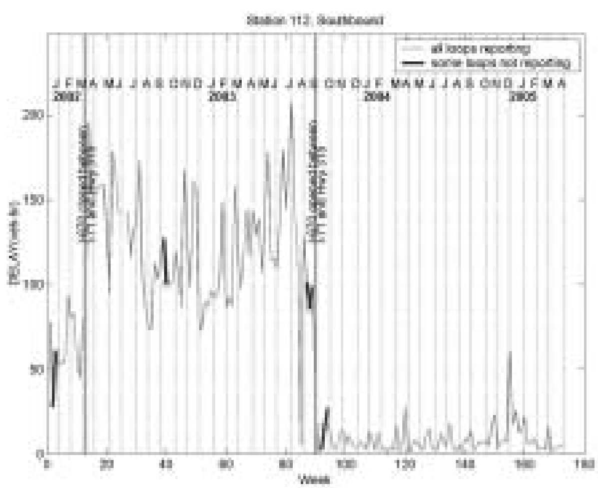

Station 108, Southbound
all loops reporting
some loops not reporting
ACT(10,000veh)
Week


Station 108, Southbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

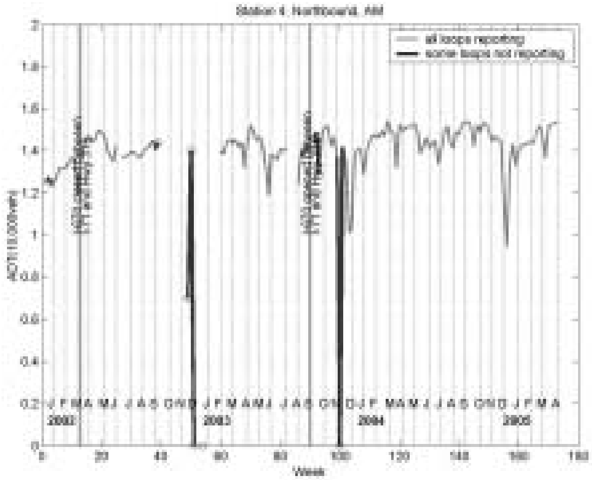

Station 110, Southbound
all loops reporting
some loops not reporting
ACT(10,000veh)
Week

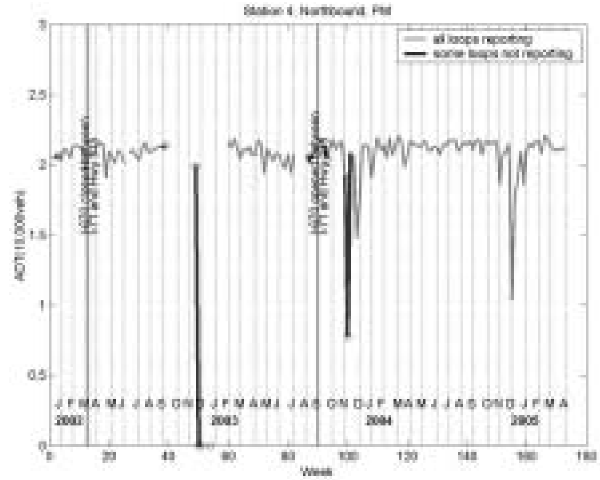

Station 110, Southbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

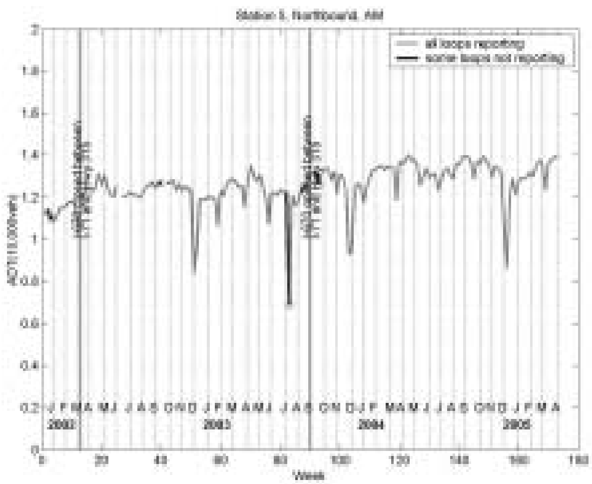

Station 112, Southbound
all loops reporting
some loops not reporting
ACT(10,000veh)
Week

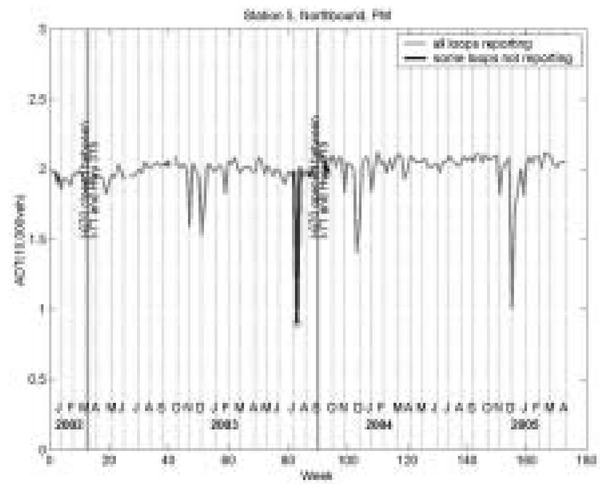

Station 112, Southbound
all loops reporting
some loops not reporting
DELAY(veh-hr)
Week

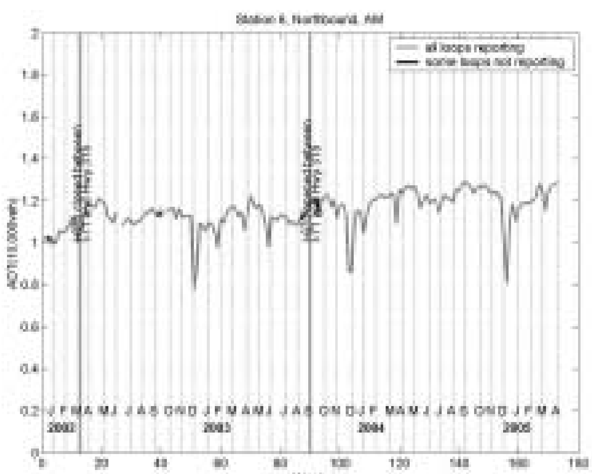
NORTHBOUND- AM PEAK (6:00 AM -9:30 AM) PM PEAK (3:30 PM - 7:00 PM)

