AIR QUALITY CLIMATE IN THE COLUMBIA RIVER BASIN

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INTRODUCTION

Climate patterns in the Columbia River Basin are dominated by topographic features. Surrounding mountain ranges prevent frequent intrusion from progressing air masses and create an isolated, sometimes stagnant, basin atmosphere. Gaps through the mountains, however, allow a striking pattern of mixing that is unique to the Basin. The following describe several components of climate that influence air quality.

MIXING HEIGHT

Mixing height may be considered as a level in the atmosphere above which vertical exchange of air is inhibited. Low mixing heights mean that the air is generally stagnant with very little vertical motion and pollutants usually are trapped near the ground surface. High mixing heights allow vertical mixing within a deep layer of the atmosphere and good dispersion of pollutants.

One way to determine mixing height is to consider a parcel of air near the ground, whose temperature equals the daily maximum surface temperature, that is lifted dry adiabatically until it reaches the temperature of the ambient air, which is measured from a radiosonde observation (RAOB). The level at which the lifted parcel's temperature equals the ambient air temperature is defined as the mixing height. Above the mixed layer, further lifting of the parcel would cause it to become cooler than ambient air temperatures.

The afternoon RAOBs were used to approximately coincide with the time of maximum daily surface temperature. Afternoon RAOBS occur near 0 Greenwich Mean Time (GMT), which coincides with 4 to 6 pm in the Columbia River Basin. Data include approximately 1000 RAOBs from the period between 1966 and 1989. Mixing heights were calculated by the Western Regional Climate Center (P.O. Box 60220, Reno, Nevada 89506-0220). The stations analyzed included: Quillayute, Washington (58 meters elevation), the only station on the Pacific coast; Salem, Oregon (61 meters) and Medford, Oregon (421 meters), between the coast and Cascade mountain ranges; Spokane, Washington (722 meters) and Boise, Idaho (871 meters), inside the Basin; and Winnemucca, Nevada (1310 meters), just south of the Basin in northern Nevada.

During spring Winnemucca begins to "mix out" first because the air is not constrained by Basin topography (Figure 2). During summer (Figure 3) Winnemucca experiences consistently high mixing heights because the summer sunshine efficiently warms the inland continent. Within the Basin, the mean summer mixing height is about 1800 meters at Spokane and Boise. The range of mixing heights, however, includes levels below 900 meters, especially at Boise where topographic constraints from the Snake River valley are even more dominant than the overall Basin topography. The coastal stations are influenced by frequent intrusions of marine clouds that increase atmospheric stability. This mostly is observed at Quillayute on the Washington coast.

To illustrate potential areal extent of stagnant air, constant height levels of 1000 meters and 1400 meters were plotted over the basin topography. The first plot (Appendix Q-26) shows where stagnant air may occur if the mixing height is constant at 1000 meters, near the lowest summer mixing heights. Stagnant air is confined to the central plateau of the Basin and the lower Snake River valley. If the mixing height is constant around 1400 meters (Appendix Q-27), there is relatively good dispersion in the central plateau of the Basin. High basins and some high valleys in Oregon and western Montana may trap air, however, and cause pockets of stagnation.

RAIN DAYS PER MONTH

Airborne pollutants may fall out of the atmosphere by attaching to precipitating particles. Liquid precipitation (rain) is more efficient at scavenging gas and particles than solid precipitation (snow, hail, etc.). Therefore, a simple analysis of rain days per month was conducted to help determine the frequency of wet deposition onto plants and into soils and snowcover.

To determine rain days in wild-land regions data from all National Weather Service (NWS) cooperative observation station sites above 900 meters elevation were selected. Days of rain were defined as those days with measured precipitation and mean temperatures greater than 5°C. When near-surface air temperatures are above 5°C, 100 percent of observed precipitation is rain (Ferguson, 1994; Ferguson and Breyfogle 1994). Because mean temperature was used, there may be some periods during the day when temperatures are lower and snowfall may occur, but these should be rare. This definition omits days with cold rain, mixed periods of rain and snow, and purely snow.

Rain days per month were calculated for January during three characteristic climate years, 1982, 1988, and 1989. In all years, there were few days of mid-winter rain at elevations above 900 meters. Although significant precipitation occurred during winter 1982, most fell as snow and rain was confined to lower elevations in eastern Oregon and western Idaho (Appendix Q-28). Only a small amount of precipitation occurred in January 1988 (Appendix Q-29) so a similar pattern of rain days occurred with some rain at higher elevations in central Idaho and western Montana. The "normal" year of 1989 (Appendix Q-30) again showed few mid-winter rain days, mostly at lower elevations.

The number of rain days per month become greater than snow days per month as seasonal temperatures increase. Slightly fewer stations observed rain during April in 1982 (Appendix Q-31) than other years because snowfall continued through spring that year. In 1988 there were a number of stations throughout the Basin that experienced 50 percent to 75 percent days with spring rain (Appendix Q-32). In 1989, most stations experienced at least 25 percent days with rain, which is typical of spring (Appendix Q-33).

Summer precipitation in the Basin is dominated by atmospheric convection. During wet years, like 1982 (Appendix Q-34) a large number of stations experience more than 50 percent days with rain, especially in places where summertime convection dominates precipitation. In 1988 (Appendix Q-35) no station measured significant precipitation as dryness pervaded the Basin. During a normal year (Appendix Q-36) typical summer patterns of precipitation prevailed with most rain days occurring in places where convection is common like eastern Idaho and western Montana.

During autumn, convection remains important in precipitation distribution. In addition, the significance of frontal and orographic precipitation begin to increase but snow also may occur. In 1982 (Appendix Q-37) most of the mountain sites show over 25 percent of the days with rain. Cool than normal seasonal temperatures also may have caused days with snow. In 1988 (Appendix Q-38) few stations measured more than a few days with rain. Most of those occurred in Idaho and western Montana where convection probably remained important. During a typical year (Appendix Q-39) most stations observe about 25 percent of days with rain.

