Summary of DRI Upper Air Measurements during the Clark County Regional Ozone and Precursor Study (CCROPS)

FINAL REPORT

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1.SODAR and Radar Wind Profiler Measurements

During the Clark County Regional Ozone and Precursor Study, four SODARs and one radar wind profiler were operated to measure winds aloft. SODAR and profiler sites were chosen based on conceptual models of surface wind patterns and historical locations of high ozone. DRI also processed level II NEXRAD radar data to provide VAD vertical wind profiles from three sites in the region.

Site ID	Location	Elev. (m MSL)	Instrumentation	Site Purpose
NLVA	Northern boundary just outside of North Las Vegas Airport	669	Vaisala LAP-3000 profiler and AeroVironment Model 4000 MiniSodar	Central valley transport; close proximity to North Las Vegas Airport (KVGT)
JNAP	Jean Airport	862	AeroVironment Model 2000 Sodar	Upwind transport
SPWY	Las Vegas Motor Speedway at northeast corner of property	607	AeroVironment Model 2000 Sodar	Northeast valley flow and flow exiting valley toward Apex Valley
FLSP	Floyd Lamb State Park	753	AeroVironment Model 2000 Sodar	Northwest valley flow near high ozone concentrations
SUMM	Summerlin	917	Pibal and Rawinsonde	West valley flows, investigate slope flows and return flows aloft from the Spring Mountains

NOAA ARL/SORD conducted episodic upper air measurements in support of the SODAR audits as well as filling in gaps in the upper air monitoring network during the CCROPS field study. The NOAA measurements were made using pilot balloons (pibals) and radiosondes. The following schedule was planned for each sampling day for SODAR audits.

Local Time	Local Time 24-hr	Operation
3:00 AM	03:00	Arrive at site, set up and perform calibrations
4:00 AM	04:00	
5:00 AM	05:00	radiosonde release
6:00 AM	06:00	pibal release
7:00 AM	07:00	pibal release
8:00 AM	08:00	pibal release
9:00 AM	09:00	radiosonde release
10:00 AM	10:00	pibal release
11:00 AM	11:00	pibal release
12:00 PM	12:00	pibal release
1:00 PM	13:00	pibal release
2:00 PM	14:00	pibal release
3:00 PM	15:00	pibal release
4:00 PM	16:00	pibal release
5:00 PM	17:00	pibal release
6:00 PM	18:00	radiosonde release
7:00 PM	19:00	pibal release
8:00 PM	20:00	pibal release
9:00 PM	21:00	pibal release
10:00 PM	22:00	radiosonde release
11:00 PM	23:00	pibal release

Audits soundings were taken at the Jean Airport, Floyd Lamb State Park and Speedway locations. Radiosondes from T&B Systems' North Las Vegas Airport site was used to audit the MiniSODAR at that location. To supplement the upper air network in the event that a SODAR is not operational the following table describes the sounding schedule.

Local Time	Local Time 24-hr	Operation
4:00 AM	04:00	Arrive at site, set up and perform calibrations
5:00 AM	05:00	
6:00 AM	06:00	radiosonde release
7:00 AM	07:00	pibal release
8:00 AM	08:00	pibal release
9:00 AM	09:00	pibal release
10:00 AM	10:00	radiosonde release
11:00 AM	11:00	pibal release
12:00 AM	12:00	pibal release
1:00 PM	13:00	pibal release
2:00 PM	14:00	pibal release
3:00 PM	15:00	pibal release
4:00 PM	16:00	radiosonde release

A complete list of pibal soundings during the summer of 2005 is provided below in chronological order.

Site Name	Date	LaunchTime (PST)	Max Height (ft)	Max Height (m)
Speedway	05/22/05	7:00	17,500	5,334
Speedway	05/22/05	8:00	15,000	4,572
Speedway	05/22/05	9:00	13,500	4,115
Speedway	05/22/05	11:00	19,500	5,944
Speedway	05/22/05	12:00	12,000	3,658
Speedway	05/22/05	13:00	15,000	4,572
Speedway	05/22/05	14:00	13,500	4,115
Speedway	05/22/05	15:00	18,500	5,639
Speedway	05/23/05	7:00	20,000	6,096
Speedway	05/23/05	8:00	20,000	6,096
Speedway	05/23/05	9:00	20,000	6,096
Speedway	05/23/05	11:00	20,000	6,096
Speedway	05/23/05	12:00	20,000	6,096
Speedway	05/23/05	13:00	20,000	6,096
Speedway	05/23/05	14:00	20,000	6,096
Speedway	05/23/05	15:00	19,500	5,944
Speedway	05/24/05	7:00	20,000	6,096
Speedway	05/24/05	8:00	20,000	6,096
Speedway	05/24/05	9:00	20,000	6,096
Speedway	05/24/05	11:00	20,000	6,096
Speedway	05/24/05	12:00	20,000	6,096
Speedway	05/24/05	13:00	20,000	6,096
Speedway	05/24/05	14:00	20,000	6,096
Speedway	05/24/05	15:00	13,500	4,115
Jean	07/01/05	7:00	20,000	6,096
Jean	07/01/05	8:00	20,000	6,096

Jean	07/01/05	9:00	20,000	6,096
Jean	07/01/05	11:00	20,000	6,096
Jean	07/01/05	12:00	20,000	6,096
Jean	07/01/05	13:00	20,000	6,096
Jean	07/01/05	14:00	20,000	6,096
Jean	07/01/05	15:00	20,000	6,096
Jean	07/02/05	7:00	20,000	6,096
Jean	07/02/05	8:00	20,000	6,096
Jean	07/02/05	9:00	20,000	6,096
Jean	07/02/05	11:00	20,000	6,096
Jean	07/02/05	12:00	20,000	6,096
Jean	07/02/05	13:00	20,000	6,096
Jean	07/02/05	14:00	20,000	6,096
Jean	07/02/05	15:00	20,000	6,096
Jean	07/14/05	7:00	20,000	6,096
Jean	07/14/05	8:00	16,000	4,877
Jean	07/14/05	9:00	20,000	6,096
Jean	07/14/05	11:00	20,000	6,096
Jean	07/14/05	12:00	20,000	6,096

Site Name	Date	LaunchTime (PST)	Max Height (ft)	Max Height (m)
Jean	07/14/05	13:00	20,000	6,096
Jean	07/14/05	14:00	20,000	6,096
Jean	07/14/05	15:00	20,000	6,096
Jean	07/15/05	7:00	13,000	3,962
Jean	07/15/05	8:00	20,000	6,096
Jean	07/15/05	9:00	11,000	3,353
Jean	07/15/05	11:00	20,000	6,096
Jean	07/15/05	12:00	20,000	6,096

Jean	07/15/05	13:00	20,000	6,096
Jean	07/15/05	14:00	20,000	6,096
Jean	07/15/05	15:00	20,000	6,096
Jean	07/17/05	7:00	20,000	6,096
Jean	07/17/05	8:20	10,000	3,048
Jean	07/17/05	9:00	6,500	1,981
Jean	07/17/05	11:00	20,000	6,096
Jean	07/17/05	12:00	20,000	6,096
Jean	07/17/05	13:00	20,000	6,096
Jean	07/17/05	14:00	20,000	6,096
Jean	07/17/05	15:00	20,000	6,096
Summerlin	07/18/05	7:00	20,000	6,096
Summerlin	07/18/05	8:00	20,000	6,096
Summerlin	07/18/05	9:00	20,000	6,096
Summerlin	07/18/05	11:00	20,000	6,096
Summerlin	07/18/05	12:00	20,000	6,096
Summerlin	07/18/05	13:00	20,000	6,096
Summerlin	07/18/05	14:00	20,000	6,096
Summerlin	07/18/05	15:00	20,000	6,096
Summerlin	07/19/05	7:00	20,000	6,096
Summerlin	07/19/05	8:00	20,000	6,096
Summerlin	07/19/05	9:00	20,000	6,096
Summerlin	07/19/05	11:00	20,000	6,096
Summerlin	07/19/05	12:00	20,000	6,096
Summerlin	07/19/05	13:00	20,000	6,096
Summerlin	07/19/05	14:00	20,000	6,096
Summerlin	07/19/05	15:00	15,000	4,572
Summerlin	07/20/05	7:00	20,000	6,096
Summerlin	07/20/05	8:00	20,000	6,096

Summerlin	07/20/05	9:00	20,000	6,096
Summerlin	07/20/05	11:00	20,000	6,096
Summerlin	07/20/05	12:00	19,500	5,944
Summerlin	07/20/05	13:00	20,000	6,096
Summerlin	07/20/05	14:00	20,000	6,096
Summerlin	07/20/05	15:00	20,000	6,096
Floyd Lamb	07/26/05	6:00	20,000	6,096
Floyd Lamb	07/26/05	7:00	20,000	6,096
Floyd Lamb	07/26/05	8:00	20,000	6,096
Floyd Lamb	07/26/05	10:00	20,000	6,096
Floyd Lamb	07/26/05	11:00	20,000	6,096

Site Name	Date	LaunchTime (PST)	Max Height (ft)	Max Height (m)
Floyd Lamb	07/26/05	12:00	20,000	6,096
Floyd Lamb	07/26/05	13:00	17,500	5,334
Floyd Lamb	07/26/05	14:00	20,000	6,096
Floyd Lamb	07/26/05	15:00	20,000	6,096
Floyd Lamb	07/26/05	16:00	16,000	4,877
Floyd Lamb	07/26/05	17:00	20,000	6,096
Floyd Lamb	07/26/05	19:00	20,000	6,096
Floyd Lamb	07/27/05	6:00	20,000	6,096
Floyd Lamb	07/27/05	7:00	20,000	6,096
Floyd Lamb	07/27/05	8:00	20,000	6,096
Floyd Lamb	07/27/05	10:00	20,000	6,096
Floyd Lamb	07/27/05	11:00	20,000	6,096
Floyd Lamb	07/27/05	12:00	20,000	6,096
Floyd Lamb	07/27/05	13:00	20,000	6,096
Floyd Lamb	07/27/05	14:00	20,000	6,096
Floyd Lamb	07/27/05	15:00	20,000	6,096

Floyd Lamb	07/27/05	16:00	20,000	6,096
Floyd Lamb	07/27/05	17:00	20,000	6,096
Jean	08/22/05	7:00	14,500	4,420
Jean	08/22/05	8:00	20,000	6,096
Jean	08/22/05	9:00	13,500	4,115
Jean	08/22/05	11:00	20,000	6,096
Jean	08/22/05	12:00	20,000	6,096
Jean	08/22/05	13:00	20,000	6,096
Jean	08/22/05	14:00	15,500	4,724
Jean	08/22/05	15:00	20,000	6,096
Speedway	08/30/05	7:00	20,000	6,096
Speedway	08/30/05	8:00	20,000	6,096
Speedway	08/30/05	10:00	17,500	5,334
Speedway	08/30/05	11:00	13,500	4,115
Speedway	08/30/05	12:00	20,000	6,096
Speedway	08/30/05	13:00	7,500	2,286
Speedway	08/30/05	14:00	20,000	6,096
Speedway	08/30/05	15:00	20,000	6,096
Speedway	08/30/05	16:00	20,000	6,096
Speedway	08/30/05	17:00	20,000	6,096
Speedway	08/30/05	19:00	20,000	6,096
Speedway	08/31/05	6:00	20,000	6,096
Speedway	08/31/05	7:00	20,000	6,096
Speedway	08/31/05	8:00	20,000	6,096
Speedway	08/31/05	10:00	20,000	6,096
Speedway	08/31/05	11:00	20,000	6,096
Speedway	08/31/05	12:00	20,000	6,096
Speedway	08/31/05	13:00	20,000	6,096
Speedway	08/31/05	14:00	20,000	6,096

Speedway	08/31/05	15:00	20,000	6,096
Speedway	08/31/05	16:00	20,000	6,096
Speedway	08/31/05	19:00	20,000	6,096

A complete list of soundings (standard radiosondes) during the summer of 2005 is provided below.

Site Name	Date	LaunchTime (PST)	Max Height (m)	Max Press (hPa)
Jean	07/01/05	6:00 AM	14,765	136
Jean	07/01/05	9:58 AM	15,158	128
Jean	07/01/05	3:58 PM	14,699	138
Jean	07/02/05	5:59 AM	12,833	187
Jean	07/02/05	9:59 AM	14,657	139
Jean	07/02/05	4:05 PM	14,225	149
Jean	07/14/05	6:01 AM	15,604	121
Jean	07/14/05	10:00 AM	15,725	118
Jean	07/14/05	3:59 PM	15,280	128
Jean	07/15/05	10:00 AM	5,444	534
Jean	07/15/05	10:58 AM	15,472	123
Jean	07/15/05	4:00 PM	14,808	138
Jean	07/17/05	6:01 AM	15,207	129
Jean	07/17/05	10:06 AM	16,449	105
Jean	07/17/05	4:00 PM	15,740	118
Jean	07/20/05	6:02 AM	17,112	94
Jean	08/22/05	6:09 AM	15,096	130
Jean	08/22/05	10:01 AM	15,661	118
Jean	08/22/05	3:57 PM	15,179	128
Floyd Lamb State Park	07/26/05	5:22 AM	15,686	118
Floyd Lamb State Park	07/26/05	8:59 AM	15,351	125
Floyd Lamb State Park	07/27/05	6:06 PM	12,513	199
Floyd Lamb State Park	07/27/05	10:04 PM	7,482	408
Floyd Lamb State Park	07/27/05	5:03 AM	14,624	141
Floyd Lamb State Park	07/27/05	9:00 AM	15,172	129
Speedway	06/22/05	5:58 AM	15,204	127
Speedway	06/22/05	10:12 AM	15,153	128
Speedway	06/23/05	5:58 AM	6,352	468
Speedway	06/23/05	9:58 AM	15,298	123
Speedway	06/23/05	3:58 PM	13,929	154
Speedway	06/24/05	6:02 AM	14,139	149
Speedway	06/24/05	10:00 AM	15,232	125
Speedway	06/24/05	3:58 PM	14,585	138
Speedway	08/30/05	5:00 AM	14,893	134
Speedway	08/30/05	8:59 AM	13,746	161
Speedway	08/31/05	6:03 PM	13,613	164
Speedway	08/31/05	10:01 PM	14,715	138
Speedway	08/31/05	5:00 AM	15,467	121
Speedway	08/31/05	8:59 AM	17,508	86

Speedway	09/01/05	6:00 PM	15,690	116
Speedway	09/01/05	10:08 PM	16,799	97
Summerlin	07/18/05	6:09 AM	15,509	122
Summerlin	07/18/05	10:01 AM	14,469	145
Summerlin	07/18/05	4:00 PM	15,726	118

Site Name	Date	LaunchTime (PST)	Max Height (m)	Max Press (hPa)
Summerlin	07/19/05	6:01 AM	14,509	144
Summerlin	07/19/05	10:00 AM	13,859	161
Summerlin	07/19/05	4:00 PM	15,932	114
Summerlin	07/20/05	6:00 AM	15,516	122
Summerlin	07/20/05	10:00 AM	16,712	100
Summerlin	07/20/05	4:00 PM	15,346	126
Summerlin	07/23/05	4:00 PM	15,726	118
Floyd Lamb State Park	07/28/05	6:00 PM	14,348	149
Floyd Lamb State Park	07/28/05	8:01 PM	14,536	144
Floyd Lamb State Park	07/28/05	10:24 PM	8,701	346

2.Data Validation and Audits

All SODAR, radar wind profiler, NOAA ARL/SORD pibal and radiosonde and NEXRAD profiles have been stored and quality assured to level 1 in the database. We used the Watson et al. (2001) validation methodology for assigning flags to suspect and invalid data. We expect further validation in the coming months while we refine the algorithms. For reporting performance of the remote sensing systems, we follow the guidance from Baxter (2002) to estimate systematic differences and the operational comparability between the collocated sonde measurements.

Systematic Differences

$$d = \frac{1}{n}\sum\left(W - W_{ref}\right)$$

where:

n = number of measurements;
W = measured winds from remote sensor, and
W_{ref} = measured winds from balloon-borne system.

Root Mean Square Error

$$RMSE = \sqrt{\frac{1}{n}\sum\left(W - W_{ref}\right)^2}$$

where:

n = number of measurements;

W = measured winds from remote sensor, and
W_{ref} = measured winds from balloon-borne system.

Tables 2.1 through 2.5 summarize the audit results at all SODAR and profiler sites.

Table 2.1. North Las Vegas Airport Radar Wind Profiler audit results for WS greater than 2 m/s

Parameter	Systematic Difference	RMSE
u	1.1 m/s	2.8 m/s
v	-0.4 m/s	2.4 m/s
WS	0.3 m/s	2.2 m/s
WD	25°	N/A

Table 2.2. Jean Airport SODAR audit results

Parameter	Systematic Difference	RMSE
u	2.4 m/s	3.7 m/s
v	4.0 m/s	5.3 m/s
WS	3.9 m/s	5.3 m/s
WD	22°	N/A

Table 2.3. North Las Vegas Airport MiniSODAR audit results

Parameter	Systematic Difference	RMSE
u	0.2 m/s	1.8 m/s
v	0.9 m/s	2.2 m/s
WS	-0.1 m/s	2.2 m/s
WD	34°	N/A

Table 2.4. Speedway SODAR audit results

Parameter	Systematic Difference	RMSE
u	-4.6 m/s	6.1 m/s
v	-1.2 m/s	6.1 m/s
WS	3.0 m/s	7.0 m/s
WD	58°	N/A

Table 2.5. Floyd Lamb State Park SODAR audit results

Parameter	Systematic Difference	RMSE
u	1.5 m/s	2.9 m/s

v	-1.5 m/s	2.4 m/s
WS	1.0 m/s	2.5 m/s
WD	66°	N/A

2.1 Percent Data Recovery by Height

Figures 2.1 to 2.4 show data recovery percentage plots for each of the SODAR sites. The blue bars on the plots show the percent data recovered for the wind speed/wind direction. The gray bars on the plot show recovery percentages for sigma w, the standard deviation of the vertical wind velocity. Note that the overall data recovery for the MiniSODAR was low because of the instrument problems from the middle of June to the beginning of July. The software problem was resolved after a visit from AeroVironment in July. Data recovery is very good excluding that time period.

