Dust Deposits from Anthropogenic Sources on the Snowpack of the Glaciers in the Cordillera Blanca, Peru

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Title Page Photo. *The view north over the city of Huaraz. In the background are the Huascaran and Huandoy Massifs* (Photo by: R. Semborski).

ABSTRACT

The tropical glaciers in the Cordillera Blanca are currently experiencing rapid melting due to climate change and increased human activity. To understand better whether anthropogenic airborne particulates, such as dust or black carbon, are having an effect on the retreat of the glaciers, snow samples from five separate mountains located throughout the range were collected, melted and then filtered through 25 mm quartz filters (Pallflex Tissuquartz, 0.7 μm pore size). The filters were analyzed for dust concentrations and for percentage of organic carbons. By comparing the spatial variability of the dust concentration throughout the range, the percentage of carbon in the snowpack, and present-day dust concentrations to that of the paleo-dust concentrations from the entire Holocene and into the Late Glacial Stage derived from ice-cores on Huascaran Sur, this study shows that glaciers on the west side and southern end of the Cordillera Blanca are indeed being affected by albedo-reducing anthropogenic dust.

INTRODUCTION

The Cordillera Blanca (approximately $9^{\circ}30'$S and $77^{\circ}49'$W) is located within Huascaran National Park in the Department of Ancash in North Central Peru. In recognizing its international importance, UNESCO declared Huascaran National Park a World Heritage Site in 1985 *(Shoobridge, 2005).* The Cordillera Blanca (Spanish for "*White Range"*) is the highest tropical mountain range in the world, containing some 200 mountains exceeding 5,000 meters in elevation and more than 25 mountains exceeding 6,000 meters. The highest peak in the range, and in all of the world's tropics, is Huascaran Sur rising to 6,768 meters above sea level. As shown in Figure 1, this long, narrow range is compact, stretching approximately 180 kilometers along its North-South axis and only 20 kilometers wide along its East-West axis *(Johnson, 2003).*

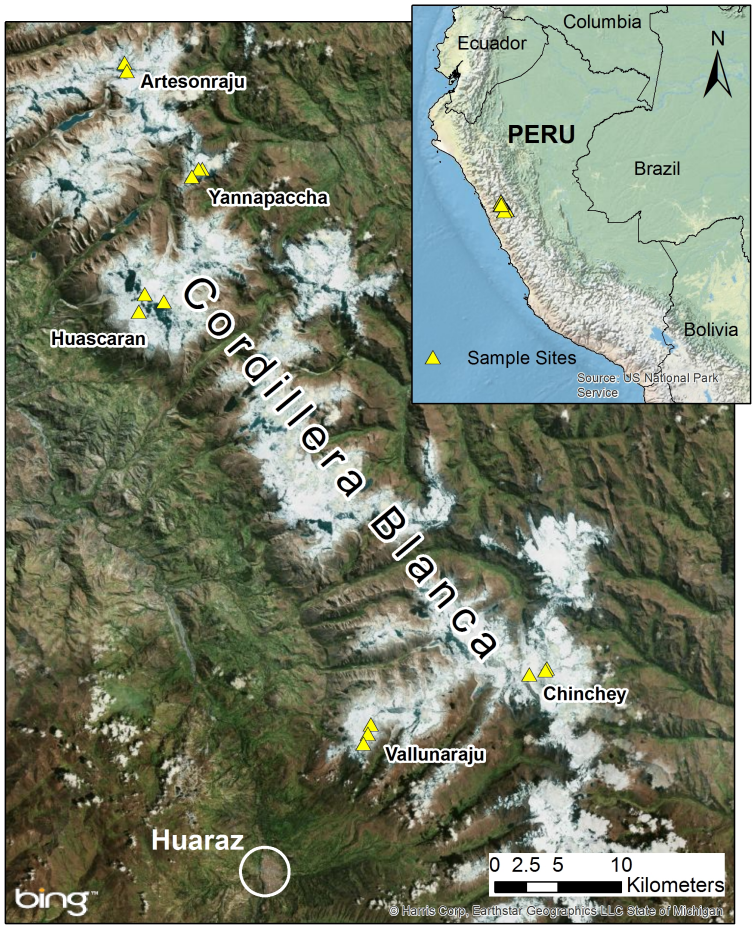


Figure 1. ***The Southern Cordillera Blanca:*** *The locations of the five mountains on which samples were collected and the corresponding sample sites within the Cordillera Blanca. This map also represents the spatial variability between these five mountains and the city of Huaraz* (Map by: R. Semborski).

In spite of its relatively small size, the Cordillera Blanca contains more than 25 percent of the world's tropical glaciers *(Bryan et al., 2010)*. The estimated total area of glaciation, as of 2003, was 569.6 ± 21 km^2 *(Racoviteanu et al., 2008).* The glaciers of the Cordillera Blanca have receded more than 22% since 1970, and more than 30% since their maximum extent during the early eighteenth century *(Racoviteanu et al., 2008; Vuille et al., 2008, Rabatel et al., 2013).* These glaciers are threatened by global climate change that is increasing temperatures at higher altitudes in the tropical latitudes *(Bradley et al., 2009).* While global climate change is clearly responsible for much of the glacial retreat in the Cordillera Blanca, recent research is also suggesting that increased dust and black carbon (BC) deposits on snow can significantly contribute to the melting of the world's high-mountain glaciers *(Ramanathan et al., 2007*; *Takeuchi et al., 2008; Kaspari et al., 2009).* Surface dust and other impurities on glaciers can affect the glacial heat budget and hence mass balance (*Takeuchi et al., 2001).* These light-absorbing impurities decrease the spectral albedo of snow, change the snowpack's energy balance and result in increased melt rates *(Painter et al*., *2012).*

This research project focuses on the effects of these light-absorbing impurities on the melting of the Cordillera Blanca's glaciers. Snow samples were collected from five different mountain glaciers during a 10-week field expedition. The goals of this research project are two-fold: first, to measure the amount of dust and carbon deposited on the snowpack of the glaciers in the Cordillera Blanca; and second, to determine whether these impurities could be due to local anthropogenic sources by comparing concentrations of dust in the snow with its proximity to potential sources.