UPPER LEVEL WINDS

Winds in the upper atmosphere may carry buoyant pollutants long distances. Land managers have shown concern about the possibility of pollutants from the Basin reaching the Grand Canyon. This may occur if upper level winds over the Basin are strong northerly.

The distribution of wind speed and direction was calculated by the Western Regional Climate Center (P.O. Box 60220, Reno, Nevada 89506-0220). Winds at the 700 millibar (mb) level are shown because that level usually is above the influence of terrain surrounding the Basin (about 3000 meters) and most likely to carry pollutants out of the Basin.

At Spokane, the mean winter 700 mb wind direction is westerly with a normal variation between SSW-W-NNW (Figure 5). Nine per cent of the winds have a northerly component with speeds greater than 11 m/s. Spring winds are highly variable with mean directions between SW and WSW. Twelve percent of the winds have a northerly component but all are less than 9 m/s and most are less than 2 m/s. A similar wind distribution occurs during summer (Figure 6) with a little more preference to SW and WSW directions. In autumn, prevailing winds begin to shift back to westerly. Four per cent of autumn winds have northerly components greater than 11 m/s.

Upper level winds at Boise have a slightly different distribution. This may be because the Snake River valley, which is oriented northwest to southeast may influence winds, even those well above the surrounding topography. Over Boise, winter winds prevail from the WNW and 15 percent have a strong (greater than 11 m/s) northerly component (Figure 7). Spring winds prevail from the W, WNW, to NW and 9 percent have strong northerly components. In summer winds over Boise prevail from the WSW and 14 percent of the winds have a northerly component, but all are less than 9 m/s (Figure 8). In autumn the westerly dominate. Seven per cent have a strong northerly component.

These results suggest that strong northerly winds are most common during winter when there is very little biomass burning. The northerly winds could scour away pollution trapped under the Basin=s frequent winter inversion, however. Whether the scoured components can reach the Grand Canyon or deposit along the way is unknown. Strong northerly winds are possible during spring and autumn burning seasons, but are rare. Summer northerly winds usually are too weak to transport material for long distances.

SURFACE WINDS

Winds near the earth's surface are most efficient at transporting non or neutrally-buoyant pollutants. They can carry smoke from biomass burning into nearby towns and cities. In addition, surface winds can carry pollutants from industrial sources into wild-land areas.

The characteristics of upper level wind can be determined from a few observations because above the influence of topography, atmospheric patterns usually change slowly over space and time. Near the ground surface, however, winds are strongly influenced by small undulations in topography. There are not enough observations of surface wind to show the true variation in wind. Therefore, simple mesoscale wind model was adapted to analyze the effect of surface wind on pollution transport.[1]

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[1] Ferguson, S.A.; Peterson, M.R.; Hayes, P.S. and Akram, T. [In preparation]. Surface wind patterns in the Pacific Northwest.

Surface wind during winter primarily is controlled by pressure gradient forces between a persistent region of high pressure over the continent and frequent low centers from approaching Pacific storms (Appendix Q-5). This pressure gradient causes strong easterly winds to persist through the Cascade mountain passes. It also causes much of the stagnant air, which is trapped under the frequent winter temperature inversion, to be pulled against the eastern Cascades.[2] The passing storms also cause winds to accelerate over the higher ridge tops, especially in the Rocky mountains. Converging winds are common, like in the lee of the Blue mountains and head of the Snake River. Stagnant winds also occur, usually below the persistent inversions (see the central Snake River valley and central Columbia plateau).

During summer (Appendix Q-7), surface winds are dominated by downslope flows caused by cooling air that drains into the valleys at night. An onshore flow also prevails, causing weak to moderate westerly winds through the Cascade passes. Areas of weak convergence or stagnation occur most frequently in valleys and basins where the downslope winds are trapped by surrounding topography.

DROUGHT

Drought stress causes plants to close stomata and become less susceptible to pollution. The frequency and spatial pattern of drought is discussed in Chapter 17C of this volume.

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[2] Steenburgh, W.J; Mass, C.F; Ferguson, S.A. [In preparation]. Mesoscale structure of gap flows in the Pacific Northwest.

IMPLICATIONS OF GLOBAL CHANGE ON AIR QUALITY IN THE BASIN

Atmospheric concentrations of greenhouse gases are increasing. Major carbon constituents that contribute to the greenhouse effect are increasing at the following known rate: CO_2 - 0.4 percent or 1.5 parts per million (ppm) per year; CH_4 - 0.9 percent or 0.015 ppm per year; CFCs - 4.0 percent or 0.015 ppm (Intergovernmental Panel on Climate Change, IPCC, 1990 and 1992). A recent report by the Pacific Global Change Research Program (PacGCRP) summarized the effective sources and sinks of greenhouse gases and discussed possible implications for management (Bytnerowicz and others, in press). For example, major sources for CO_2 are listed as decomposition, respiration, biomass fires, volcanic emissions, fossil fuel burning, and changes in land use. It also was recognized, however, that more nitrogen can produce a cofertilization effect in the terrestrial biomass, which would lead to sequestration of additional carbon. In addition, a discrepancy in the global nitrous oxide budget was attributed to emissions from forest soils and proper management practices could minimize these emissions. The PacGCRP report also explains that sources of atmospheric methane include cattle, wetlands, and termites. Like CO_2 and nitrous oxides, CH_4 emissions can change by altering management practices.

Another implication of increasing greenhouse gases is their possible effect on global climate. Although uncertainty remains in the rate and magnitude of expected change, a general warming trend due to increasing concentrations of greenhouse gases is almost certain. A climate change scenario that considered the regional effect of doubling the global atmospheric concentrations of carbon dioxide ($2xCO_2$) on regional climate is discussed in Chapter 17B of this volume. The following summarize possible effects on air pollution.