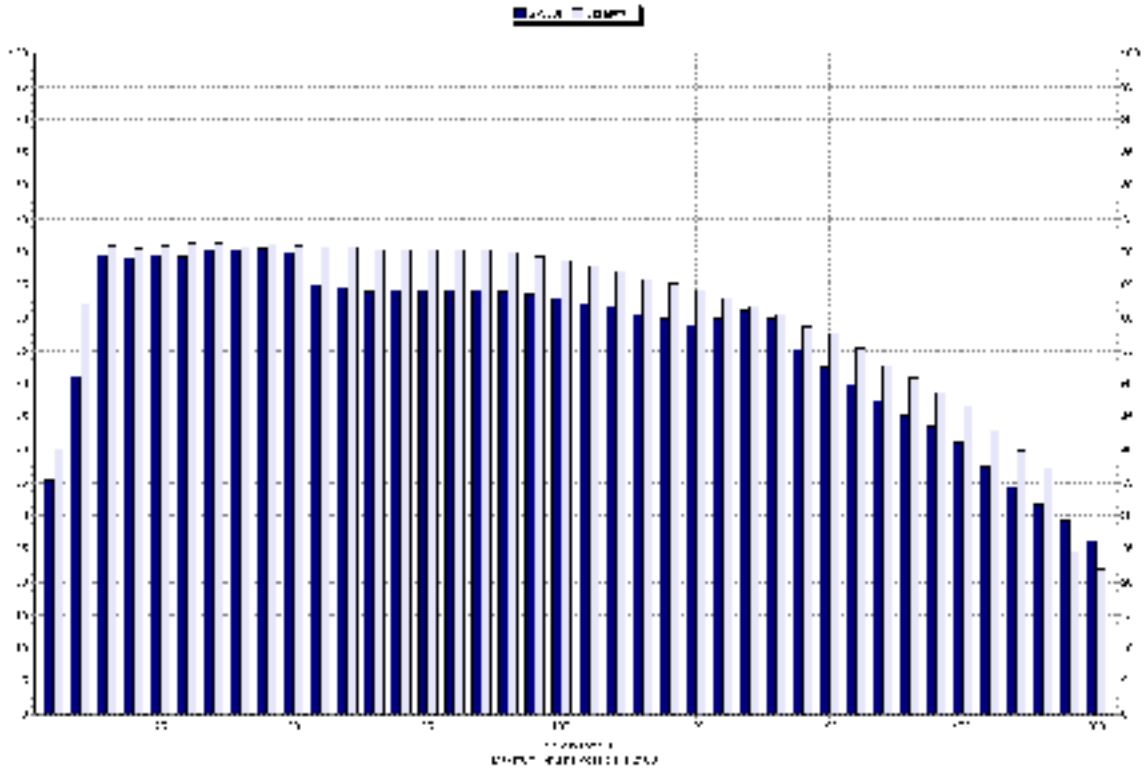


Figure 2.1 North Las Vegas Airport MiniSODAR data recovery from installation date to August 31, 2005. Dark bars represent data recovery for the wind speed/wind direction, while the lighter gray bars indicate the sigma w recovery.

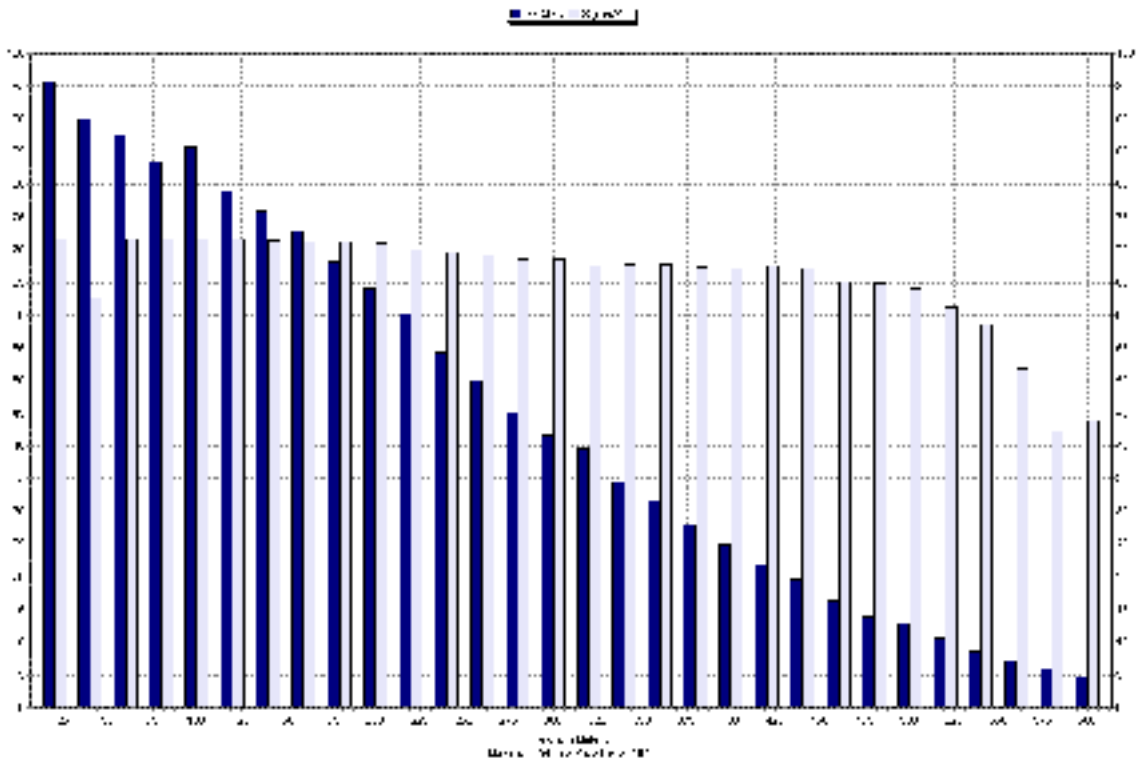


Figure 2.2 **Data recovery for Jean airport site from installation date to August 31, 2005. Dark bars represent data recovery for the wind speed/wind direction, while the lighter gray bars indicate the sigma w recovery.**

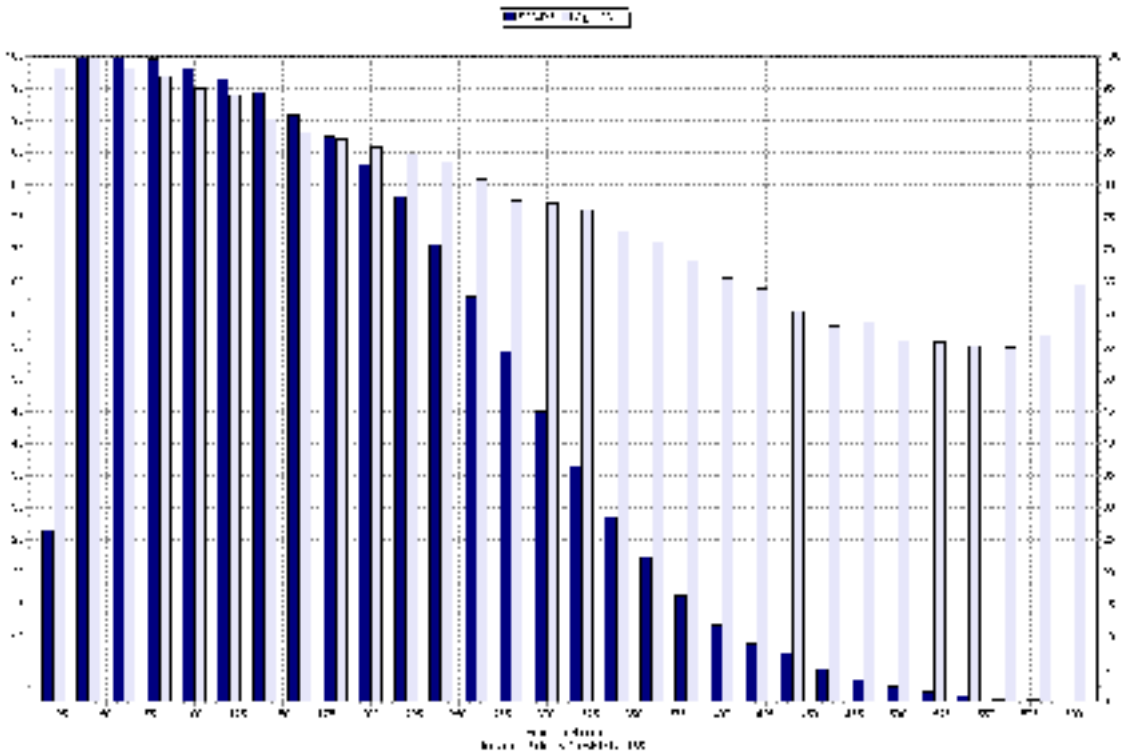


Figure 2.3 **Data recovery of the Speedway SODAR from installation to August 31, 2005. Dark bars represent data recovery for the wind speed/wind direction, while the lighter gray bars indicate the sigma w recovery.**

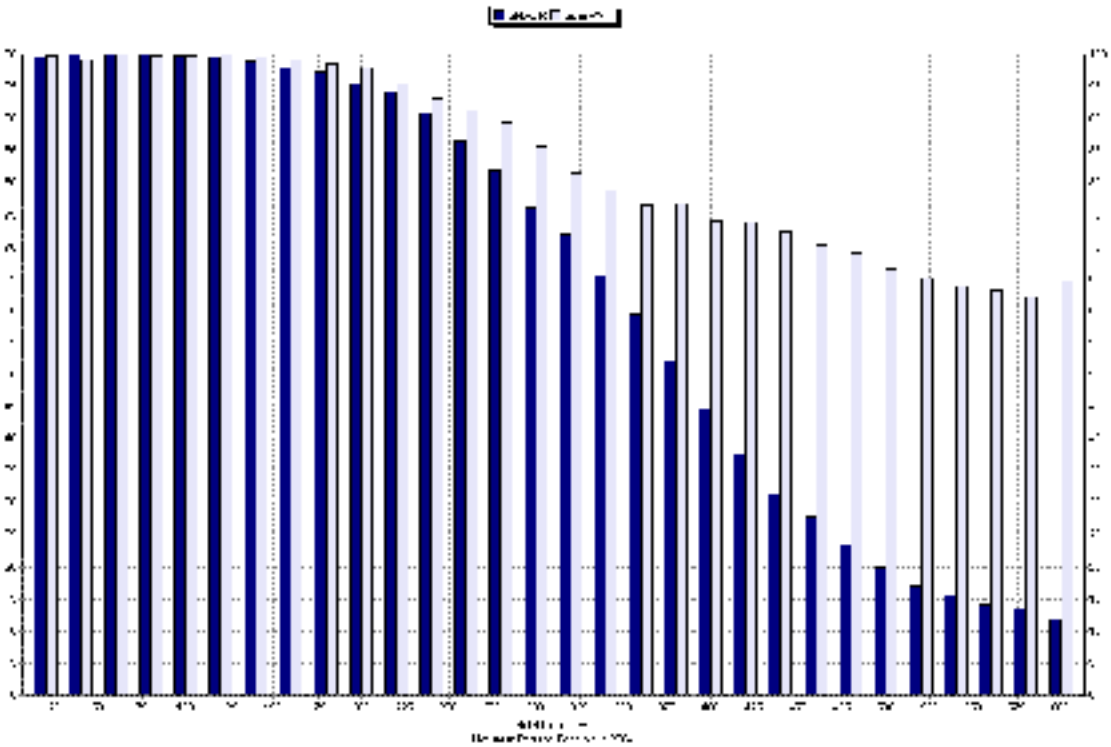


Figure 2.4 Data recovery at the Floyd Lamb State Park site from installation to August 31, 2005. Dark bars represent data recovery for the wind speed/wind direction, while the lighter gray bars indicate the sigma w recovery.

3.Relationship between wind and ozone patterns

In this section we consider the relationships between surface ozone levels and their diurnal and spatial patterns and surface and upper level winds and transport paths.

3.1 Methodology

It is expected that variations in ozone concentrations are largely driven by temporal variations in meteorological conditions rather than variations in emissions (with exception due to fires, e.g.). Furthermore, it is proposed that surface level winds in the area are determined from a combination of local forcing factors associated with topography (e.g. differential heating/cooling, channeling) and forcing on a regional to synoptic scale. It may be reasonably expected that days with similar spatial wind field patterns and a similar diurnal variation of these patterns will have similar ozone levels. Thus we performed an analysis (cluster analysis) to form groups of days that had similar wind field patterns. This analysis used surface wind sites from the standard Clark County

DAQEM network plus additional sites operated in support of CCROPS. We only used sites that had a nearly complete data set for the period of May 15, 2005- August 31, 2005. Figure 3.1 indicates the sites that were used in the cluster analysis:

For each hour for each day winds at all sites used were decomposed into their U (west-east) and V (south-north) components. The clustering algorithm computed differences between each pair of days on an hour-by-hour, site-by site basis. A hierarchical method was used that shows the grouping of days and the difference levels where groups are joined. We selected a difference level that resulted in 14 groups. Many of these groups had only one day. On inspection it was noted that these single day groups typically had passage of some type of front or were affected by thunderstorm downdrafts that resulted in different diurnal patterns in winds from any other day (e.g. if one day had a cold front pass at 3 pm, it would not be grouped with a day that had a cold front pass at 9 am).

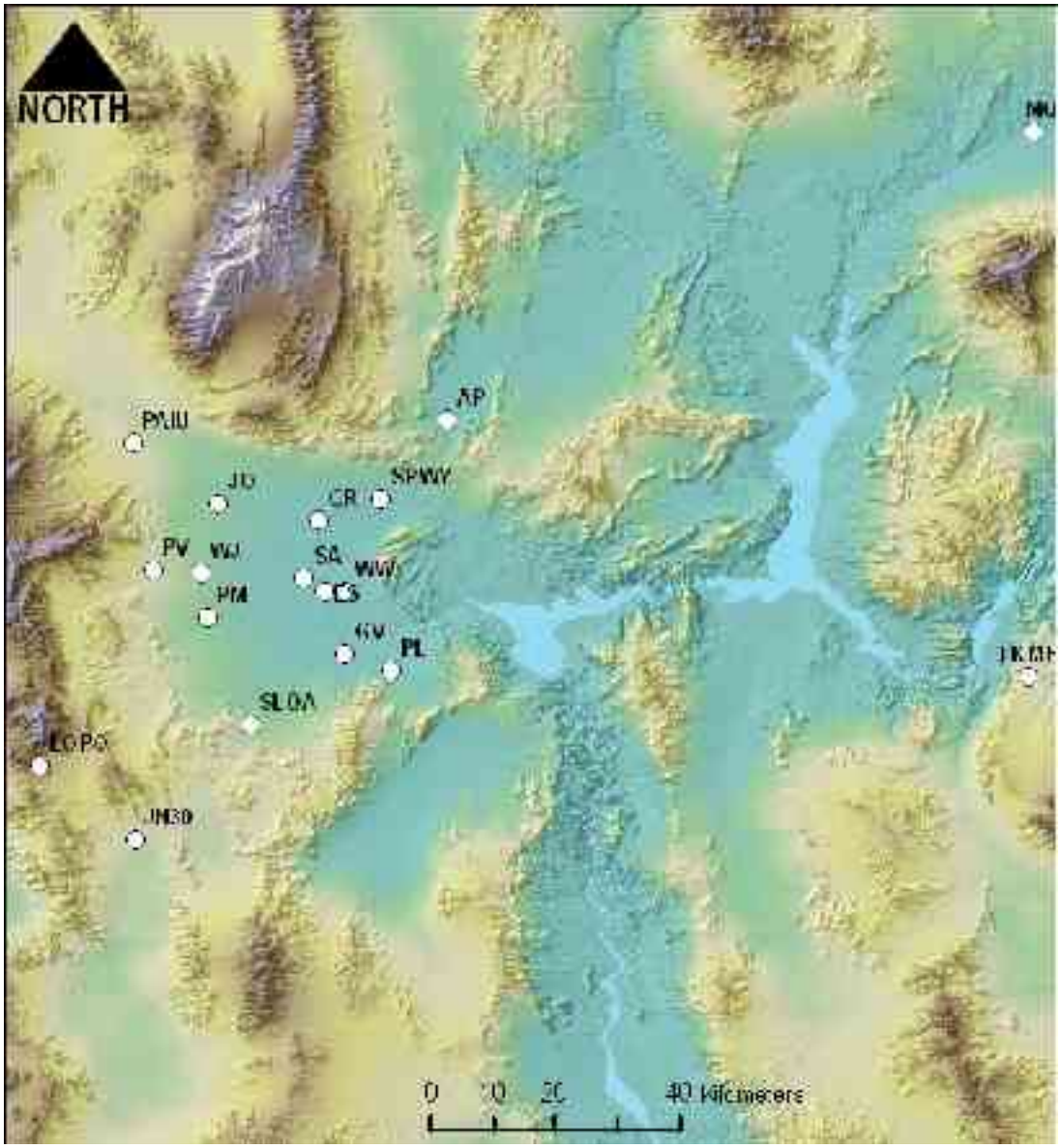


Figure 3.1 Sites used in the cluster analysis

There were 4 groups containing 5 or more days. We did detailed analysis of these groups. To further reduce the dimensionality of the data set, we formed groups of hours with similar spatial wind field patterns by clustering hours for each daily cluster. Average ozone concentrations were computed for each ozone monitoring site for each of these four clusters and for each diurnal period. Resultant winds were also computed for each wind site used in the cluster analysis for each diurnal time period and day cluster. The winds and ozone concentrations were then plotted on maps to aid the interpretation.