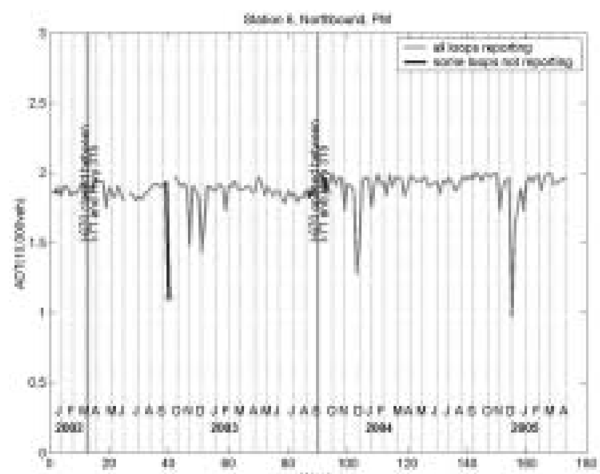


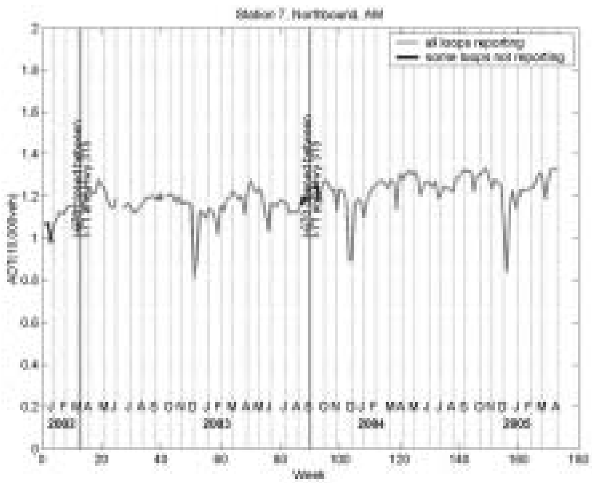


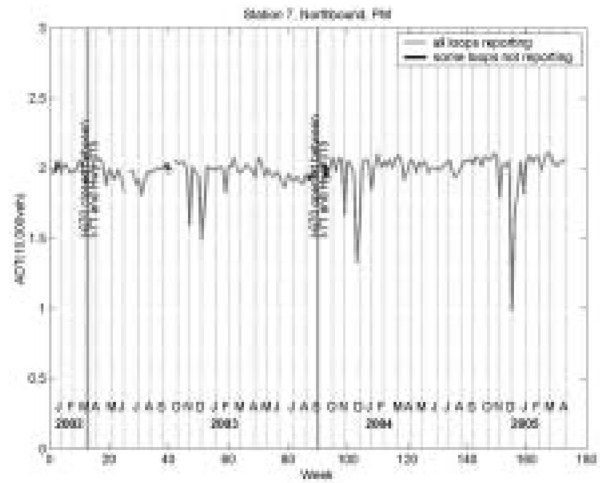


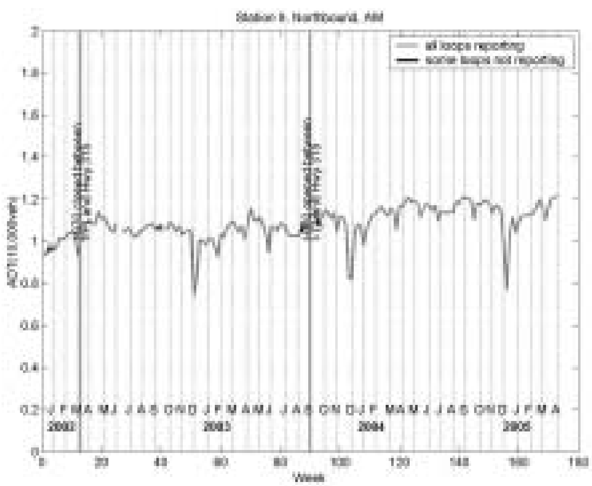


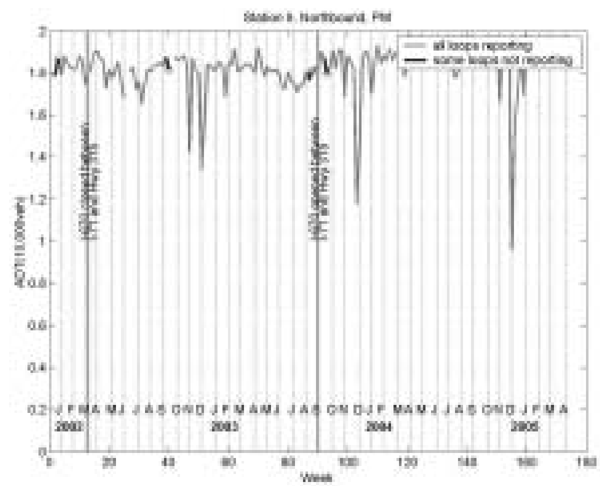


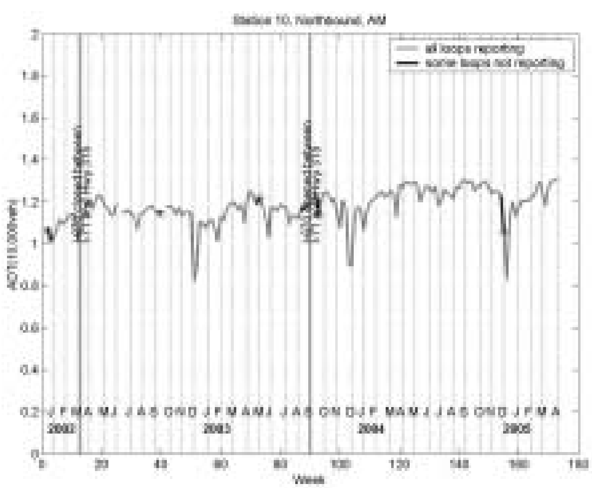


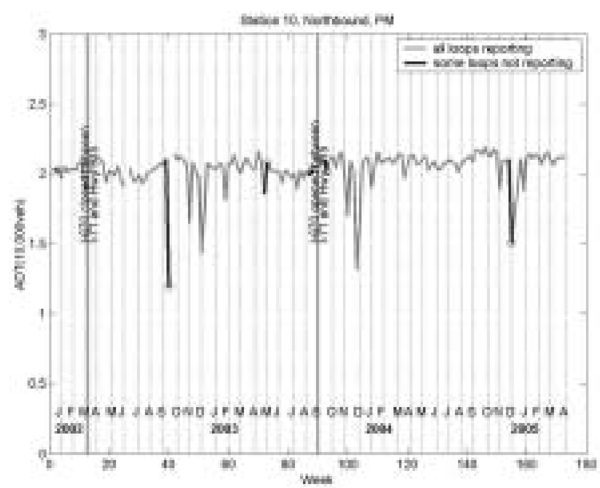

Station 7, Northbound, AM
all loops reporting
some loops not reporting
Week

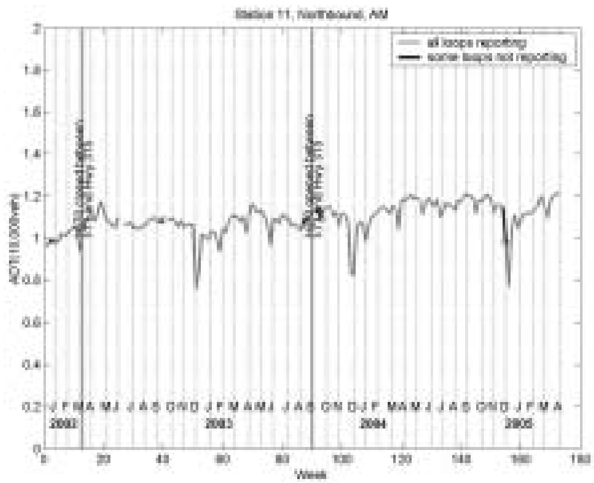

Station 7, Northbound, PM
all loops reporting
some loops not reporting
Week

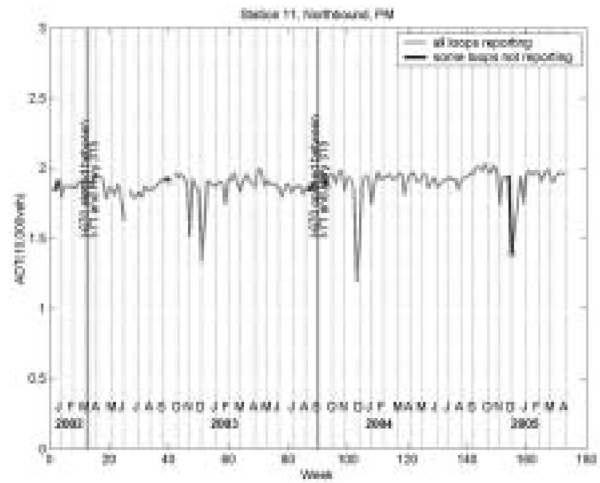

Station 8, Northbound, AM
all loops reporting
some loops not reporting
Week

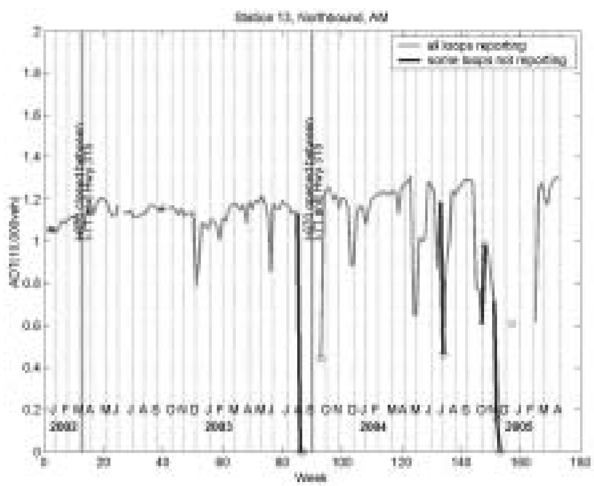

Station 8, Northbound, PM
all loops reporting
some loops not reporting
Week

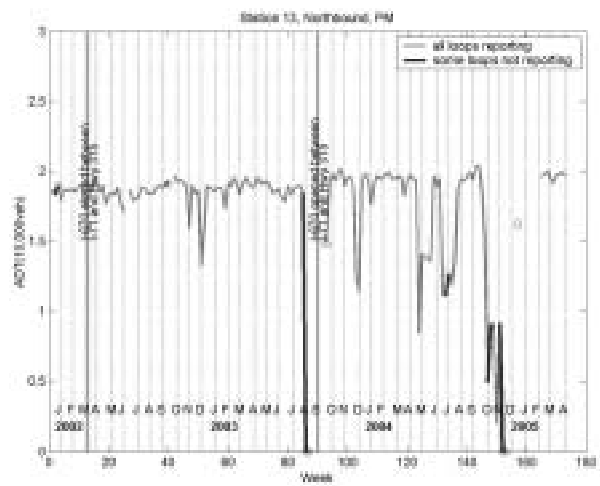

Station 10, Northbound, AM
all loops reporting
some loops not reporting
Week

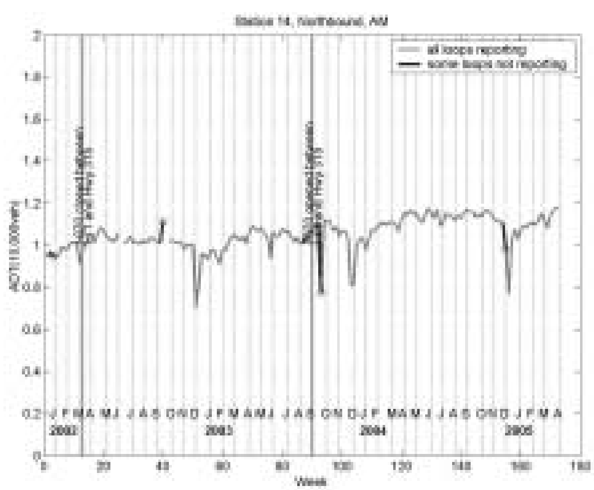

Station 10, Northbound, PM
all loops reporting
some loops not reporting
Week

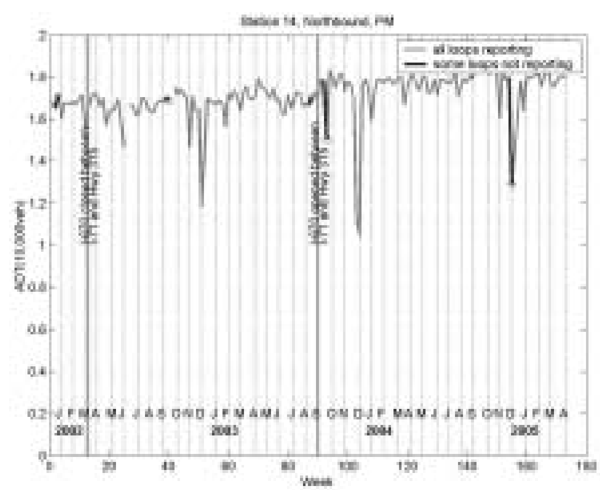

Station 11, Northbound, AM
all loops reporting
some loops not reporting
Week

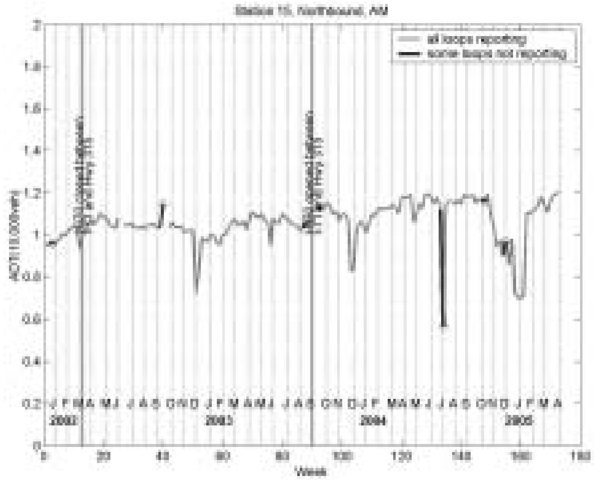

Station 11, Northbound, PM
all loops reporting
some loops not reporting
Week

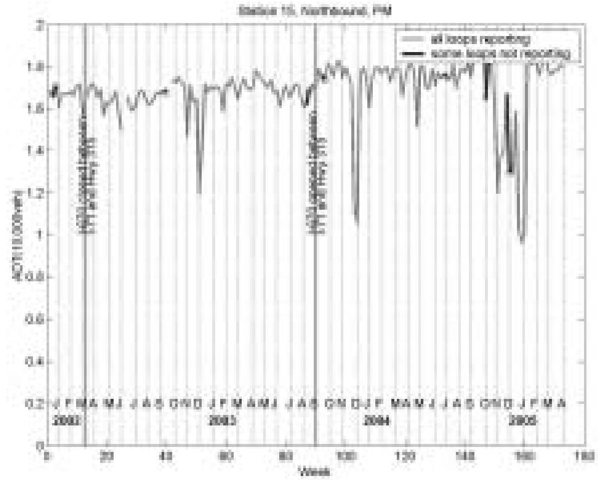

Station 13, Northbound, AM
all loops reporting
some loops not reporting
Week

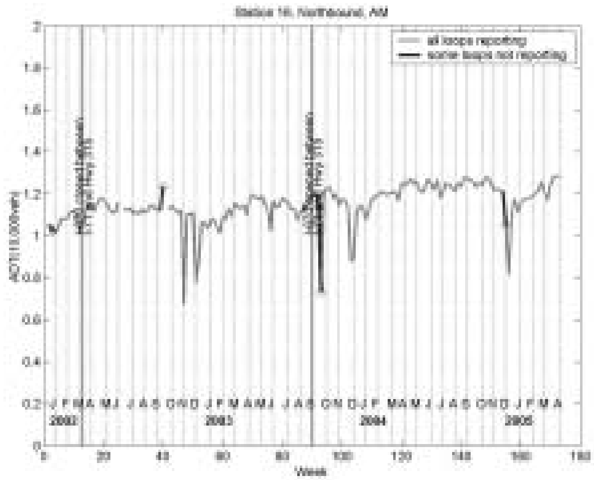

Station 13, Northbound, PM
all loops reporting
some loops not reporting
Week

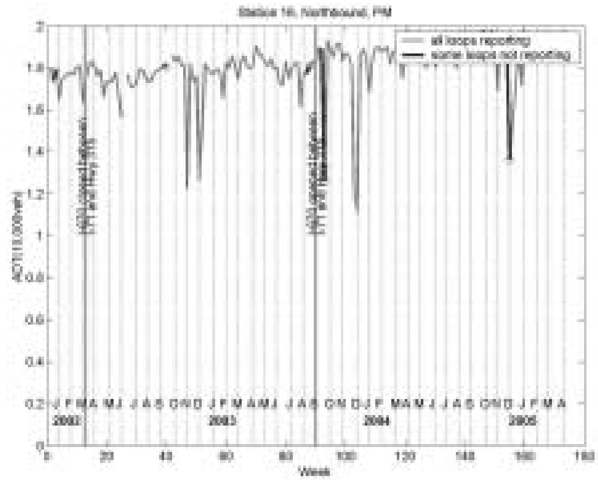

Station 14, Northbound, AM
all loops reporting
some loops not reporting
Week

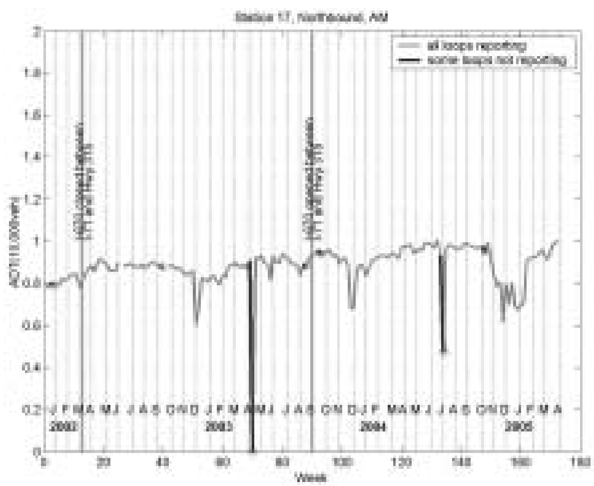

Station 14, Northbound, PM
all loops reporting
some loops not reporting
Week

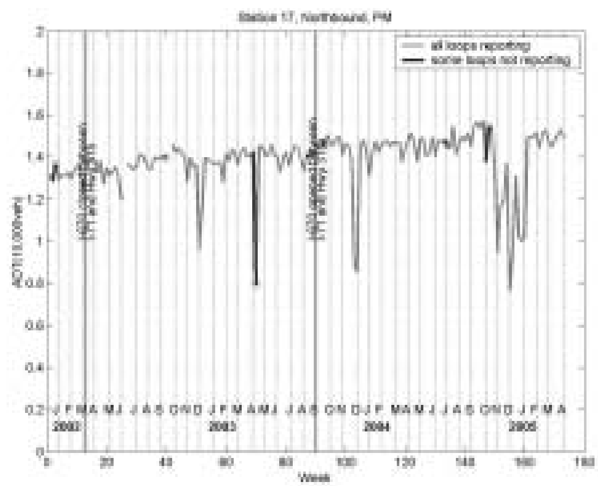

Station 15, Northbound, AM
all loops reporting
some loops not reporting
Week

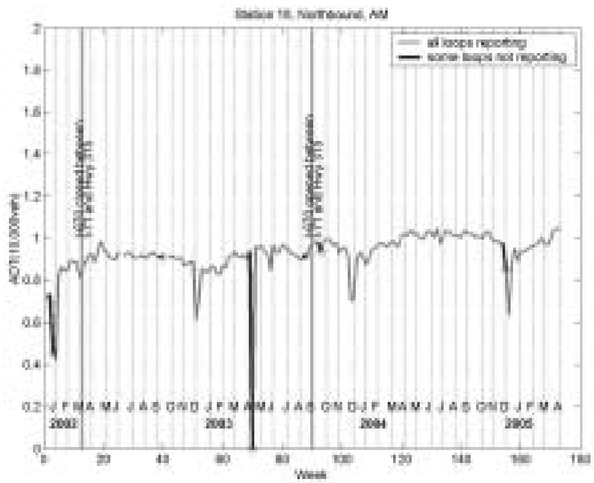

Station 15, Northbound, PM
all loops reporting
some loops not reporting
Week

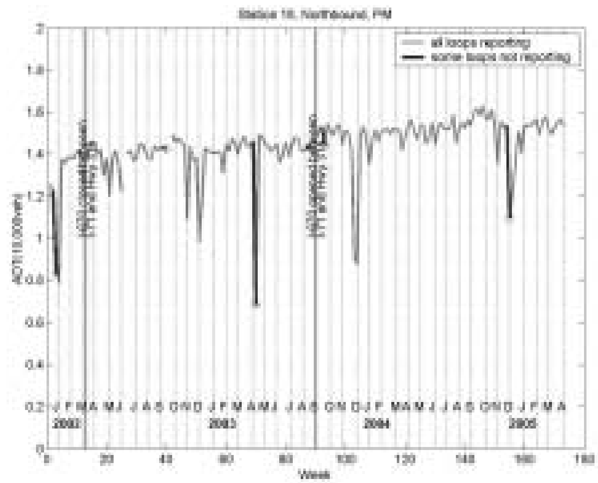

Station 16, Northbound, AM
all loops reporting
some loops not reporting
Week

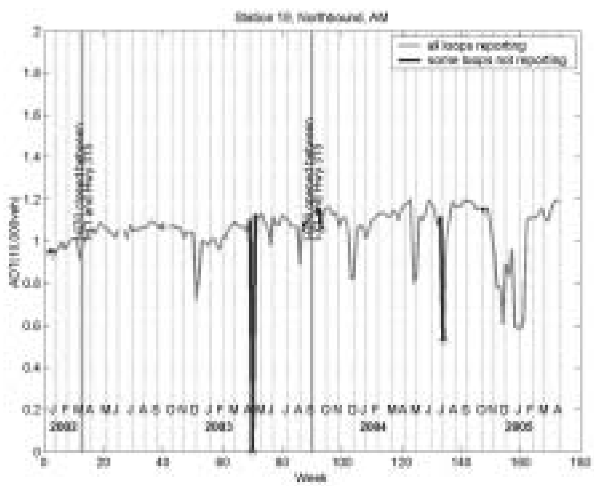

Station 16, Northbound, PM
all loops reporting
some loops not reporting
Week

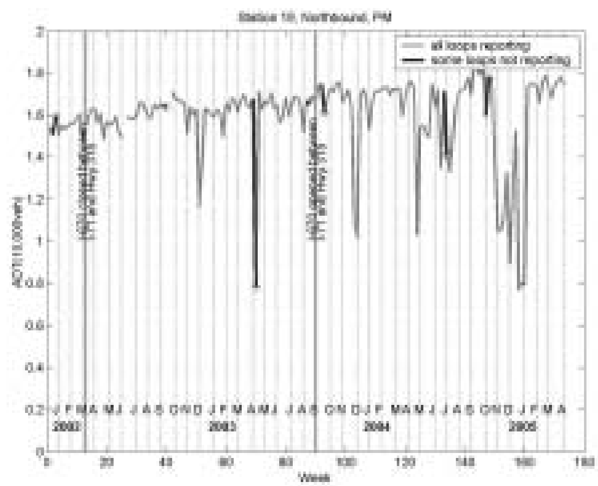

Station 17, Northbound, AM
all loops reporting
some loops not reporting
Week

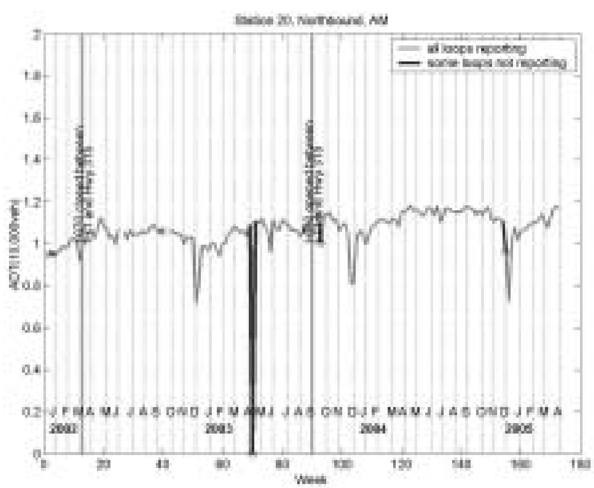