1) greatest warming over high-latitude continents: less intense Arctic influence and thus weaker temperature inversions during winter,

2) continents could warm more than oceans: higher summer mixing heights,

3) decreased snow cover: less intense winter stagnation and earlier seasonal discharge of pollutants held in the snowpack,

4) increased convection over continents: more wet deposition in spring and summer with less frequent drought in southeast portions of the Basin,

5) decreased soil moisture during summer: greater summer drought, especially in the central Basin,

6) fewer, but stronger, winter cyclones: less frequent but more significant disruption of winter stagnation.

SUMMARY

The Columbia River Basin experiences similar air pollution patterns as typical basins. For example, temperature inversions, which can trap pollution in stagnant air near the ground, are common. The Basin's topography and influence from three distinct air mass types (marine, arctic, and continental), however, create unique patterns of climate that can influence the trajectories of polluting gases and particles. Winds through the mountain gaps can transport pollution into and out of the Basin, or scour away stagnant air that is trapped in the Basin. Also, rainfall is common enough to cause relatively efficient scavenging of air borne pollution during all seasons.

A few, relatively simple, analytical tools were used to show the general pattern of climate in the Basin that influences air pollution. More comprehensive analyses is possible with mesoscale meteorological models and atmospheric dispersion and deposition models. These tools could help to show greater details in the timing and extent of stagnation periods, distance and concentration of pollution gases and particles, and pollution distribution patterns under different climate and management scenarios.

LITERATURE CITATIONS

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Intergovernmental Panel on Climate Change. 1990. Climate change: the IPCC assessment. Houghton, J.T.; Jenkins, G.J.; Ephraums, J.J., eds. Cambridge University Press. Cambridge, England. 364 p.

Intergovernmental Panel on Climate Change. 1992. Climate change 1992: the supplemental report to the IPCC scientific assessment. Houghton, J.T.;Callander, B.A.;Varney, S.K., eds. Cambridge University Press. Cambridge, England. 200 p.

LIST OF FIGURES

Figure 1. Distribution of mixing heights in January for Called, Washington (uil); Salem, Oregon (sle); Medford, Oregon (mfr); Spokane, Washington (geg), Boise, Idaho (boi); and Winnemucca, Nevada (wmc). Height level categories are in increments of 150 meters above ground level (AGL). Note that mixing heights were calculated in feet AGL then converted to approximate values in meters.

Figure 2. Distribution of mixing heights in April. Same as in Figure 1.

Figure 3. Distribution of mixing heights in July. Same as in Figure 1.

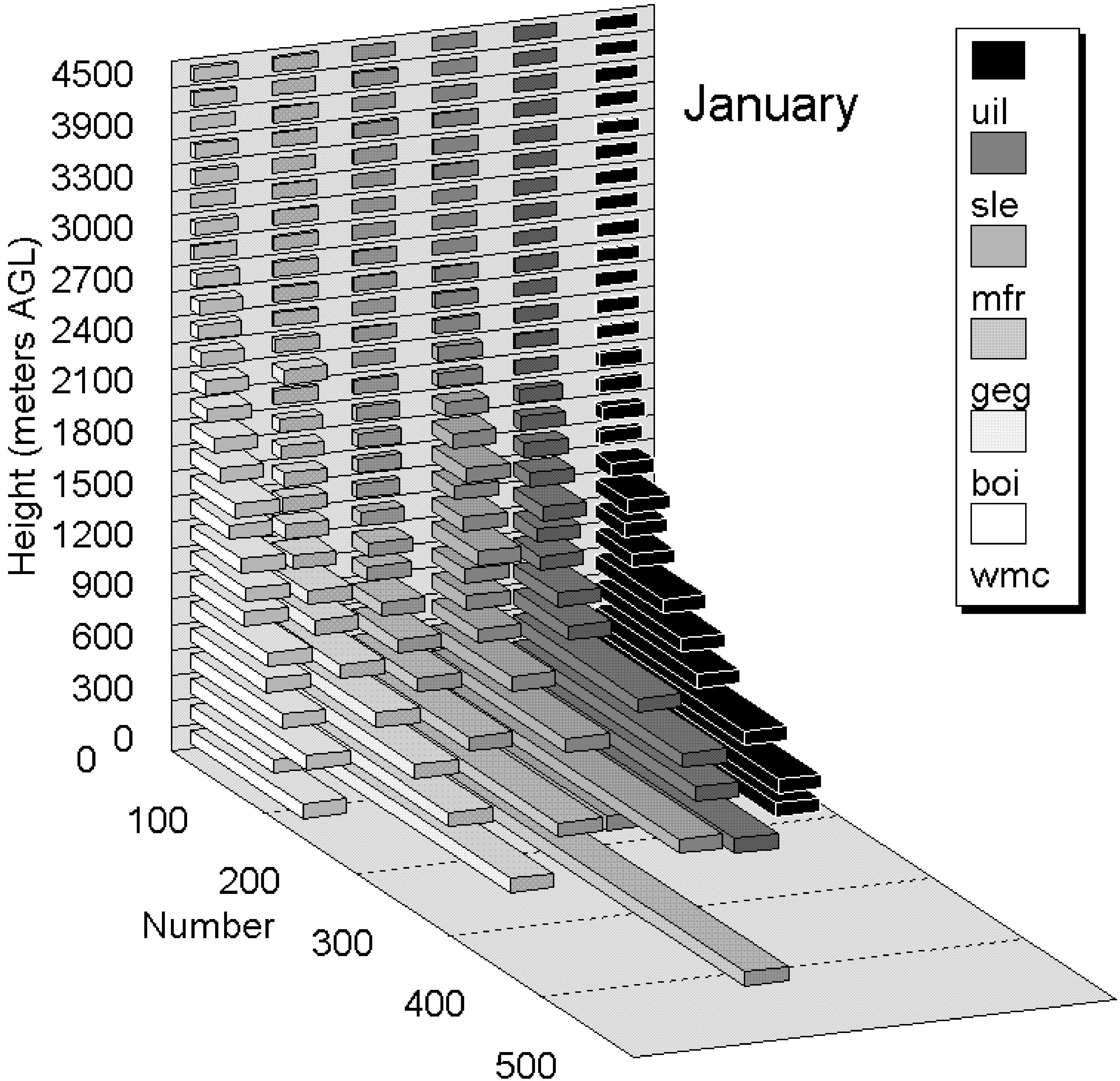
Figure 4. Distribution of mixing height in October. Same as in Figure 1.