HYSPLIT (version 4.6) backtrajectories using the EDAS meteorological fields at 40-km resolution were computed and plotted for each cluster. Eight backtrajectories per day were computed and inspected with starting heights of 500, 1500, and 2500 meters. These starting heights were selected to characterize certain air mass pathways that might occur during various mixing heights. For example, during mid-day in the summer, atmospheric pollutants are typically well mixed through a deep layer several kilometers due to heating of the surface. Input files to run the model were generated using a Visual Basic code. The 500 m results are plotted and discussed in this report.

Frequency of wind directions as measured by the radar wind profiler at the North Las Vegas airport were computed for all day and for days within each cluster. We focused on winds at the higher levels (>1200 m AGL) to consider the effects of regional flows. Differences in frequency of each cluster from the summer mean frequency were tabulated and will be discussed.

3.2 Cluster Analysis Results

The grouping of days by the cluster analysis is summarized in Table 3.1.

Table 3.1 Percentage of days in each cluster, by month; total number of days per cluster

Dates	Strong SW flow (Cluster 1)	Light northerly flow (Cluster 6)	SJV+LV increment (Cluster 7)	Local terrain forced flow (Cluster 13)	others
May 15-31	29	6	6	47	12
June	43	3	0	37	17
July	13	6	35	35	3
Aug	16	3	13	55	13
Total days per cluster	27	5	16	47	14

We have named the 4 main cluster types based upon analyses shown later in this section. They are Strong southwesterly flow; light northly flow; San Joaquin Valley + Las Vegas increment; and local terrain forced.

Strong southwesterly was most frequent in early summer (May and June). Light northerly was relatively infrequent and occurred once or twice in each month. SJV + LV increment occurred mainly in July. Local terrain forced flow occurred frequently all months and had highest frequency in August.

3.2.1 Local Terrain Forced Flow Cluster

With over 40% of the days contained in this cluster, it may be considered as representing "typical" summer conditions. Four days from this cluster exceeded the NAAQS at DAQEM sites, although two of these (June 29 and June 30) were affected by fires. Figure 1 shows winds and average ozone concentrations for Local terrain forced flow from midnight to 6 am. Winds are light and generally downslope, indicating they result mainly from local terrain features with little regional to synoptic scale forcing. This lack of synoptic scale forcing is consistent with the peak frequency of Local terrain forced flow being during August. At all sites average ozone concentrations are <60 ppb. From 7-10 am (Figure 2) winds are light and typically upslope (from the east due to morning heating of the east facing slope of the western Las Vegas Valley and the Spring Mountains. Ozone concentrations average <60 ppb at all sites. For the 11 am to 6 pm period, winds become generally southeasterly (Figure 3), possibly due to the development of a valley wind circulation with winds becoming more aligned with the axis of the Las Vegas Valley, toward higher valley elevations. Average ozone concentrations are >60 ppb at nearly all sites, > 65 ppb at sites in the northwest Las Vegas Valley and > 70 ppb at the Paiute site. Elevated concentrations in the northwestern Las Vegas Valley are likely due to reaction of precursors from the Las Vegas urban area adding ozone to the background of about 60 ppb (value at Jean). At 7-11 pm (not shown), winds are similar to the midnight – 6 am period and ozone concentrations are <60 ppb at all sites.

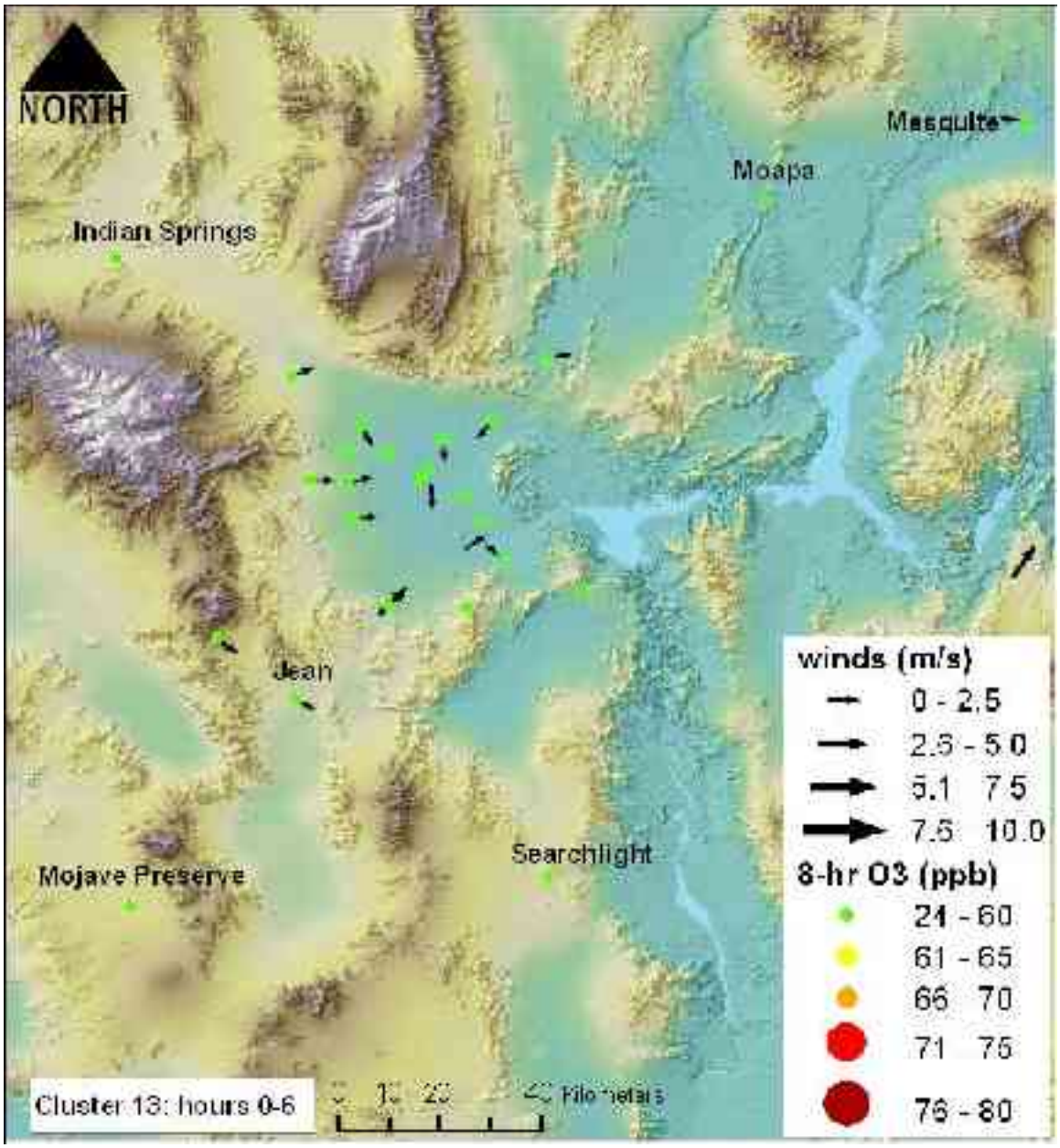


Figure 3.1 **Local Terrain Forced Flow cluster showing average winds and ozone for hours 0 to 6.**

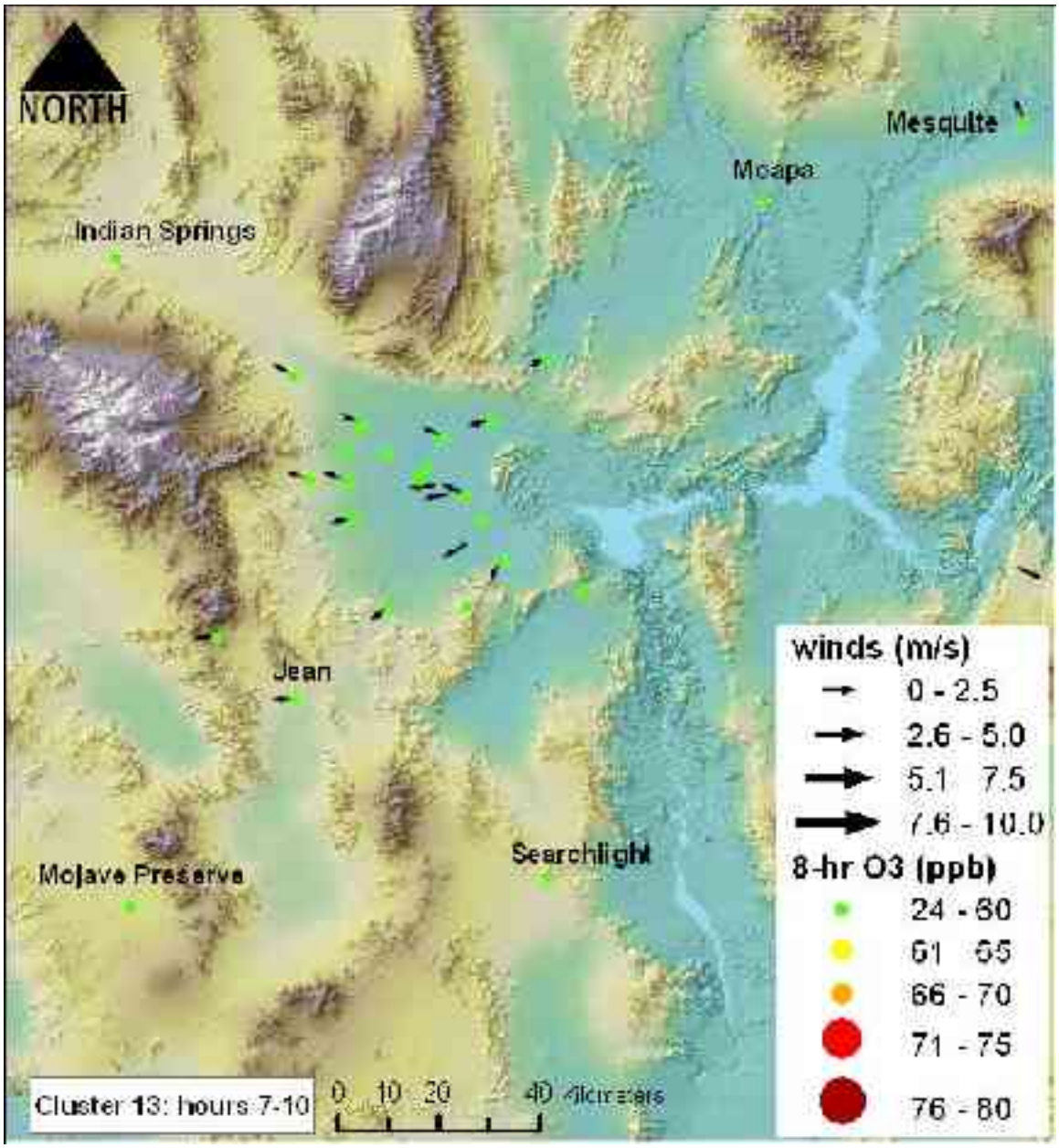


Figure 3.2 Local Terrain Forced Flow cluster showing average winds and ozone for hours 7am to 10am.

The frequency of higher level winds measured by the radar wind profiler (>1200 m AGL) from each one degree direction increment for all clusters is shown in Figure 4 (These levels are likely to be a good indicator of regional transport directions). Figure 4 shows that there is a pronounced peak in wind direction frequency from the SSW, peaking at about 202 degrees. Figure 5 shows the difference in wind direction frequency between Local terrain forced and all days. As the average of all days is strongly influenced by Local terrain forced, differences are small. We see a somewhat lower frequency of southwesterly winds and a slightly higher frequency of other directions. So the predominant SW flow during the whole summer is a little less dominant during local terrain forced days. HYSPLIT backtrajectories for all Local terrain forced days are shown

in Figure 6. As larger scale forcing is weak, we see a wide variety of flow directions, with flows from the south Coast Air Basin and from the Sea of Cortez common, as well as flows from the generally north direction. Transport from the San Joaquin Valley is not especially pronounced for Local terrain forced flow.

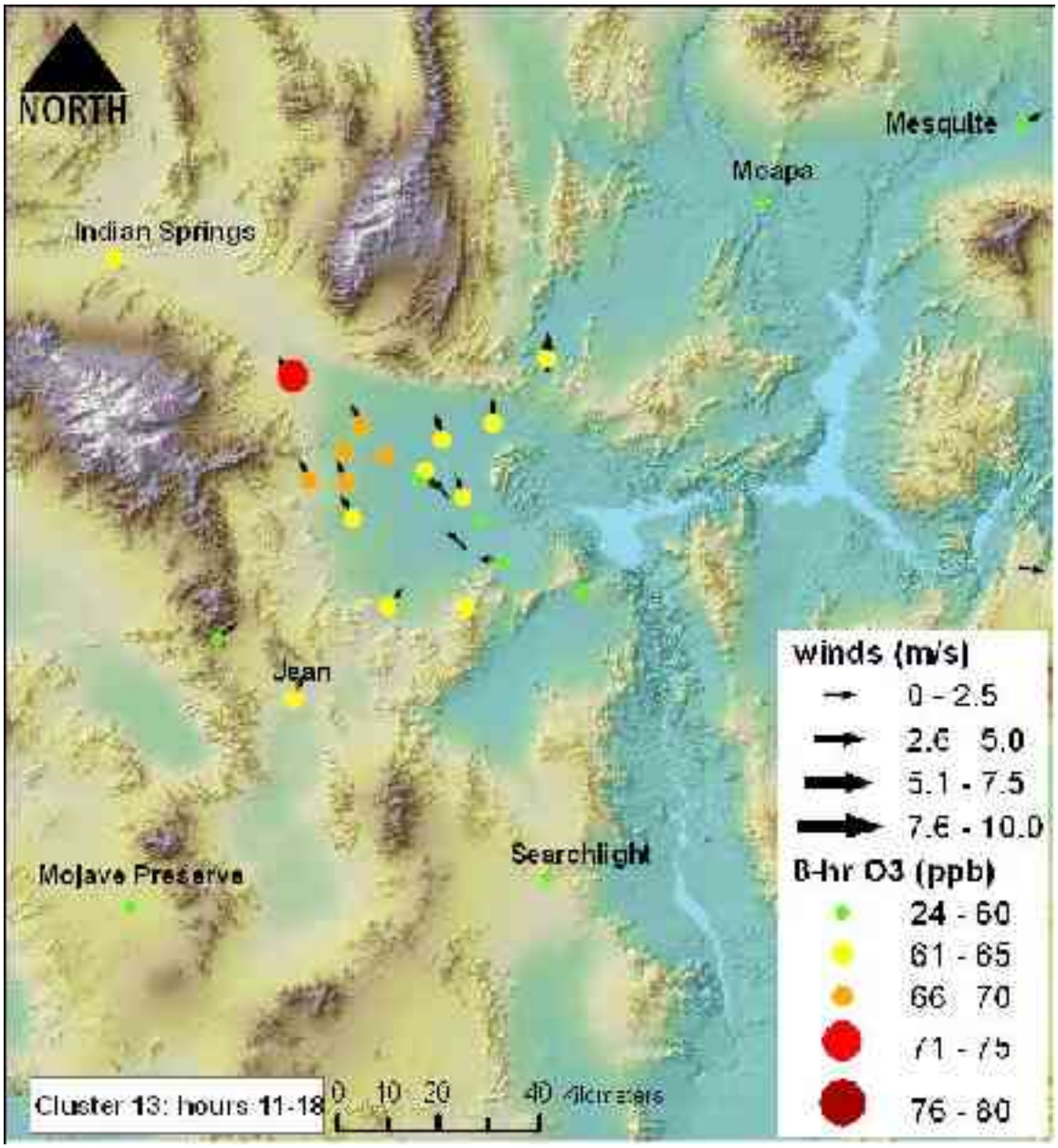


Figure 3.3 Local Terrain Forced Flow cluster showing average winds and ozone for hours 11am to 6pm.

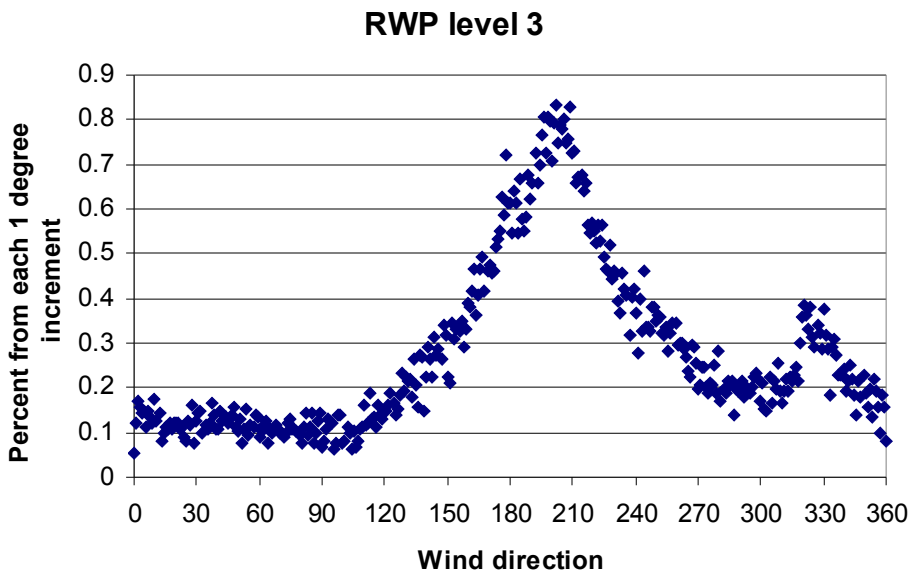


Figure 3.4.