Station 17, Northbound, PM
all loops reporting
some loops not reporting
Week

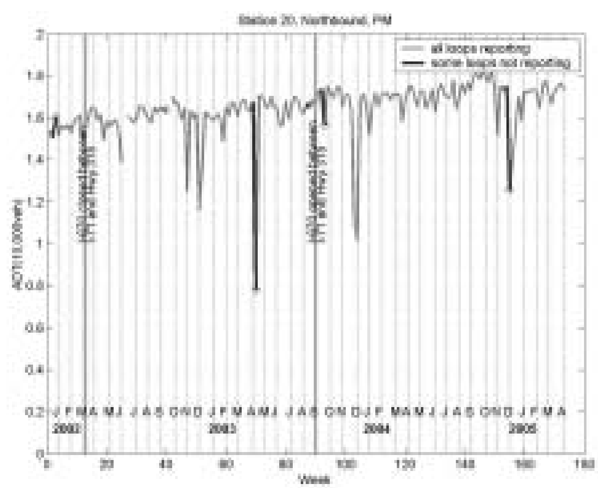

Station 18, Northbound, AM
all loops reporting
some loops not reporting
Week

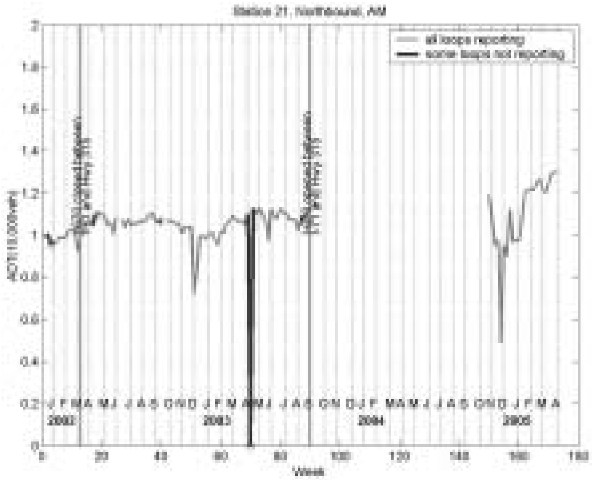

Station 18, Northbound, PM
all loops reporting
some loops not reporting
Week

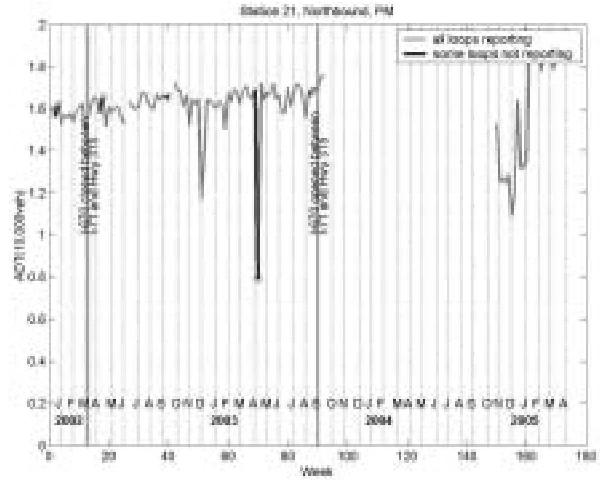

Station 19, Northbound, AM
all loops reporting
some loops not reporting
Week

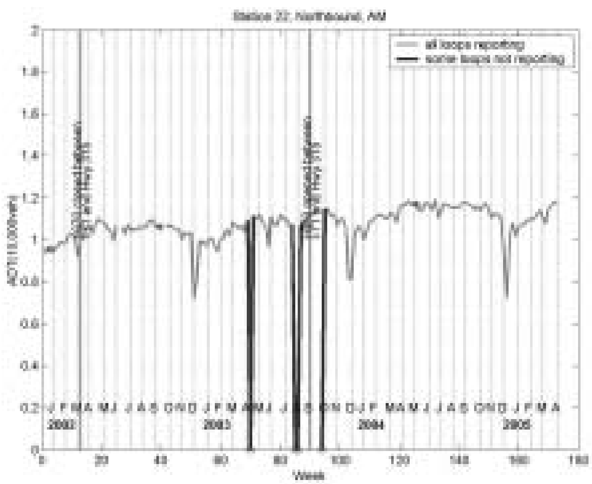

Station 19, Northbound, PM
all loops reporting
some loops not reporting
Week

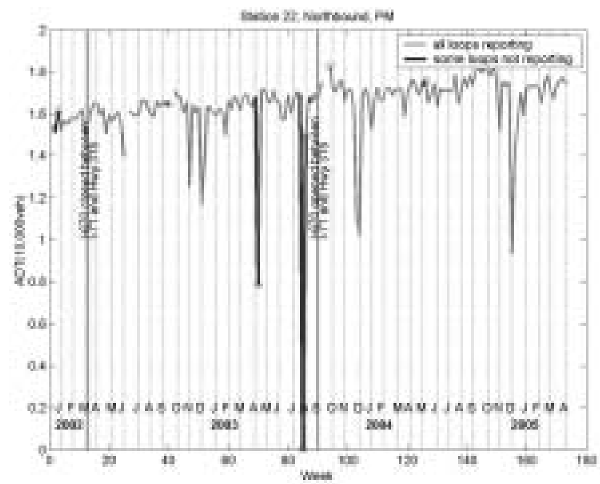

Station 20, Northbound, AM
all loops reporting
some loops not reporting
Week

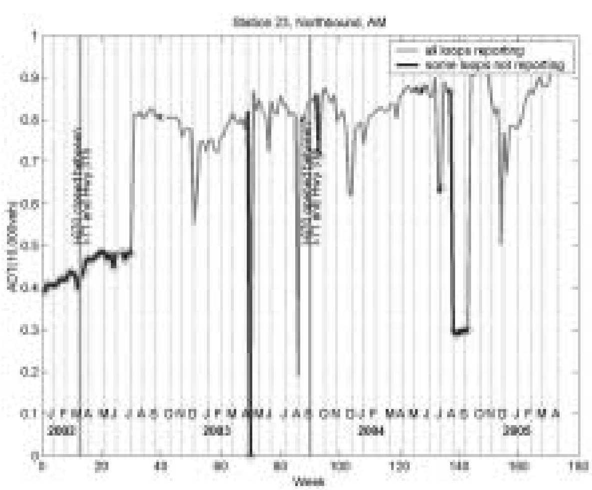

Station 20, Northbound, PM
all loops reporting
some loops not reporting
Week

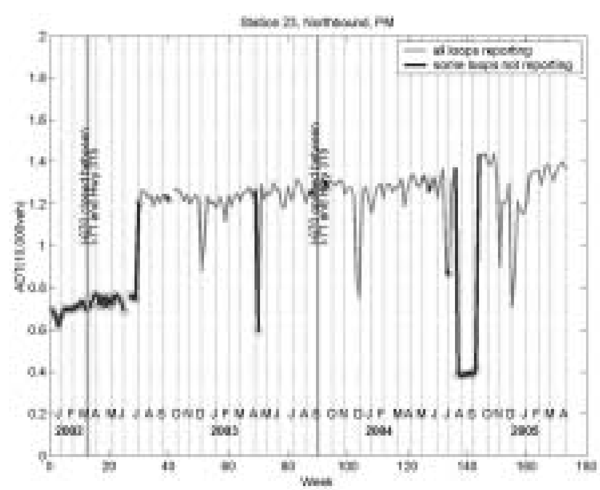

Station 21, Northbound, AM
all loops reporting
some loops not reporting
Week

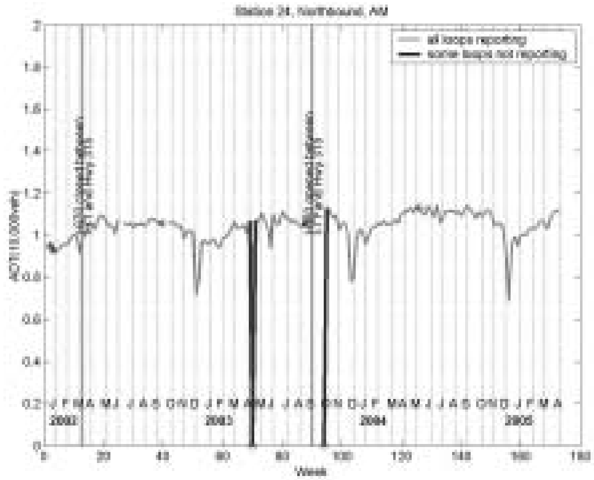

Station 21, Northbound, PM
all loops reporting
some loops not reporting
Week

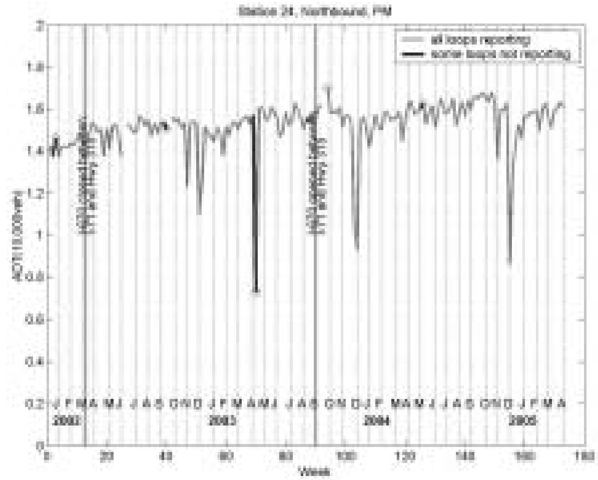

Station 22, Northbound, AM
all loops reporting
some loops not reporting
Week

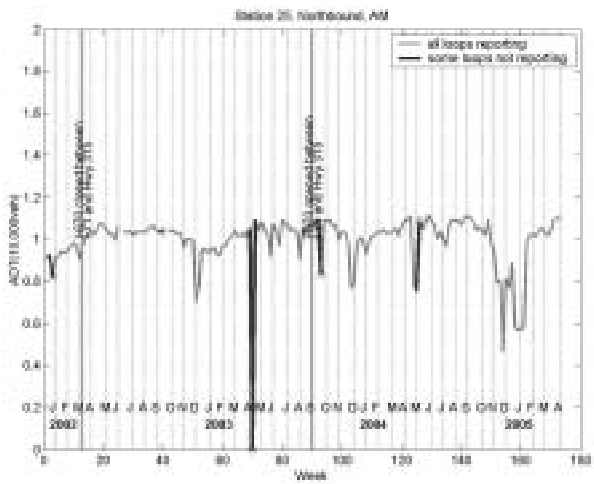

Station 22, Northbound, PM
all loops reporting
some loops not reporting
Week

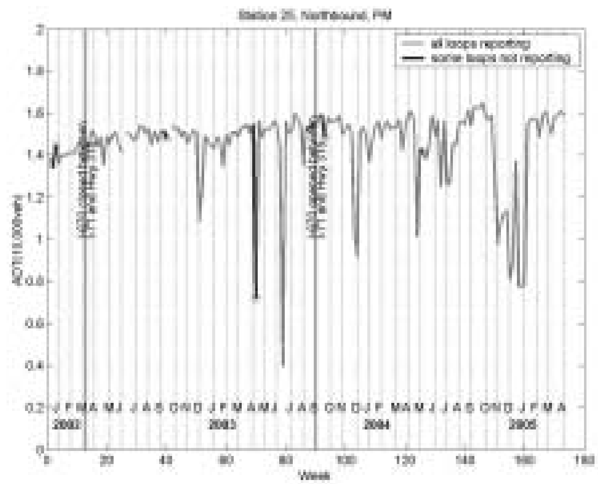

Station 23, Northbound, AM
all loops reporting
some loops not reporting
Week

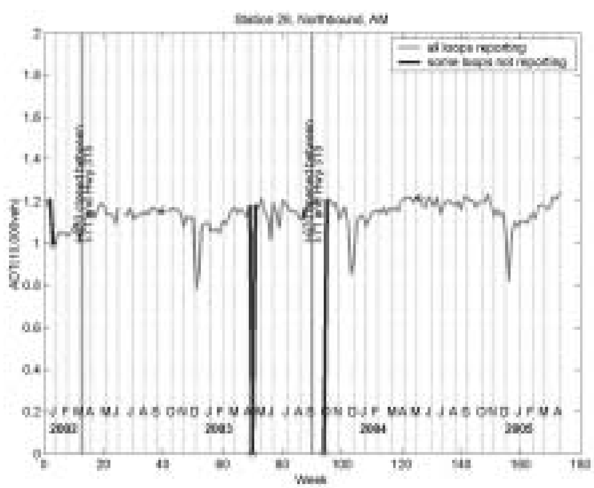

Station 23, Northbound, PM
all loops reporting
some loops not reporting
Week

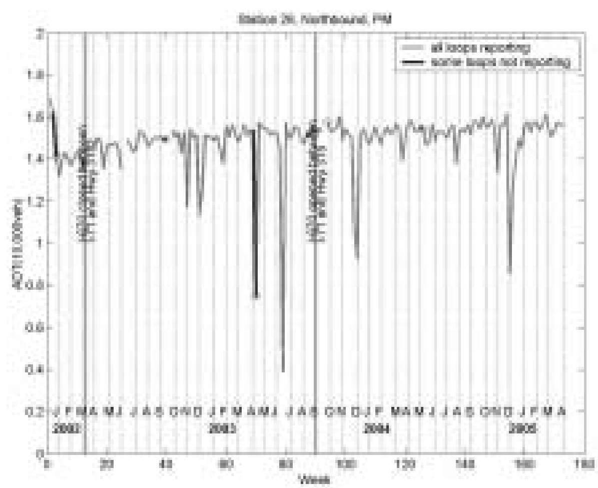

Station 24, Northbound, AM
all loops reporting
some loops not reporting
Week


Station 24, Northbound, PM
all loops reporting
some loops not reporting
Week

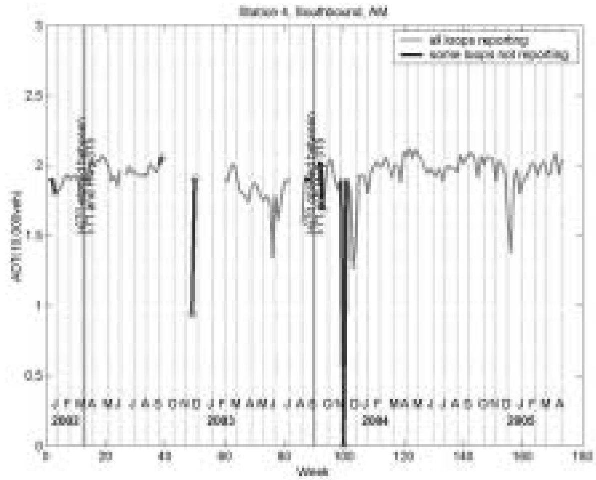

Station 25, Northbound, AM
all loops reporting
some loops not reporting
Week

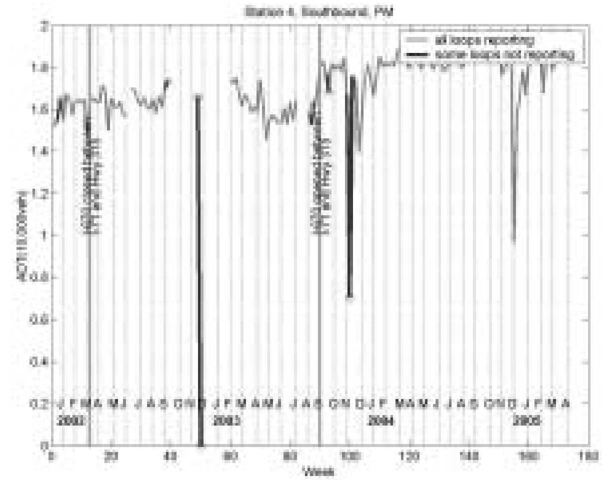

Station 25, Northbound, PM
all loops reporting
some loops not reporting
Week

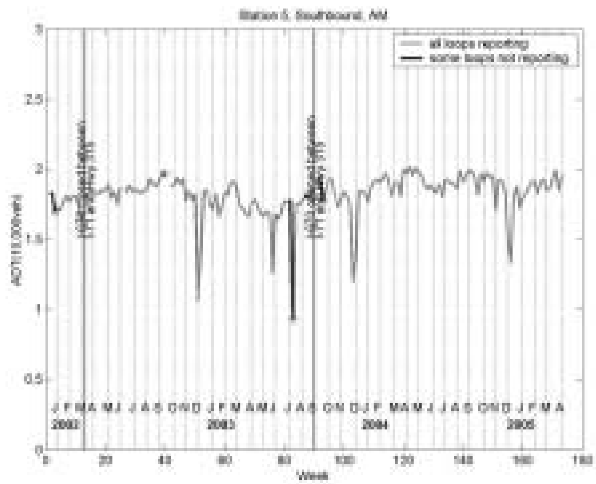

Station 26, Northbound, AM
all loops reporting
some loops not reporting
Week

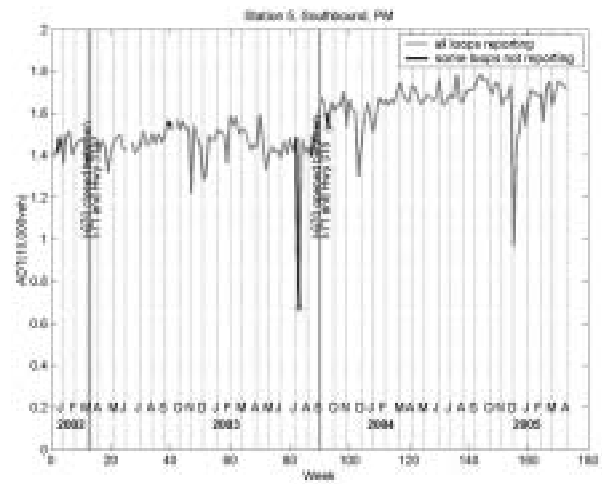

Station 26, Northbound, PM
all loops reporting
some loops not reporting
Week

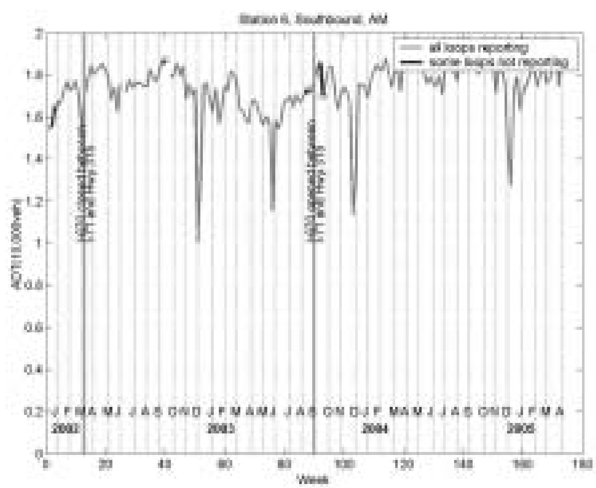
SOUTHBOUND- AM PEAK (6:00 AM -9:30 AM) PM PEAK (3:30 PM - 7:00 PM)