Figure 5. Distribution of winds at the 700 mb level over Spokane, Washington during January. Note that speed categories were calculated in miles per hour then converted to approximate values in meters per second.

Figure 6. Distribution of winds at the 700 mb level over Spokane, Washington during July. Same as in Figure 5.

Figure 7. Distribution of winds at the 700 mb level over Boise, Idaho during January. Same as in Figure 5.

Figure 8. Distribution of winds at the 700 mb level over Boise, Idaho during July. Same as in Figure 5.



January
uil
sle
mfr
geg
boi
wmc
Height (meters AGL)
4500
3900
3300
3000
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1500
1200
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Number
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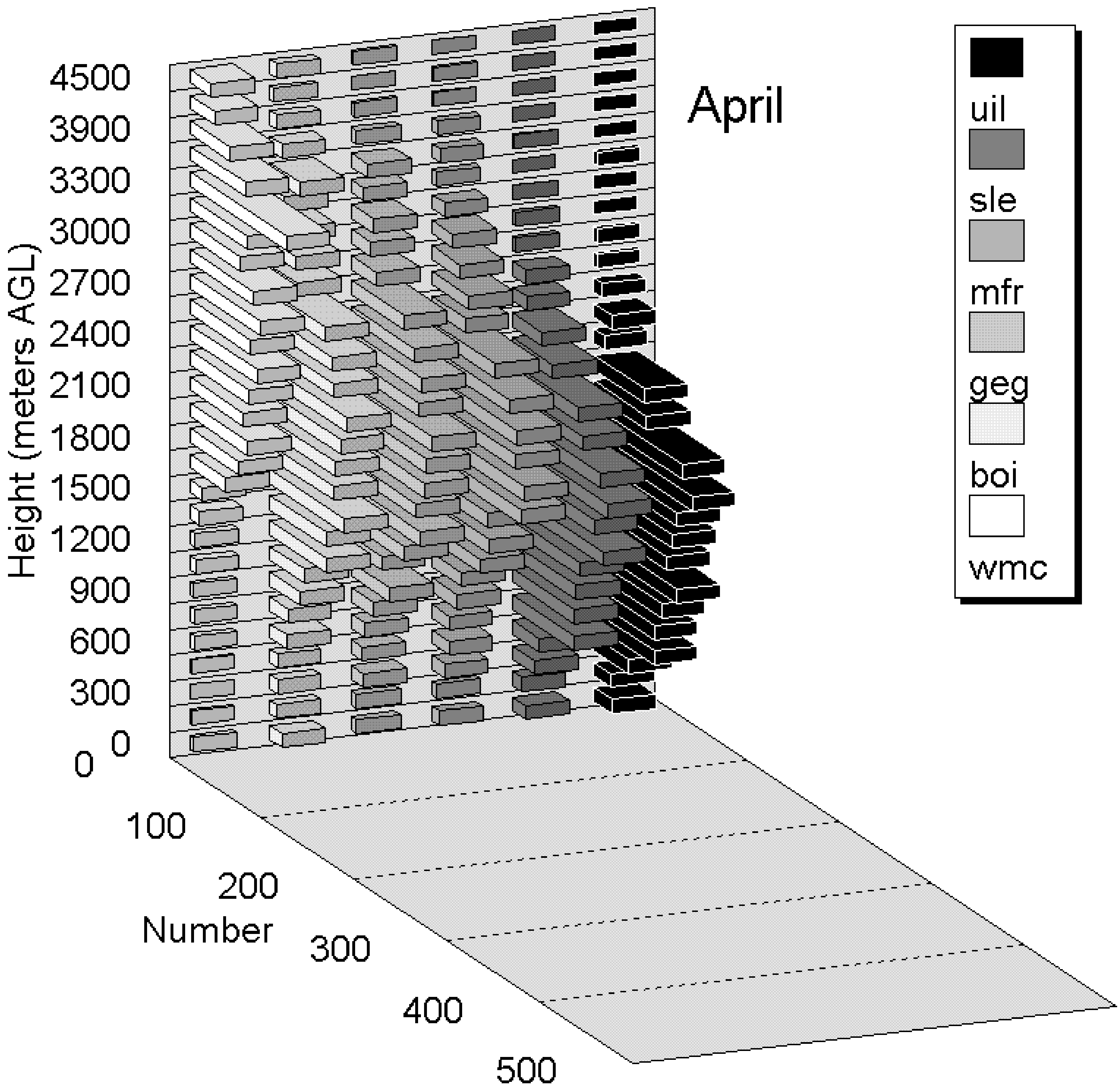