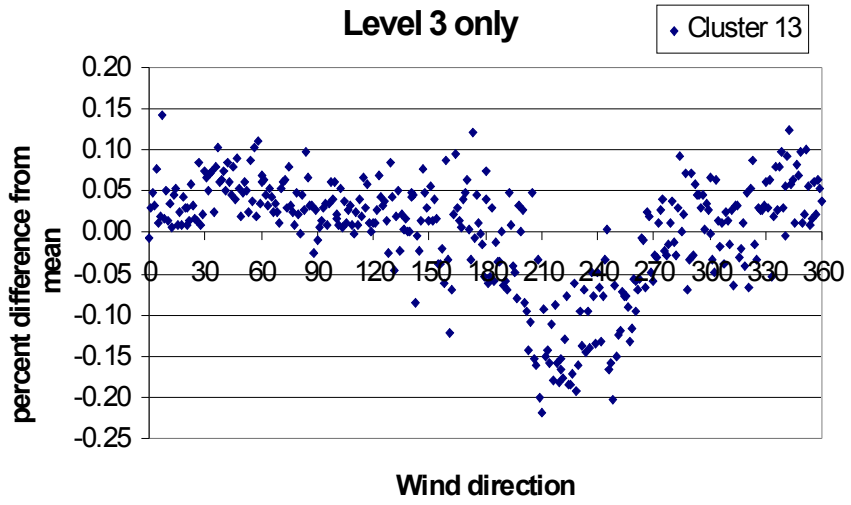


Figure 3.5.

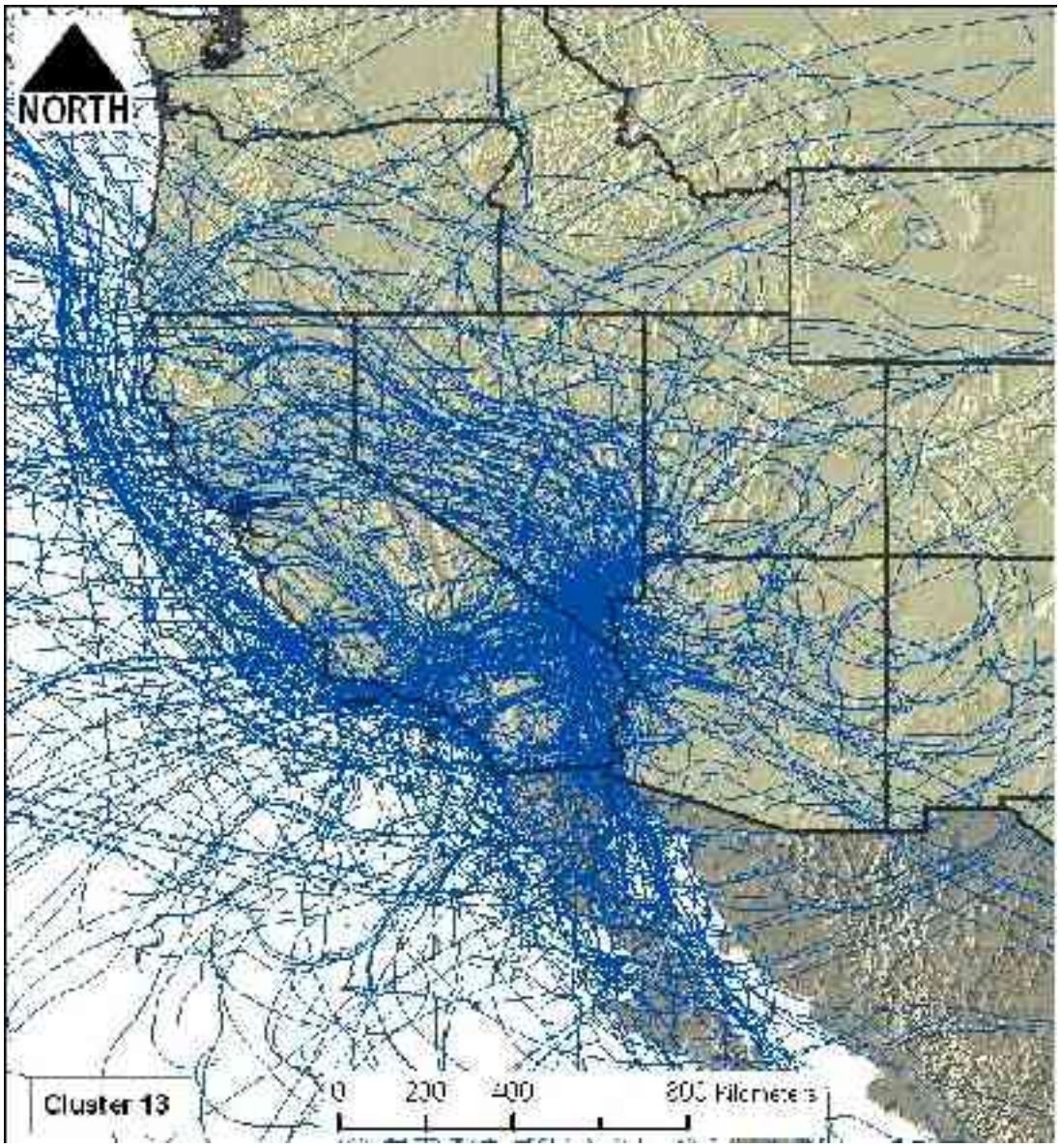


Figure 3.6 Backtrajectories during Local Terrain Forced Flow (cluster 13) conditions in the summer of 2005.

3.2.2SJV + LV Increment Cluster

SJV + LV increment had the highest average ozone concentrations at many sites. Three SJV + LV increment days (July 3, July 8, July 15) exceeded the NAAQS at DAQEM monitoring sites in northwest Las Vegas. SJV + LV increment had similar surface wind patterns to local terrain forced but typically had higher wind speeds and showed more westerly to southwesterly winds during night and morning hours at sites such as Jean, Sloane, and Lower Potosi. Background ozone concentrations at Jean, Lower Potosi, and Black Mountain were also higher compared to local terrain forced days providing a higher background to which the Las Vegas urban area effects are added. Surface winds and ozone concentration for the hours 11 pm to 6 am are shown in Figure 7. For the hours 10 am to 4 pm ozone concentrations increase dramatically in the northwestern Las Vegas Valley (Figure 8), with an average of 79 ppb at the Pauite site. Winds are from the southeast over much of the valley from the south at Apex and the SW at Jean. Average ozone at Jean for these hours was 70 ppb. The increment at Paiute due to the urban area thus appears to be about 9 ppb.

The radar wind profiler wind direction frequency plot (Figure 9) shows an enhanced frequency of flow from the WSW and less from the SSW compared to the summer average. HYSPLIT backtrajectories (Figure 10) indicate transport for most of the periods from the San Joaquin Valley. If correct, this suggests the San Joaquin Valley as the main source region for the high background ozone during SJV + LV increment days.

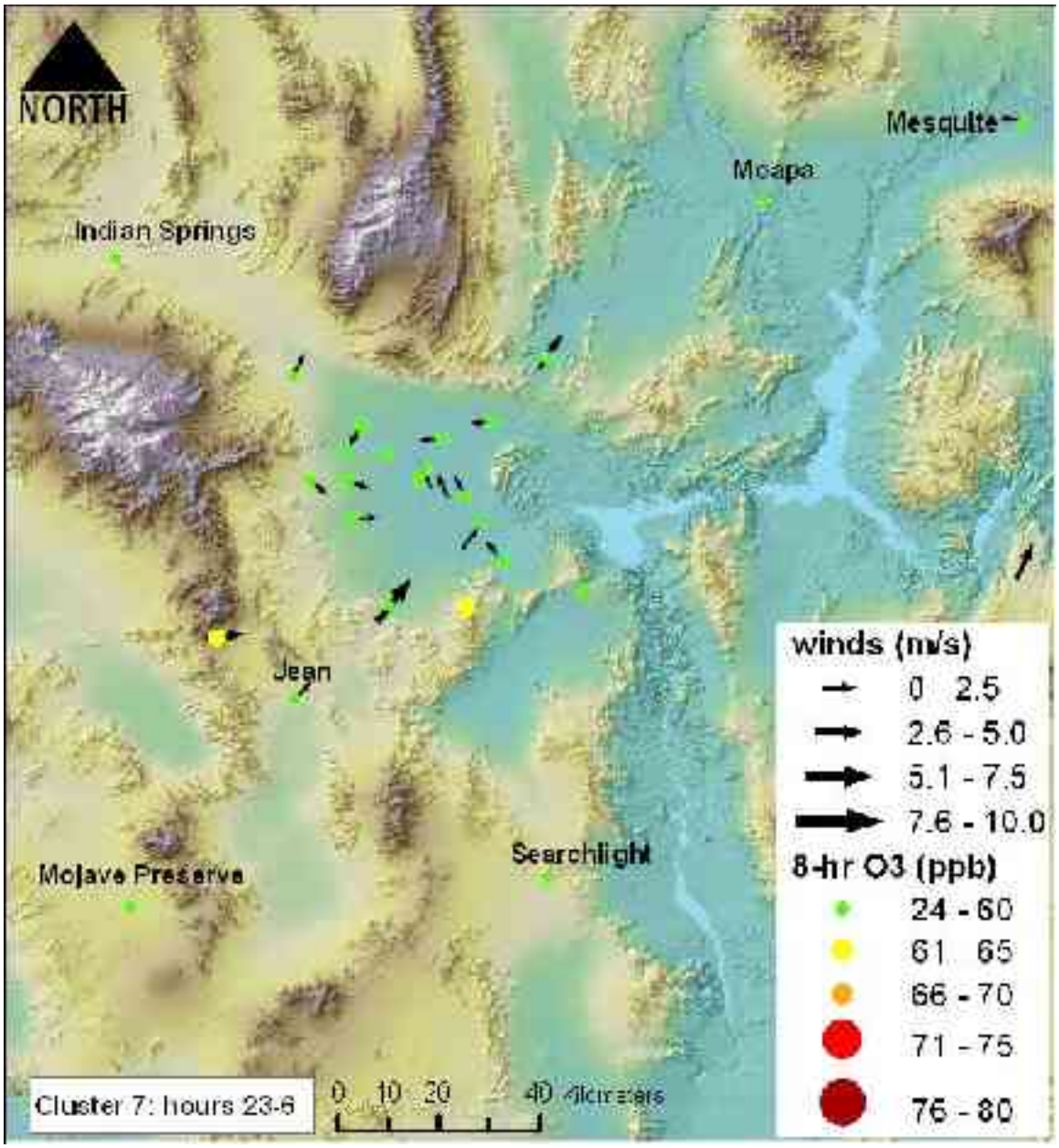


Figure 3.7 Averaged winds and 8-hour ozone for the SJV+LV Increment cluster (cluster 7) during the hours from 11 pm to 6 am.

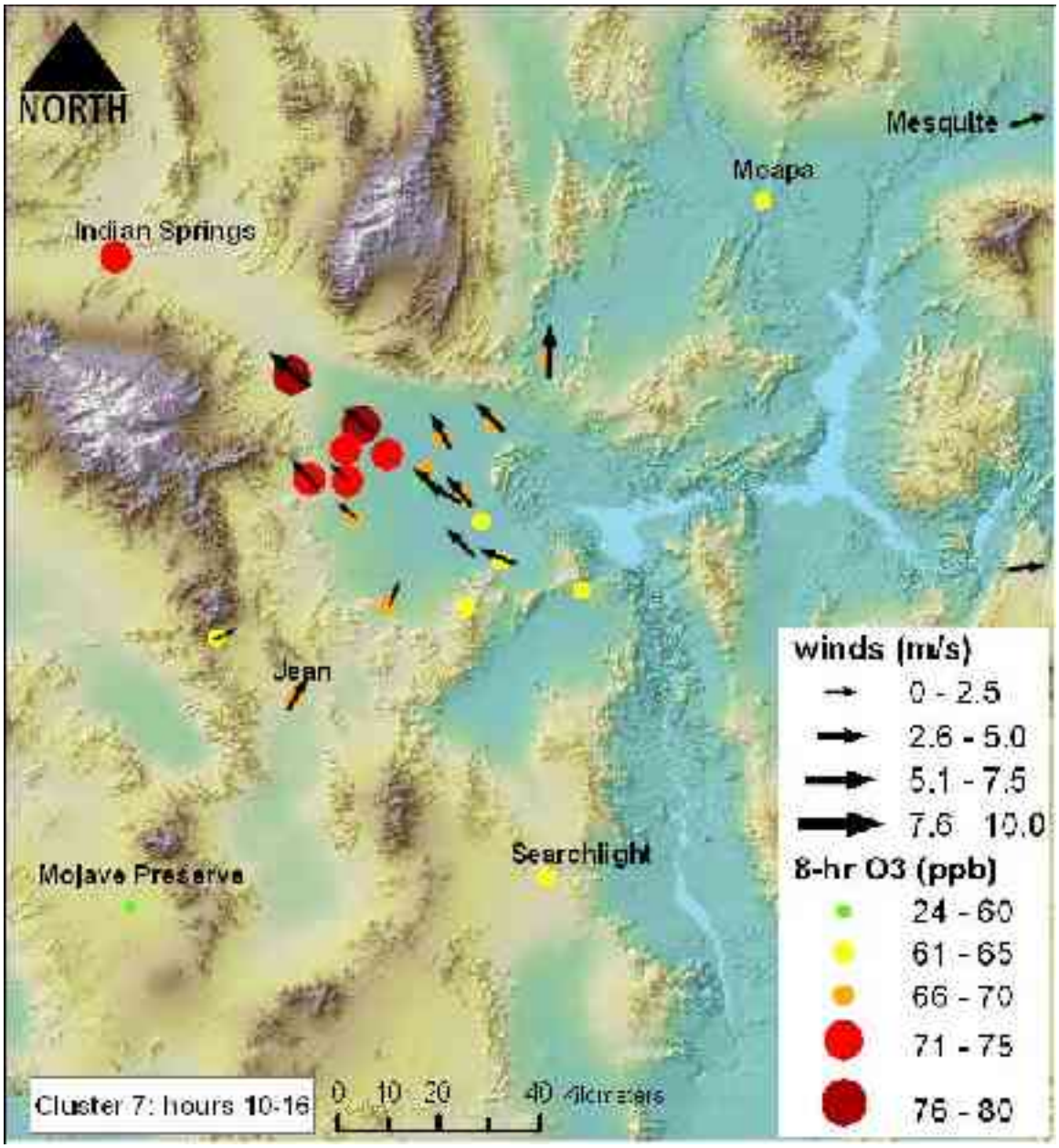


Figure 3.8 **Averaged winds and 8-hour ozone during the SJV+LV increment cluster (cluster 7) during the hours from 10 am to 4 pm**

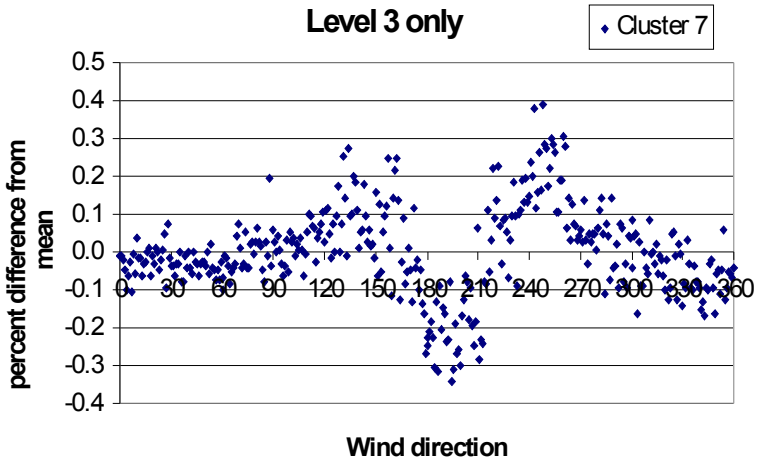

Level 3 only
Cluster 7
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
percent difference from mean
0
30
60
90
120
150
180
210
240
270
300
330
360
Wind direction

Figure 3.9.

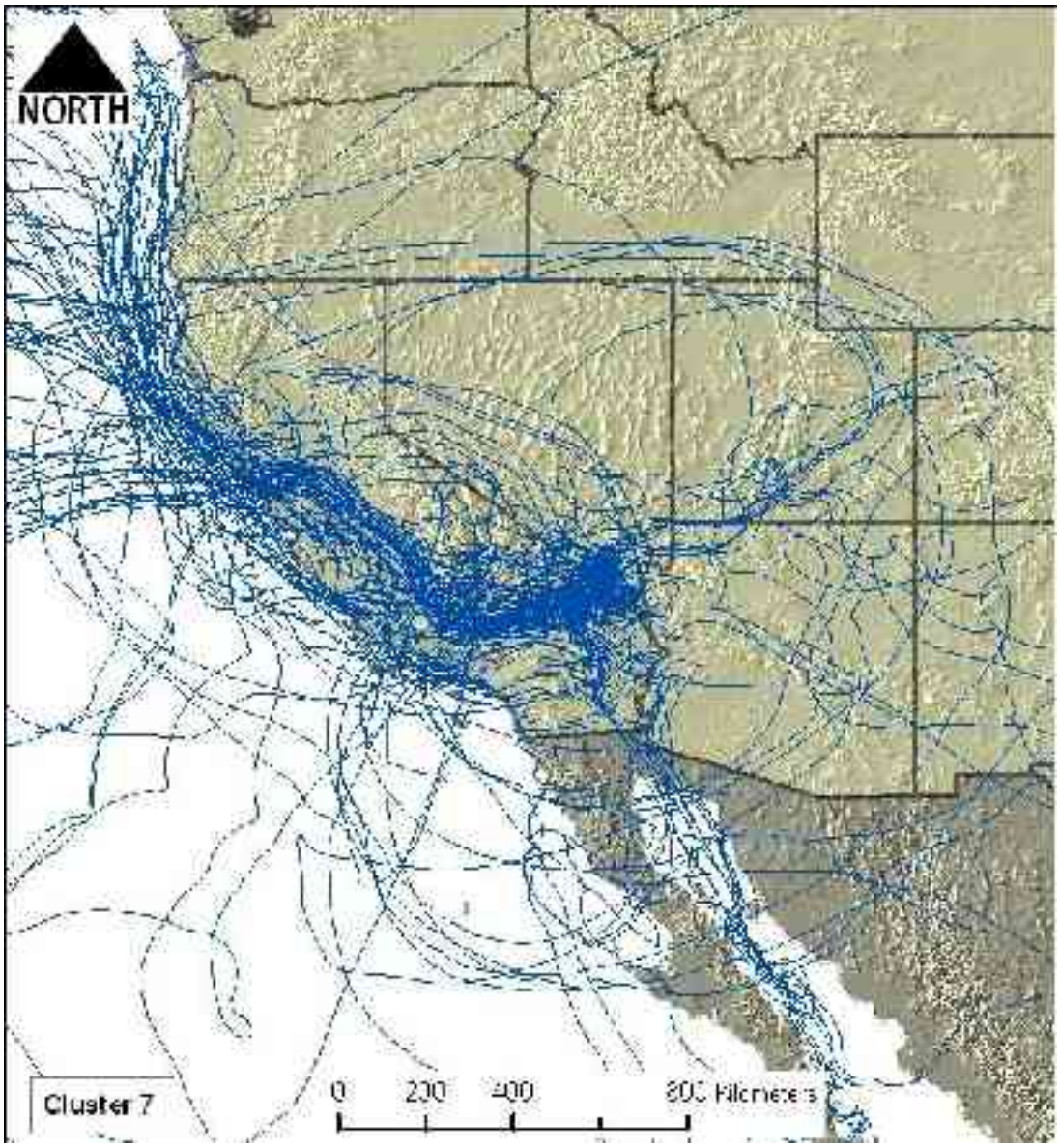


Figure 3.10 Backtrajectories that correspond to the SJV+LV increment cluster (cluster 7) during the summer of 2005.

