4 Results

4.1 Meteorological Characteristics of each cluster

The percentage frequency of occurrence of each cluster by month is shown graphically in Figure 4-1 and Tabularly in Table 4-1. A summary of cluster wind patterns and seasonality is given at the end of this section.

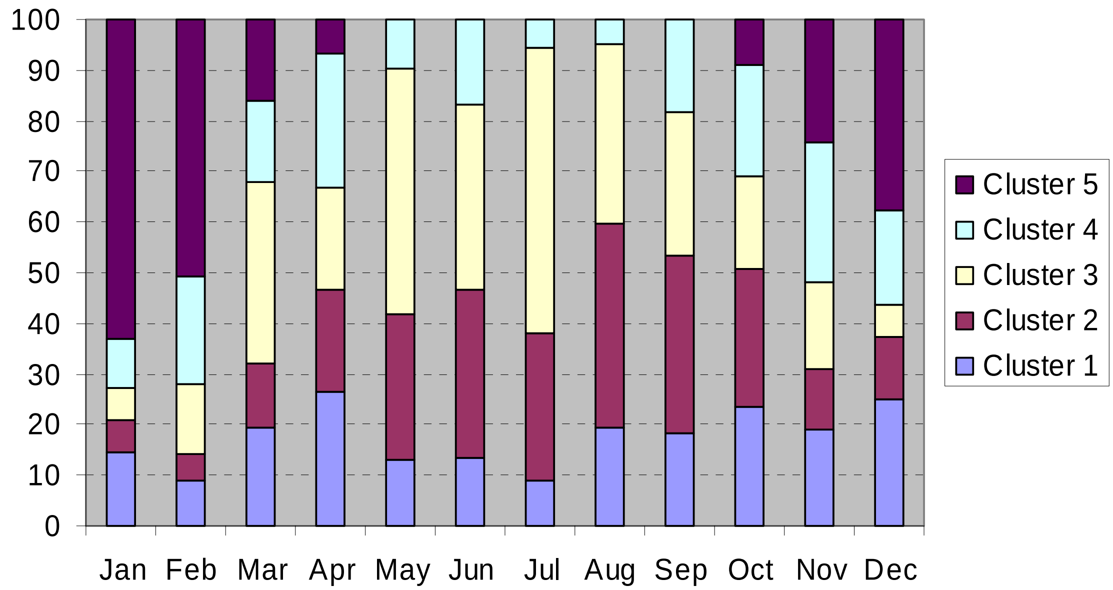


Figure 4-1. Percentage of days in each month assigned to each cluster type.

Table 4-1. Percentage of days in each month assigned to each cluster type.

Cluster	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	15	9	19	27	13	13	9	19	18	24	19	25
2	6	5	13	20	29	33	29	40	35	27	12	13
3	6	14	35	20	48	37	56	35	28	18	17	6
4	10	21	16	27	10	17	5	5	18	22	28	19
5	63	51	16	7	0	0	0	0	0	9	24	38

All months except March through June had data from two years. March-June had data from only one year (2004). Cluster 1 occurs throughout the year, with a peak in the transition months April and October. Cluster 2 peaks in the late summer to early fall (August-October). Cluster 3 occurs mainly in summer, peaking in frequency in July. Cluster 4 is another transition cluster, peaking in April and November. Cluster 5 is a winter-time cluster and never occurred from May – September.

For sites not used in the cluster analysis, we computed average winds for each hour for the days within each cluster. We used days assigned to each cluster that were close to the cluster center to calculate hourly mean upgorge (upriver) wind components. The daily average upgorge (upriver) wind component by site for each cluster is shown in Figure 4-2.

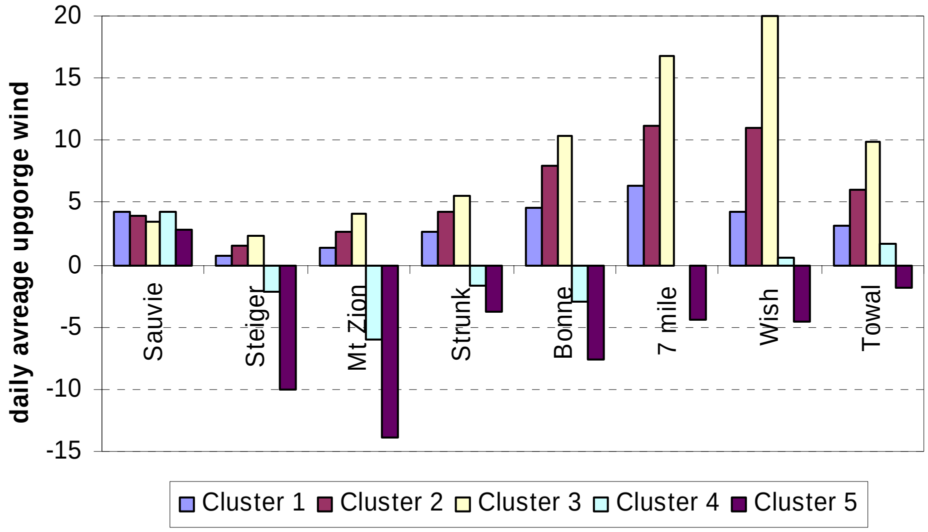
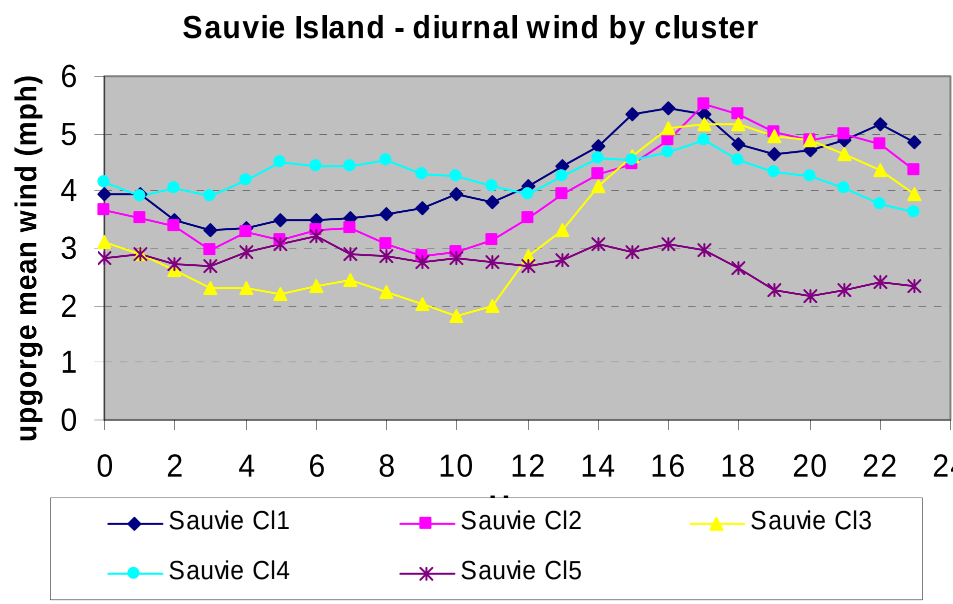
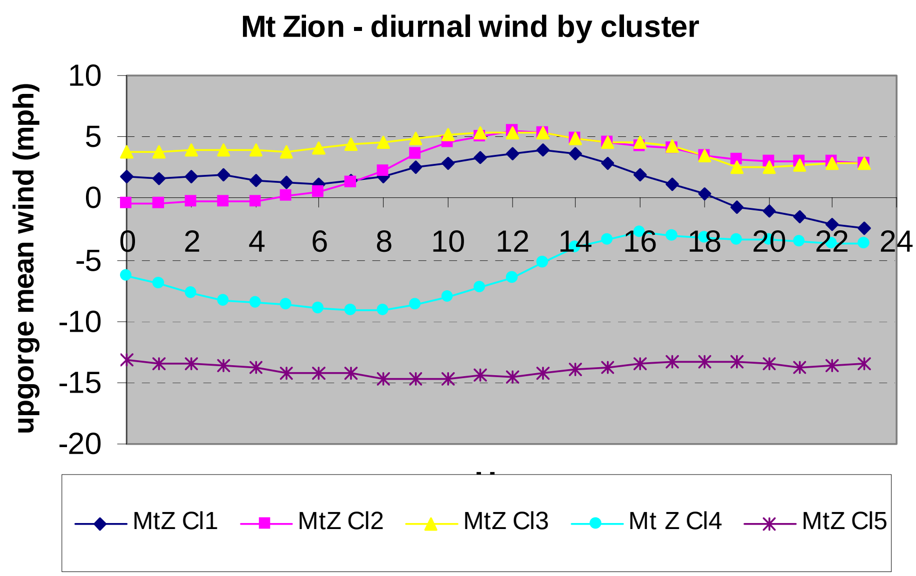


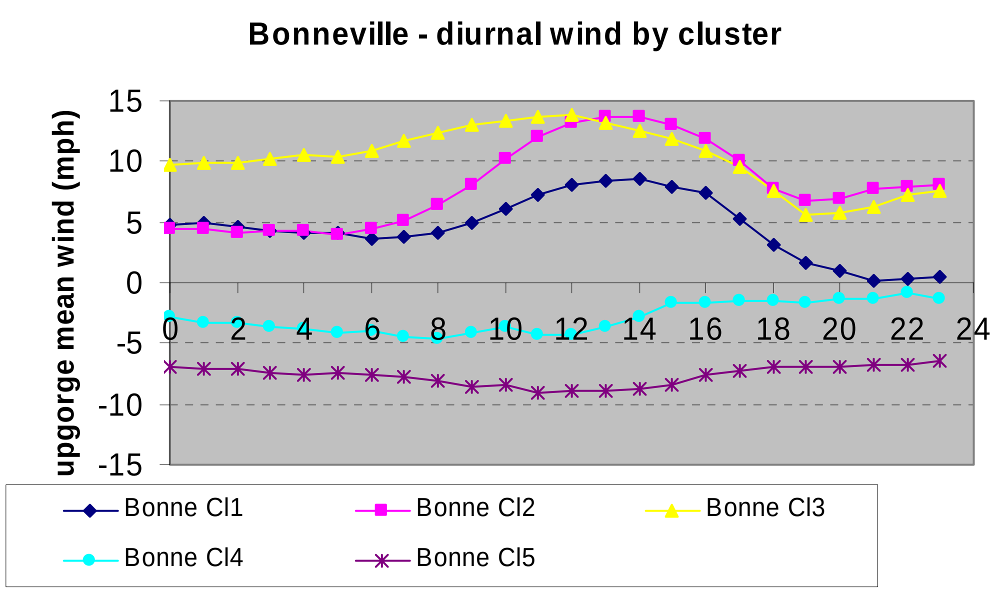
Figure 4-2. Daily average upgorge wind speed by cluster for each monitoring site.

Clusters 1-3 all have net (daily average) upgorge flow at all sites, increasing in strength by cluster number and with distance into the Gorge. Cluster 4 has either downgorge or weak upgorge net flow at all sites. Cluster 5 has downgorge flow at all sites, increasing in speed from east to west, except at Sauvie Island, which is outside of the Gorge and has light northerly flow.

The basic wind patterns, including their relative diurnal variations were similar for the following groups of sites: west- Strunk Road, Mt. Zion, and Steigerwald; east- Wishram, Towal Road, Sevenmile Hill. Sauvie Island and Bonneville were unique in their patterns. Figure 4-3 shows the diurnal wind variation for one representative site for the west end (Mt. Zion), one for the east end (Wishram), and for Sauvie Island and Bonneville Dam. Sauvie Island can be affected by Willamette Valley flows as well as flows channeled along the Columbia River; thus the concept of upgorge or downgorge is less meaningful for Sauvie Island as for other sites.