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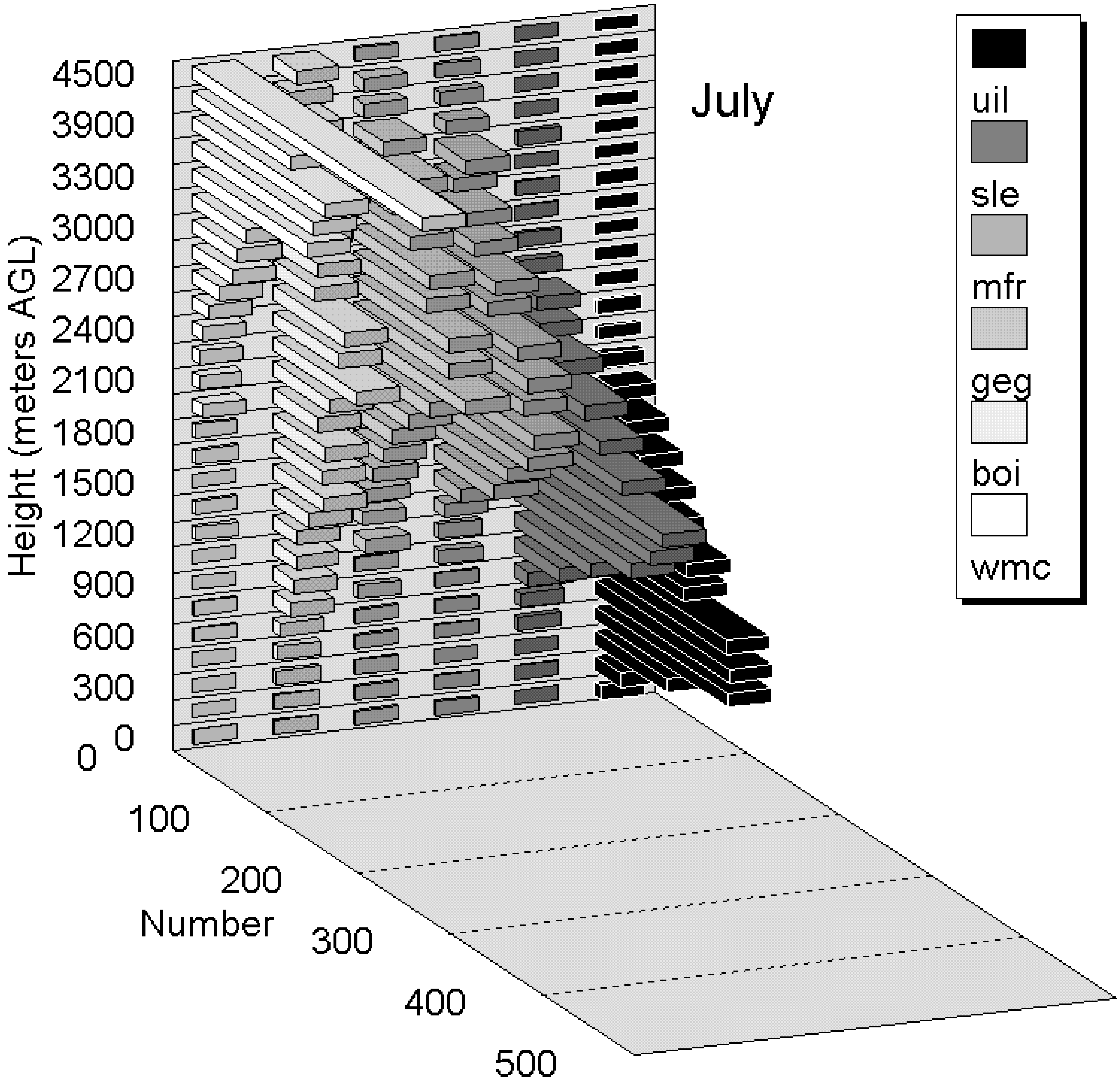

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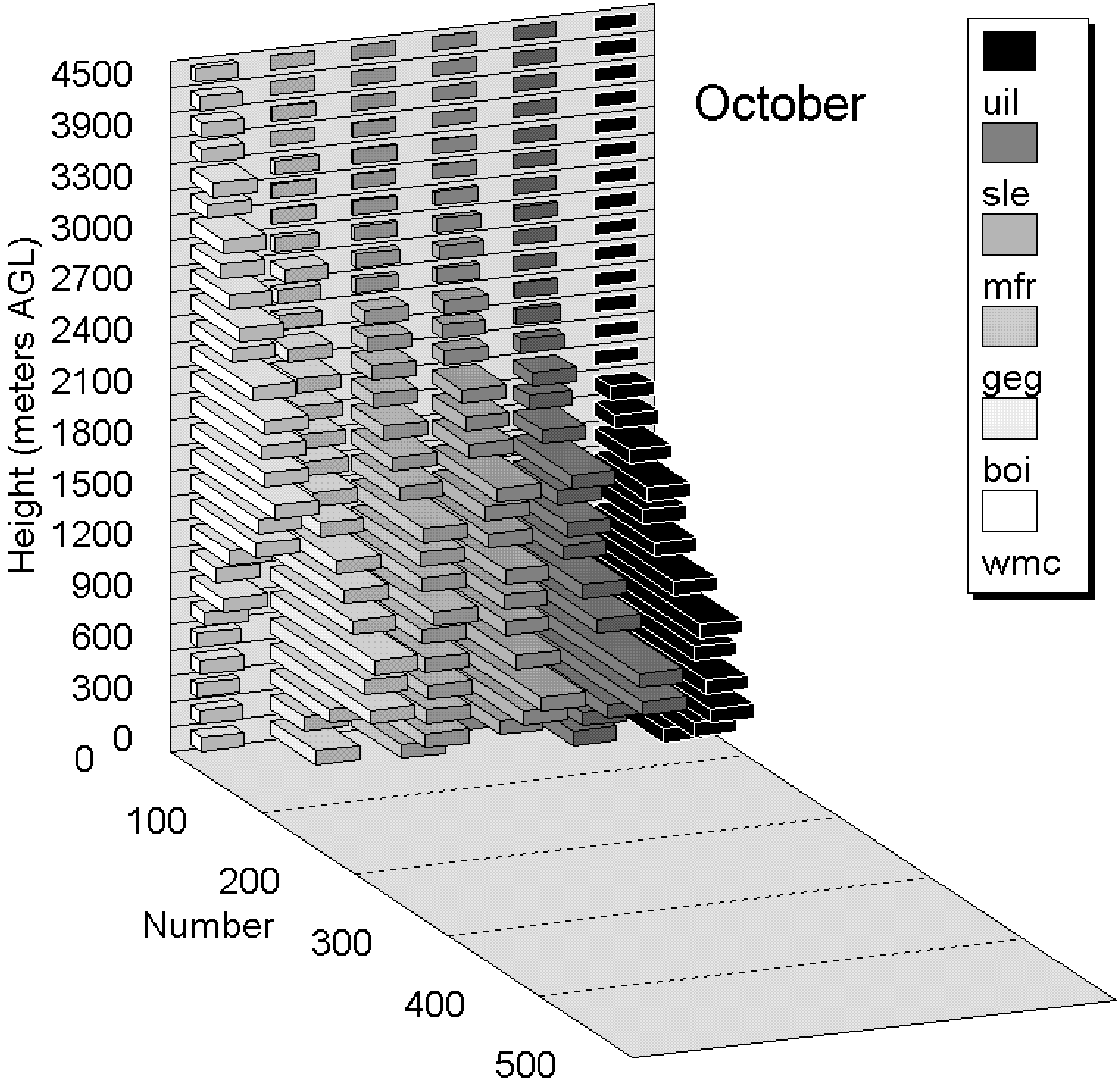