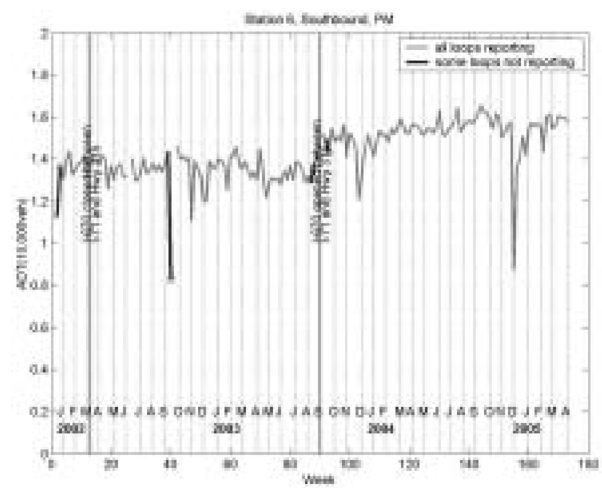


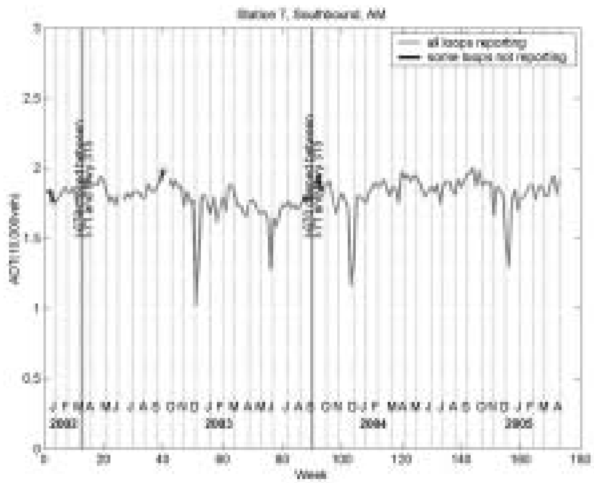


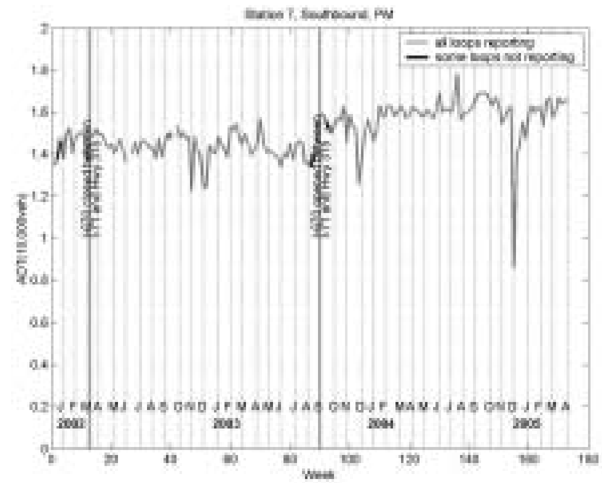


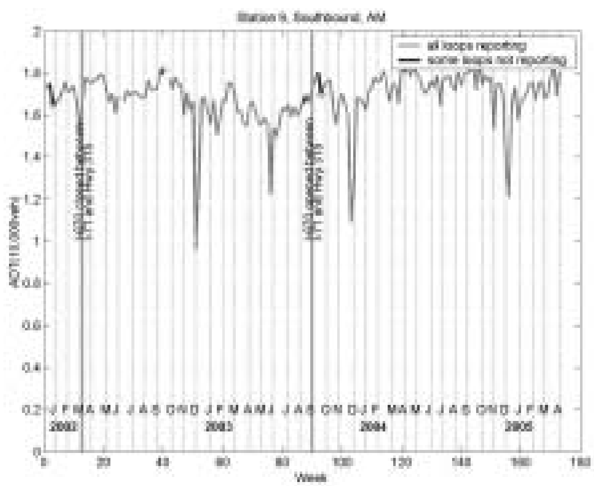


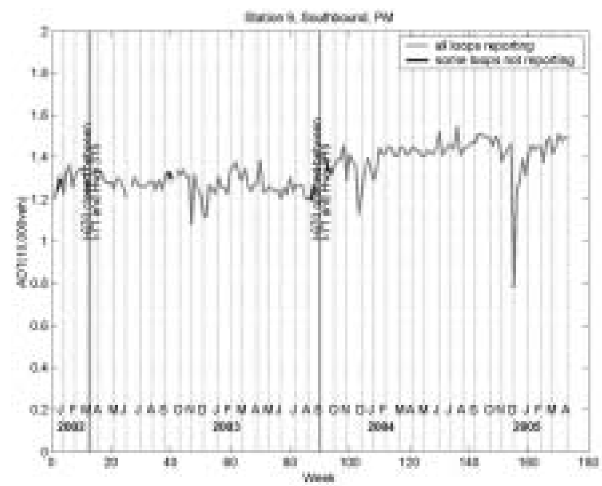


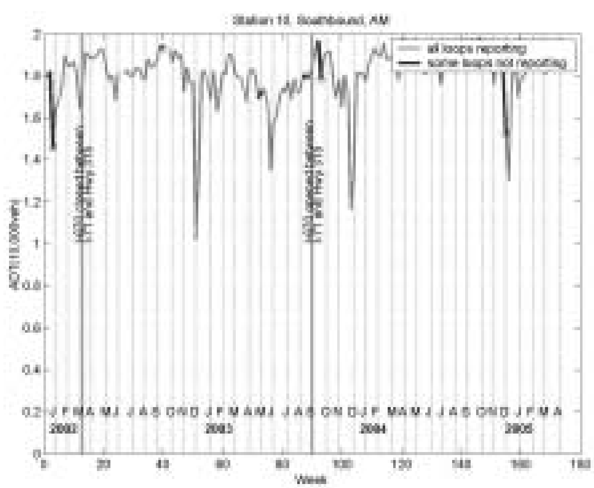


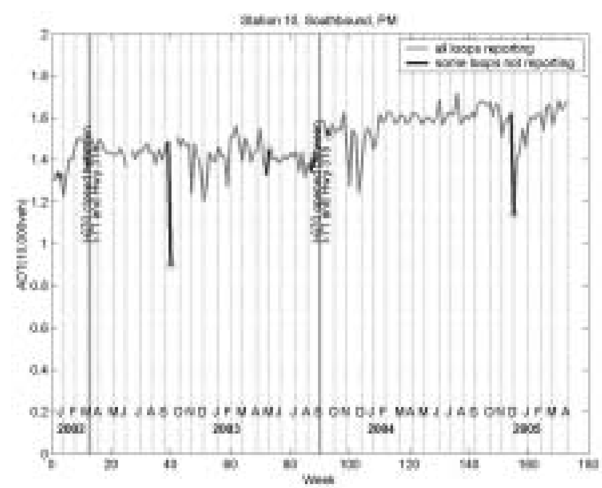

Station 7, Southbound, AM
all loops reporting
some loops not reporting
Week

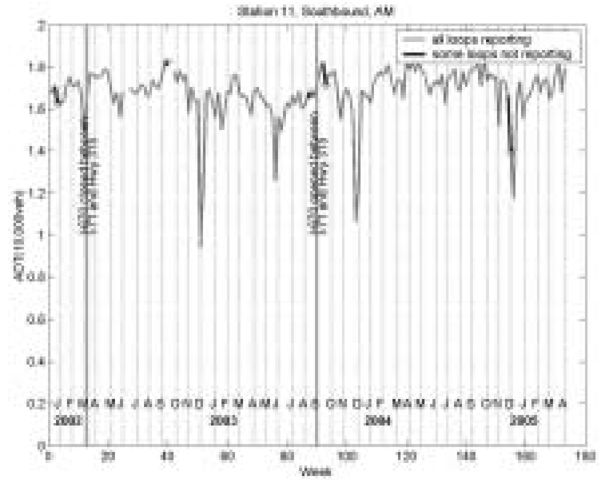

Station 7, Southbound, PM
all loops reporting
some loops not reporting
Week

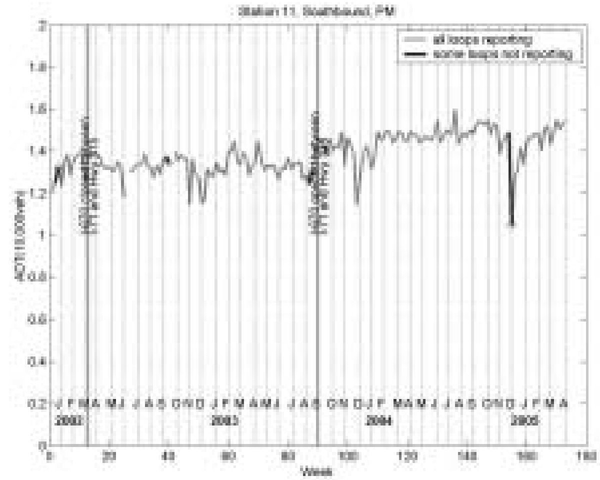

Station 9, Southbound, AM
all loops reporting
some loops not reporting
Week

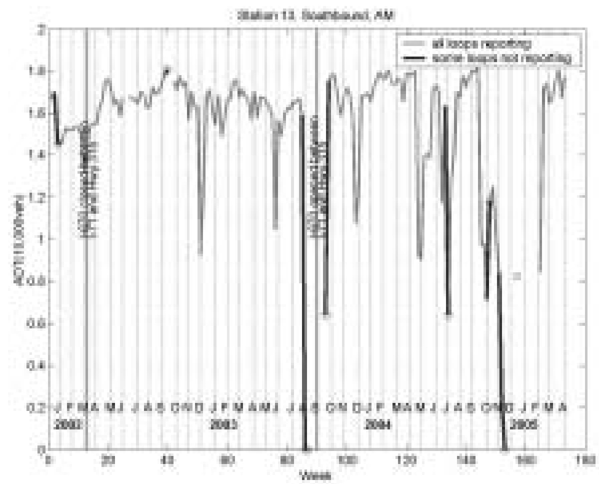

Station 9, Southbound, PM
all loops reporting
some loops not reporting
Week

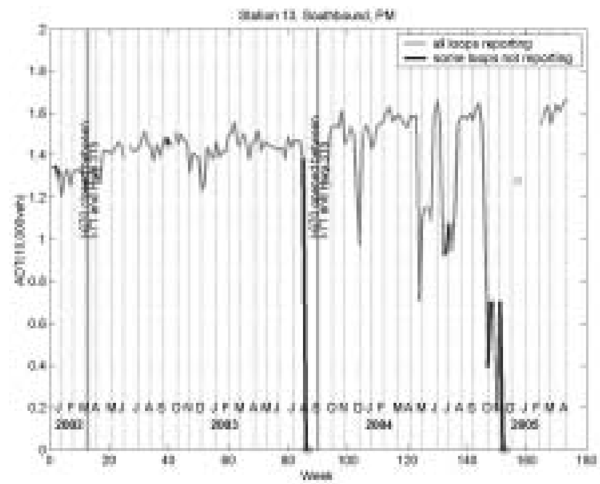

Station 10, Southbound, AM
all loops reporting
some loops not reporting
Week

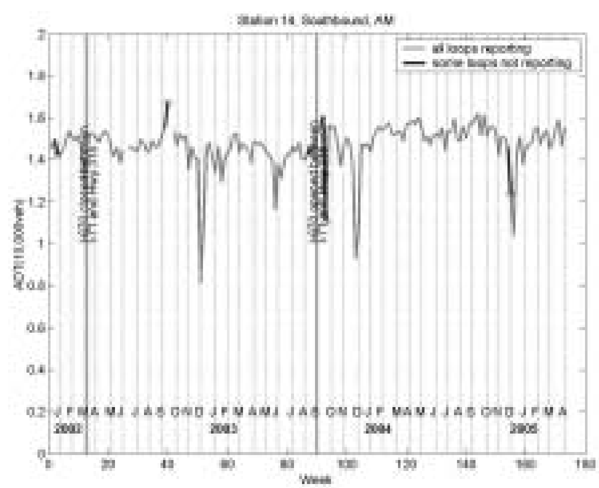

Station 10, Southbound, PM
all loops reporting
some loops not reporting
Week

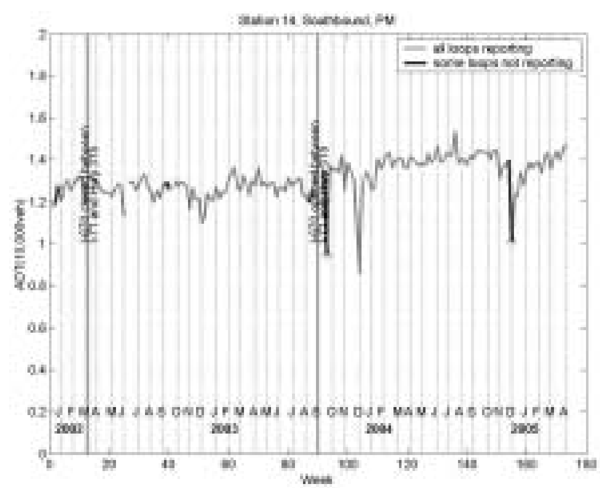

Station 11, Southbound, AM
all loops reporting
some loops not reporting
Week

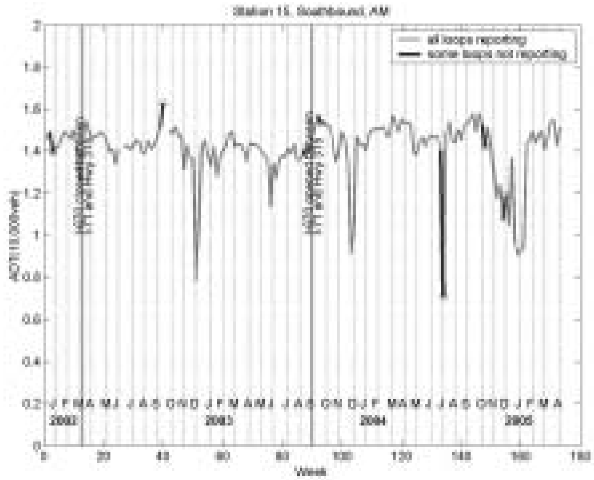

Station 11, Southbound, PM
all loops reporting
some loops not reporting
Week

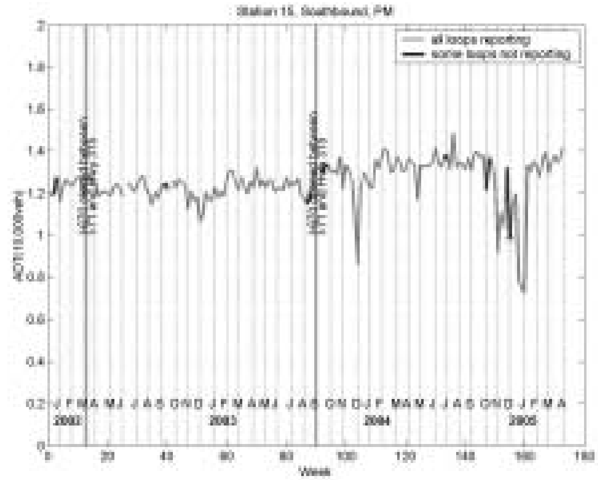

Station 13, Southbound, AM
all loops reporting
some loops not reporting
Week

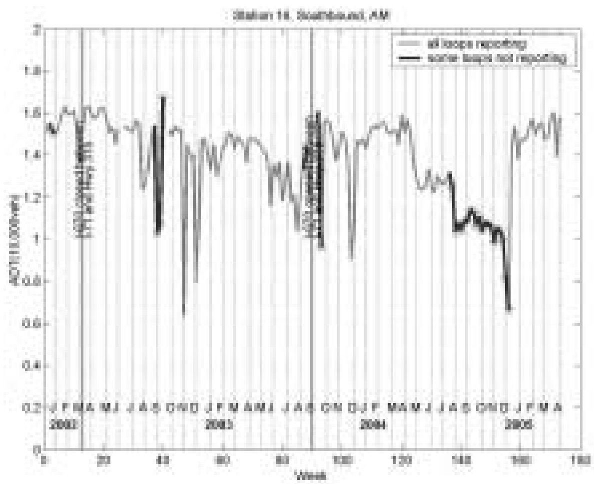

Station 13, Southbound, PM
all loops reporting
some loops not reporting
Week

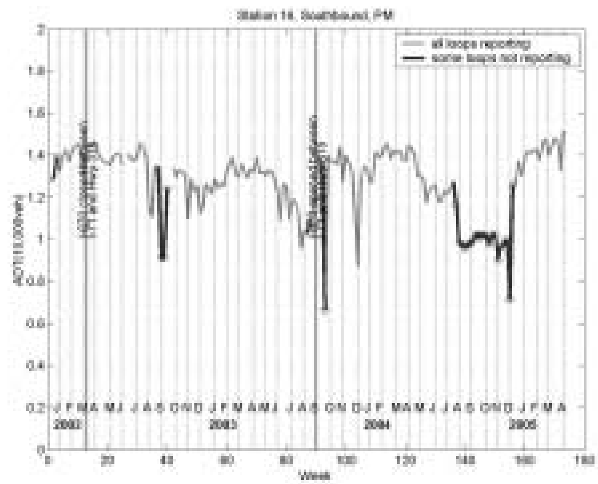

Station 14, Southbound, AM