Sauvie Island - diurnal wind by cluster
upgorge mean wind (mph)
0
1
2
3
4
5
6
0 2 4 6 8 10 12 14 16 18 20 22 24
Sauvie Cl1
Sauvie Cl2
Sauvie Cl3
Sauvie Cl4
Sauvie Cl5


Mt Zion - diurnal wind by cluster
upgorge mean wind (mph)
10
5
0
-5
-10
-15
-20
0 2 4 6 8 10 12 14 16 18 20 22 24
MtZ Cl1
MtZ Cl2
MtZ Cl3
Mt Z Cl4
MtZ Cl5


Bonneville - diurnal wind by cluster
upgorge mean wind (mph)
15
10
5
0
-5
-10
-15
0 2 4 6 8 10 12 14 16 18 20 22 24
Bonne Cl1
Bonne Cl2
Bonne Cl3
Bonne Cl4
Bonne Cl5

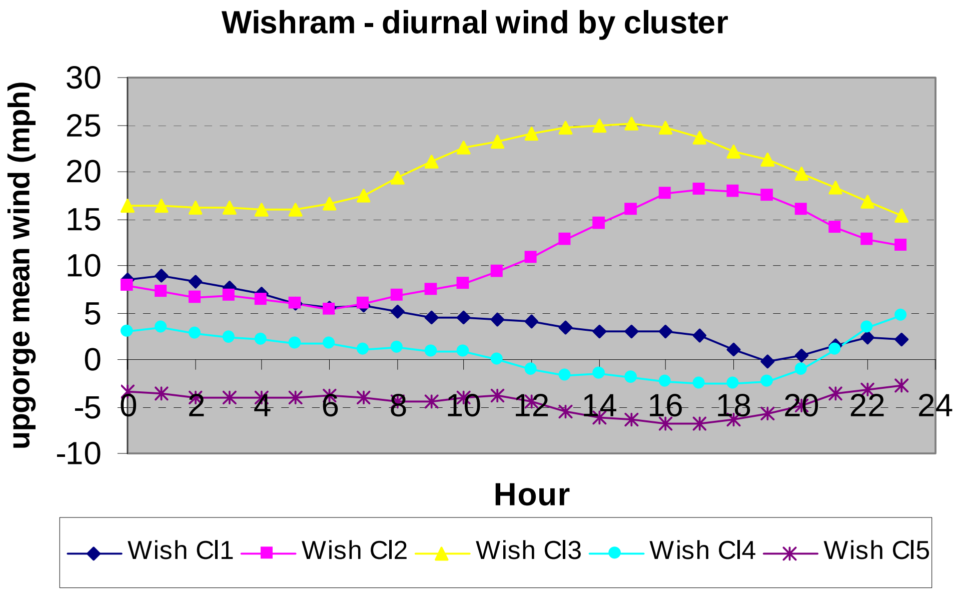


Figure 4-3. Diurnal variation in mean upgorge wind component by cluster at selected sites: a) Sauvie Island; b) Mt. Zion; c) Bonneville; d) Wishram.

A summary of the precipitation associated with each cluster is shown in Table 4-2.

Table 4-2. Fraction of days with no precipitation, precipitation at PDX and The Dalles, PDX only, and The Dalles only by Cluster number. If a day has greater than 0.01 inches of precipition, it is classified as having precipitation.

Cluster	Fraction no precip	Fraction with precip	Fraction both precip	Fraction PDX only precip	Fraction Dalles only precip
1	0.56	0.44	0.20	0.21	0.03
2	0.66	0.34	0.18	0.16	0.00
3	0.62	0.38	0.12	0.25	0.01
4	0.71	0.29	0.12	0.12	0.04
5	0.63	0.37	0.25	0.07	0.05
All days	0.61	0.39	0.18	0.18	0.03

Overall 61% of the days had 0.01” of precipitation or less at Both Portland International Airport and The Dalles. Of the 39% of days with precipitation >0.01” at one or both sites, about one-half had precipitation at both sites, about one-half has precipitation at Portland only, and a small number of days had precipitation at The Dalles only. Cluster 2 had no days with precipitation at The Dalles but not at PDX. Cluster 5 was about equally likely to have precipitation only at The Dalles as only at PDX.

4.1.1 Cluster 1

Figure 4-4 shows the daily average upgorge wind speed by site. Cluster 1 showed weak up-gorge flow that decreased in evening at most sites to near zero on average (At Sevenmile Hill and Sauvie Island upgorge flow increased in the evening. Sauvie Island is outside of the Gorge, so upgorge should be interpreted as upriver, downgorge - downriver). This pattern occurred most frequently in April and then again in late Autumn to early winter. The cluster 1 pressure pattern is shown in Figure 4-5.

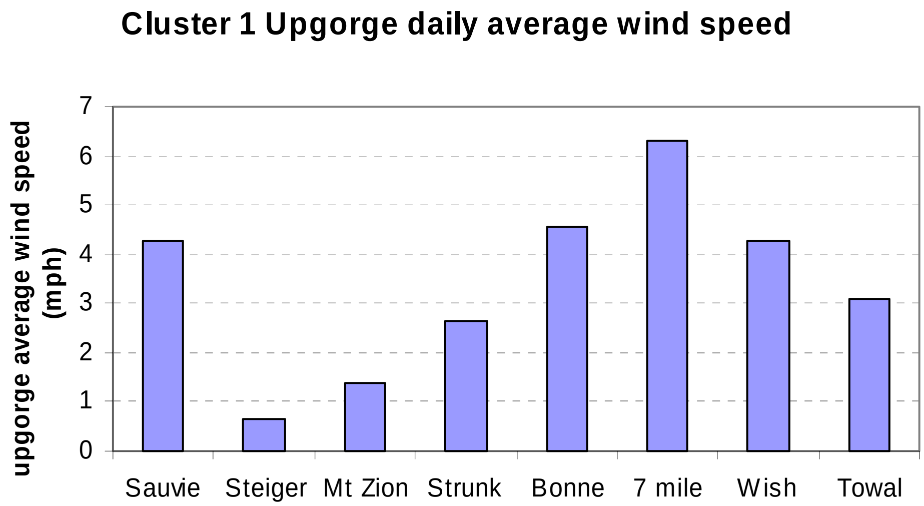


Figure 4-4. Cluster 1 average upgorge wind speed by site.

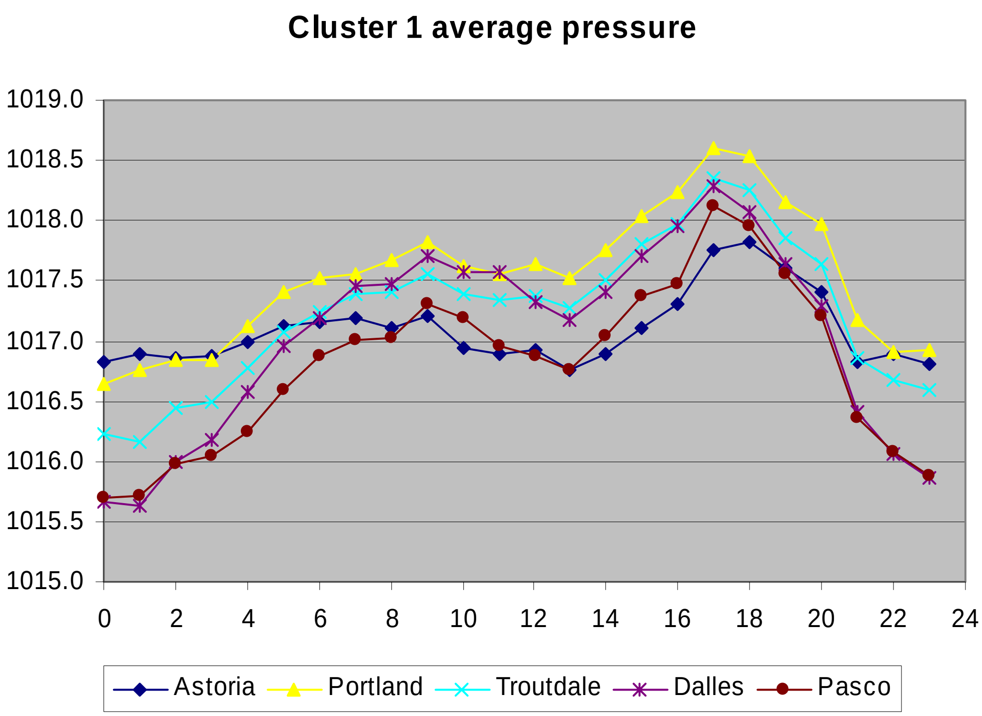


Figure 4-5. Average pressure (mb) by time of day at selected sites for Cluster 1.

The pressure gradient across the Gorge (from Troutdale to The Dalles is small and changes direction during the day. Upgorge winds at Sevenmile Hill are compared to the Troutdale – The Dalles pressure gradient in Figure 4-6. Upgorge wind and pressure gradient decreases during morning and then increases in the second half of the day.

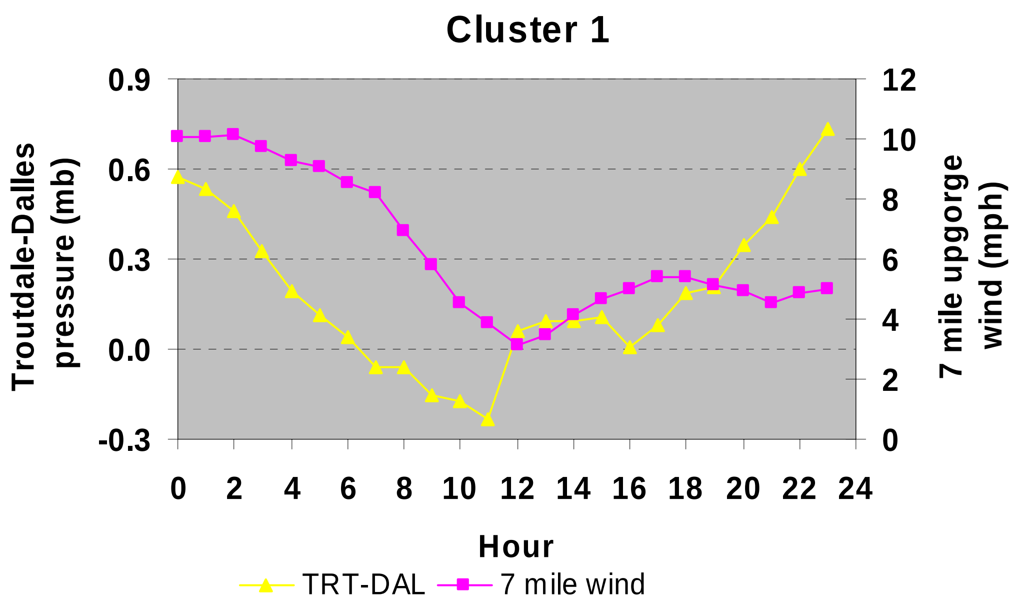


Figure 4-6. Relationship between Sevenmile Hill winds and Astoria – Pasco and Troutdale- The Dalles pressure gradients for cluster 1.

4.1.2 Cluster 2

Cluster 2 is the most frequent cluster for the months August-October and has a peak frequency (40%) in August. Figure 4-7 shows the average upgorge wind speed by site. Like Clusters 1 and 3, it is consistently up-gorge, but has a more pronounced diurnal cycle in speed than do Clusters 1 and 3. Cluster 2 diurnal variations in winds are shown in Figures 4-8 and 4-9. Cluster 2 speed increases from about 6 am to noon at the western sites and a steady increase from about 6 am to 4-5 pm at Wishram. At Mt. Zion from about midnight to 6 am the up-gorge wind component is near zero. This pattern is something of a modification of the Cluster 3 summer pattern and with lighter wind speeds implies weaker pressure gradients and a substantial diurnal variation of these gradients. The pressure patterns associated with cluster 2 is shown in Figure 4-10. The along river pressure gradient is greatest in the morning and evening and a minimum about 5 pm. Winds accelerating in response to this pressure gradient peak early in the western Gorge The wind peak in the eastern Gorge occurs later and with greater magnitude as the acceleration in response to the imposed gradient takes longer to be fully realized.