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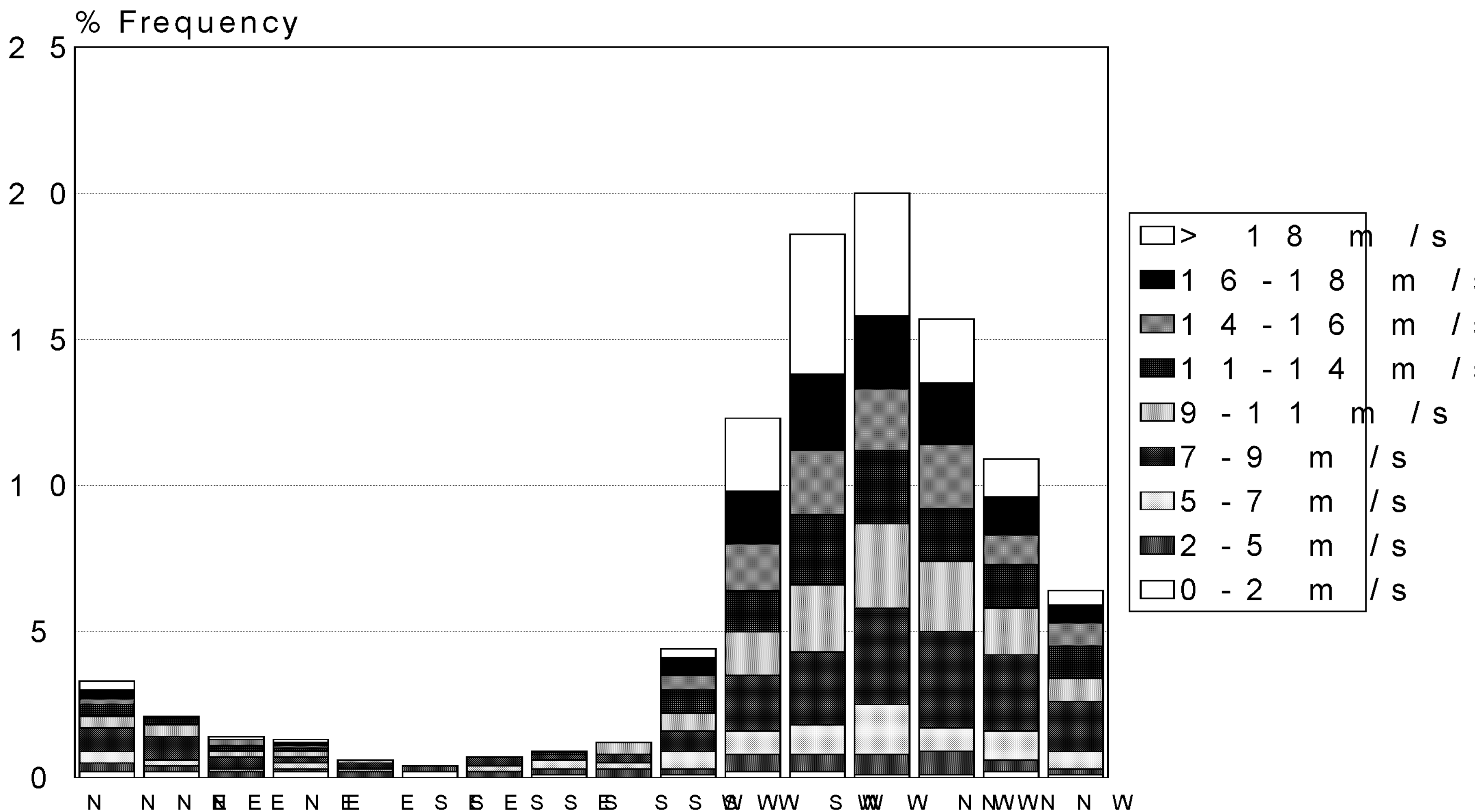