all loops reporting
some loops not reporting
Week

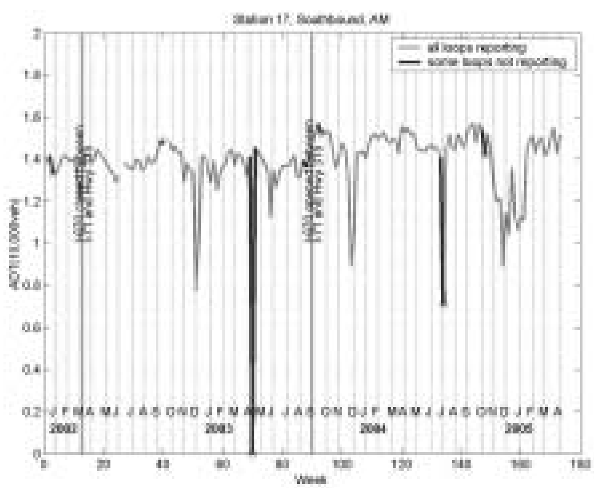

Station 14, Southbound, PM
all loops reporting
some loops not reporting
Week

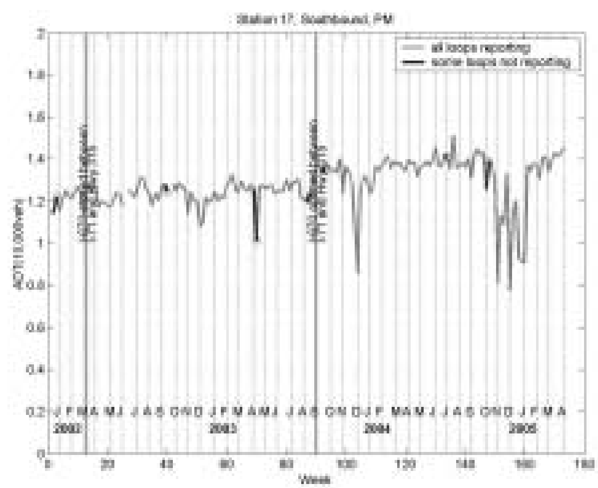

Station 15, Southbound, AM
all loops reporting
some loops not reporting
Week

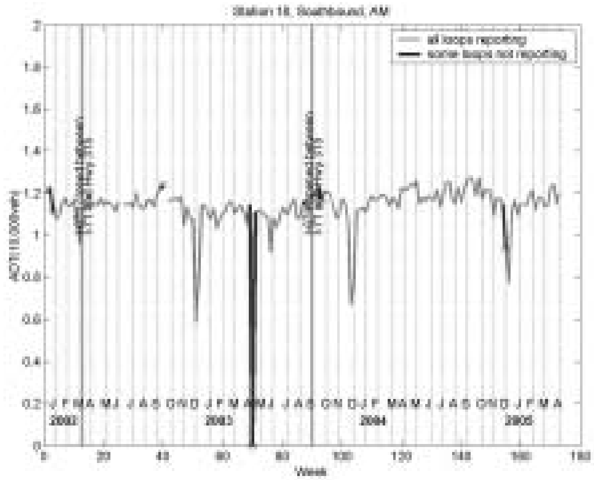

Station 15, Southbound, PM
all loops reporting
some loops not reporting
Week

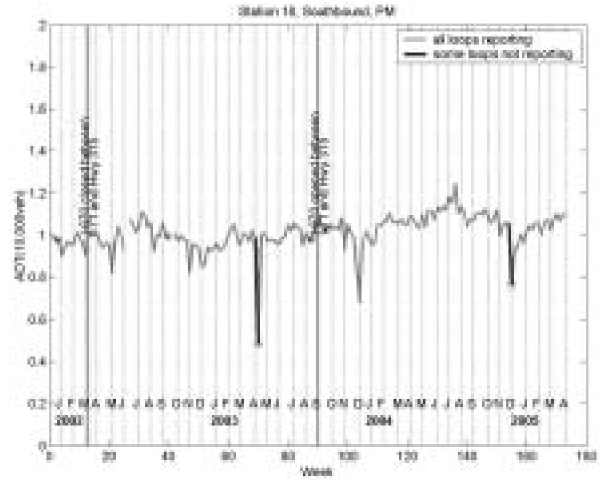

Station 16, Southbound, AM
all loops reporting
some loops not reporting
Week

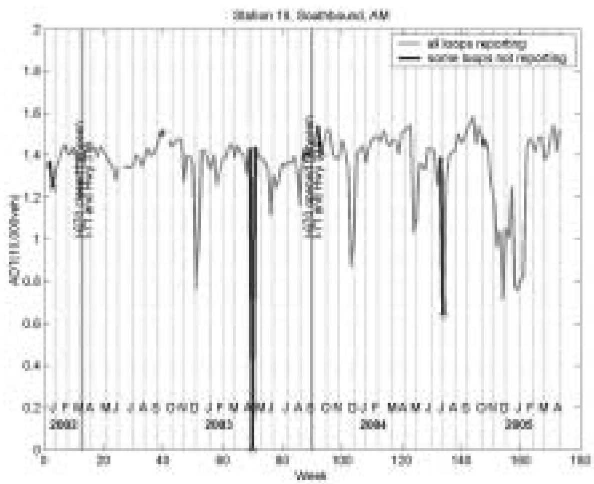

Station 16, Southbound, PM
all loops reporting
some loops not reporting
Week

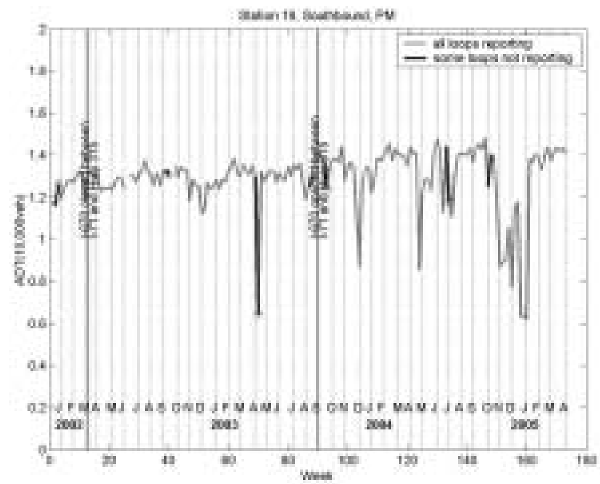

Station 17, Southbound, AM
all loops reporting
some loops not reporting
Week

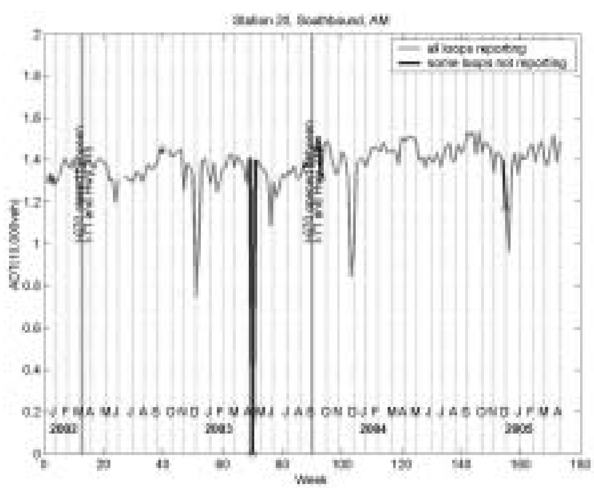

Station 17, Southbound, PM
all loops reporting
some loops not reporting
Week

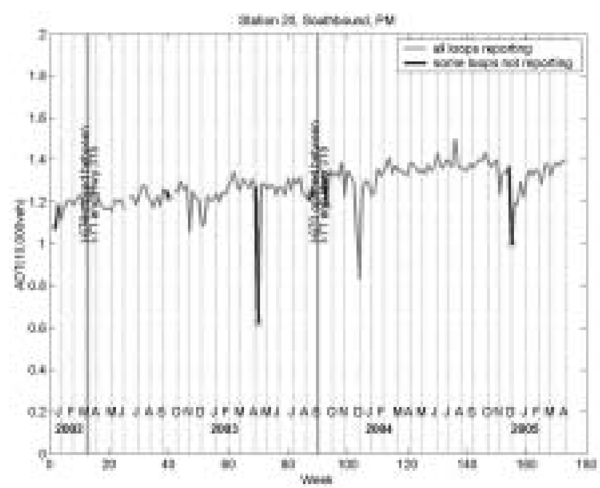

Station 18, Southbound, AM
all loops reporting
some loops not reporting
Week

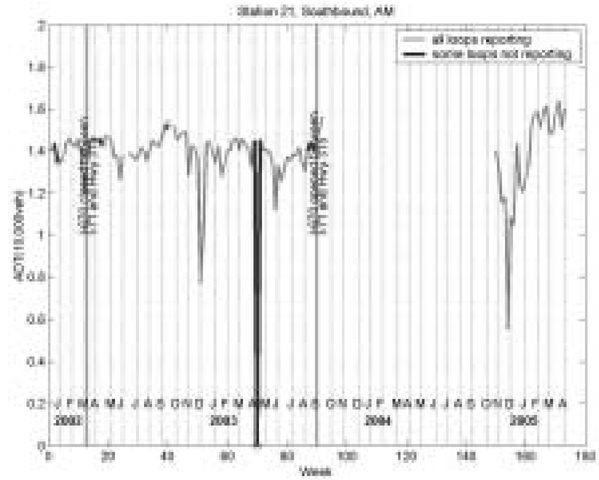

Station 18, Southbound, PM
all loops reporting
some loops not reporting
Week

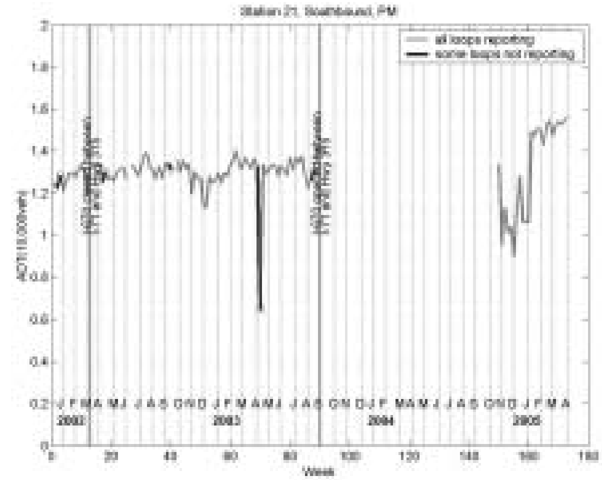

all loops reporting
some loops not reporting
Week

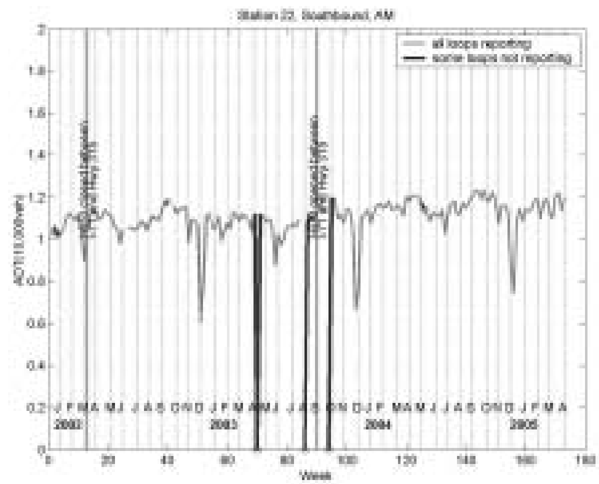

all loops reporting
some loops not reporting
Week

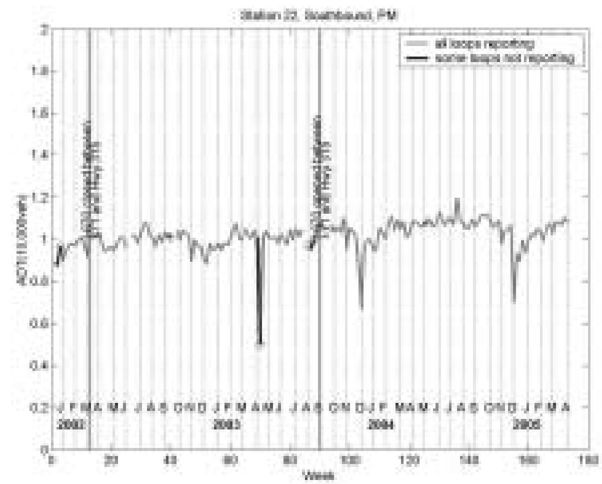

all loops reporting
some loops not reporting
Week

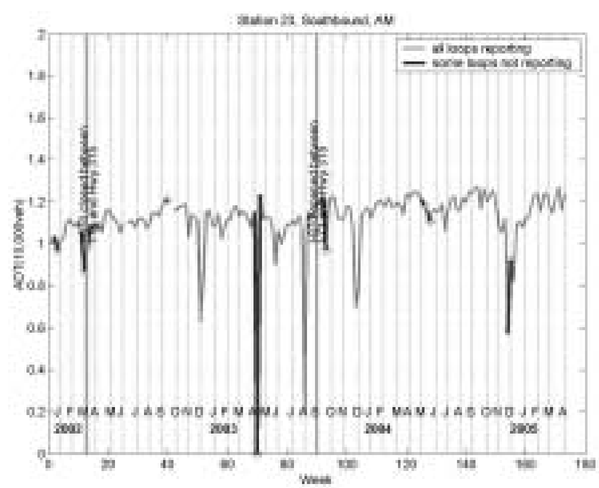

all loops reporting
some loops not reporting
Week

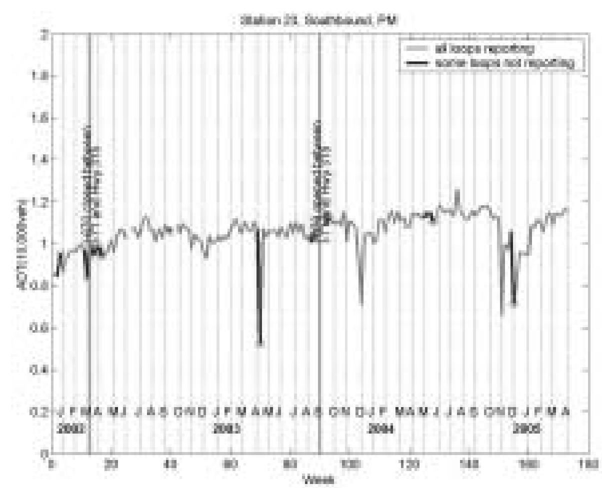