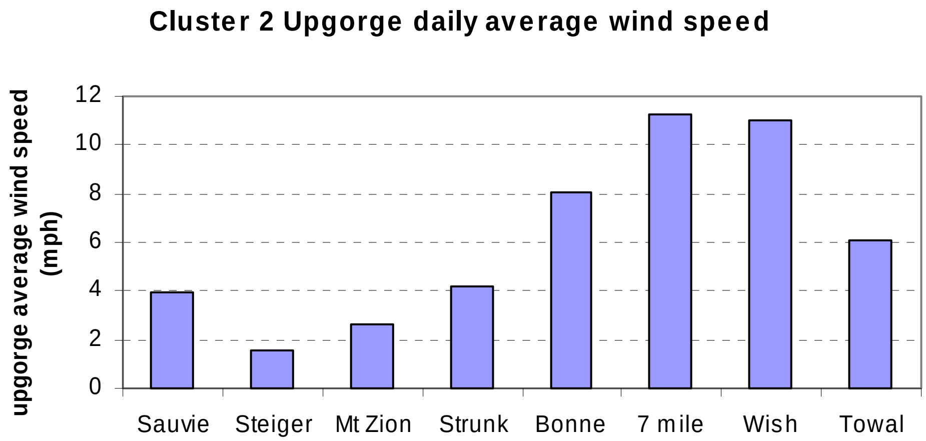


Figure 4-7. Cluster 2 average upgorge wind speed by site.

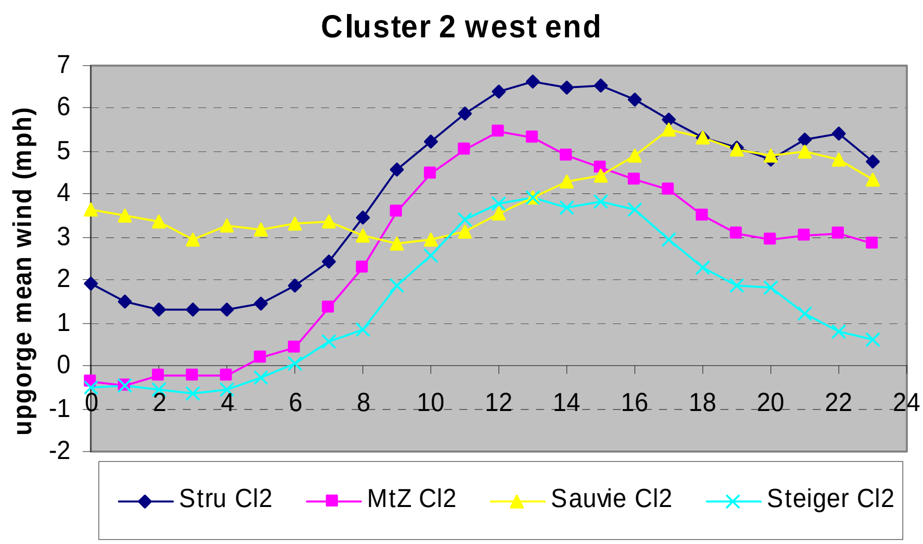


Figure 4-8. Cluster 2 diurnal patterns in upgorge wind for western sites.

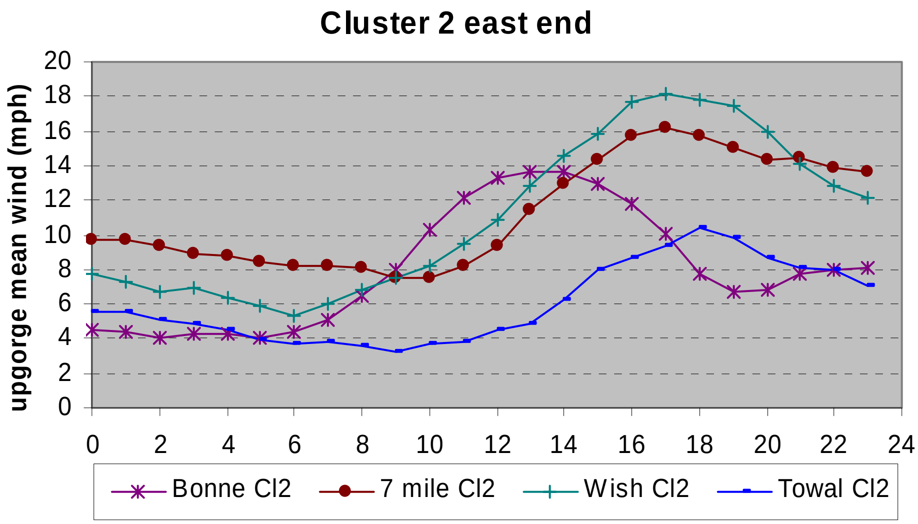


Figure 4-9. Cluster 2 diurnal patterns in upgorge wind for eastern sites.

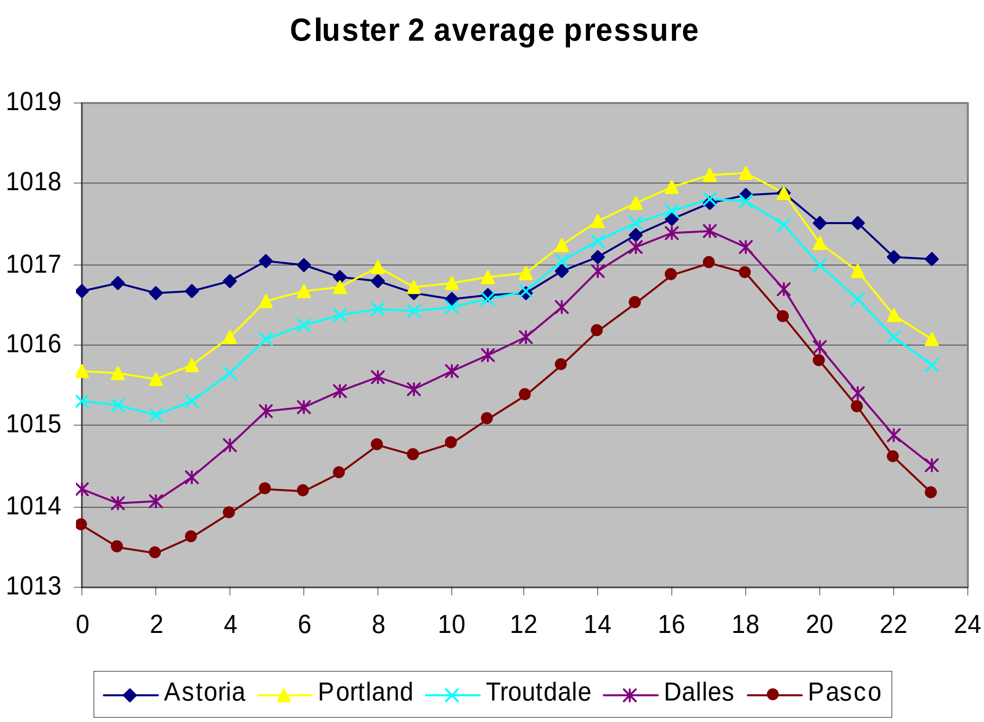


Figure 4-10. Cluster 2 diurnal patterns in average sea-level pressure for selected sites.

4.1.3 Cluster 3

Figure 4-11 shows the cluster 3 average upgorge wind speed by site. Cluster 3 was associated with persistent upgorge flow, increasing in speed toward the east end of the gorge and peaks in frequency in July. Clusters 3 and 5 appear to represent classical Gorge summer and winter patterns. Cluster 3 shows persistent up-gorge flow, increasing in speed toward the east end of the Gorge (strongest at Sevenmile Hill and Wishram), as the consistent pressure gradient continues to accelerate air moving through the Gorge. Cluster 5 shows persistent down-gorge flow, increasing in speed from Wishram to Mt. Zion. Both of these flows are expected to result from an acceleration along the Gorge due to a pressure gradient across the Gorge, as described in Sharp and Mass (2005) and elsewhere. In summer, pressure is higher to the west of the Gorge due to the northward migration of the Pacific High and lower to the east of the Gorge due to a thermal low resulting from intense heating. Hourly averaged pressure for Cluster 3 days for selected stations is shown in Figure 4-12.

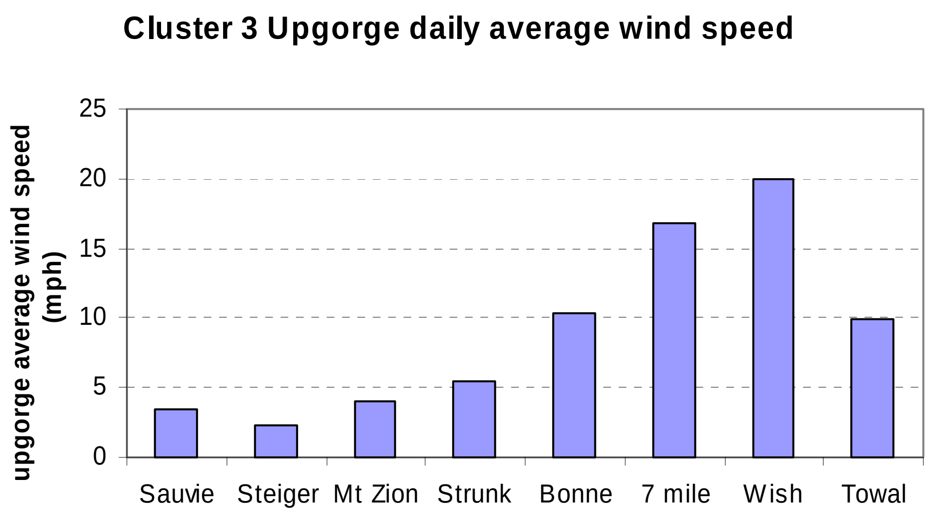


Figure 4-11. Cluster 3 average upgorge wind speed by site.

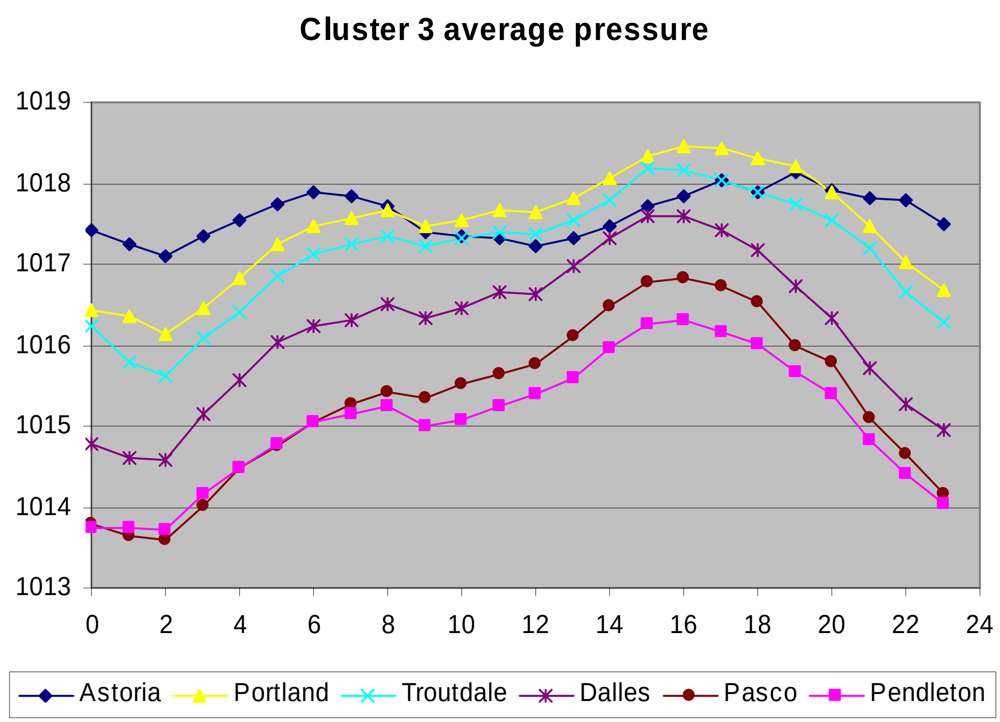


Figure 4-12. Cluster 3 diurnal patterns in average sea-level pressure for selected sites.

4.1.4 Cluster 4

Figure 4-13 shows the average upgorge wind speed by site. Cluster 4 occurred most frequently during transition periods February to April and again from October to November. Cluster 4 had downgorge flow at Mt. Zion and Bonneville, weak downgorge flow at Strunk Road and Steigerwald, and diurnally fluctuating (down in afternoon, up all other hours) flow at the 3 easternmost sites, Sevenmile Hill, Wishram, and Towal Road. Sauvie Island had upriver flow (from the north) all day. Averaged pressure data for Cluster 4 days is shown in Figure 4-14. The pressure gradient though the Gorge (From Troutdale to The Dalles decreases and changes sign during Cluster 4 days. Figure 4-15 compares the diurnal variation in Cluster 4 Sevenmile Hill winds and the Troutdale-The Dalles pressure difference.