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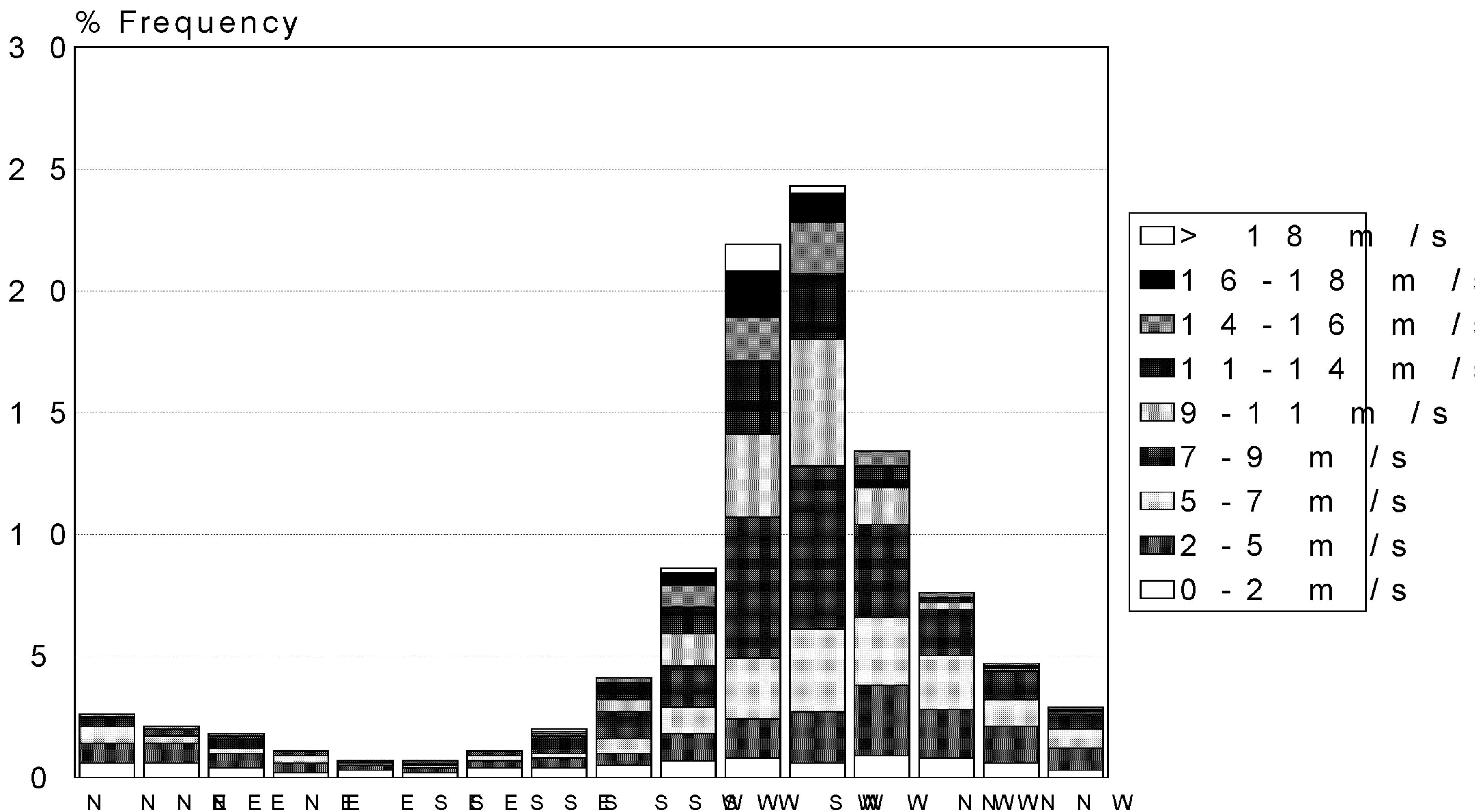
0 - 2 m/s