3.2.3 Strong Southwesterly Flow Cluster

Strong southwesterly, the second most frequent cluster had generally more southerly and southwesterly winds compared to local terrain forced and SJV + LV increment. Southeasterly upslope flow from the Las Vegas urban area was much less for Strong southwesterly. Figures 11 and 12 show the flow wind and ozone patterns for 9 am until noon and 1 pm until 7 pm for strong southwesterly. By the afternoon, winds are from the southwest at all sites, overcoming local terrain forcing effects. The occurrence of strong southwesterly flow is most frequent in May and June when regional to synoptic scale forcing is more pronounced than in July and August. The highest average 8-hour

concentrations for this cluster were at Jean (65 ppb). One day from this cluster exceeded the NAAQS at a DAQEM site (Jean, July 2, 86 ppb). The radar wind profiler data showed an enhancement of flow from the southwest for strong southwesterly days compared to the summer average (Figure 13). Backtrajectories showed a large majority going over either the San Joaquin Valley or the South Coast Air Basin. The pathways show flow just offshore along the California Coast and either entering the San Joaquin Valley through the San Francisco Bay or moving inland in the Los Angeles Basin (Figure 14). These trajectories enter the Mohave Desert and then continue toward Las Vegas. Under these conditions the South Coast area and the San Joaquin Valley would contribute in a substantial way to background ozone concentrations in Clark County.

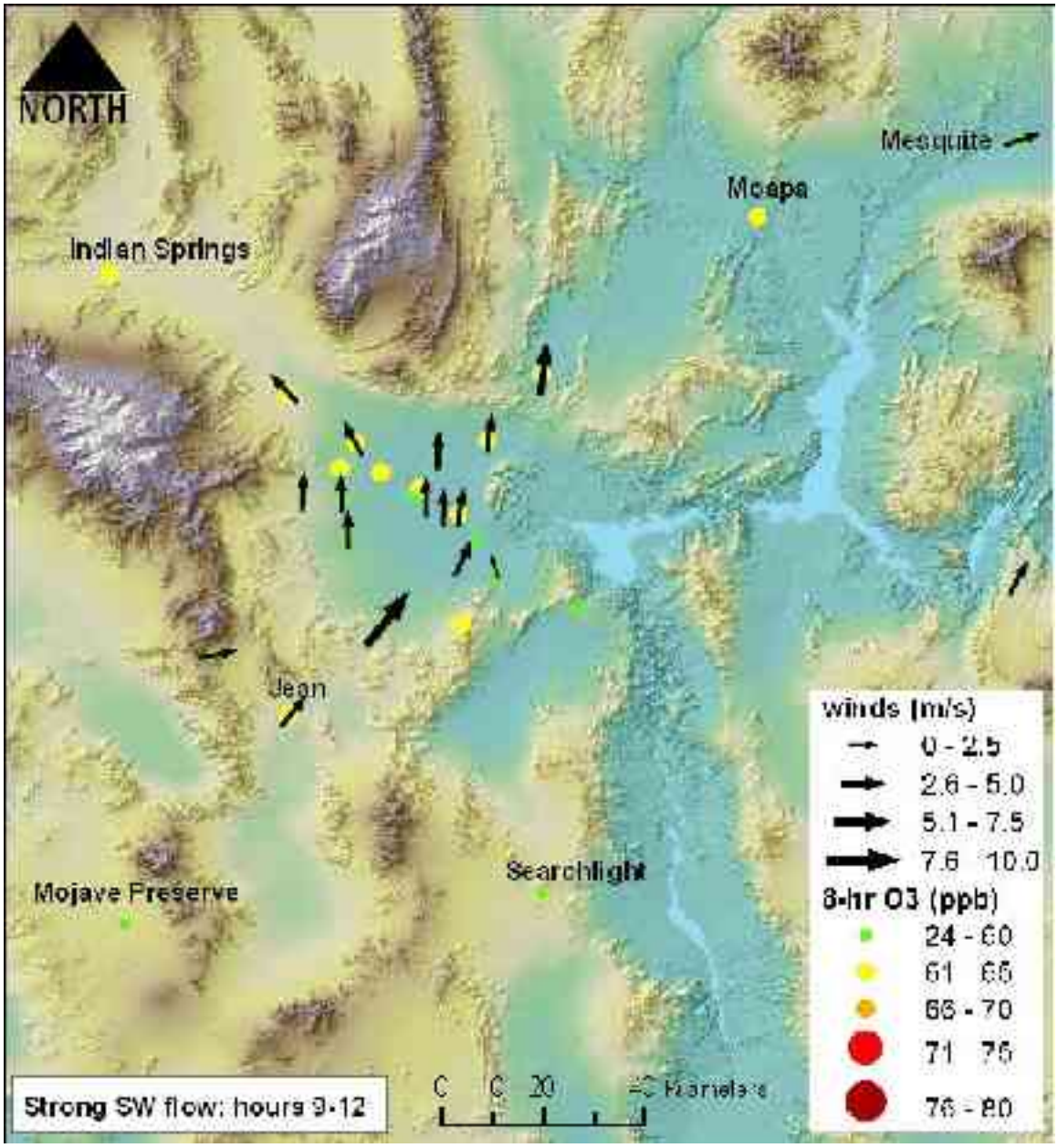


Figure 3.11 Average winds and 8-hour ozone corresponding to the Strong SW Flow cluster (cluster 1) during the hours from 9 am to noon.

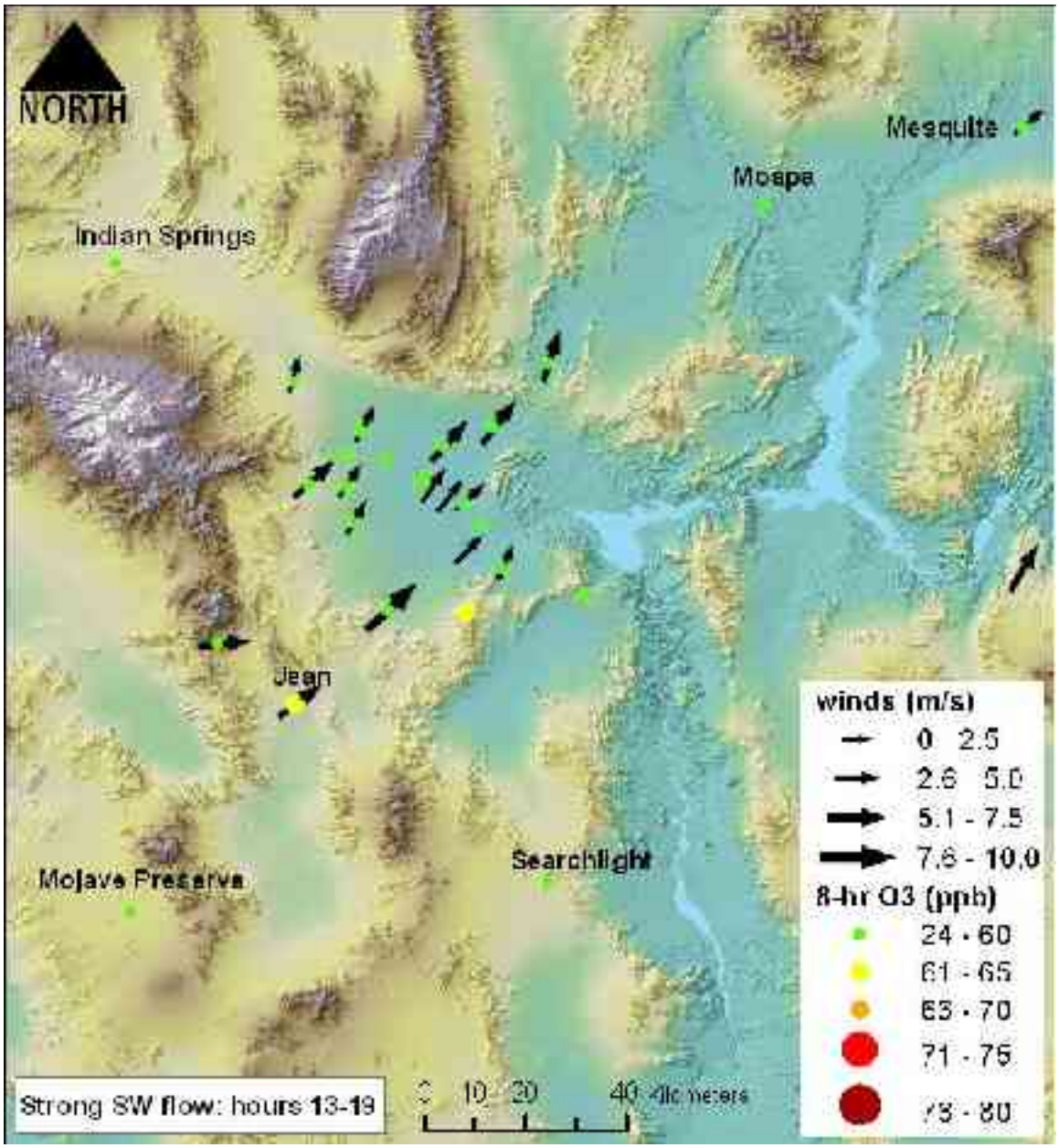


Figure 3.12 **Average winds and 8-hour ozone corresponding to the Strong SW Flow cluster (cluster 1) during the hours from 1 to 7 pm.**

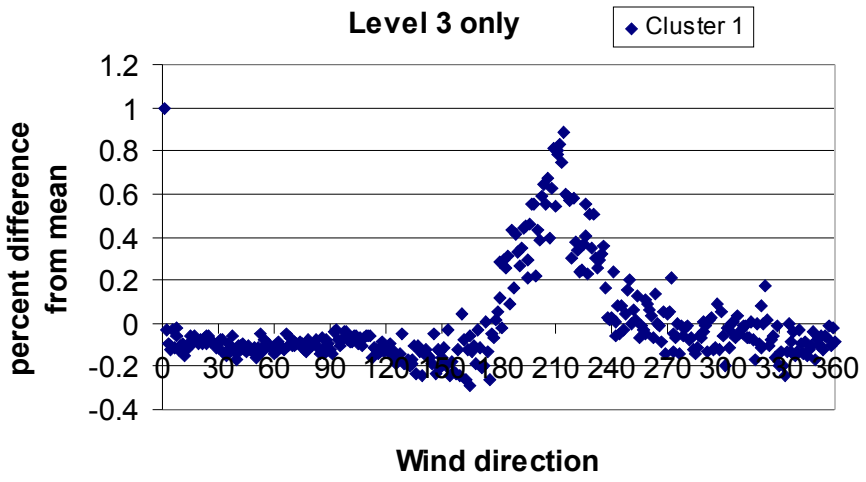

Level 3 only
Cluster 1
percent difference from mean
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
0
30
60
90
120
150
180
210
240
270
300
330
360
Wind direction

Figure 3.13.

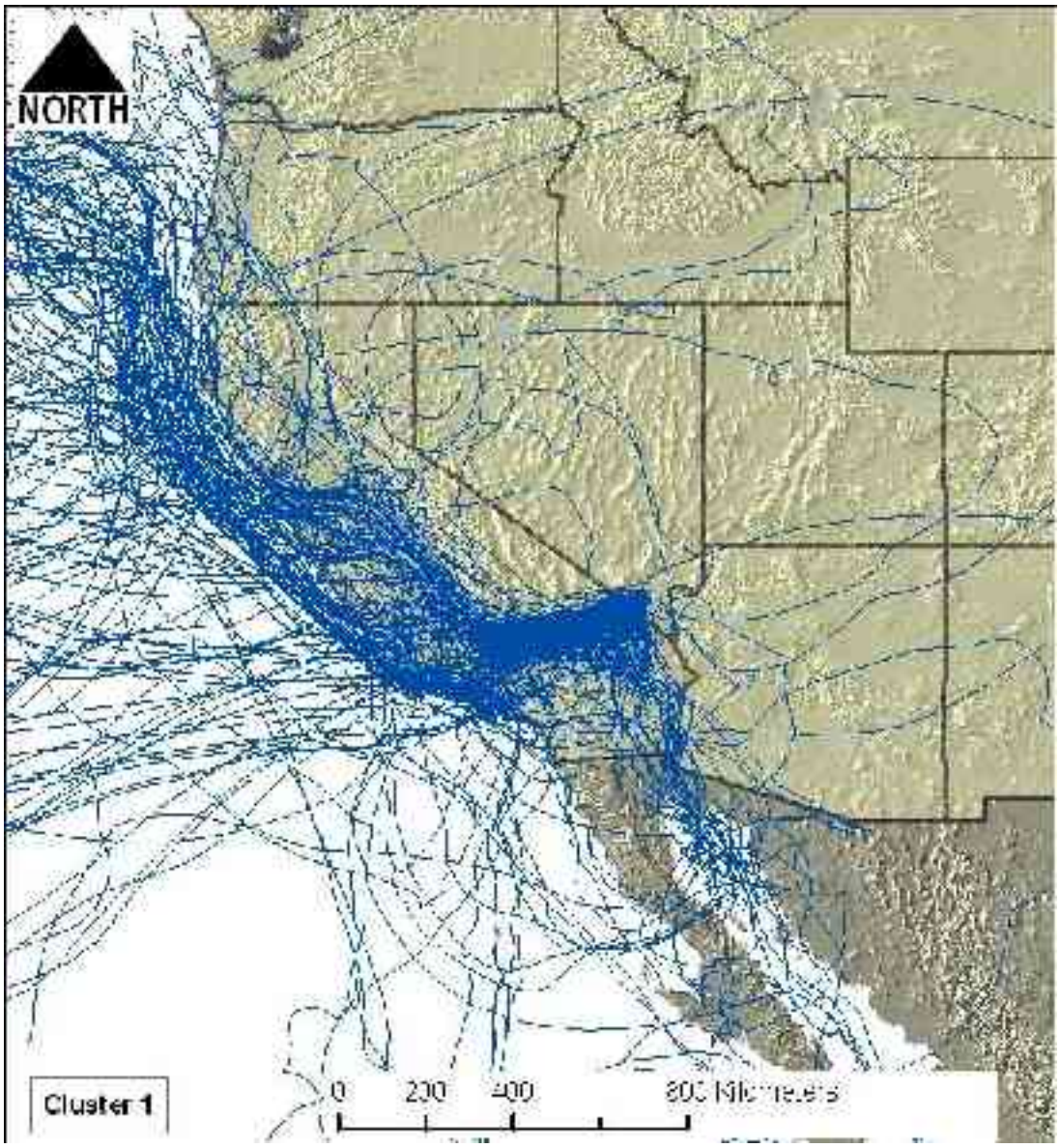


Figure 3.14 Backtrajectories that correspond to the Strong SW Flow cluster (cluster 1) during the summer of 2005.

3.2.4 Light Northerly Flow Cluster

Light northerly was characterized by generally northwesterly flow at the surface and aloft. During the afternoon, flow became more westerly to southwesterly except in the northwestern Las Vegas Valley where wind remained northwesterly. Winds and average ozone concentrations for hours 6-8 am, 9am – 1 pm, and 2-6 pm are shown in Figures 15-17. Figure 15 shows the difference in wind direction frequency for light northerly for >1200 m AGL from the wind profiler data. The data showed a much higher frequency from the NW and lower frequency from the SSW compared to the summer mean.