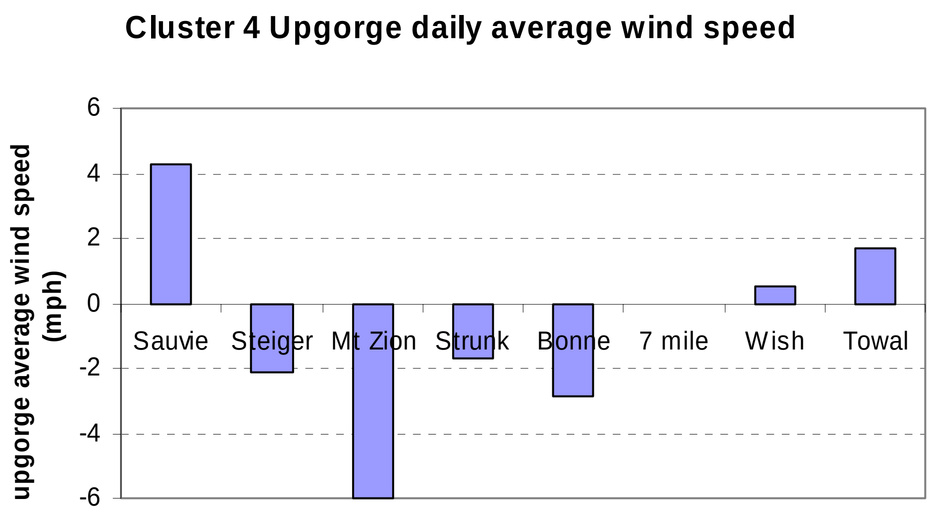


Figure 4-13. Cluster 4 average upgorge wind speed by site.

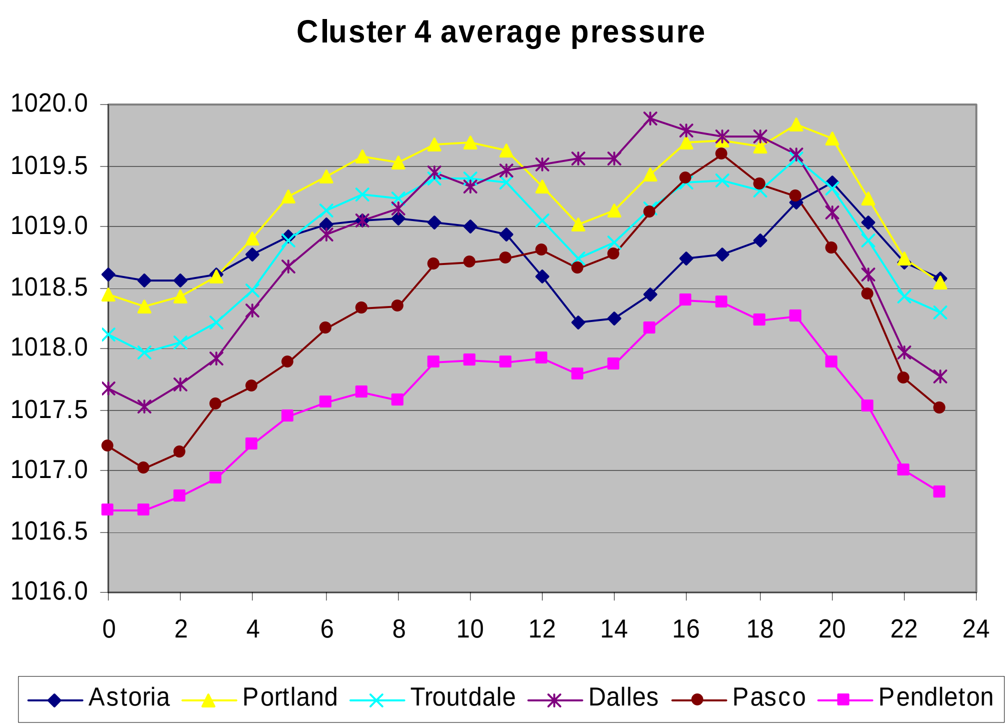


Figure 4-14. Cluster 4 diurnal patterns in average sea-level pressure for selected sites.

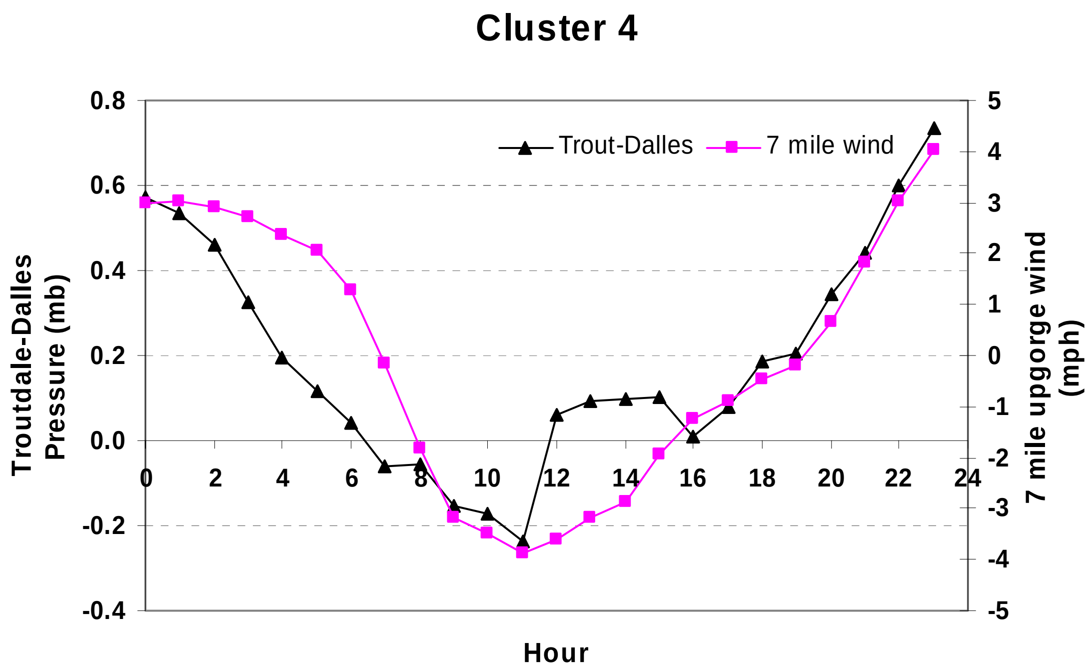


Figure 4-15. Relationship between Sevenmile Hill winds and Troutdale – The Dalles pressure gradients for cluster 4.

4.1.5 Cluster 5

Figure 4-16 shows the average upgorge wind speed by site. Hourly averaged pressure for Cluster 5 days for selected stations is shown in Figure 4-17. For cluster 5, there is:

1) essentially equal pressure all day at Pasco and The Dalles
2) a lower, but nearly equal pressure at Hilsboro, Portland Intl., and Troutdale
3) lower pressure at Astoria

Thus, the main pressure gradient through the Gorge is entirely between the Dalles and Troutdale. These 3 noted items above can explain:

1) light winds at Towal Road
2) strong down gorge winds at Bonneville, Mt. Zion, and Steigerwald
3) light winds at Sauvie Island

In winter the gradient is often reversed from summer with higher pressure east of the Gorge due to a cold, synoptic scale high pressure area and lower to the west of the Gorge, often due to Pacific lows. The less strong down-gorge winds for cluster 5 at Strunk Road compared to the nearby Mt. Zion probably are due to the Strunk Road site being farther from the center of the Gorge and thus out of the zone of the strongest winds.

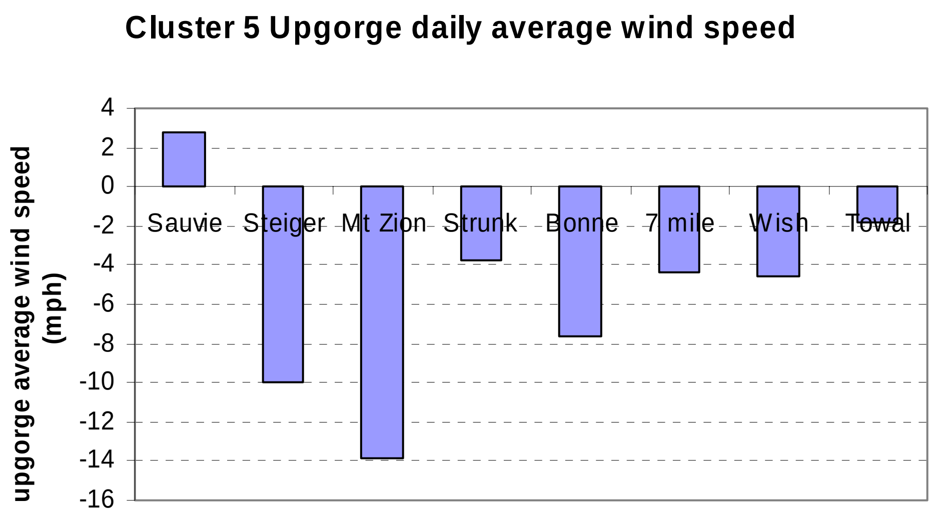


Figure 4-16. Cluster 5 average upgorge wind speed by site.

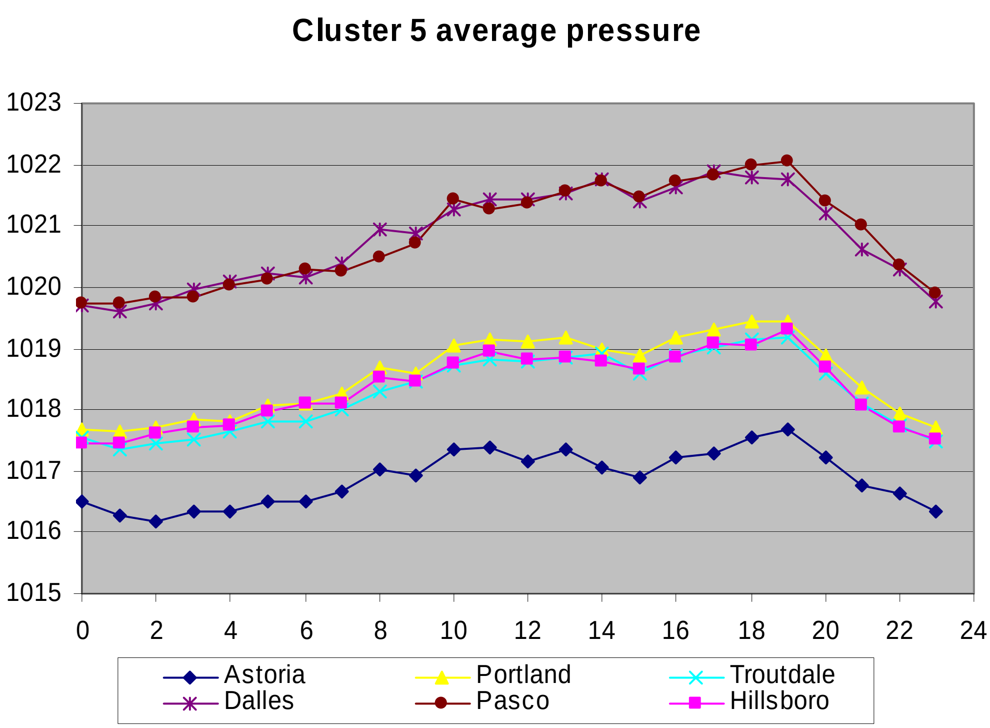


Figure 4-17. Cluster 5 diurnal patterns in average sea-level pressure for selected sites.

Before considering light scattering by cluster in the next section, it is helpful to the reader to summarize the wind patterns and seasonality by cluster; these are given below. Also, added to the cluster number are short descriptors of the cluster that will be used in the next section to refer to the clusters in a way that will be easier for the reader to relate to than the cluster number.