Station 21, Southbound, AM
all loops reporting
some loops not reporting
Week

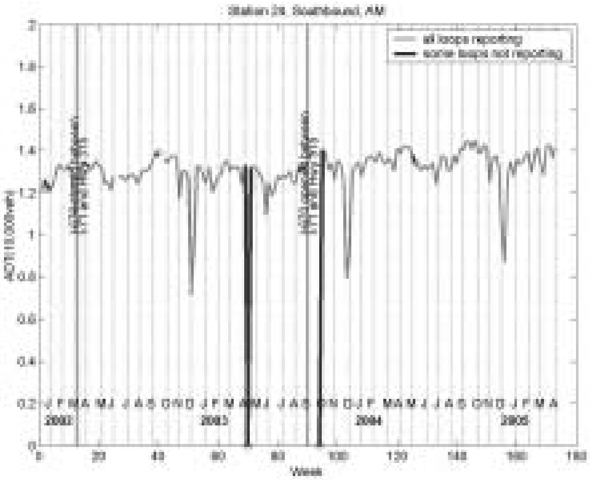

Station 21, Southbound, PM
all loops reporting
some loops not reporting
Week

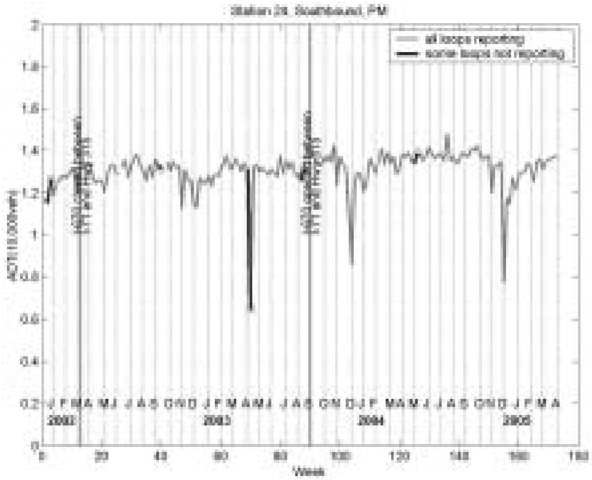

Station 22, Southbound, AM
all loops reporting
some loops not reporting
Week

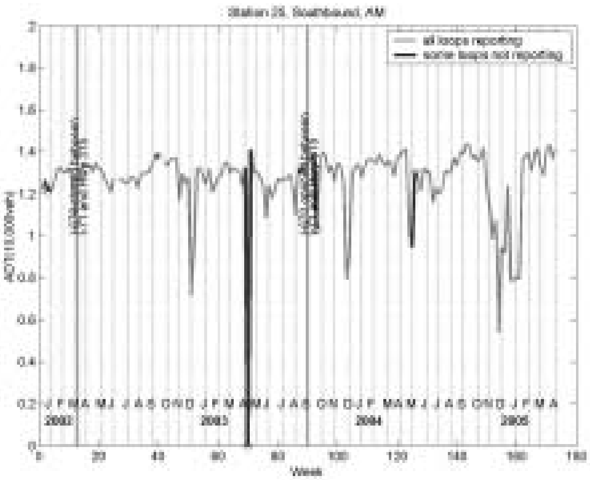

Station 22, Southbound, PM
all loops reporting
some loops not reporting
Week

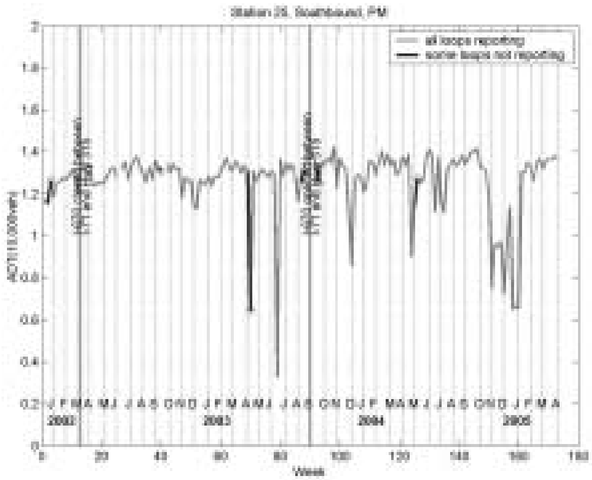

Station 23, Southbound, AM
all loops reporting
some loops not reporting
Week

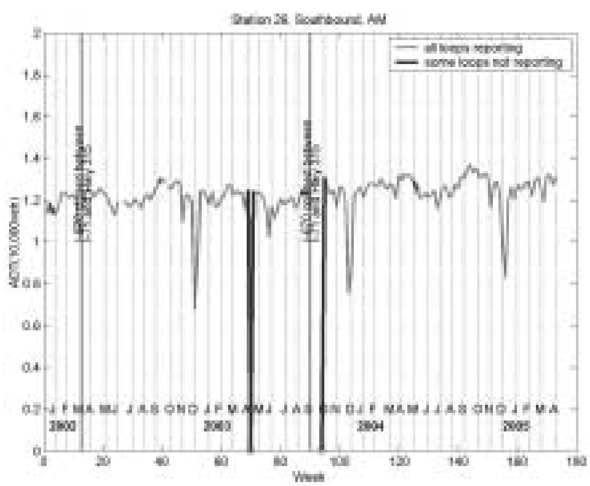

Station 23, Southbound, PM
all loops reporting
some loops not reporting
Week

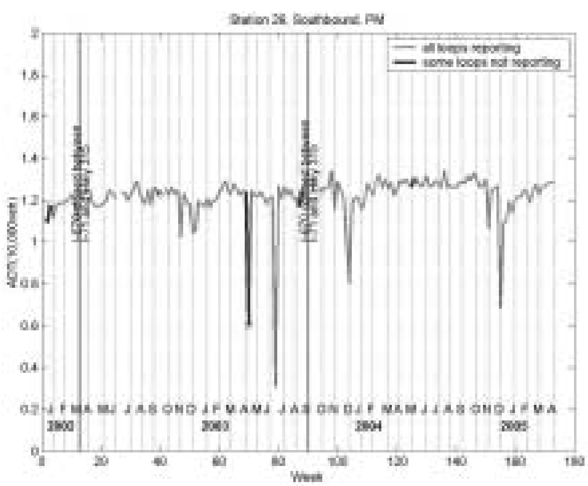

all loops reporting
some loops not reporting
2002
2003
2004
2005
Week


all loops reporting
some loops not reporting
2002
2003
2004
2005
Week


all loops reporting
some loops not reporting
2002
2003
2004
2005
Week

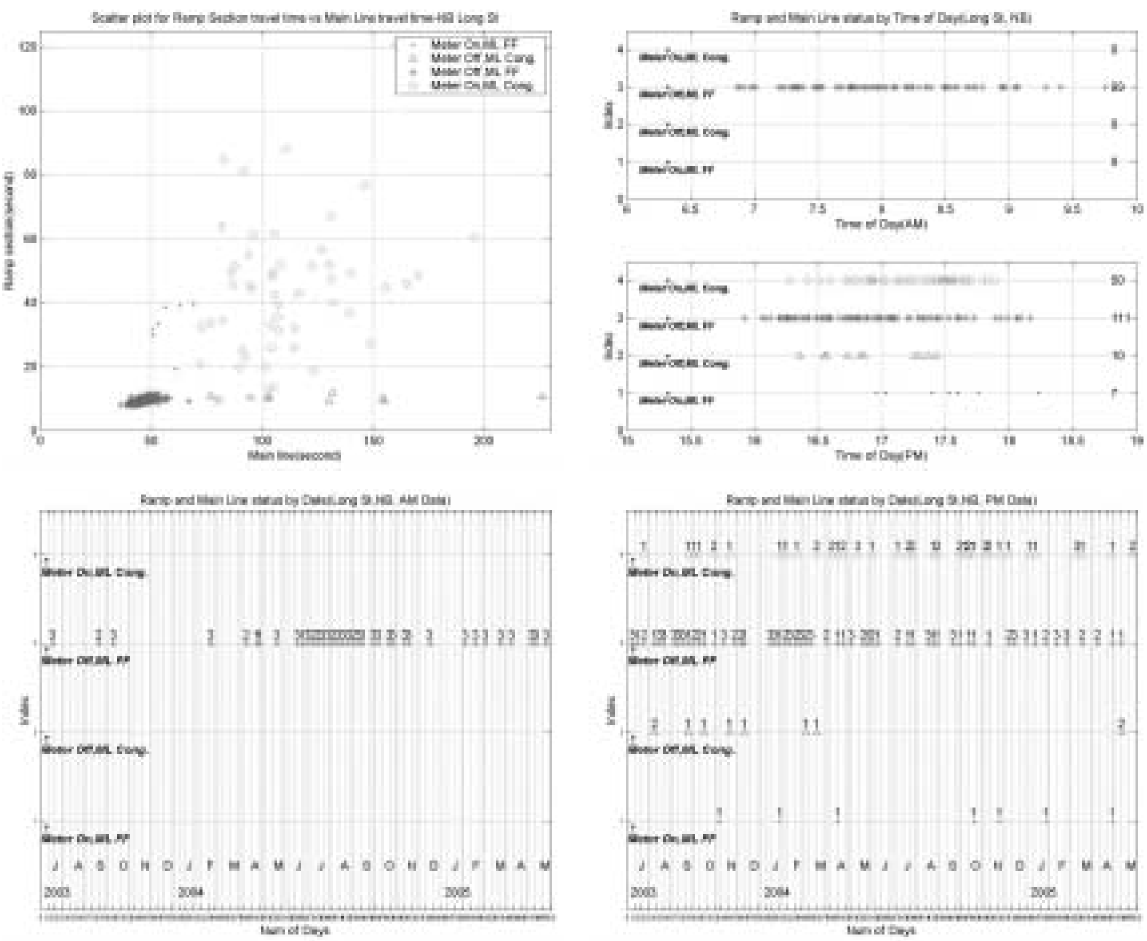

all loops reporting
some loops not reporting
2002
2003
2004
2005
Week


all loops reporting
some loops not reporting
2002
2003
2004
2005
Week


all loops reporting
some loops not reporting
2002
2003
2004
2005
Week

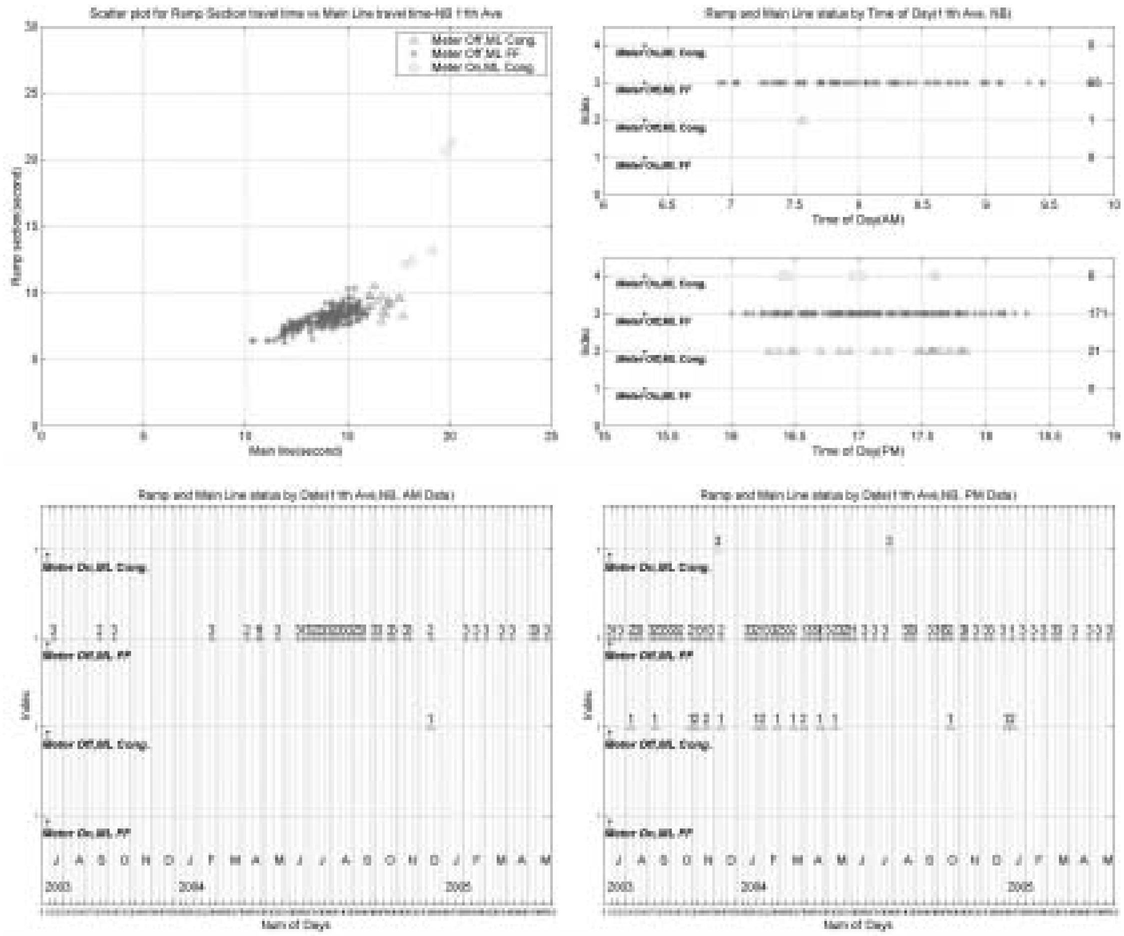
APPENDIX G: THE STATUS OF RAMP METERS USING RAMP RUN DATA

- Long St (NB)

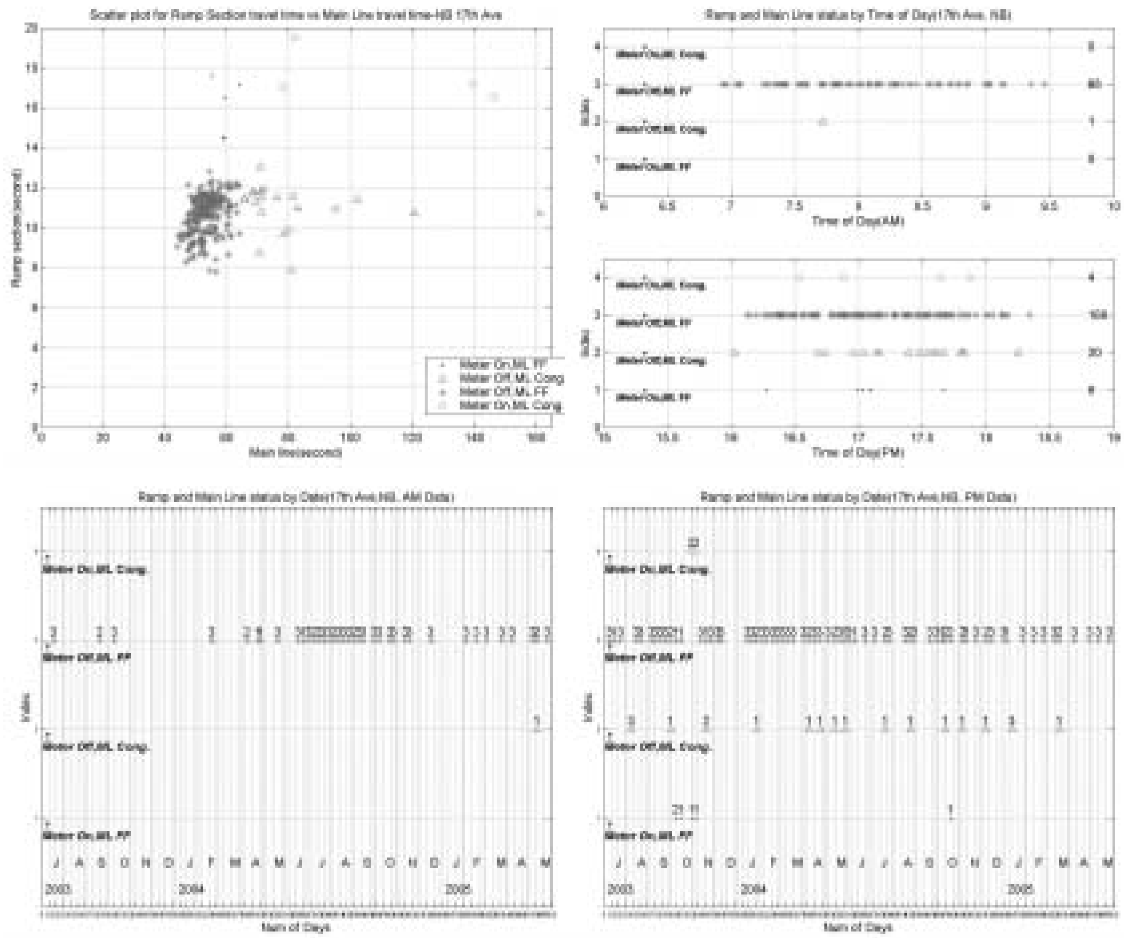


Meter On,ML FF
Meter Off,ML Cong.
Meter Off,ML FF
Meter On,ML Cong.
Time of Day(AM)
Time of Day(PM)
Num of Days

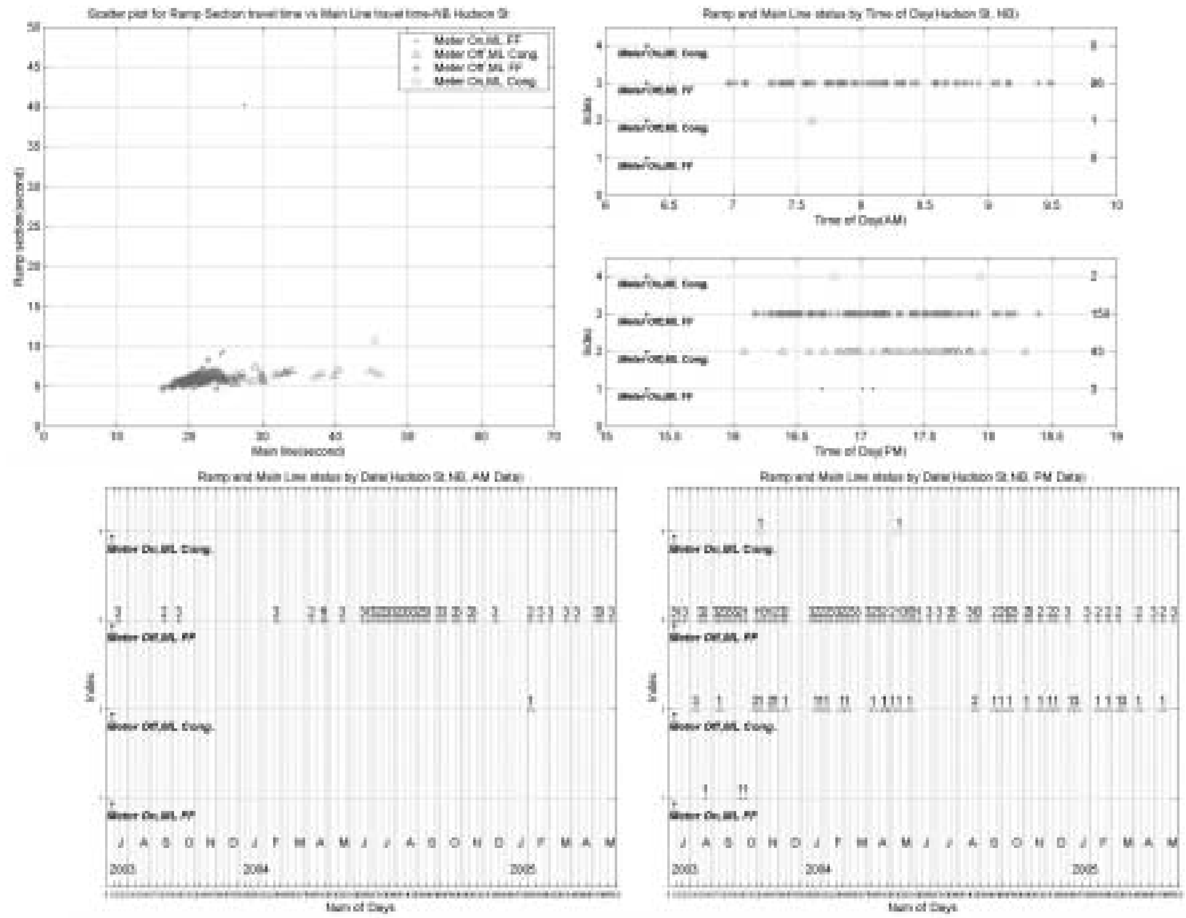
- 11th Ave (NB)