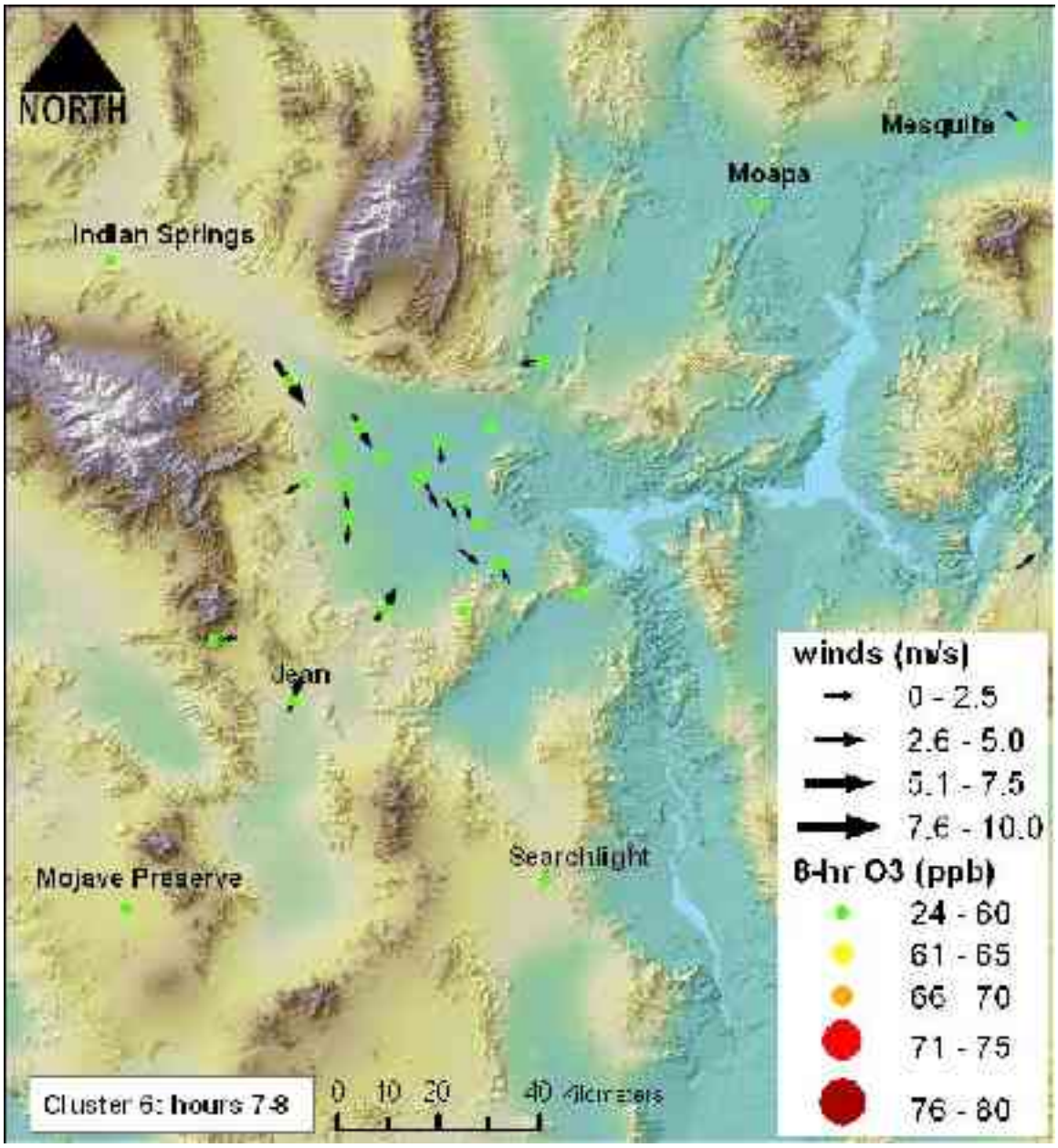


Figure 3.15 Average winds and 8-hour ozone corresponding to the Light Northerly Flow cluster (cluster 6) during the hours from 7 to 8 am.

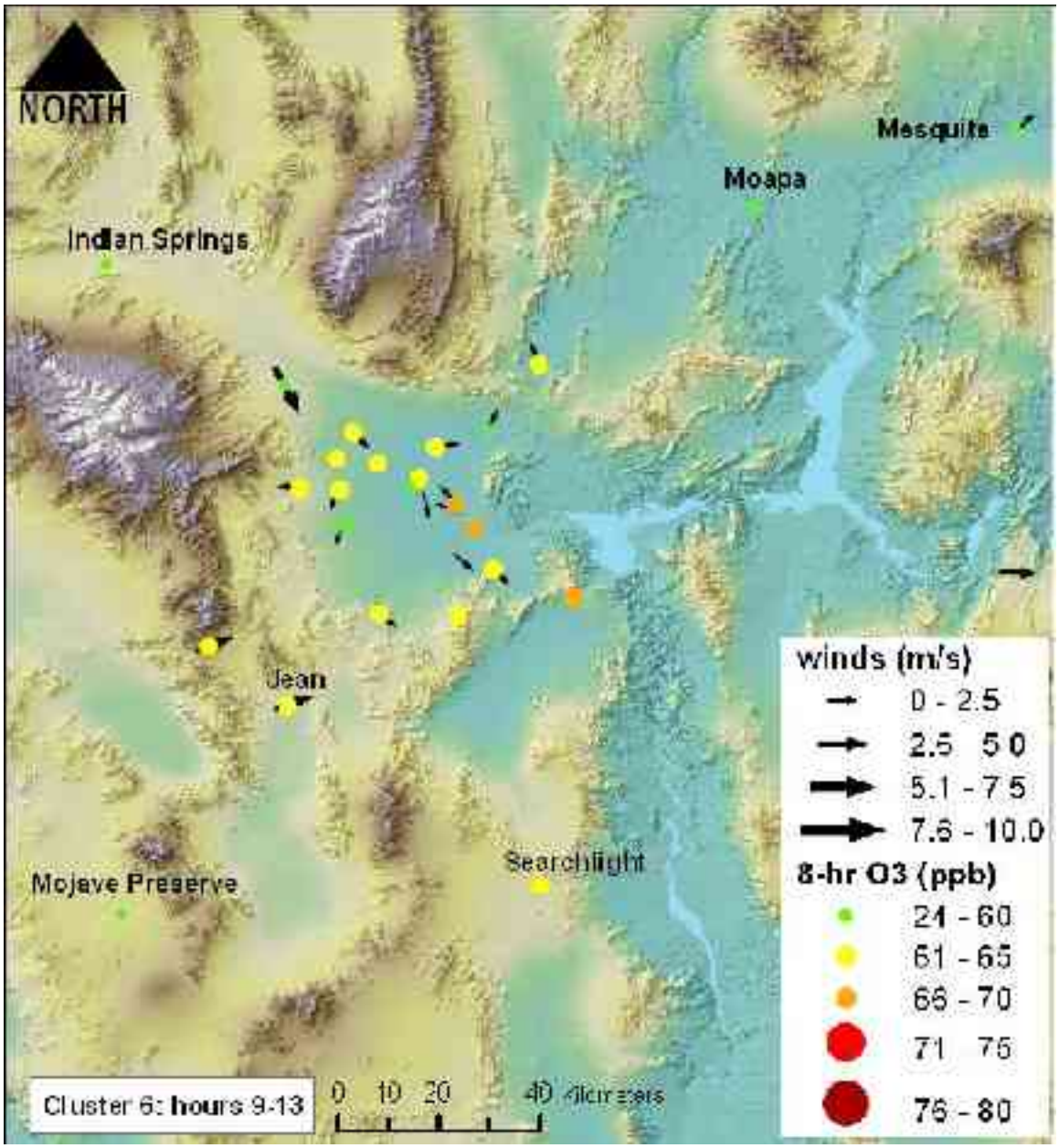


Figure 3.16 Average winds and 8-hour ozone corresponding to the Light Northerly Flow cluster (cluster 6) during the hours from 9 am to 1 pm.

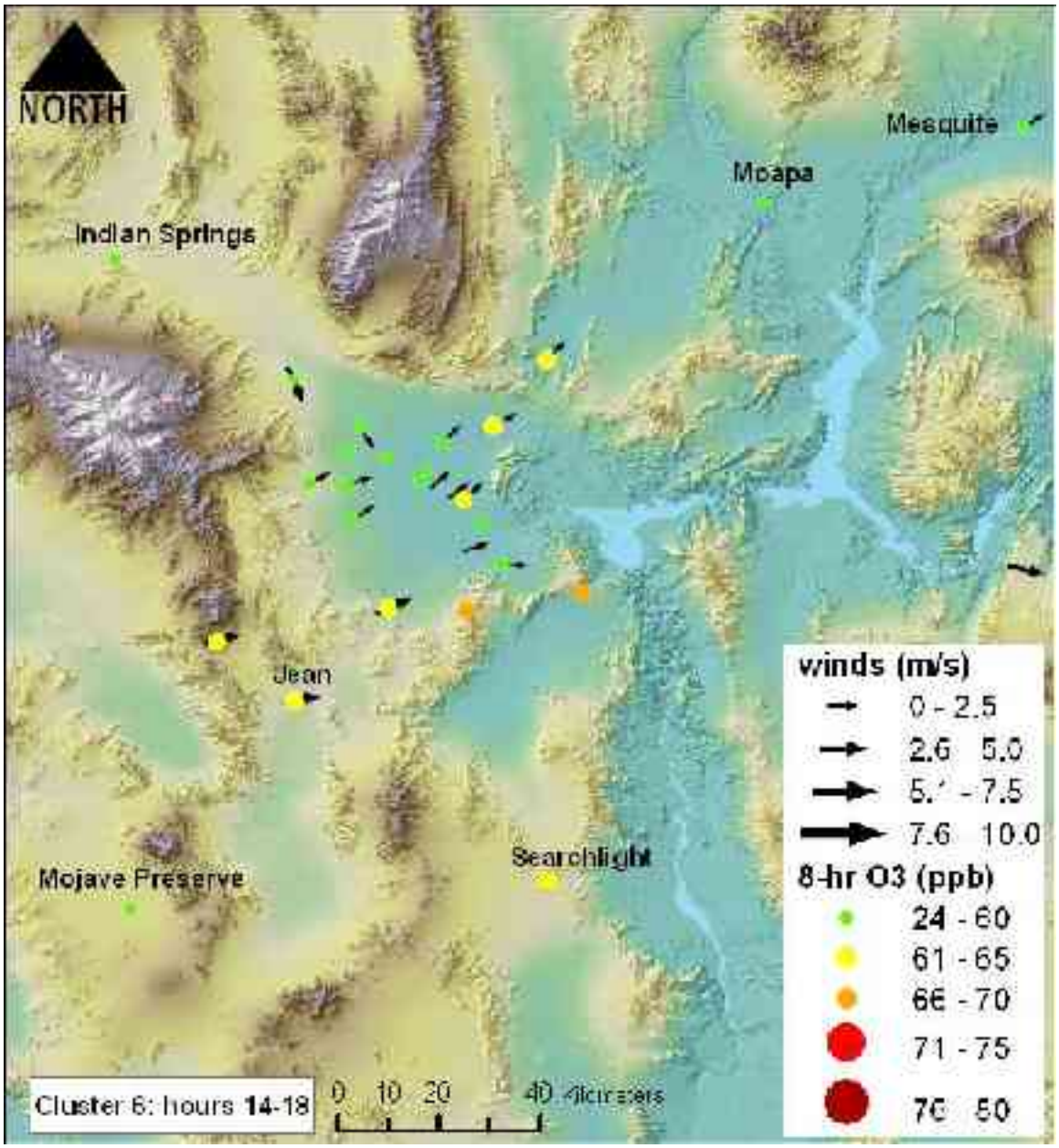


Figure 3.17 Average winds and 8-hour ozone during the Light Northerly Flow cluster for the hours 2 to 6 pm

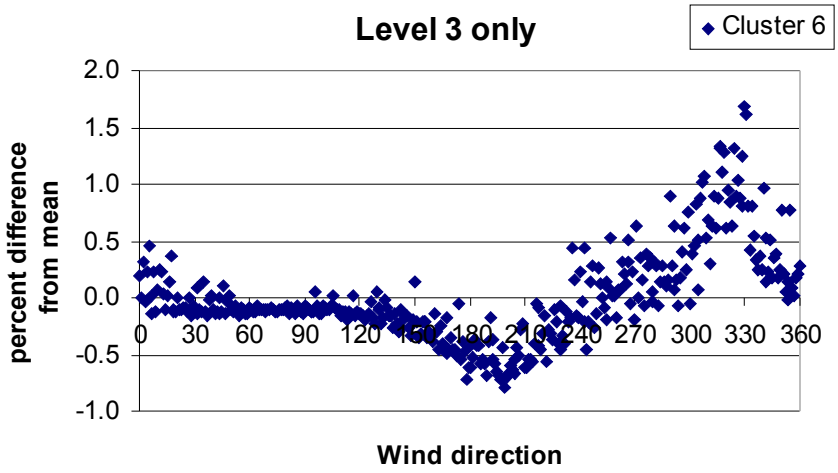


Figure 3.18.

3.3 Summary of transport patterns and their relationship to ozone patterns

A brief summary of the relationships uncovered between ozone and transport is given for each cluster.

Cluster 1- Strong Southwesterly Flow: regional to synoptic scale forcing- early summer. transport from San Joaquin Valley and South Coast Air Basin. Highest ozone concentrations at background sites (Jean and Black Mountain, average 8 hour maximums of 65 and 68 ppb, respectively). One exceedance day (at Jean).

Cluster 6- Light Northerly Flow: Highest concentrations at Boulder City. About 11 ppb increment from urban area, but no exceedances.

Cluster 7- San Joaquin Valley + Las Vegas increment: Transport aloft from San Joaquin Valley, low-level transport in urban area to northwestern Las Vegas Valley. Occurred mainly in July. Highest concentration pattern due to high background and 8 ppb urban increment, 3 exceedance days.

Cluster 13- Local Terrain Dominated Flow Weak synoptic forcing, low-level flow dominated by local terrain features. Regional transport from north, South Coast area, and the south; little apparent San Joaquin Valley transport. Highest concentrations in northwestern Las Vegas Valley. Four exceedance days, 2 of which are believed to be largely fire-related (June 29-30). About 9 ppb increment due to urban area.

In tabular format:

Cluster	Regional Winds	Surface Winds (midday)	Trajectory pathways	Ozone levels	Las Vegas ozone increment
Strong SW	SW	SW	SJV, South Coast	Highest at background sites – 1 exceedance	None apparent
Light N	N	N	N	Highest at Boulder City – No exceedances	11 ppb
SJV + LV	WSW	SE	SJV	Highest NW LV Valley – 3 exceedances	8 ppb
Local Terrain Forced	Varied	SE	Varied	Highest in NW LV Valley – 4 exceedances (2 fire days)	9ppb

4.Summary of Upper Air Data

The upper air data contains a large amount of information regarding how wind speed and direction vary with height and spatially. We have done some case study analysis of the upper air data to help understand certain time periods (e.g. those with high ozone concentrations). To more fully utilize the data, it is helpful to summarize the entire data set. This was done in part by compiling wind roses for various levels and time of day periods.

4.1 Cluster analysis to group heights and time periods with similar patterns

Because the radar wind profiler (RWP) data has far greater vertical extent than the SODARS, the wind profiler data was used most extensively. A statistical technique called "cluster analysis" was applied to the RWP data to form groups of heights with similar wind directions over each hour of the day. Hours of the day were also clustered to form groups of hours with similar vertical profiles of wind direction. Cluster analysis minimizes within group variance while maximizing between group variances. This method allows the analyst to greatly reduce the number of patterns to look at, while still maintaining information about all vertical levels and diurnal periods.

The cluster analysis formed the following clusters of heights for the RWP data:

Level 1: 176 m - 544 m AGL
Level-2: 590 m – 1047 m AGL
Level-3: 1183 m – 3711 m AGL

The following time periods were clustered:

2200-0300 hrs (10 pm- 3 am)
0400-0800 hrs (4am- 8am)
0900-1000 hrs (9-10 am)
1100-1400 hrs (11 am–2 pm)
1500-1800 hrs (3 pm- 6 pm)
1900-2100 hrs (7 pm-9pm)

This resulted in a total of 18 unique height/time period combinations. For each of these a wind rose was constructed to help visualize the characteristics by time/height. For the SODAR data at Jean, the Speedway, and Tule Springs, cluster analysis was used to form three height groups within the 40-300 m range that most frequently had valid data. For comparison purposes the same diurnal time periods were used to group the SODAR data as were used for the RWP data.

The appendix includes all 18 height/time period combination wind roses at each site. Here a few are shown to accompany the narrative of wind patterns.

4.1.1Radar wind profiler data summary

Not surprisingly, the highest level shows the least diurnal variation in wind direction. For all hours, winds at level 3 (1183-3711 m AGL) are predominantly from the south to southwest. Lower level winds are more variable, being significantly affected by upslope/downslope flows and mountain/valley circulations. Higher level winds will be closer to winds measured above the influence of local terrain.

4.1.2Summary of level 3 – (1183 to 3711 m) RWP data

In Figure 1 the level-3 RWP winds for 3 times of day- hrs 19-21, 22-3, and 11-14 are shown. At the 19-21 hr period, the upper winds show their greatest variability. Winds almost equally distributed in the directions S to WSW, with a smaller fraction from the northwest and few easterlies. In the overnight hours 22-03, winds become more southerly dominated, with somewhat more from the SE and SSE and fewer from the NW quadrant. This may represent more channeling by the north-south oriented mountain ranges at nighttime, with less downward mixing of southwesterly winds above the Spring Mountains. At 11-14 hrs the winds at level-3 have their least variation in direction and are mainly from the southwest. (The wind rose for hrs 15-18 is very similar).

4.1.3Summary of level-1 winds (178-544 m AGL)

Level 1 winds are the most likely to be similar to surface layer winds and driven largely by local terrain features. Because the wind roses look noticeably different for all time

periods at level-1 (178m- 544m AGL), we plot (see Figure 2) and discuss all of them below. The 22-03 hr period has the greatest variation in wind direction. Predominant directions are from the southwest, followed by the northwest and northeast. Currently, we can only speculate as to the reason for the wind direction distribution. Northwesterly winds are presumably due to drainage flow from the northwestern Las Vegas Valley (along US95). The northeasterlies are less obvious. They may be due to drainage flow from the Las Vegas Range and/or other ranges near the northeastern Las Vegas Valley. The southwesterlies are likely the continuation of earlier evening southwesterlies driven mostly by the regional winds. At 04-08 hrs, the southwesterlies essentially disappear and NNW and ENE are the most frequent directions. From 09-10 hrs and 11-14 hrs the winds are almost totally from the east to southeast and have virtually no westerly component. These are presumably upslope flows due to morning heating of the southeast facing slopes of the Spring Mountains. There is a rotation from 09-10 hrs to 11-14 hrs with winds shifting in a clockwise manner from the east to the southeast. From 15-18 hrs the winds have a broad distribution from the southeast through southwest. Finally by 19-21 hrs winds become dominated by westerlies, with a peak frequency from the WSW. It is worth noting that winds with a northerly component are frequent during nighttime (22-03 and 04-08), they are almost non-existent for RWP level-1 from 11-21 hrs.