Cluster	Wind Pattern	Seasonality
Light upgorge transition (1)	Light upgorge, increasing with distance into Gorge	Peak in transition months April and October, more common in winter than summer
Moderate upgorge late-summer (2)	Moderate upgorge, increasing with distance into Gorge, large diurnal variation in speed	Late summer- early fall Peak in August, most common cluster August to October
Strong upgorge (3)	Strong upgorge, increasing with distance into Gorge	Peak in July, most common cluster May-July
Light downgorge transition (4)	Light downgorge, except diurnally changing direction at eastern sites, upgorge Sauvie Island	Mainly Autumn and Spring (most common cluster November), uncommon summer
Winter downgorge (5)	Downgorge, light in eastern end, increasing through Gorge, except light northerly at Sauvie Island	Predominantly winter – most common cluster December-February, no occurrences May-September

4.2 Light scattering patterns by cluster

A summary of average light scattering by site and cluster is shown in Figure 4-18 and Table 4-3.

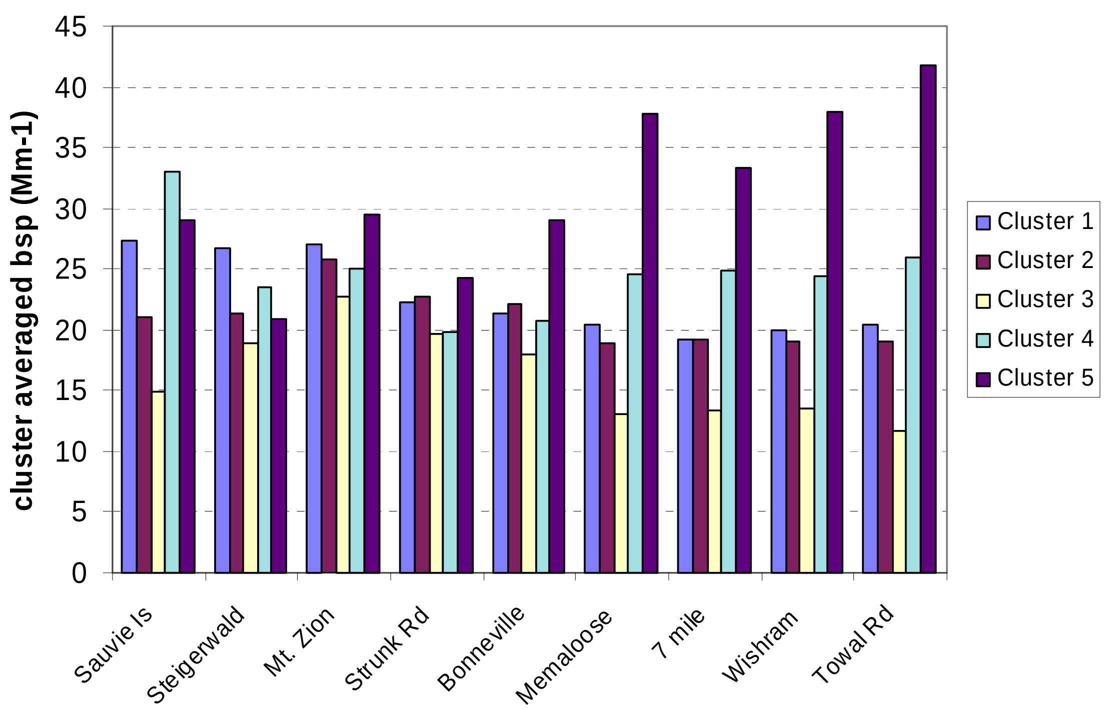


Figure 4-18. Average bsp (Mm^{-1}) at each nephelometer site for each cluster. Average is over all hours for all days within each cluster.

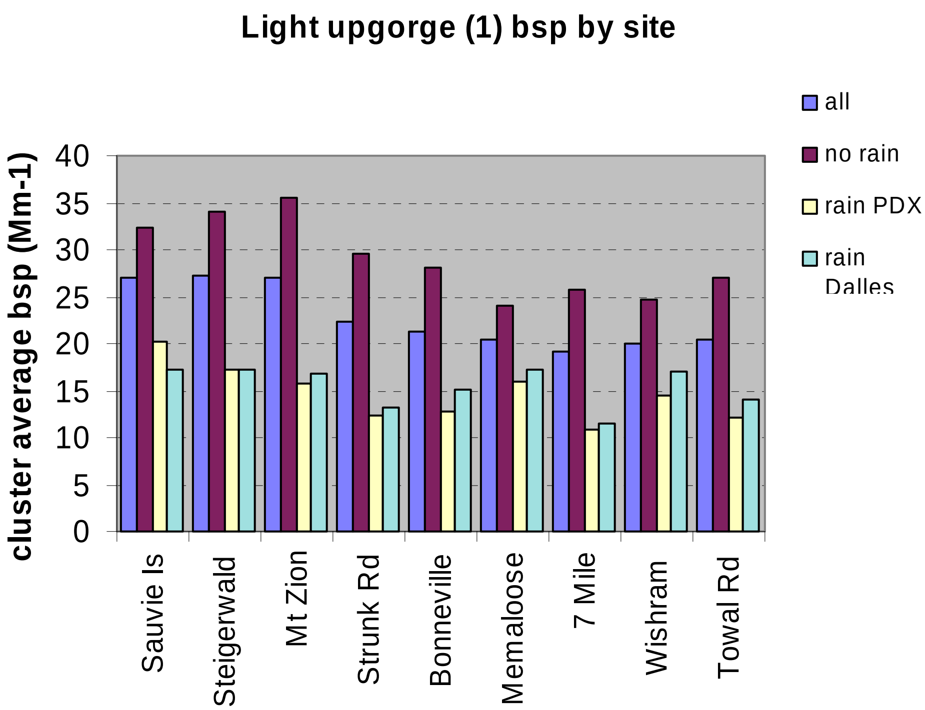
Table 4-3. Average bsp (Mm-1) by cluster by site.

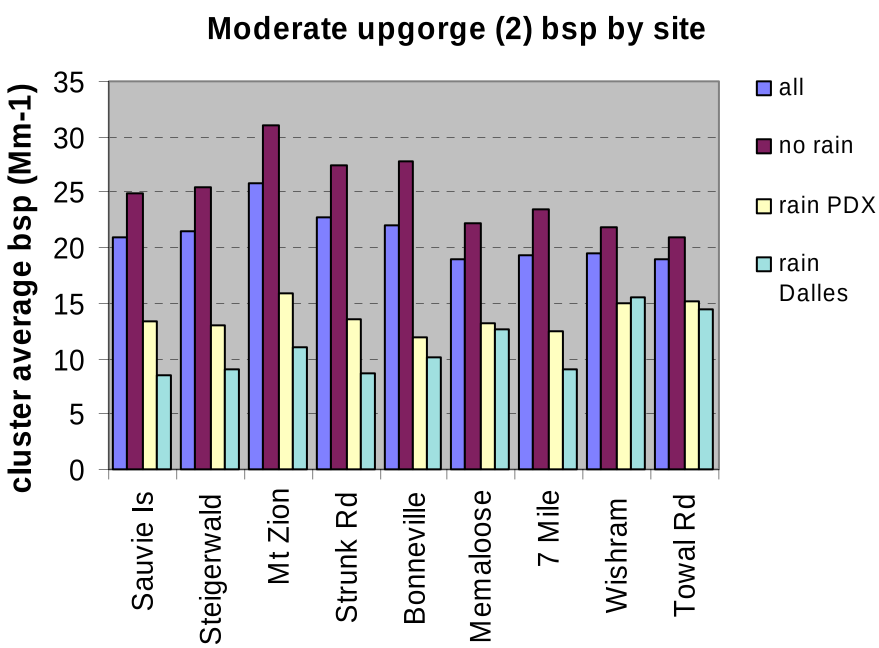
	Light upgorge (1)	Moderate upgorge (2)	Strong upgorge (3)	Light downgorge (4)	Winter downgorge (5)
Sauvie Is	27.4	21.1	14.8	33.0	29.1
Steigerwald	26.8	21.4	18.9	23.4	21.0
Mt Zion	27.0	25.9	22.7	25.1	29.6
Strunk Rd	22.3	22.7	19.7	19.8	24.3
Bonneville	21.3	22.2	18.0	20.7	29.0
Memaloose	20.4	19.0	13.1	24.6	37.7
7 Mile	19.3	19.3	13.3	24.9	33.4
Wishram	20.0	19.1	13.6	24.4	37.9
Towal Rd	20.5	19.0	11.7	26.0	41.7

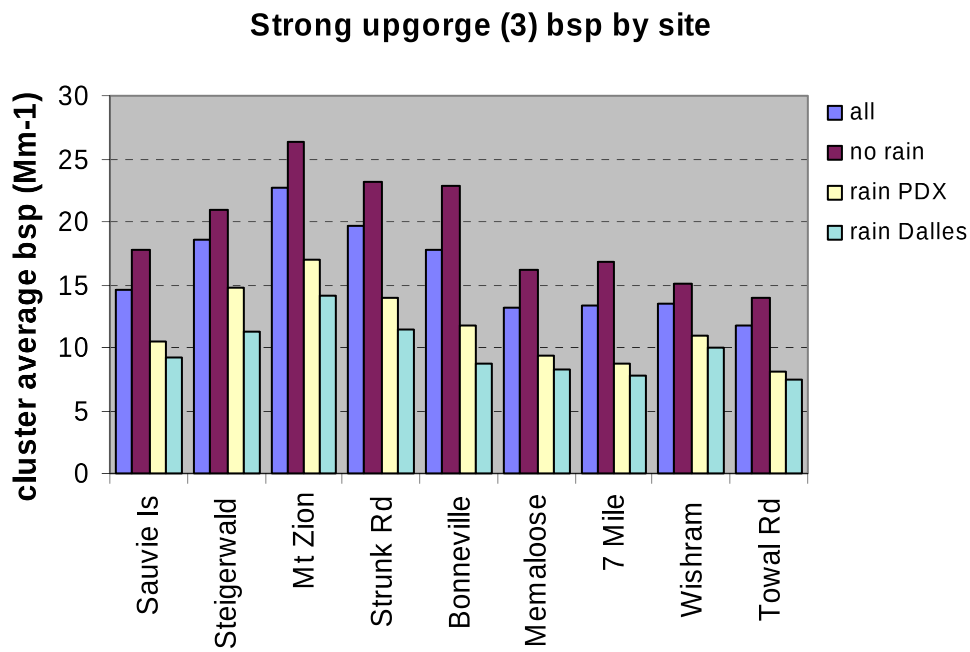
While there is a lot of information to process from Figure 4-18 (or Table 4-3), the following facts may be easily noted:

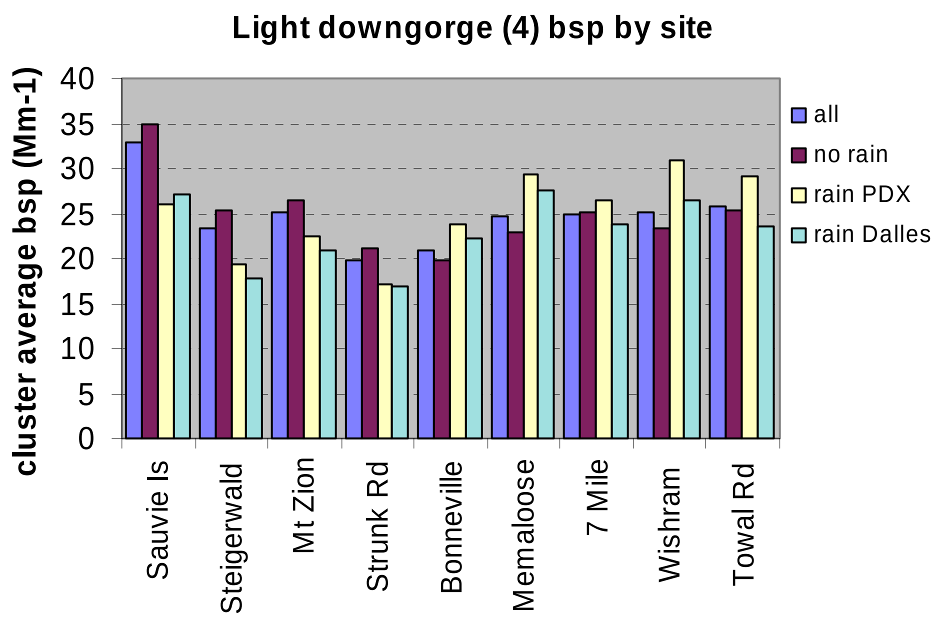
1) For all sites except Sauvie Island and Steigerwald, winter downgorge (cluster 5) has the highest average bsp of all clusters. For all sites, strong upgorge (cluster 3) has the lowest average bsp. Thus, the most typical summer pattern and most typical winter pattern have the lowest and highest bsp, respectfully for nearly all sites
2) The westernmost site (Sauvie Island, west of the Gorge), and the eastern sites (from Memaloose east) have much larger variations in average bsp between clusters than do the other sites (Steigerwald, Mt Zion, Strunk, and Bonneville).