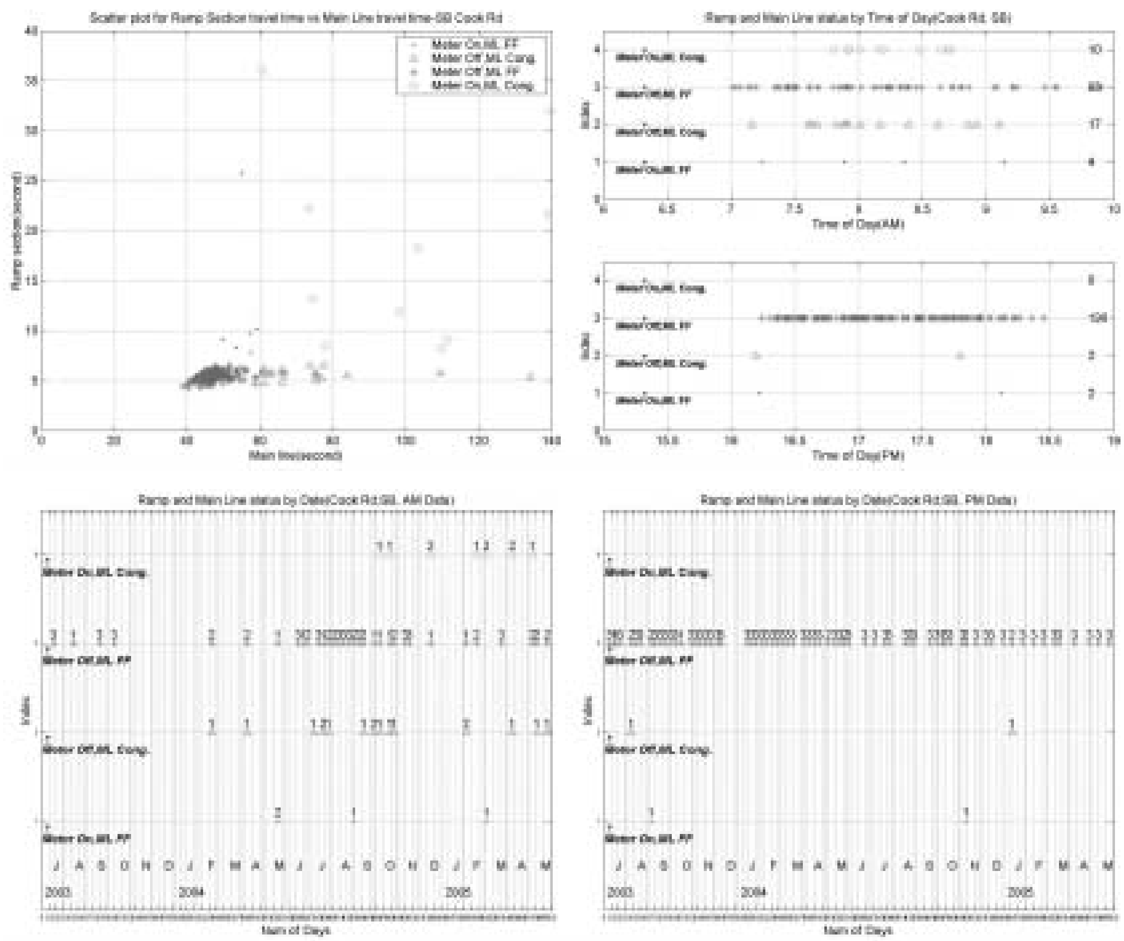
- 17th Ave (NB)


Scatter plot for Ramp Section travel time vs Main Line travel time-NB 17th Ave
Ramp and Main Line status by Time of Day(17th Ave, NB)
Ramp and Main Line status by Date(17th Ave,NB, AM Data)
Ramp and Main Line status by Date(17th Ave,NB, PM Data)
Meter On,ML FF
Meter Off,ML Cong.
Meter Off,ML FF
Meter On,ML Cong.
Time of Day(AM)
Time of Day(PM)
Num of Days

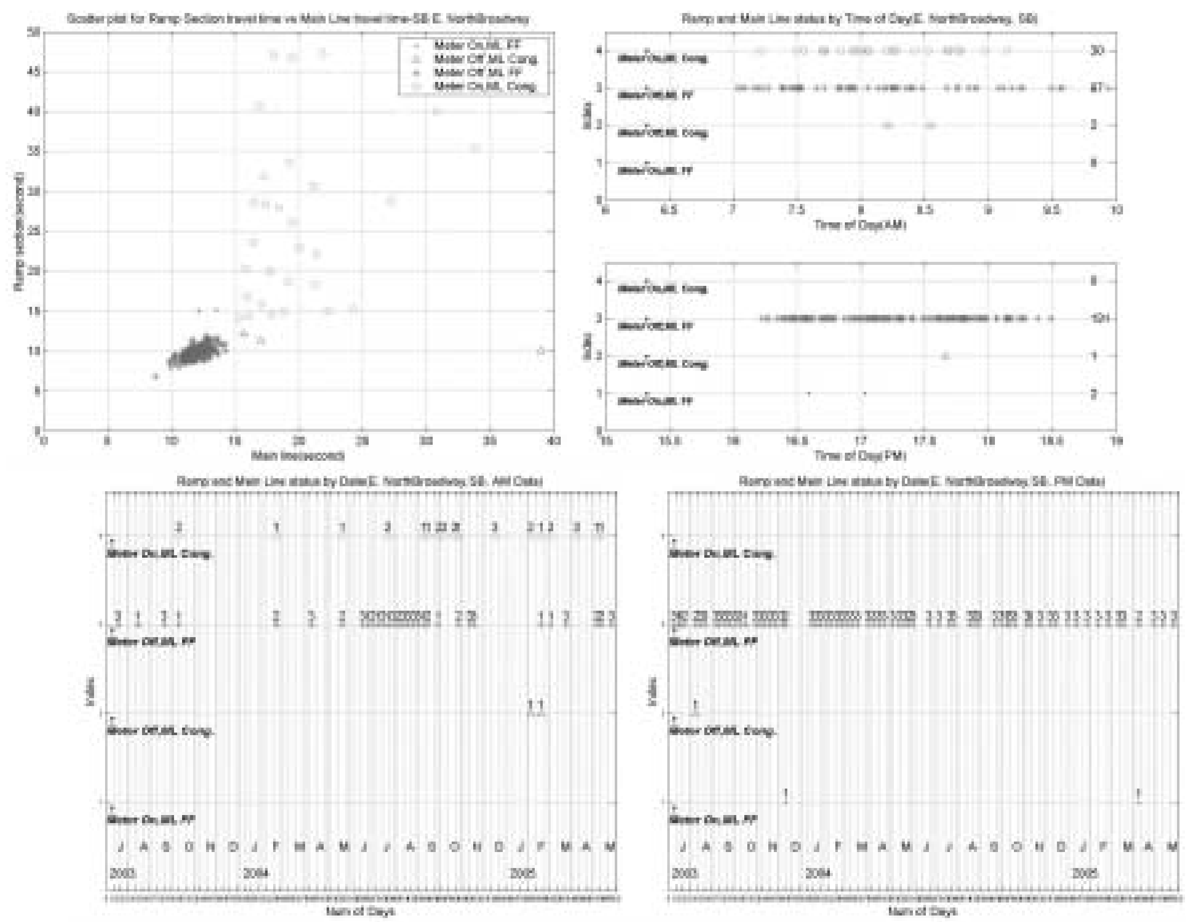
- Hudson St (NB)



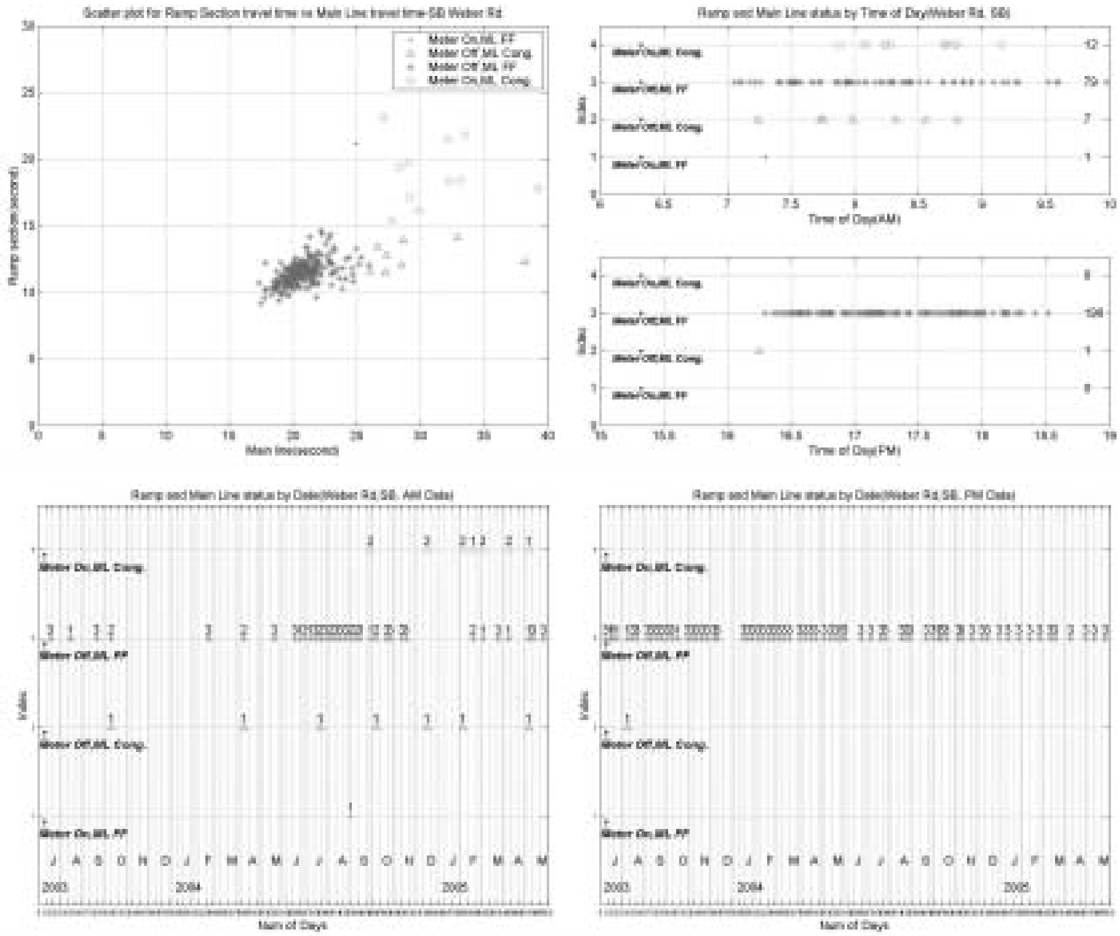
- Cook Rd (SB)



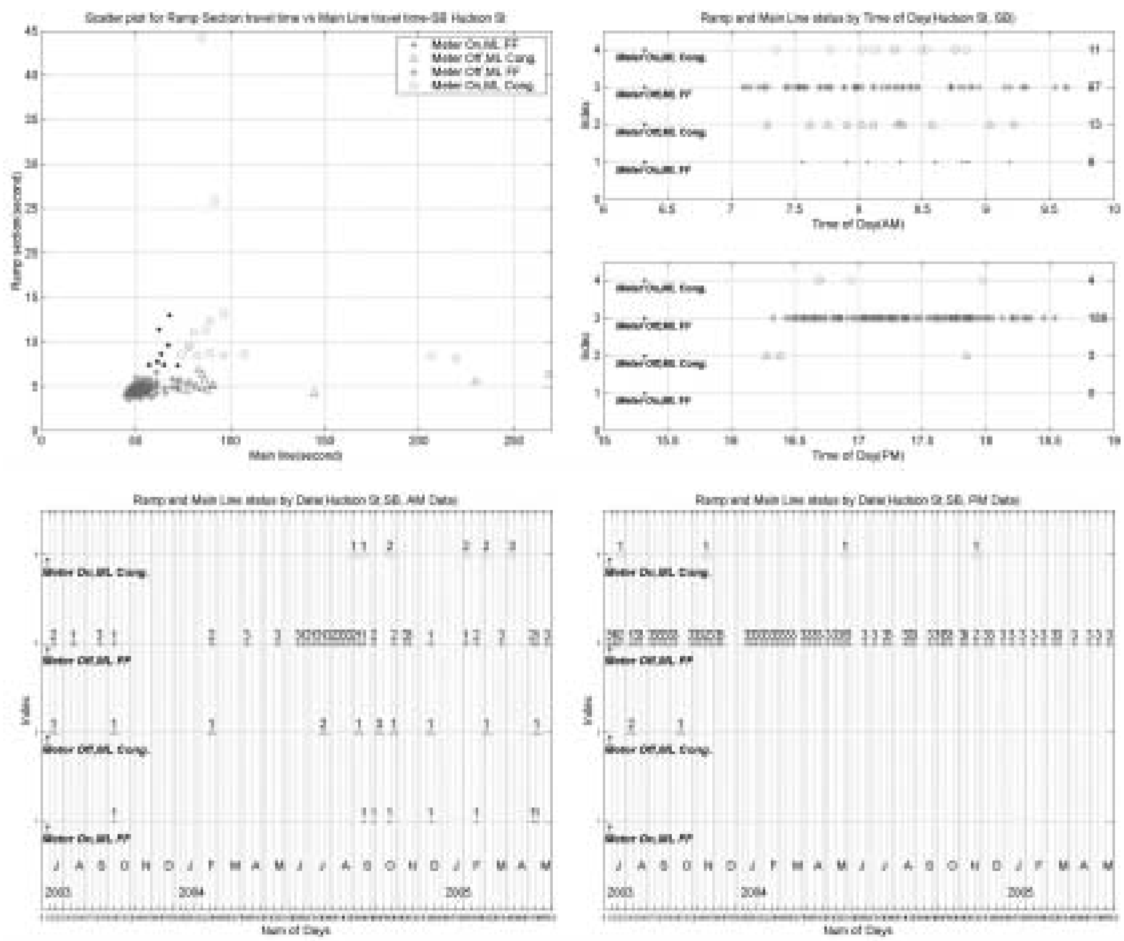
- E. Northbroadway (SB)



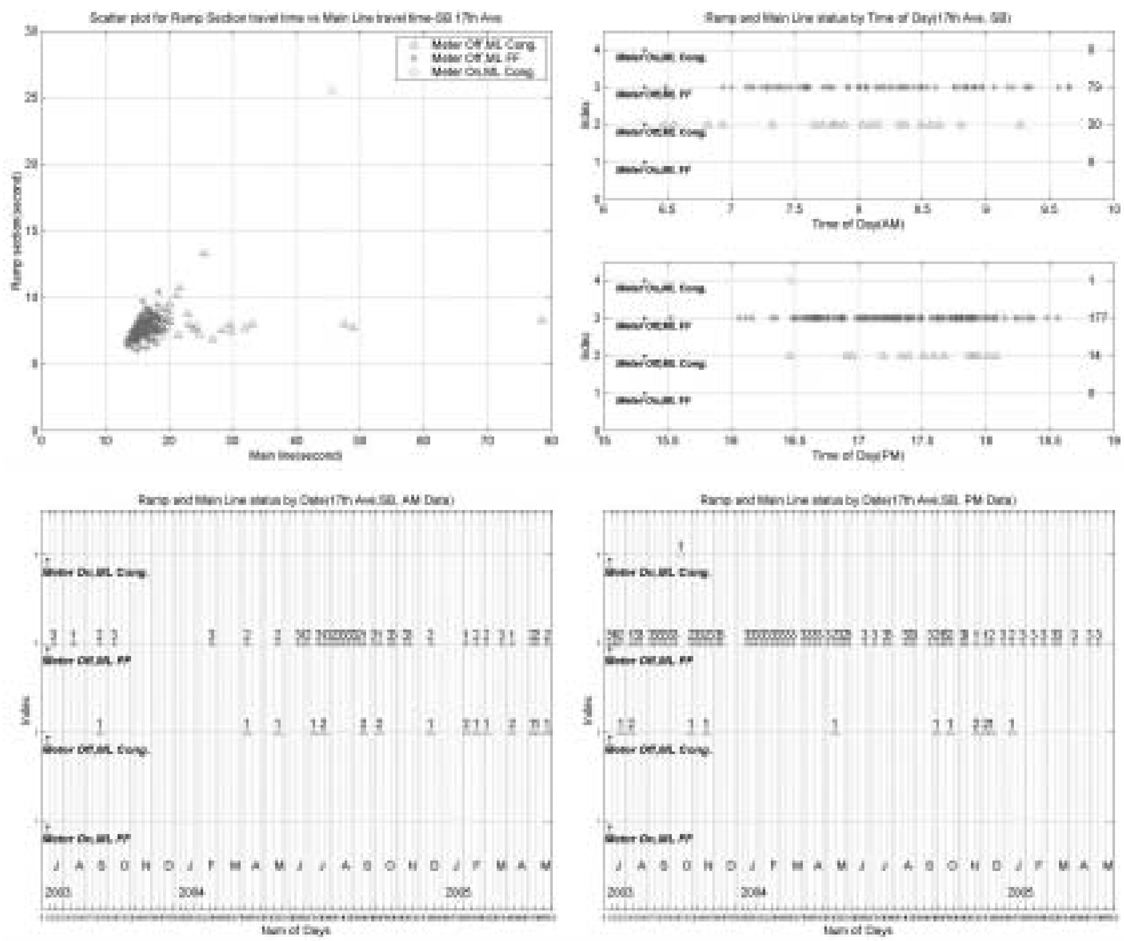
- Weber Rd (SB)



- Hudson St(SB)