4.1.4Summary of level-2 winds (590-1047 m AGL)

Level-2 winds (590-1047 m AGL) not surprisingly show characteristics intermediate between level-1 and level-3, but are more similar to level-1 winds. They are not shown separately here, but appear in the Appendix and are shown in some examples comparing winds at the three levels in the subsection below.

5.References

Baxter, R.A. (2002) Innovative procedures for the performance auditing of radar wind and RASS profilers. Sixth Symposium on Integrated Observing Systems, 16 January 2002 at the 2002 Annual Meeting of the American Meteorological Society.

Watson, J.G., B.J. Turpin, and J.C. Chow, (2001). The Measurement Process: Precision, Accuracy, and Validity, Chapter 10 in Air Sampling Instruments for Evaluation of Atmospheric Contaminants, 9th Ed. ACHIH.

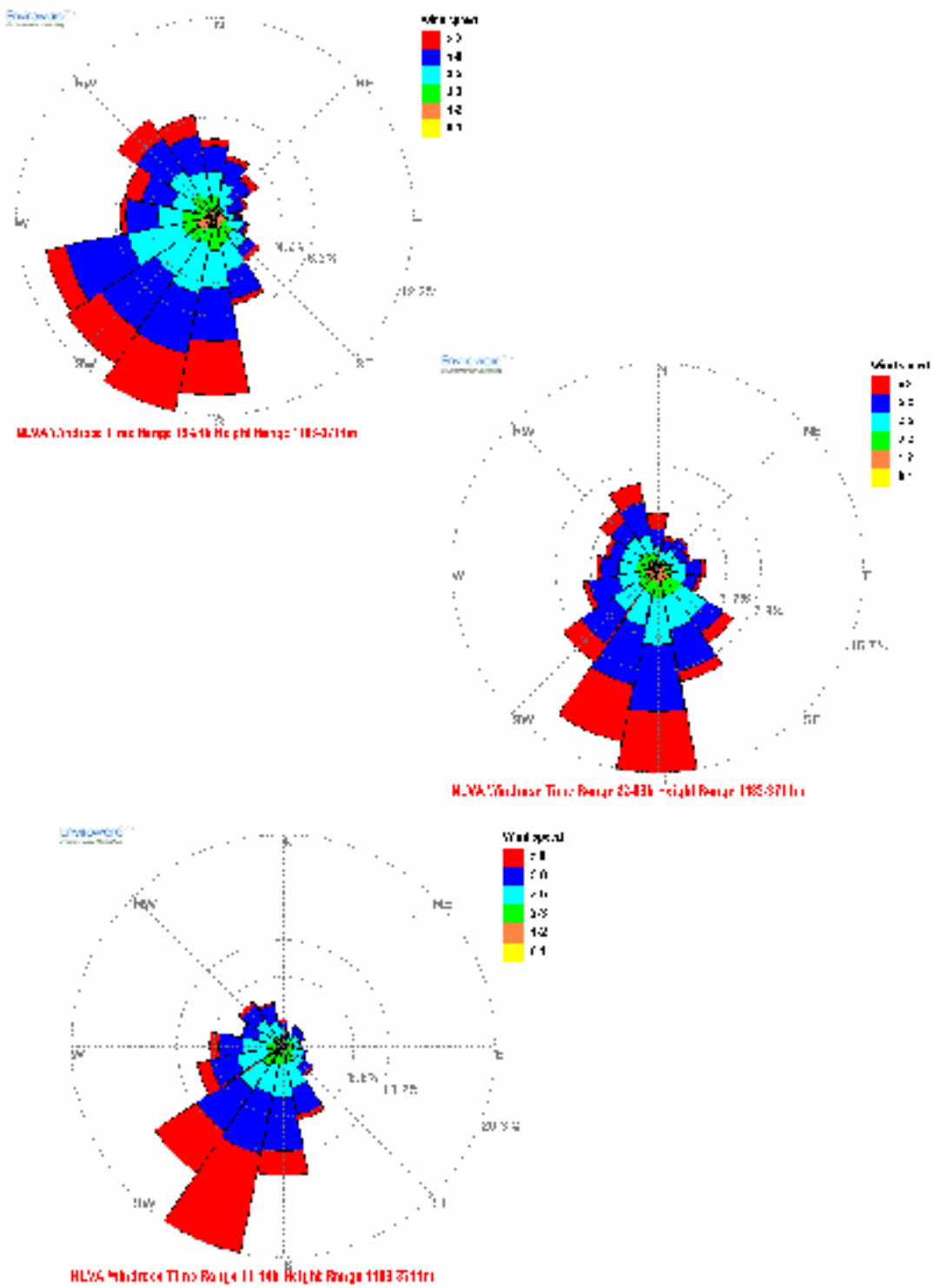


Figure 1. Level-3 wind roses for hours 19-21, 22-03, and 11-14. for the Radar wind profiler at the North Las Vegas Airport.

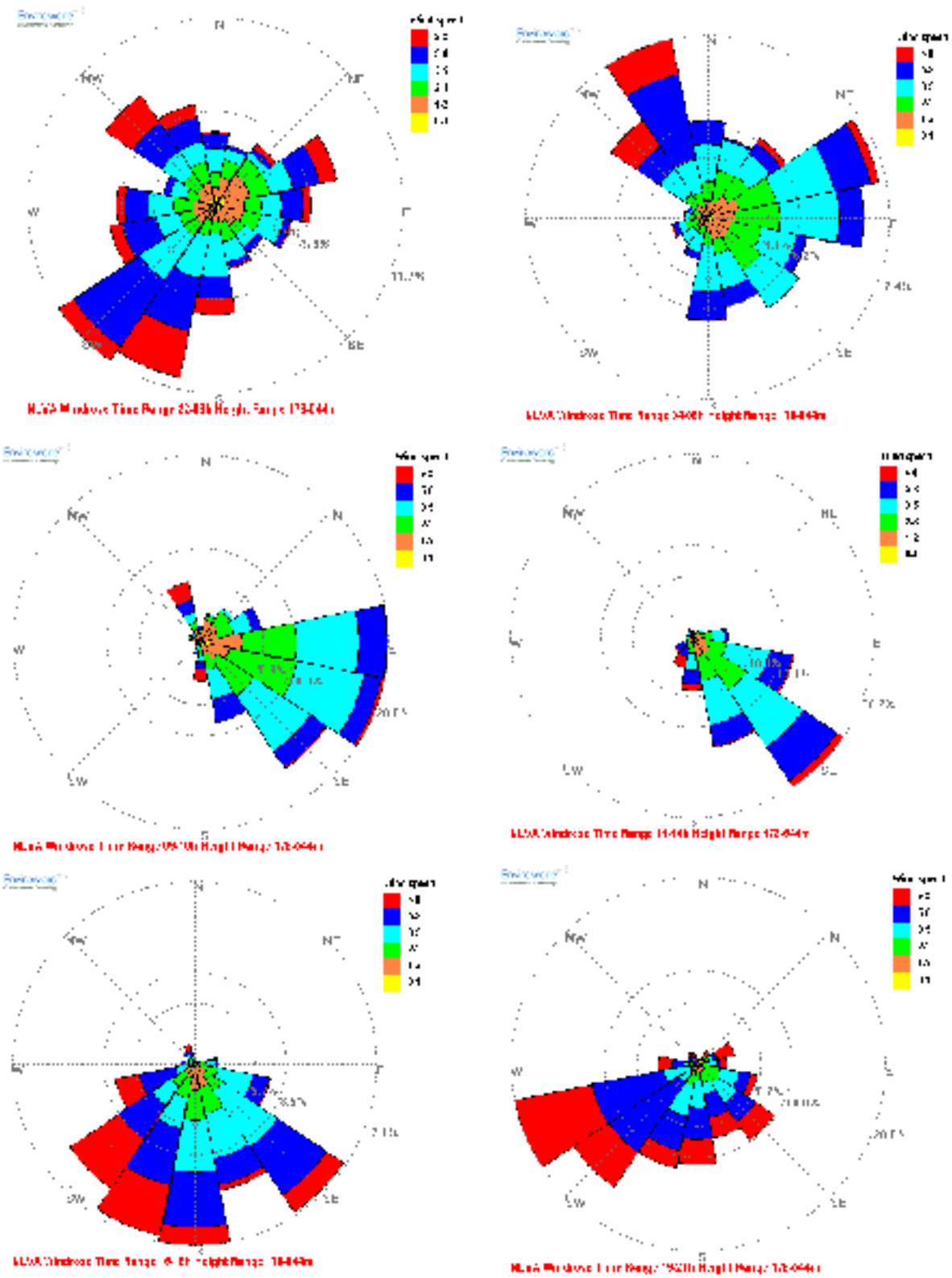


Figure 2. Level -1 winds (177-544 m AGL) by time of day for the Radar wind profiler at the North Las Vegas Airport.

Comparison of lower and higher level winds by time of day

During nighttime and morning we see more difference between lower layer and higher layer winds (vertical wind shear). This is expected as lower layers are less coupled to upper layers and more likely to represent local upslope/downslope flows than regional flows.

At hours 04-08 (Figure 3) we see the peak frequencies from the NW and NE at level-1and few SW winds; at level-2 we also see the NW & NE peak but see a significant fraction from the SW; at level-3 we see winds dominated from the south.

At hours 9-10 (Figure 3) we see upslope flows from the E and ESE at level-1, with a clockwise shift toward SSE at level 2 and continuing shift to SSW at level 3. Wind speed increase with height as well.

By hours 15-18, (Figure 4), winds at all levels (especially 1 and 2) continue their clockwise rotation. They become broadly southerly at levels 1 and 2 and mostly southwesterly at level-3. There is virtually no frequency of wind with a northerly component at levels 1 and 2.

At hours 19-21 (Figure 4) for levels 1 and 2 are from the SE through WSW, with a peak frequency of WSW at level 1 and SW at level 2. At level-3 we see a greater fraction of winds with a northerly component (mainly NW) than at levels 1 and 2

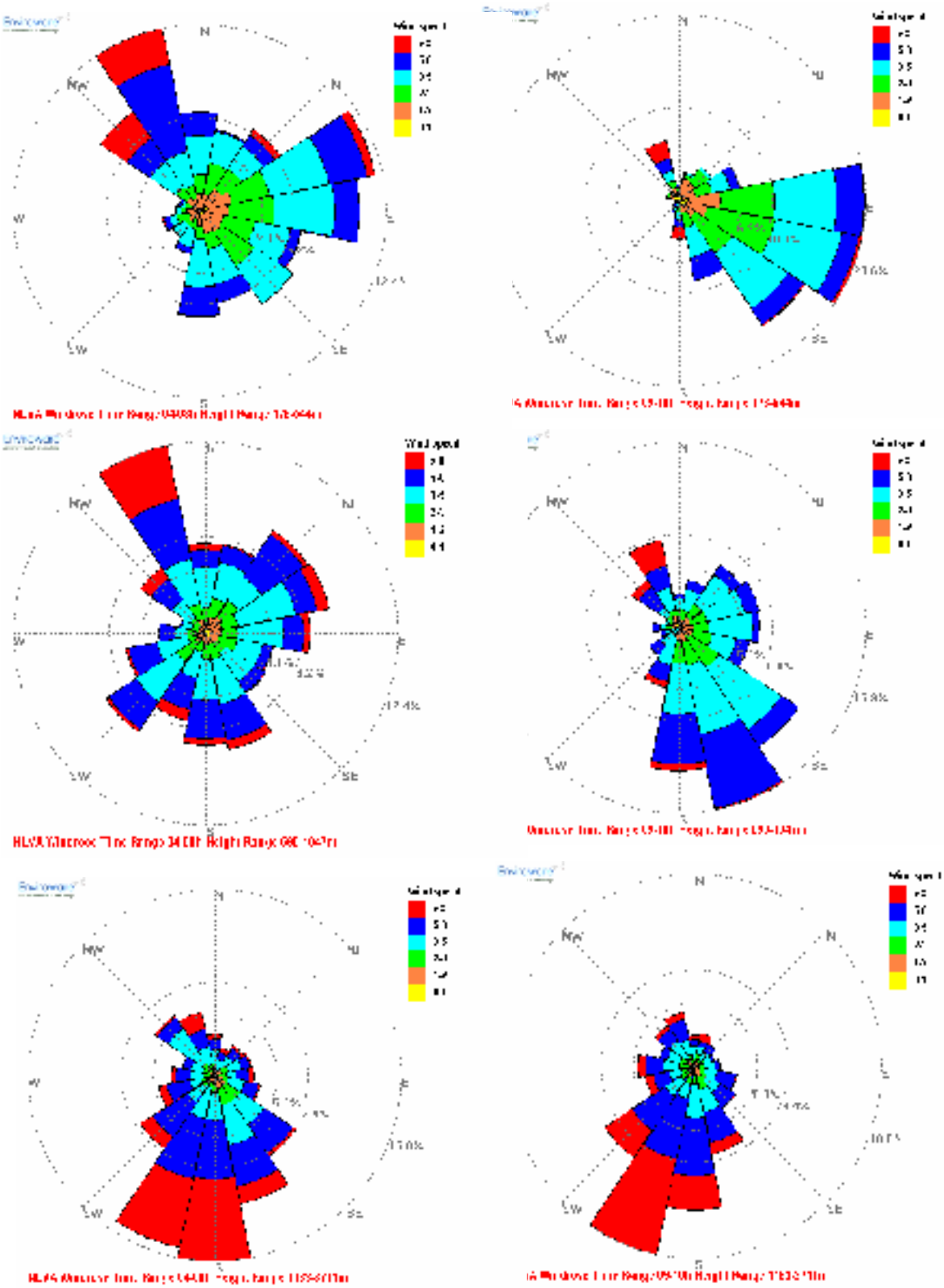
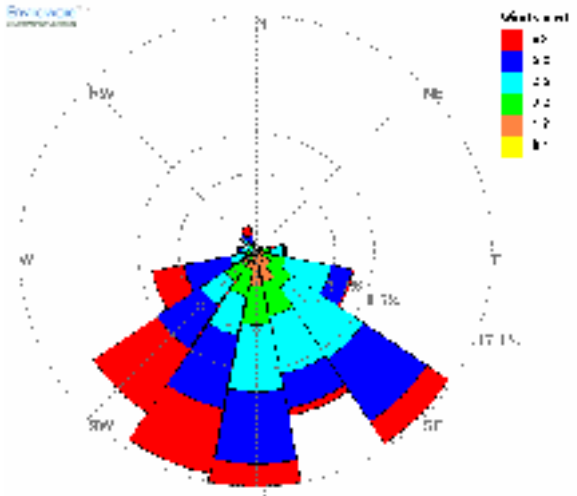
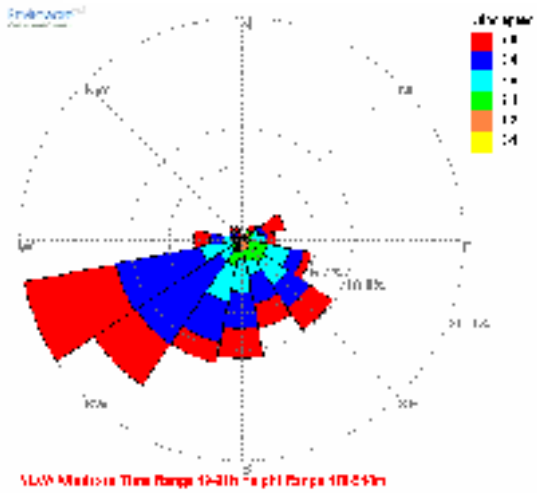
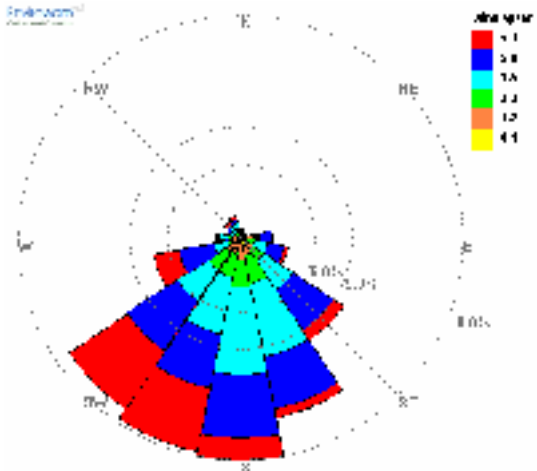
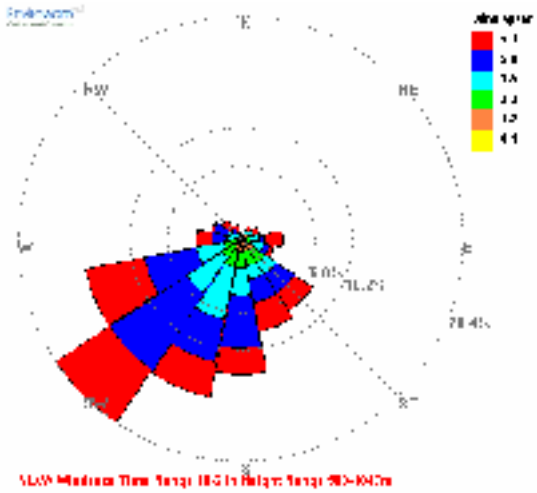


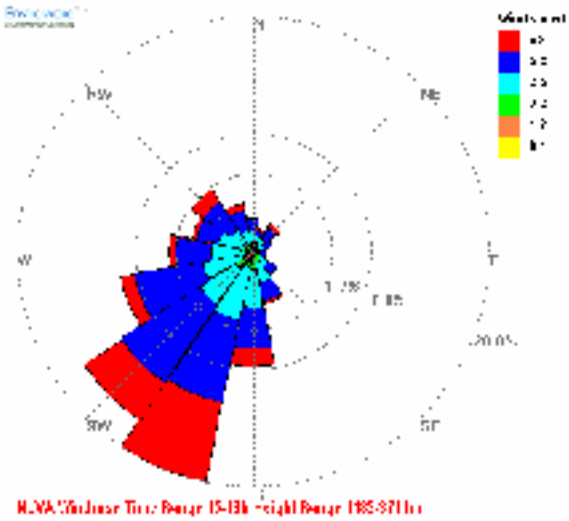
Figure 3. Vertical profile of RWP winds at North Las Vegas airport for hours 04-08 and 09-10.