To more easily discern the spatial patterns corresponding to each cluster and to understand effect of precipitation on bsp, we present in Figure 4-19 bar charts of cluster averaged bsp by site (ordered west to east) individually by cluster. For each cluster bsp is averaged over all days, days without precipitation, days with precipitation at Portland International Airport (PDX) , and days with precipitation at The Dalles. (Some clusters also show interesting diurnal patterns for some sites. Diurnal patterns for selected sites for some clusters will be shown later to illustrate these patterns).


Light upgorge (1) bsp by site
all
no rain
rain PDX
rain Dalles
cluster average bsp (Mm-1)
40
35
30
25
20
15
10
5
0
Sauvie Is
Steigerwald
Mt Zion
Strunk Rd
Bonneville
Memaloose
7 Mile
Wishram
Towal Rd


Moderate upgorge (2) bsp by site
all
no rain
rain PDX
rain Dalles
cluster average bsp (Mm-1)
35
30
25
20
15
10
5
0
Sauvie Is
Steigerwald
Mt Zion
Strunk Rd
Bonneville
Memaloose
7 Mile
Wishram
Towal Rd


Strong upgorge (3) bsp by site
cluster average bsp (Mm-1)
30
25
20
15
10
5
0
Sauvie Is
Steigerwald
Mt Zion
Strunk Rd
Bonneville
Memaloose
7 Mile
Wishram
Towal Rd
all
no rain
rain PDX
rain Dalles


Light downgorge (4) bsp by site
cluster average bsp (Mm-1)
40
35
30
25
20
15
10
5
0
Sauvie Is
Steigerwald
Mt Zion
Strunk Rd
Bonneville
Memaloose
7 Mile
Wishram
Towal Rd
all
no rain
rain PDX
rain Dalles

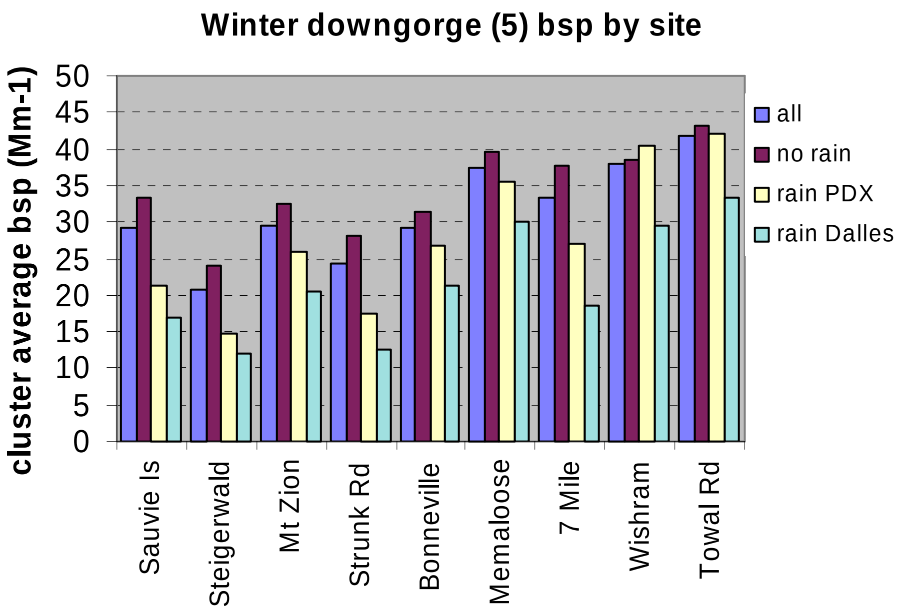


Figure 4-19. Cluster average bsp (Mm-1) for each nephelometer monitoring site. Site order is from west to east.

With some exceptions, days without precipitation have considerably higher bsp than days with precipitation at one or both sites. For light downgorge (4) days with precipitation at PDX had higher average bsp at sites from Bonneville on east than did days with no precipitation. In most cases, days with precipitation at The Dalles have the lowest bsp. As Table 4-2 showed, most days that had precipitation at The Dalles also had precipitation at PDX; this implies widespread precipitation resulting in scavenging of aerosol by precipitation throughout the Gorge.

The remaining discussion refers to all days in each cluster (not stratified by precipitation category). For strong upgorge (3), while it was the cleanest at all sites, there is a large gradient in bsp with the sites from Memaloose east being much lower than sites west of Memaloose. Average bsp at Towal Road was half that at Mt. Zion. Low bsp at the eastern sites is likely a result of two effects: 1) deeper mixing layers due to greater heating; and 2) dispersion due to stronger winds from acceleration caused by the along-gorge pressure gradient. Note that the highest bsp is at Mt. Zion and for the western sites, lowest bsp is at Sauvie Island. Flow is consistently upriver for strong upgorge (3) and Sauvie Island would therefore be upwind of the Portland/Vancouver urban area, possibly accounting for its lower values relative to other western sites. For all clusters except weak upgorge (1), Mt. Zion average bsp is higher than that of neighboring sites Strunk Road and Steigerwald. Furthur investigation is needed to determine if there is a physically explainable reason for this, such as localized mixing conditions or measurement bias in the nephelometer data. In any case, for strong upgorge (3), it is reasonable to expect that the Portland/Vancouver urban area may be the reason for the higher bsp levels in the western Gorge compared to the eastern Gorge and Sauvie Island sites.

For winter downgorge (5), highest bsp is at the eastern sites, with lower values in the western Gorge and an increase at Sauvie Island, downwind of the urban area. High bsp levels at the eastern sites are associated with consistent light down gorge flow, except at Towal Road which alternates between light upgorge and light downgorge flow. This common winter pattern allows for buildup of aerosols in the eastern Gorge area that then gets transported down through the Gorge. There is a decrease in bsp from Wishram to Sevenmile Hill, then an increase from Sevenmile Hill to Memaloose. Memaloose bsp is much higher than Sevenmile Hill in mid-morning (Figure 4-20) when the 7 mile site is likely above the mixed layer depth. However, Memaloose, essentially at River level is within the layer carrying high concentrations of aerosols downgorge. From about 1 pm on, Memaloose and Sevenmile Hill bsp is very similar in magnitude as aerosols are mixed upward.

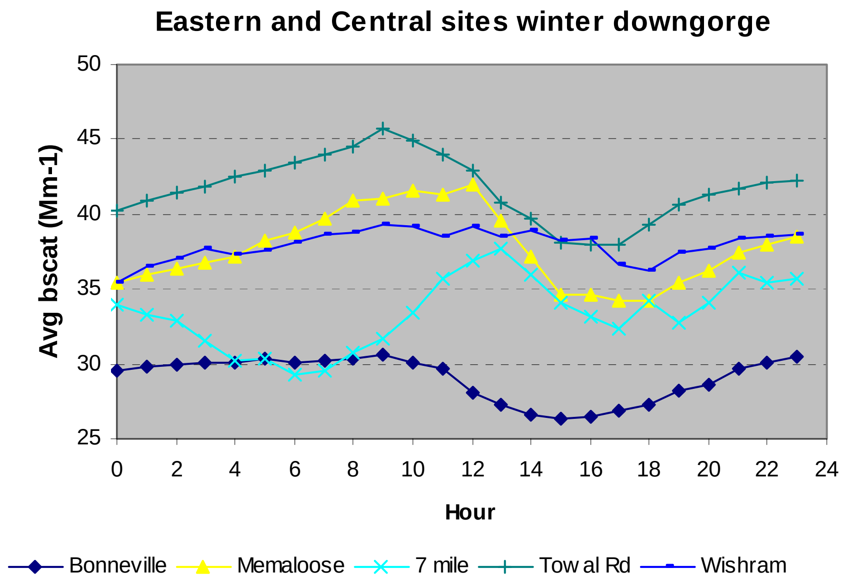


Figure 4-20. Diurnal patterns of bsp for Cluster 5 eastern and central sites.

Again Mt Zion had higher average bsp than Strunk Road; a possible explanation is that the Strunk Road site, being further from the Columbia River is not within the strong downgorge flow and may thus be less affected by transport of haze causing particles down the Gorge. The winds are much lighter at Strunk Road compared to Mt. Zion for winter downgorge (5). (Figure 4-16). Bsp for river level sites is shown in Figure 4-21.

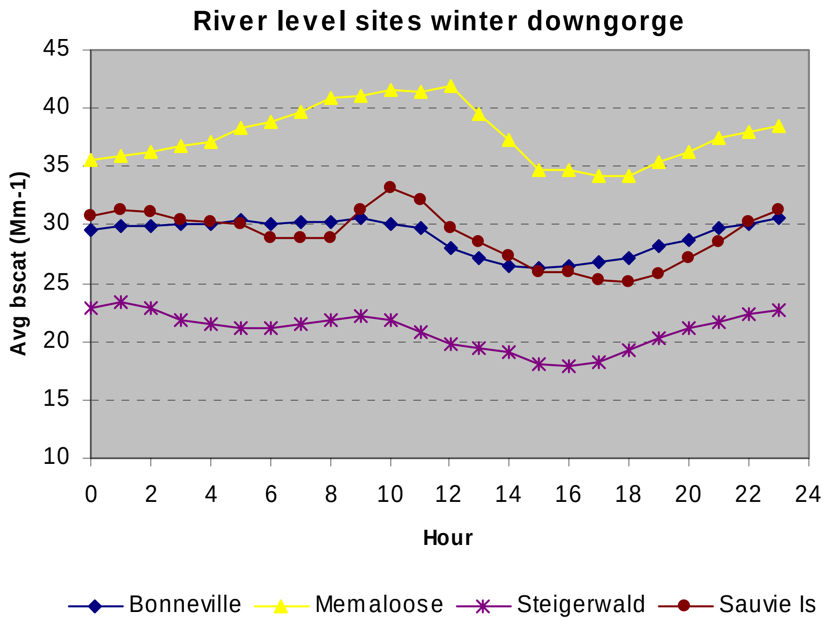


Figure 4-21. Diurnal patterns of bsp for winter downgorge (5), river level sites.

Diurnal bsp patterns for the western sites for moderate upgorge (2) are shown in Figure 4-22. Moderate upgorge is a typically late summer to autumn flow pattern with strong diurnal variation in wind speed.

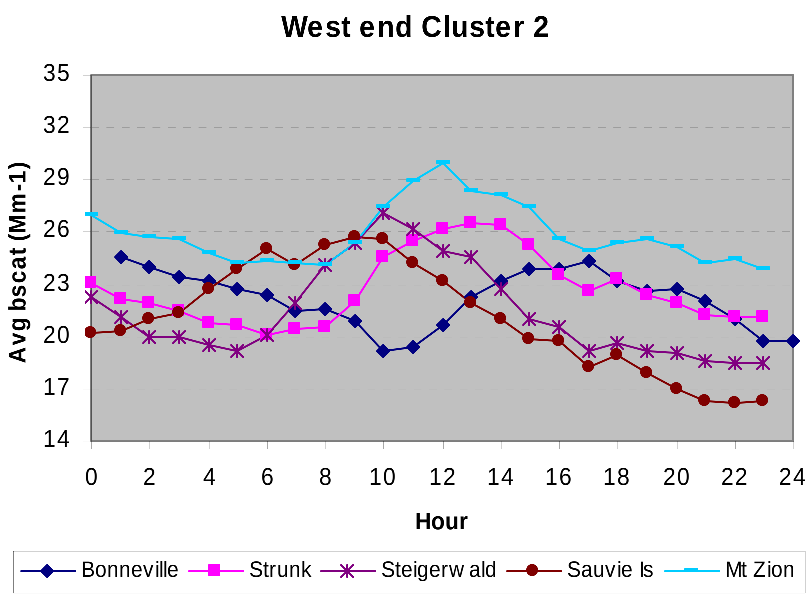


Figure 4-22. Diurnal patterns of bsp for moderate upgorge (2), western sites.