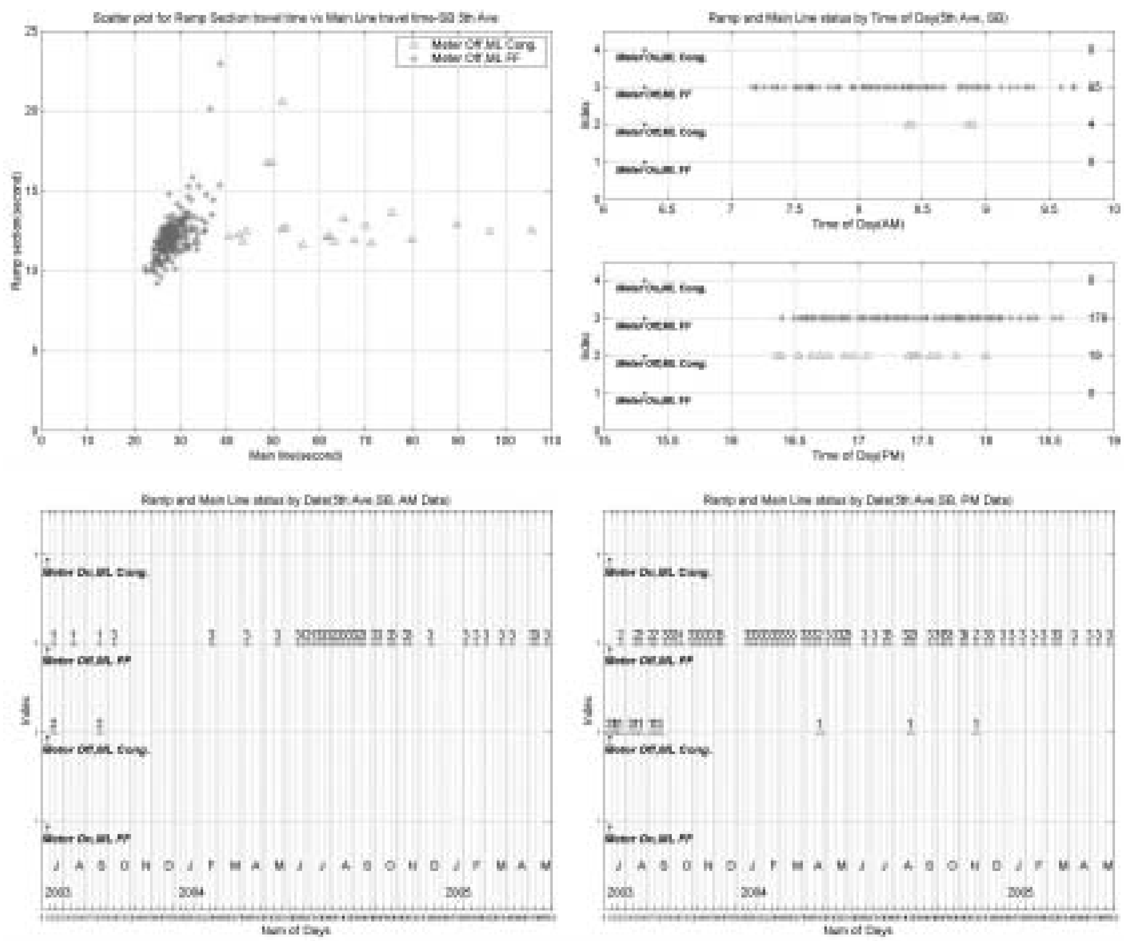


- 17th Ave (SB)



Scatter plot for Ramp Section travel time vs Main Line travel time-SB 17th Ave
Meter Off,ML Cong.
Meter Off,ML FF
Meter On,ML Cong.
Ramp and Main Line status by Time of Day(17th Ave, SB)
Time of Day(AM)
Time of Day(PM)
Ramp and Main Line status by Date(17th Ave,SB, AM Data)
Ramp and Main Line status by Date(17th Ave,SB, PM Data)
Num of Days

- 5th Ave (SB)



Scatter plot for Ramp Section travel time vs Main Line travel time-SB 5th Ave
Meter Off,ML Cong.
Meter Off,ML FF
Ramp and Main Line status by Time of Day(5th Ave, SB)
Time of Day(AM)
Time of Day(PM)
Ramp and Main Line status by Date(5th Ave,SB, AM Data)
Ramp and Main Line status by Date(5th Ave,SB, PM Data)
Meter On,ML Cong.
Meter Off,ML FF
Meter Off,ML Cong.
Meter On,ML FF
2003
2004
2005
Num of Days

APPENDIX H: ADDENDUM TO THE DETECTOR MAPPING ANALYSIS

As discussed in the body of this document, the south innerbelt (where eastbound I-70 and northbound I-71 overlap) was resurfaced starting in June 2003, knocking out most of the loops at stations 102 to 105. These loops were re-cut over the following months and it appears that there were detector mapping errors, as show in Table 2. Our mapping for station 102 used flows at the adjacent station (104) to correct the problem, and we assumed that the loops at station 104 northbound were without mapping errors. We have subsequently discovered evidence to suggest that both of these stations might suffered from the same mapping error, as follows. First, Figure H1 compares (A) flow and (B) CDF of vehicle length, between station 104 and station 103 northbound by lane over 24 hrs, before resurfacing. Each plot compares a different lane. In lanes 1 and 2, the time series of flow and CDF of vehicle lengths at both stations fall on top of one another. Note that no data were reported in lane 3 at station 103. In contrast, Figure H2 repeats this analysis after the resurfacing. Now only lane one reports any data at station 103, and its trends differ significantly from the corresponding data from lane 1 at station 104. In fact lane 2 at station 104 looks to be very similar to lane 1 at station 103. The CDF in Figure H2B for lane 1 at station 103 shows few long vehicles (as one would expect for lane 1). The CDF for lane 1 at station 104 has 15-20 percent long vehicles while the CDF for lane 2 has very few long vehicles, suggesting the lanes might be switched. Likewise, the low flow in lane 1 of station 103 is similar to the low flow of lane 2 at station 104 (consistent with what one would typically expect for the median lane).

Now consider the weekly median weekday peak flow (9am-3pm) for all northbound lanes for stations 102, 104, and 103 (a driver would pass them in this order), as shown in Figure H3. We see similar trends in a given lane across stations prior to resurfacing, but very different trends afterwards. Station 102 was the first station to come back on line, in August 2003. Next I-670 reopened after the long refurbishing in September. Then Station 104 came on line in October and 103 in November. Initially it would appear as if flow in lane 2 at station 102 dropped off significantly after I-670 reopened and that a similar trend was observed at station 104. Looking closer at Figure H3A, one can see that the time series for lanes 1 and 2 swap trends around March 2005, suggesting that the lane mapping for these two detector inputs were swapped. No such swap was apparent at station 104 as of the end of the analysis period in May 2005. So by May 2005, the detectors associated with lane 1 at station 102 and 103 give data consistent with one another and consistent with the detector associated with lane 2 at station 104.

We believe the exchange of lanes at station 102 in March 2005 is probably correct, though it is not reflected in Table 2 for two reasons. First, ODOT crews manually remapped station 102 at the time of the swap and the careful attention would likely have caught additional errors. Secondly, careful study of the schematics in Appendix A reveals that if a driver in lane 1 at any of these stations does not change lanes, they will wind up on I-670 westbound. Since these stations are on I-70 eastbound, it is unlikely that many drivers would take this route to ultimately head in the opposite direction. Meanwhile, a driver in lane 2 has the option of remaining on I-71 northbound or diverging to I-670 westbound when the two facilities split. Finally, a driver in lane 3 will either wind up on I-70 eastbound if they do not change lanes or exit the freeway. The fact that the error appeared at station 104 may be due to the fact that the contractor used flows at station 102 when doing the initial calibration after re-cutting the loops.

It would appear that as of May 2005 detector inputs for northbound lane 1 and 2 are swapped at station 104, that our mapping for northbound lane 1 and 2 in Table 2 should be exchanged, and that ODOT has already fixed the problem in the field at station 102.

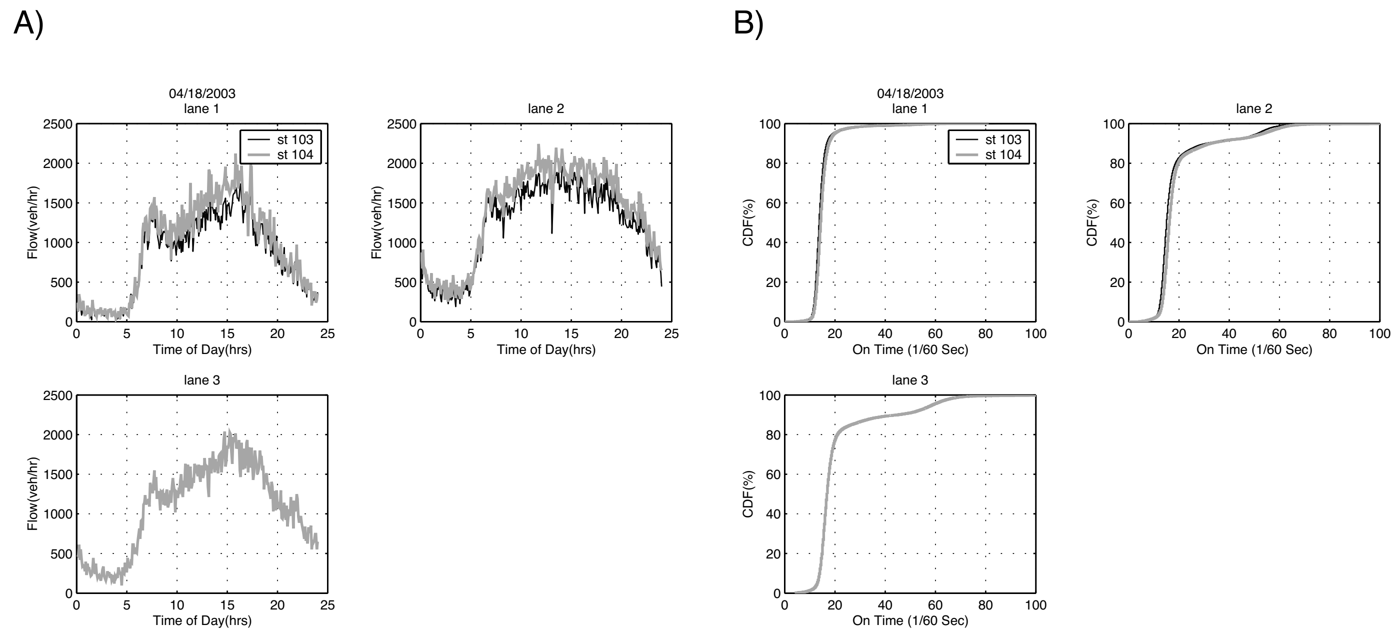


Figure H1, Comparison between (A) flow and (B) CDF of vehicle length, between station 104 and station 103 northbound by lane over 24 hrs, **before** resurfacing.

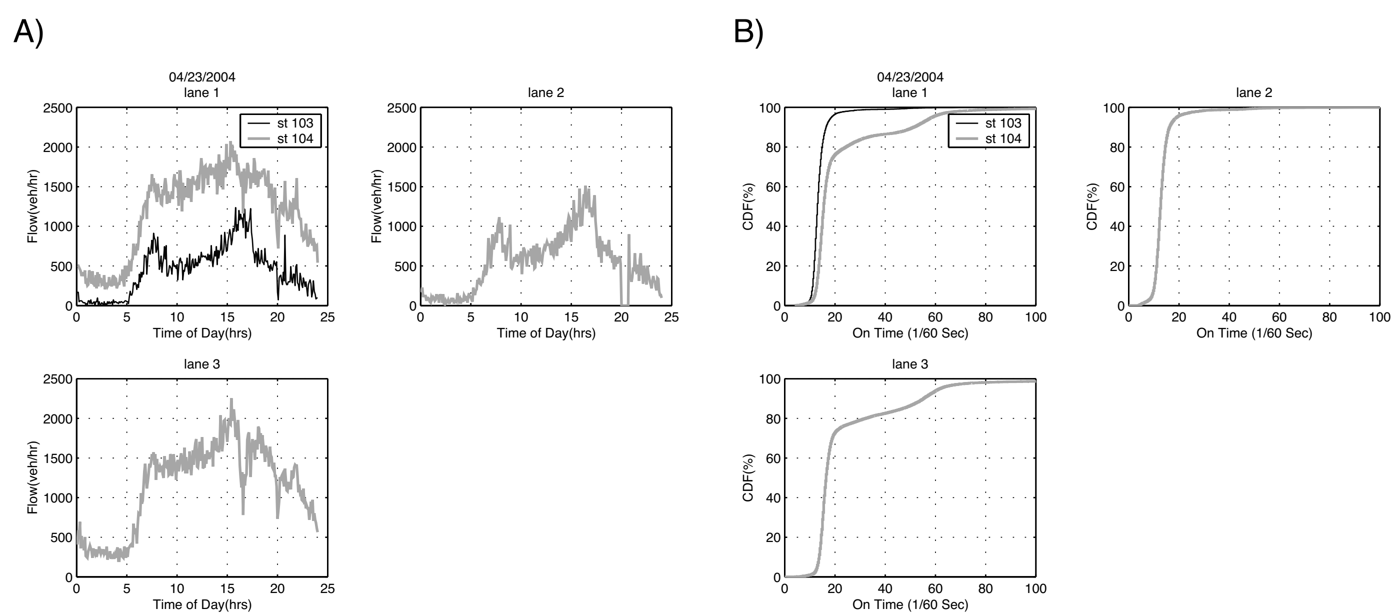
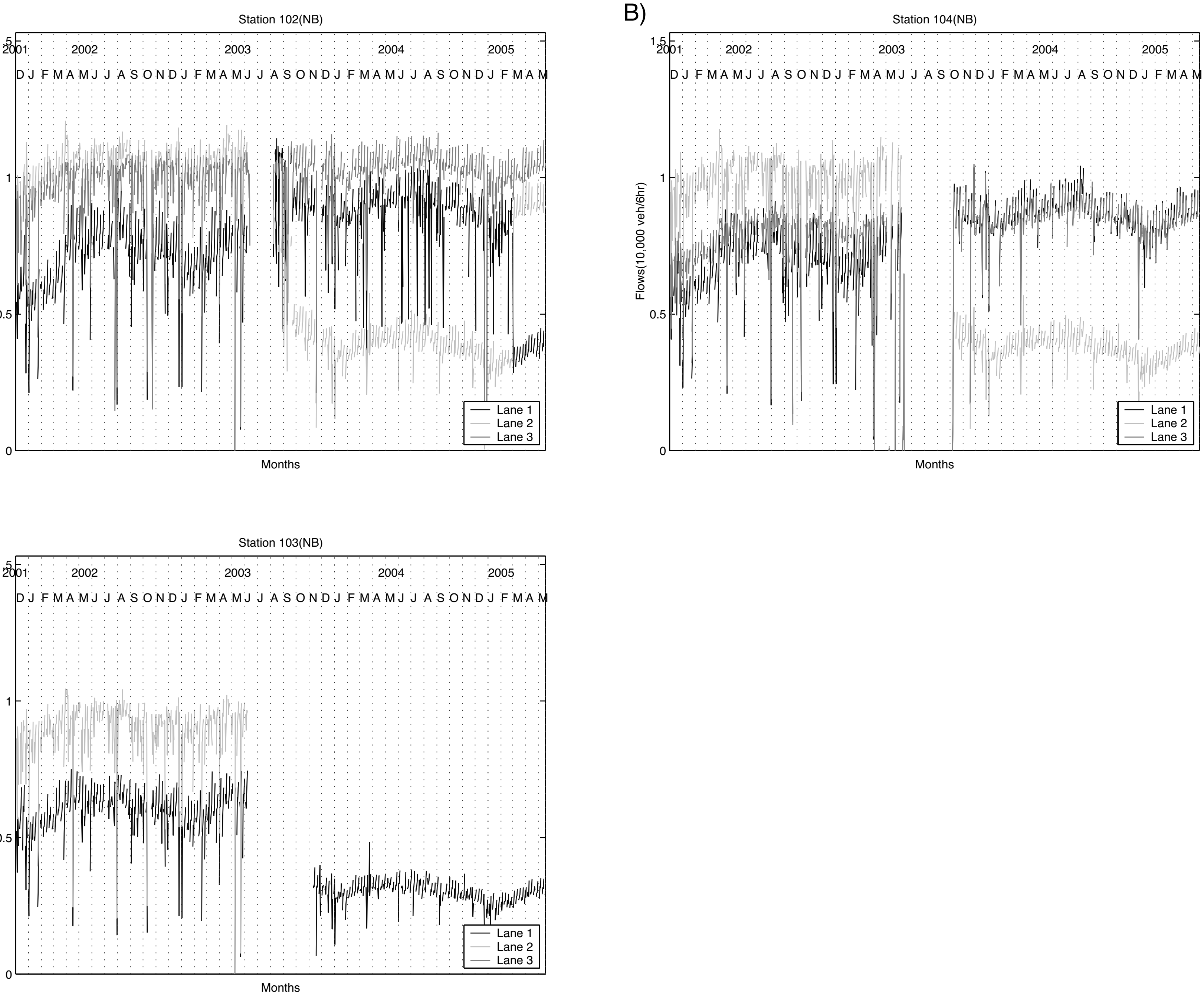


Figure H2, Comparison between (A) flow and (B) CDF of vehicle length, between station 104 and station 103 northbound by lane over 24 hrs, **after** resurfacing.



Comparison between weekly median weekday peak flow (9am-3pm), all northbound lanes, (A) station 102, (B) statio
(C) station 103 (note a driver would pass these stations in this order).