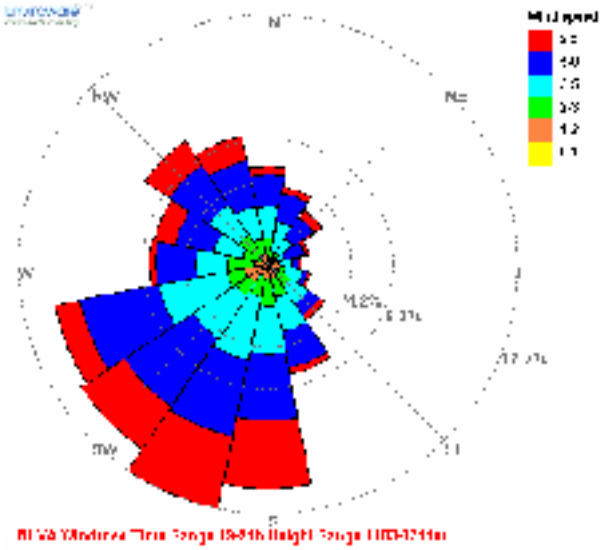












SODAR data summary

Jean

At Jean, the SODAR data clustered into the following heights:
40-80 m AGL
100-180 m AGL
200-300 m AGL

The Jean SODAR data showed that winds at all levels were nearly always from the generally southwest direction. Wind roses for each of the 3 levels at hours 04-08 and 19-21are shown in Figure 5. Differences in wind with height were minor in direction, but become consistently stronger with height. At 200-300 m the winds were nearly always greater than 8 m/s. At the 2 lower layers, wind direction frequency peaks from the SSW at all hours except 15-21 where it is slightly higher from the SW. At the highest level (200-300 m), wind direction frequency is highest from the southwest for all hours with a peak frequency from this one 22.5 degree sector of 61% at hours 19-21. At all hours the higher level has less variation in wind direction than the lower 2 levels.

We see a slight clockwise rotation in wind direction at all three levels as the day progresses.

Tule Springs

The most frequent wind direction at Tule Spring at nighttime and early is from the northwest, with a secondary maximum from the northeast (Figure 6). The northwest flow is expected to be drainage flow from the Spring Mountians. At hours 09-10 flow from the E to ESE is dominant (Figure 6), consistent with upslope flow caused by heating of the east facing slopes of the Spring Mountains.

At hours 15-18 there is substantial vertical shear in the wind direction with a clockwise rotation in direction with height (Figure 7). For this time period, winds are mainly from the SE at 40-80 m, S at100-180 m, and W to NW at 200-300 m.

Las Vegas Motor Speedway

At the Speedway SODAR site, except for hours 22-3, winds at all levels for all time are dominated by E or ESE directions. For the hour 22-3 time period, wind directions are more variable and show a clockwise rotation with height (Figure 8). At hours 9-10 the range of wind directions is narrowest, reaching 61% frequency from the ESE at the 220-300 m level. There is a substantial increase in wind speed with height for the 9-10 am period with most of the winds at 200-300 m being above 8 m/s, and nearly noneat the 40-80 m level being > 8m/s (Figure 8).

Conclusions regarding radar wind profiler and SODAR data

During the periods most important for generation of ozone and transport of ozone and precursors, wind at all the sites measured except Jean show predominant flow from the southeast. At Jean flow is from the southwest all hours. The exception is winds higher level winds from the radar wind profiler which are mainly from the SSW. By late afternoon, wind become more variable in direction at all sites except Jean. All sites except Tule Springs show significant vertical shear in wind speed. The radar wind profiler, covering a much deeper depth than the SODARS also show substantial changes in wind direction frequencies with a clockwise rotation with height (e.g. from SE to SW).

During midday when ozone concentration are likely to be highest, low level transport is mainly upslope (from SE in northern Las Vegas Valley) and more south-southwesterly aloft. This allows for transport of ozone from southern California at higher levels and from the Las Vegas Valley at lower levels, with significant mixing expected due to the deep mixing depths for these hours. Overall, the winds show some complicated patterns that may be important in transport of ozone and precursors.

We see significant shear in wind speed direction with height at all sites. The directional shear is greatest at night while the speed shear is present both day and night.

Regarding the boundary layer growth, we see that late in the afternoon to early evening directional shears are less with height. The lower level winds come more into alignment with the upper level winds implying mixing from the increased boundary layer depth.

We have not see an indication of a nocturnal jet although we saw significant increases in wind speed with height even in the first 300 meters or so with SODAR data.

Spatial variation is also discussed- Jean always showed southwesterly winds a all levels. The sites in the northern valley (NLV Airport, Tule Spring, and Speedway) showed mostly southeasterly flow at low levels during peak ozone hours and the wind profiler showed southwesterly flow aloft.

Recommendations for additional study

Additional upper level wind measurements should be made to better characterize winds in the Las Vegas Valley during the ozone season. Because the low level winds are mainly from the SE in the northern Las Vegas Valley and from the SW at Jean, additional SODAR measurements should be made. Possible areas are in the southeastern Valley (Henderson) as no upper air data is available there and they is a rapidly growth in population and vehicle miles traveled as well as having some industrial sources. Another area to consider is the western valley. The radar wind profiler should be continued to be operated. It is currently at DRI a good a good mid-urban area site. Funding should be made available to continue its operation.

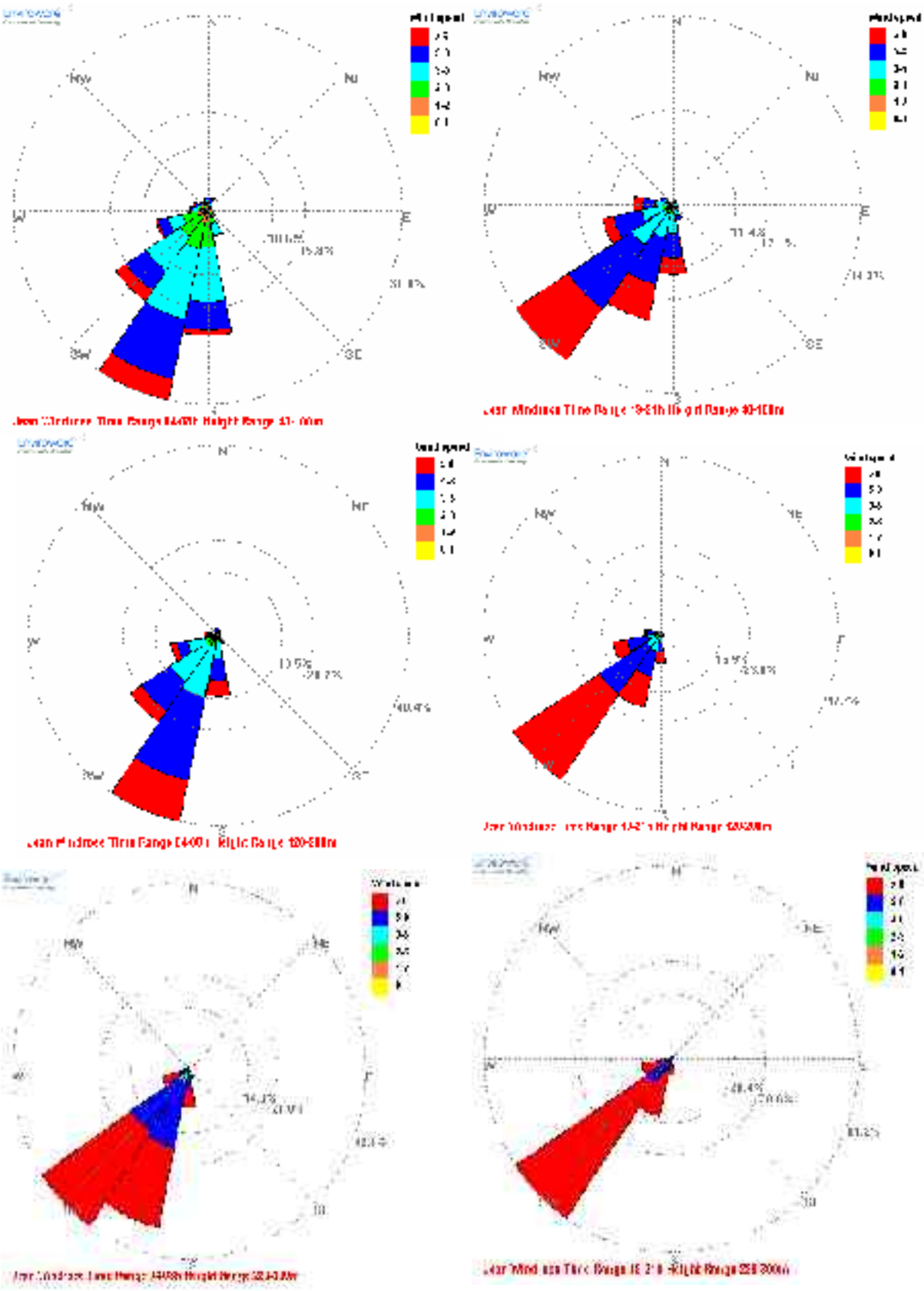


Figure 5. Vertical profile of winds for Jean SODAR site hours 04-08 and 19-21.

Figure 6 . Wind roses for 40-80 m, 100-180 m, and 200-300 m AGL at Tule Springs for hours 04-08 and 09-10.

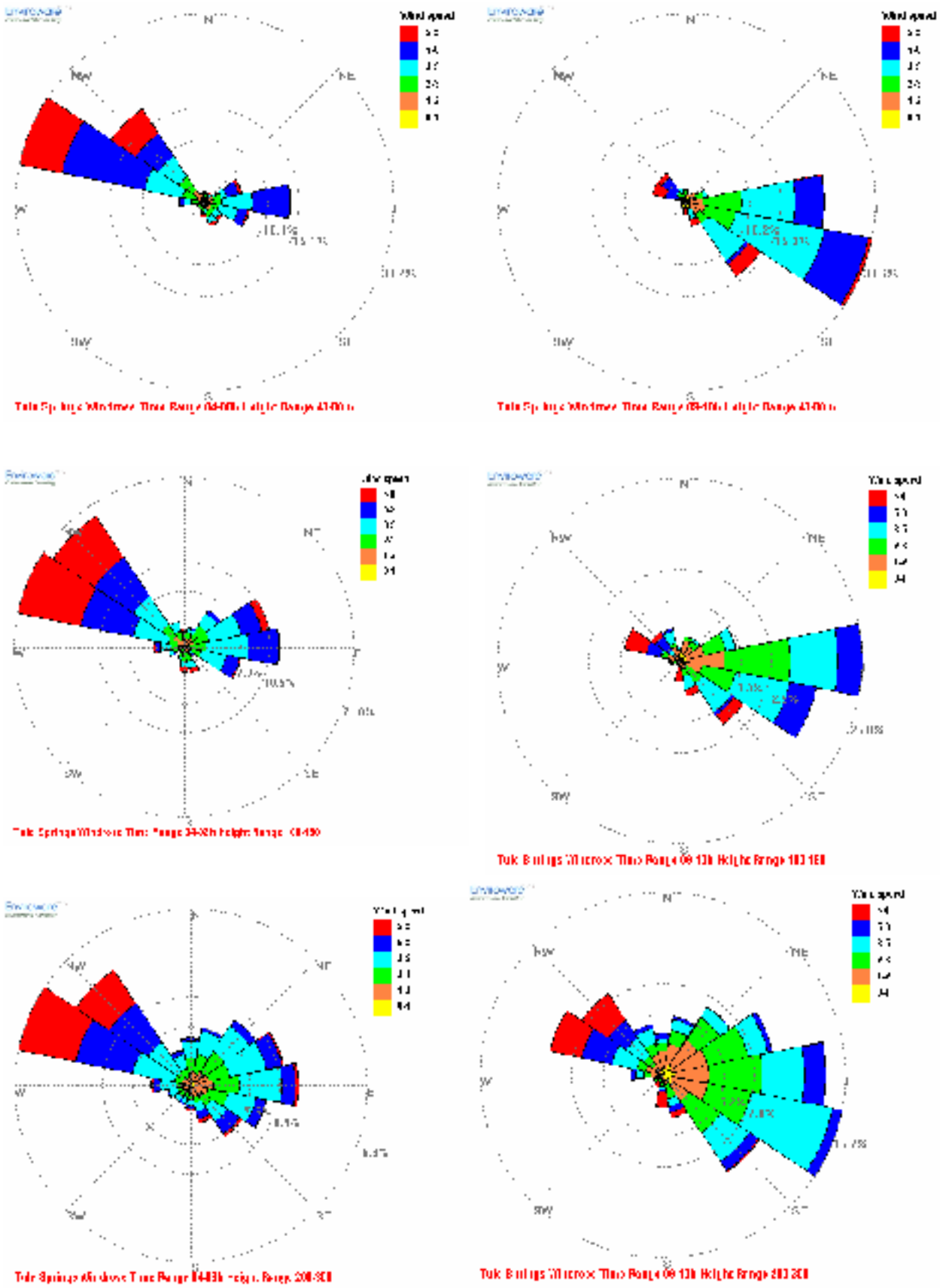


Figure 7. Vertical variation in winds at Tule Springs for hours 15-18.

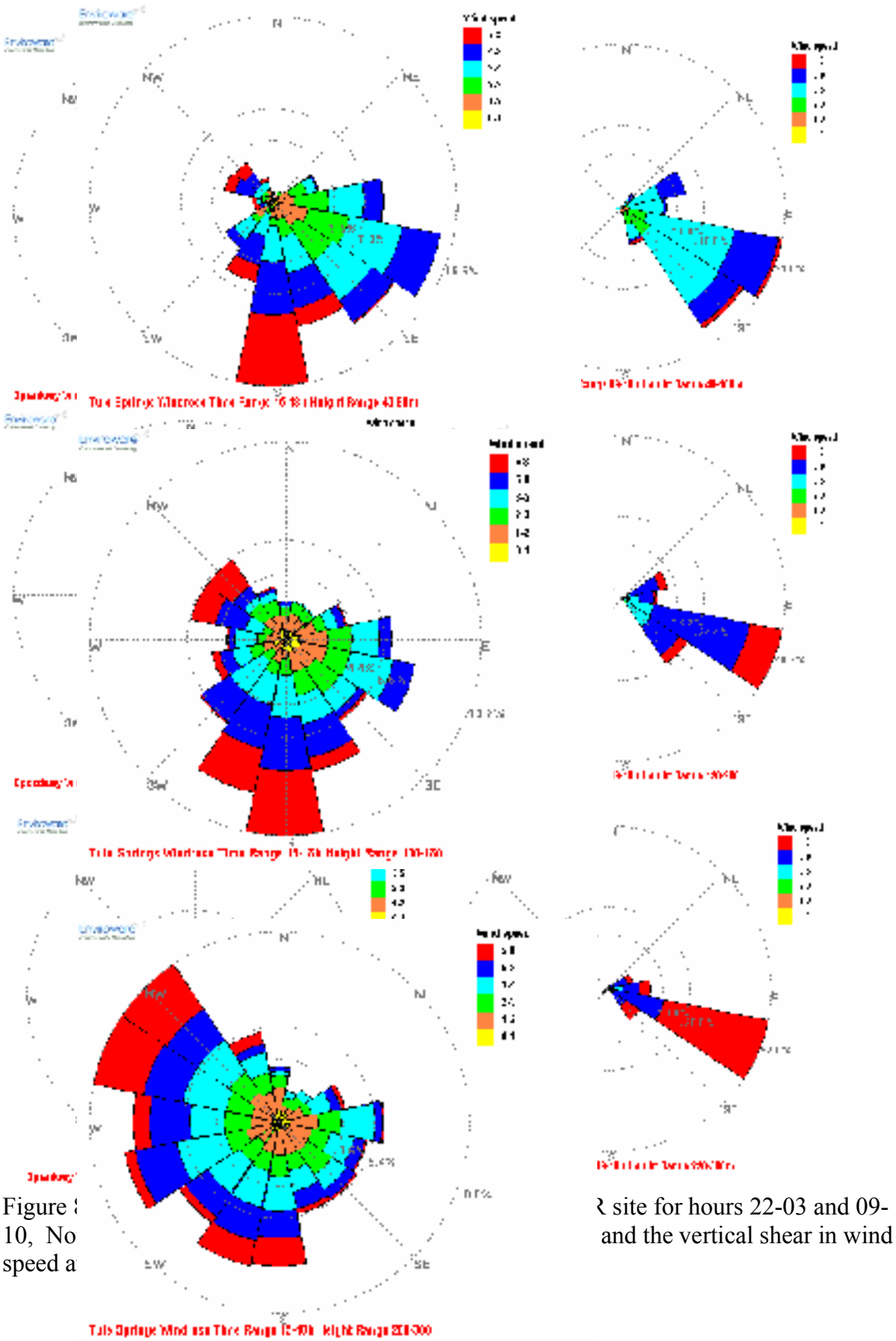


Figure 8 R site for hours 22-03 and 09-
10, No and the vertical shear in wind
speed a