There are significant diurnal variations in bsp at the western sites. Steigerwald and Sauvie Island have peaks at 10 am, though the increase starts later at Steigerwald. At Mt.

Zion bsp peaks at noon, Strunk Road 1 pm, and a peak at 5 pm at Bonneville. This pattern shows an increase first at the westernmost site, then later increases in bsp progressively with eastward distance in the Gorge to Bonneville.

This apparent west to east transport of higher levels of bsp can also be noted in a plot of the diurnal variation of light scattering for all July-August days (Figure 4-23).

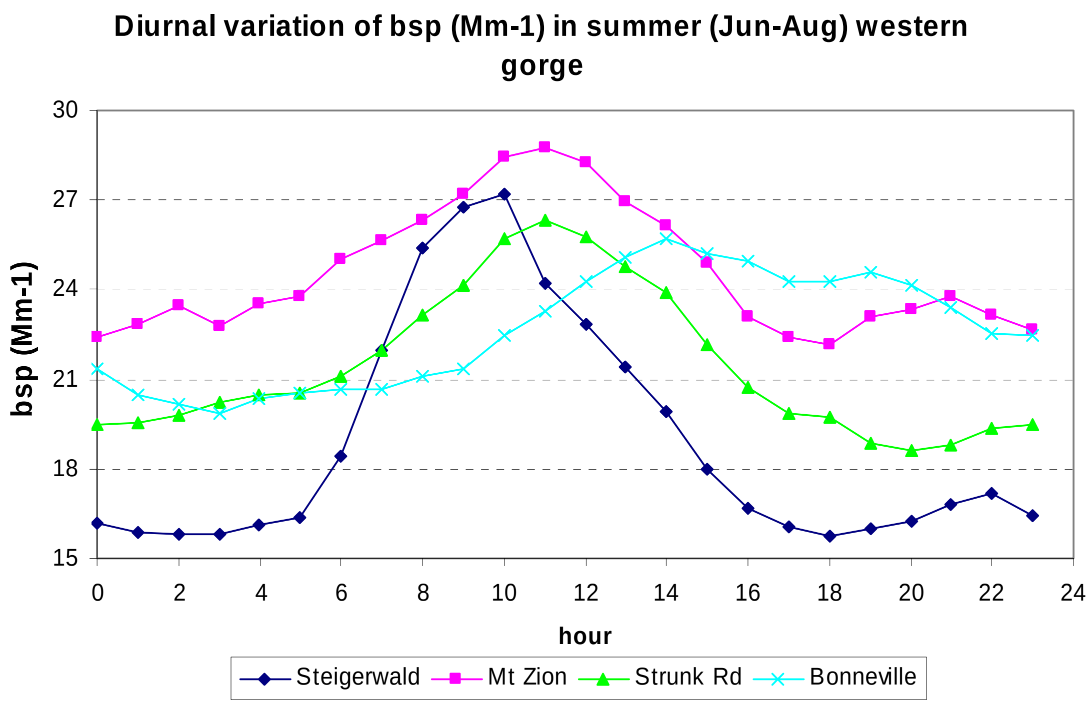


Figure 4-23. June- August average diurnal patterns of bsp at western Gorge sites and Bonneville Dam.

At Bonneville Dam, wind speed increased substantially during the mid-late morning hours for moderate upgorge (2). As shown in Figure 4-24, this increase was closely followed by an increase in bsp, further suggestion of a transport of aerosols from the Portland/Vancouver area.

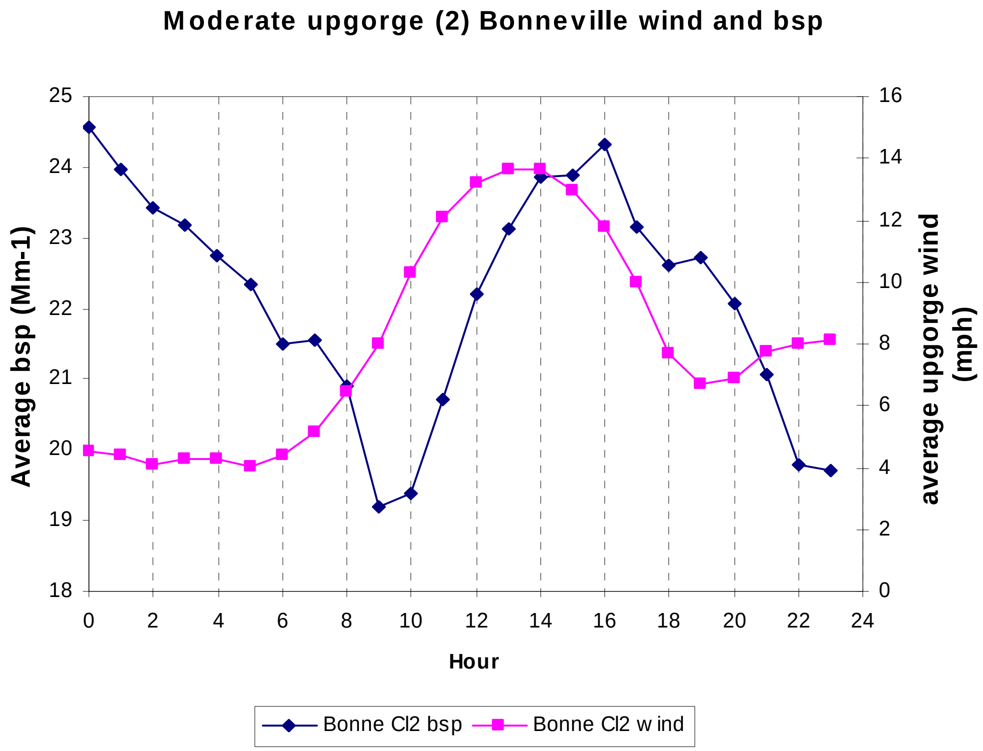


Figure 4-24. Bonneville upgorge wind component and bsp, moderate upgorge (2).

A similar pattern occurs for Light upgorge (1), as shown in Figure 4-25.

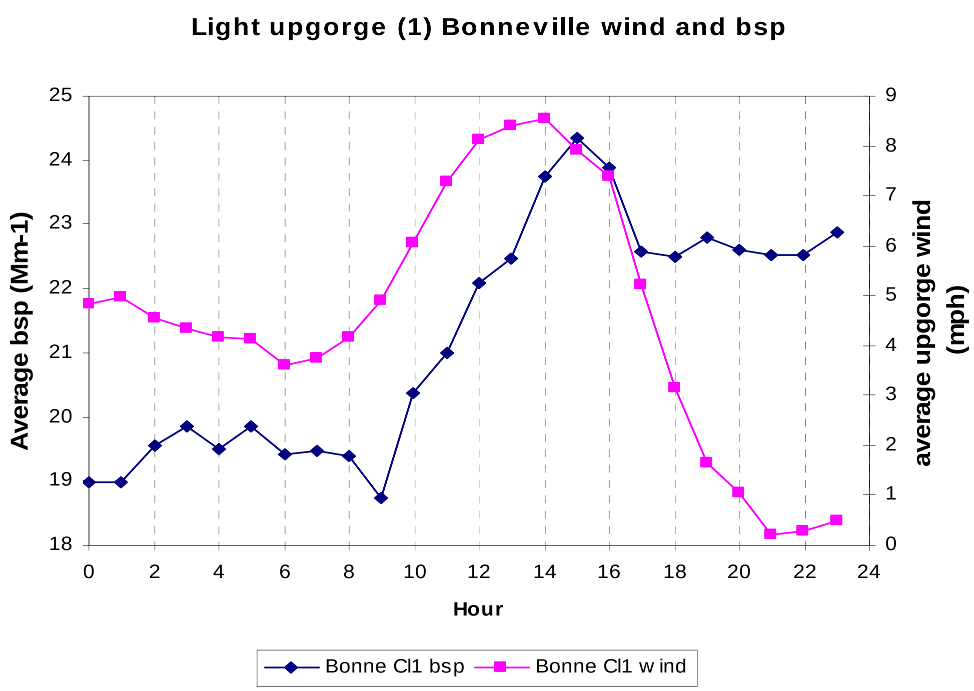


Figure 4-25. Bonneville upgorge wind component and bsp, light upgorge (1).

Light upgorge (1) has bsp highest at Sauvie Island and then decreasing with distance into the Gorge.

Light downgorge (4) has highest average bsp at Sauvie Island. While Sauvie Island has light average winds upriver all hours for light downgorge (4), nearby sites have downriver (downgorge) winds. The high average bsp at Sauvie Island for light downgorge (4) compared to other sites needs to be further investigated. High bsp at Sauvie Island may be a result of sloshing back and forth of Portland/Vancouver area emissions or sources somewhat downstream of Portland that do not impact the other sites because flow is coming down gorge at the exit. As there is light flow coming out of the Gorge, sources affecting Sauvie Island for light downgorge (4) days would not affect the in-gorge sites.

Further east in the Gorge, the Sevenmile Hill and Memaloose sites have higher average bsp than do the other sites. All sites from Memaloose east have their 2nd highest average bsp for light downgorge (4) (highest is winter downgorge (5)). Bonneville shows diurnally consistent down gorge flow for light downgorge, while Sevenmile Hill, Wishram, and Towal Road showed diurnal variation in flow direction (upgorge and downgorge both) during light downgorge(4) days. Figure 4-26 shows the diurnal variation in upgorge wind component and bsp at Sevenmile Hill for light downgorge (4) days. At 7 am the wind direction changed from upgorge to downgorge and average bsp increased from about 29 Mm-1 to 38 Mm-1. Sevenmile Hill is located nearly directly above The Dalles. As the wind changes direction and comes from the Dalles, bsp increases. This increase suggests contributions from local sources in the area of The Dalles.

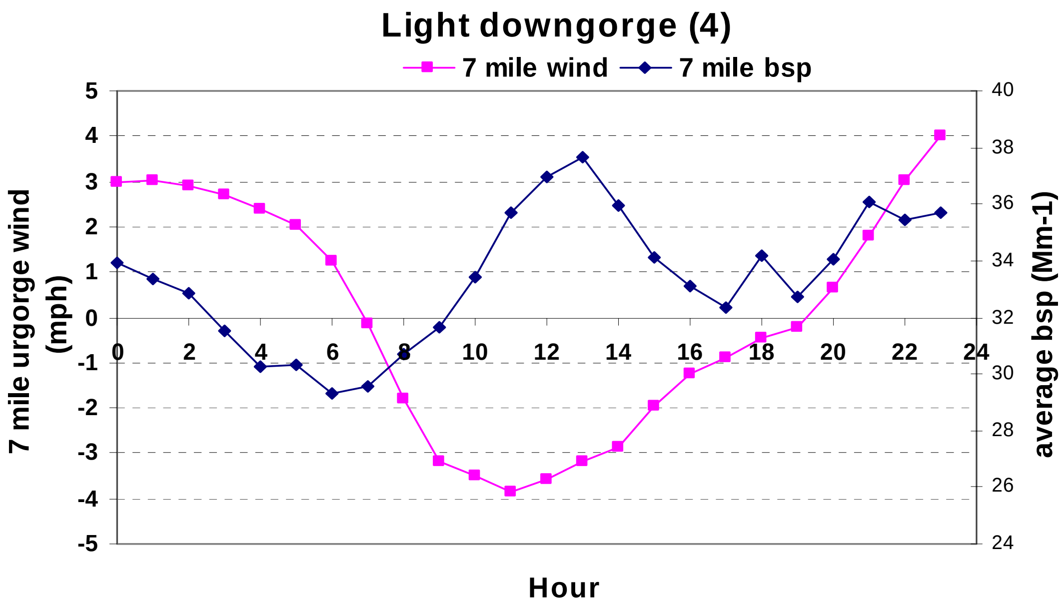


Figure 4-26. Relationship between average Sevenmile Hill upgorge wind and average bsp by time of day for light downgorge (4).