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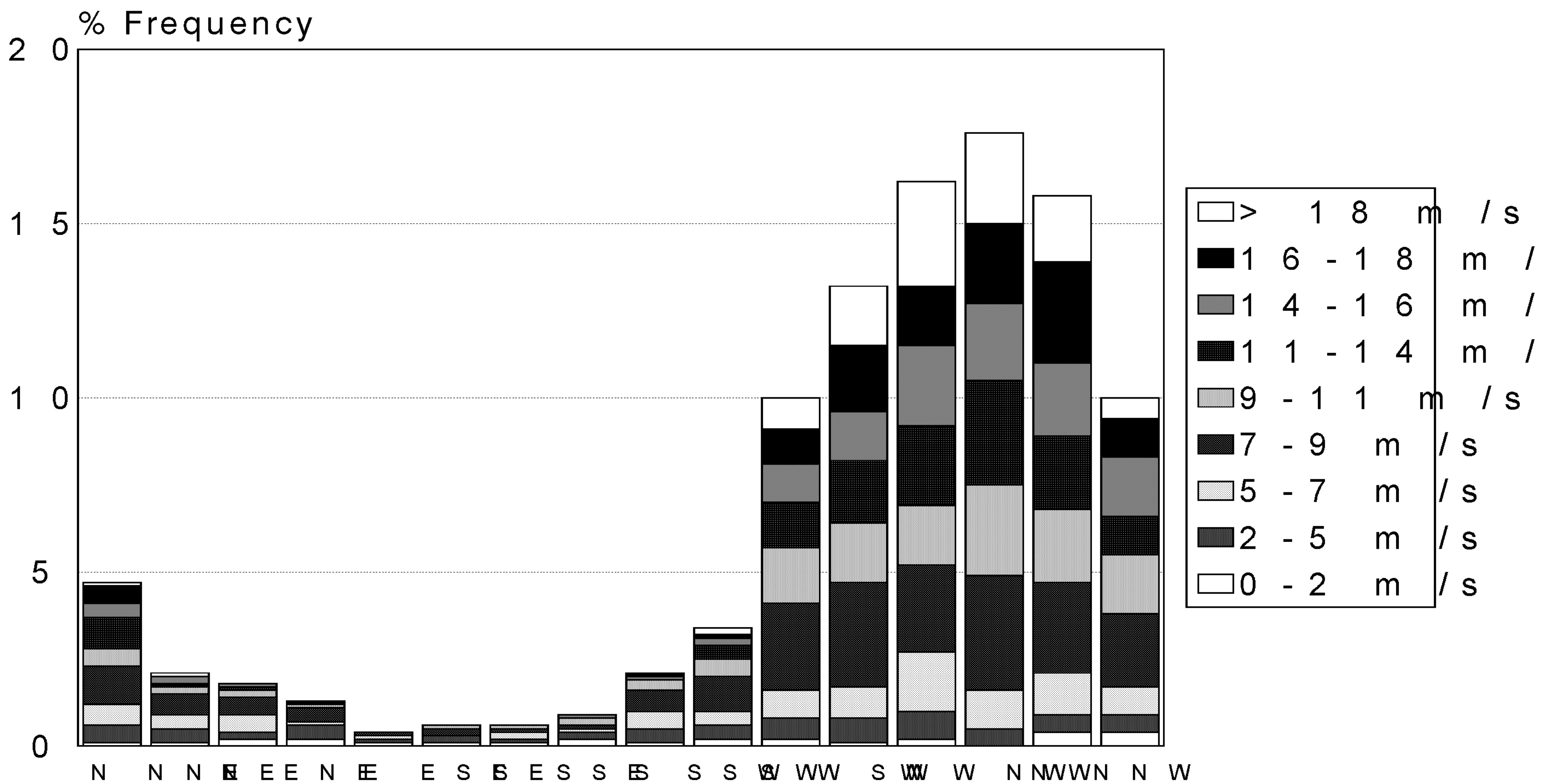
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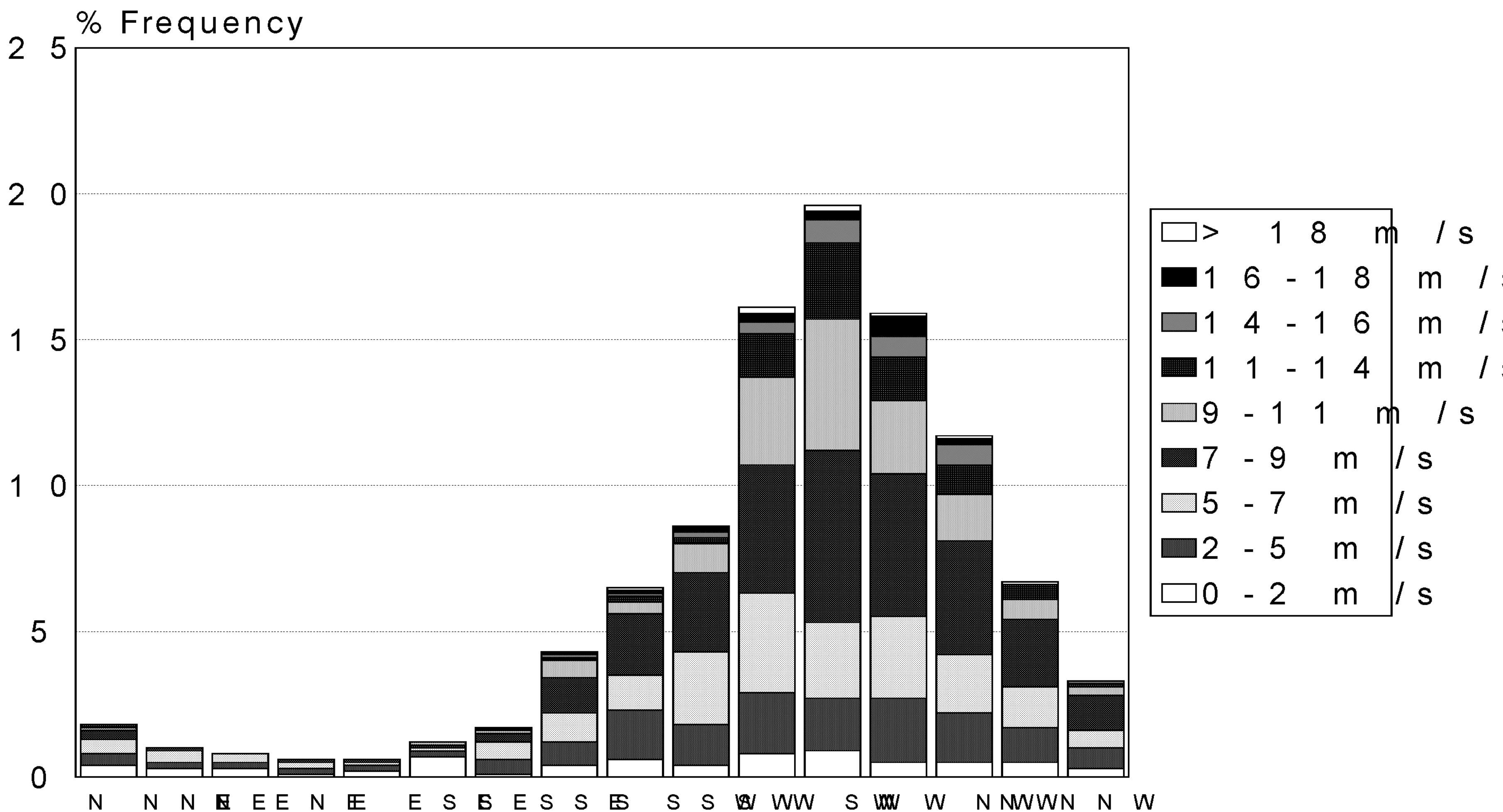

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