4.3 Aethalometer Elemental Carbon (EC) at Mt Zion and Wishram by Cluster

Aethalometers were operated at Mt. Zion and Wishram for the duration of the study. Aethalometers give a calculated elemental or black carbon concentration based upon light transmittance through a filter tape over which ambient air is drawn. While there are some limitations with aethalometers (e.g. Arnott, et al., 2005), the data are of sufficient quality to identify diurnal and seasonal patterns in elemental carbon (EC). EC affects visibility by absorbing light. The extinction efficiency of EC is on the order of 10 m^2g^{-1}. So EC concentrations in ng/m^3 divided by 100 will give a good approximation to the light absorption in Mm-1 by EC.

Average aethalometer derived EC concentrations by cluster and hour at Mt Zion and Wishram are shown in Figures 4-27 and 4-28. EC concentrations by cluster, averaged over all hours are shown in Table 4-4. EC concentrations are quite low and contribute very little to light extinction. Assuming an extinction efficiency of 10 m^2g^{-1}, the average light extinction at Mt. Zion due to EC would be 0.73 Mm^{-1}, compared to an average of 25.8 Mm-1 due to light scattering by particles (bsp). At Wishram, EC would contribute on average 0.65 Mm^{-1}, compared to 22.6 Mm^{-1} by particle scattering.

At Mt. Zion light upgorge (1) has highest EC and winter downgorge (5) the lowest. For clusters 1-3, Mt. Zion shows a similar shape in the diurnal curve for EC as for bsp, again suggesting transport from the Portland/Vancouver area. At Wishram, strong upgorge (3) has much lower EC than the others, with light downgorge (4) the greatestWishram shows a pronounced morning peak in EC for light downgorge (4) at 8-9 am, suggesting local source contributions at this time.

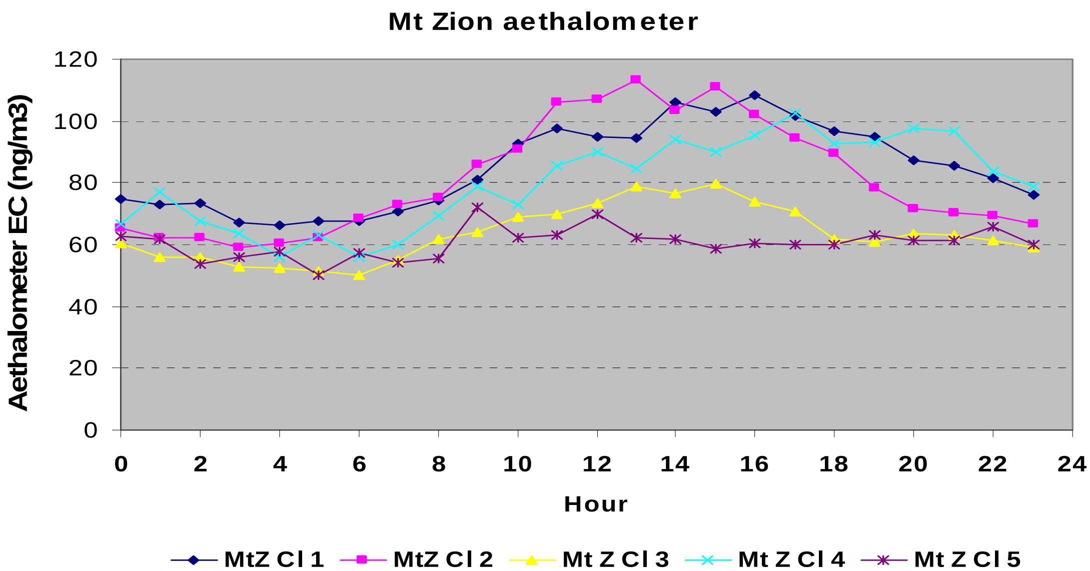


Figure 4-27. Hourly average Aethalometer derived elemental carbon at Mt. Zion by cluster.

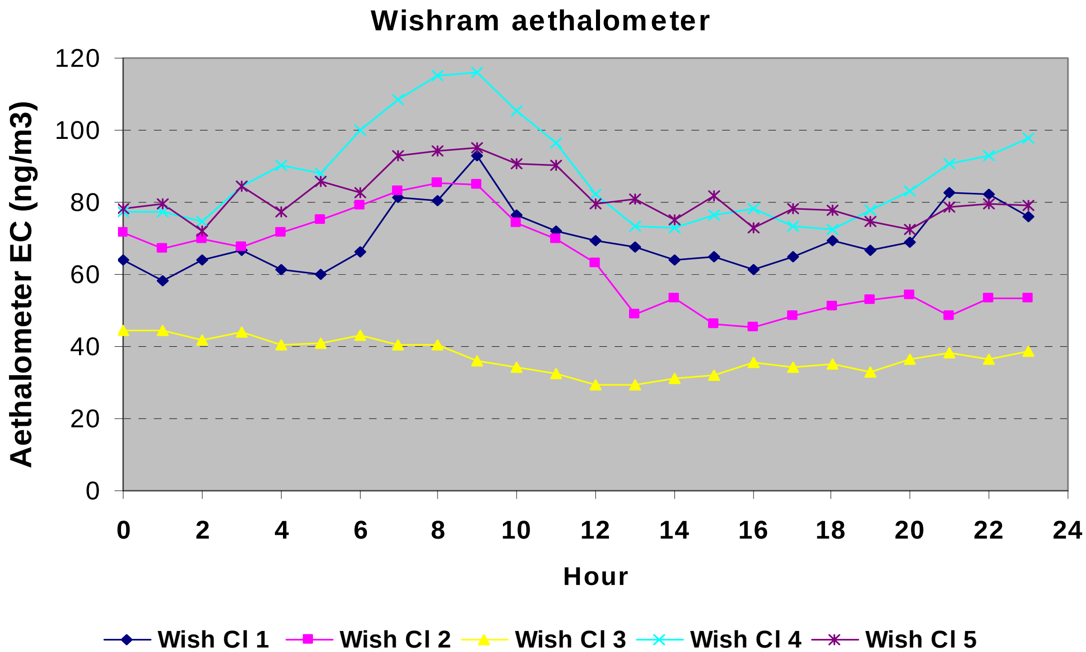


Figure 4-28. Hourly average Aethalometer derived elemental carbon at Wishram by cluster.

Table 4-4. Cluster average aethalometer derived elemental carbon (ng/m3) at Mt. Zion and Wishram.

	Mt Zion	Wishram
Light upgorge (1)	85	70
Moderate upgorge (2)	81	63
Strong upgorge (3)	63	37
Light downgorge (4)	80	87
Winter downgorge (5)	60	81
All Clusters	73	65

4.4 Summary of Cluster Wind patterns.

Table 4-5 is a summary of wind patterns and seasonal frequency for each cluster.

Table 4-5. Wind patterns and seasonal frequency by cluster.

Cluster	Wind Pattern	Seasonality
Light upgorge (1)	Light upgorge, increasing with distance into Gorge	Peak in transition months April and October, more common in winter than summer
Moderate upgorge (2)	Moderate upgorge, increasing with distance into Gorge, large diurnal variation in speed	Late summer- early fall Peak in August, most common cluster August to October
Strong upgorge (3)	Strong upgorge, increasing with distance into Gorge	Peak in July, most common cluster May-July
Light downgorge (4)	Light downgorge, except diurnally changing direction at eastern sites, upgorge Sauvie Island	Mainly Autumn and Spring (most common cluster November), uncommon summer
Winter downgorge (5)	Downgorge, light in eastern end, increasing through Gorge, light down at Sauvie Island	Predominantly winter – most common cluster December-February, no occurrences May-September

4.5 Summary of aerosol light scattering (bsp) patterns by Cluster

Light upgorge (1) Bsp is highest at Sauvie Island for all days, then decreases with distance into the Gorge. Bsp for days without precipitation was highest at Mt. Zion. Diurnal transport of aerosol was noted with peaks later in day with distance into the Gorge. Light upgorge(1) was the 2nd highest bsp cluster for western sites.

Moderate upgorge (2) Bsp was highest at Mt. Zion, gradual decreasing with distance into the Gorge. Diurnal transport of aerosol noted with peaks later in day with distance into Gorge.

Strong upgorge (3) Cleanest cluster at all sites, with a large gradient in bsp, highest bsp at Mt. Zion, lowest at eastern sites. Increase of bsp across Portland/Vancouver metropolitan area.

Light downgorge (4) Highest bsp at Sauvie Island (much higher than nearby sites), suggesting impact from Portland/Vancouver and/or downriver industry. Higher bsp at Sevenmile Hill and Memaloose than other sites, suggesting impact from The Dalles area.

Winter downgorge (5) Highest bsp among clusters for all sites except Sauvie Island. Highest at eastern sites, then decreasing westward through the Gorge until increasing at Sauvie Island (suggesting impact from Portland/Vancouver). Higher at Memaloose than Wishram and Sevenmile Hill sites, suggesting impact from the Dalles. High bsp at eastern sites suggests impacts from areas east of the gorge. Lower bsp at Sevenmile Hill than other eastern sites perhaps due to being above mixed layer at night and morning. Increase in bsp at Sevenmile Hill in afternoon, with mixing of aerosols up to the monitoring site.

5 Summary

The field portion of the Columbia River Gorge Haze Gradient Study was conducted from July 2003 through February 2005. Measurements included particle light scattering bsp at nine locations from downriver from the Gorge (Sauvie Island) to upriver from the Gorge (Towal Road), including several sites in the Gorge. Meteorological measurements were taken at all sites except Memaloose.

The objectives of the study were to characterize horizontal, vertical, and temporal patterns in haze and to gain insight into possible source regions contributing to haze in the Gorge. More detailed data analysis will be done for the Causes of Haze in the Gorge (COHAGO) study. This will include additional analyses using the nephelometer and surface meteorology data from the Haze Gradient Study and aerosol composition data collected for COHAGO (e.g. filter samples, high time resolved sulfate, nitrate, EC/OC, etc).

Because of the large number of days (>600) monitored, a statistical method (cluster analysis) was used to group days with similar wind patterns. Summaries of wind, pressure, particle light scattering (bsp), and light absorption were computed for each group of similar days (each cluster). Wind data were classified as to their component upriver (basically west to east). Upriver was termed "upgorge", downriver termed "downgorge". Light scattering data were interpreted with respect to wind transport patterns to gain insight into likely source areas for each group of days.

Five clusters of similar days were identified:

6) light upgorge flow
7) moderate upgorge flow
8) strong upgorge flow
9) light downgorge flow (diurnal reversal at eastern sites)
10) winter downgorge flow (light at east end, strong at west end)

Strong upgorge (3) was the predominant pattern in mid-summer; Winter downgorge (5) was the most frequent winter pattern. Light upgorge (1) and light downgorge (4) were most frequent in fall and spring transition months; moderate upgorge (2) was most frequent in late summer to early fall.

Winter downgorge (5) had the highest average bsp at all sites except Sauvie Island. Highest bsp for winter downgorge was at the eastern sites, with a decrease with distance downgorge. Bsp increased again at Sauvie Island as the flow exited the Gorge and crossed the Portland/Vancouver area. This transport and bsp gradient pattern suggests that sources east of the Gorge cause much of the haze and that the Portland/Vancouver area contributes additional aerosol to the Sauvie Island site.

Light downgorge (4) had the highest bsp at Sauvie Island, suggesting impact from nearby sources such as the Portland/Vancouver area and/or downriver industry.

For days without precipitation, all the upgorge clusters (1-3) had highest bsp at Mt. Zion and a decreasing bsp with distance into the Gorge. Light upgorge (1) and moderate upgorge (2) showed diurnal patterns of increasing bsp progressing upgorge to the Bonneville site during the day. Bsp also increased across the Portland/Vancouver area for each cluster, suggesting the urban area as a significant contributor to aerosol in the Gorge for these clusters.

Light downgorge (4) and winter downgorge (5) showed an increase in bsp from Wishram to Sevenmile Hill and Memaloose, suggesting impact from The Dalles area. At Sevenmile Hill for light downgorge (4), the diurnal change in wind direction from upgorge to downgorge is accompanied by an increase in bsp (when the direction is from The Dalles).

At Mt. Zion and Wishram, light absorption was a minor contributor to haze.