Hypothesis: Local anthropogenic activities, such as mining, agriculture and increased emissions due to a dense and growing population, are contributing to the retreat of the glaciers in the Cordillera Blanca.

BACKGROUND

Water Resource, Economic and Recreational Implications of Glacial Recession

The glacial retreat in the Cordillera Blanca has important implications for the available water resources in the region, in particular because Peru is the most water-stressed country in South America *(Bebbington et al., 2008).* The majority of the glaciers in the Cordillera Blanca terminate in the watersheds that drain into the Rio Santa and ultimately into the Pacific Ocean *(Baraer et al., 2012).* These glaciers constitute a major contributor to the area's hydrological system. For example, during the dry season (May to September) meltwater from the glaciers may contribute up to 40% of the total discharge into the Rio Santa *(Baraer et al., 2012).* Because these watersheds supply domestic water to several municipalities and for irrigation used in agriculture, the entire Rio Santa basin is extremely vulnerable to changes in the availability of water due to receding glaciers *(McKinney et al., 2011).* Approximately 1.7 million people living within the Rio Santa Basin depend on its water for domestic consumption *(McKinney et al., 2011).* The people of Callejón de Huaylas are also dependent upon the Rio Santa for hydroelectric power. It supplies the water to the Cañon del Pato 50 Megawatt (MW) hydroelectric power plant at Huallanca, the largest generator of electricity in the area *(Baraer et al., 2012).*

In addition, the Cordillera Blanca is one of the world's premier mountaineering and high mountain-trekking destinations, attracting climbers and tourists from all over the world. Visitors, both Peruvian and foreign, contribute significantly to the regional economy. In 2000, over 95,000 Peruvians and 13,617 international visitors came to Huascaran National Park *(Shoobridge, 2005).* The Regional Office of Industry, Tourism, and International Integration and Business within Ancash Regional Government estimates that a typical Peruvian tourist contributes $35 US dollars a day (for an average 3-day stay), and an international tourist contributes an average of $100 US dollars a day (for an average 10-day stay) to the region's economy *(Shoobridge, 2005).*

Many of the famous, classic and most popular climbing and trekking routes have become noticeably more difficult and dangerous in recent years, primarily due to effects

from the quickly retreating glaciers and drastically changing landscapes. The loss of some glaciated areas and area closures, such as the popular and easily accessible Pastoruri Glacier, might require the redevelopment of some tourist attractions and recreational opportunities at other destinations *(McKinney et al., 2011).* Huaraz is the principal population center and the main hub for tourist-based commerce in the Callejón de Huaylas *(Shoobridge, 2005).* The permanent loss of some of the most easily accessible glacial areas for visiting tourists and the loss of revenue resulting from the lower numbers of visitors would significantly and negatively affect this area's developing economy.

Snow Albedo and Effects of Dust on Snow

Snow has the largest range of spectral albedo (α) of any surface on Earth *(Painter et al., 2012).* Dust and other dark-colored, light-absorbing particulates, such as black carbon, on the surface of snow increase snowmelt because of the reduction of snow's fractional reflectivity, or albedo *(Grenfell et al., 2010).* How much shortwave radiation the snowpack absorbs is directly related to its albedo. This is most simply stated by the following formula:

$$K\uparrow = K\downarrow(\alpha)$$

where K is shortwave radiation in wavelengths (λ) = 0.4 – 2 μm, and $\downarrow\uparrow$ represents incoming and outgoing radiation flux densities *(DeWalle et al., 2008).*

Even small changes in snow's albedo can result in disproportionately large changes in the amount of absorbed shortwave radiation *(DeWalle et al., 2008).* The net flux of shortwave radiation is the single largest source of energy for snowmelt *(DeWalle et al., 2008)*. For example, as DeWalle et al. demonstrate, a 25% reduction in albedo (from 80% to 60% reflectivity), causes a 100% increase in absorbed shortwave (from 20% to 40% absorption) *(DeWalle et al., 2008).*

Snow albedo is largely controlled by two factors: snow grain size and solar radiation-absorbing impurities such as dust or black carbon *(DeWalle et al., 2008).* Snow grain size is the parameter that determines its spectral albedo in the near-infrared

wavelengths, while absorbing impurities affect its albedo largely in the visible wavelengths of the spectrum *(Painter et al., 2003).* Snow albedo decreases with increases in snow grain growth in the near-infrared (NIR) with wavelengths from 0.7 to 1.5 μm and in shortwave-infrared wavelengths from 1.5 to 3.0 μm *(Painter et al., 2012).* As shown in Figure 2, dust and other light-absorbing impurities decrease the albedo of snow most noticeably in the visible wavelengths, from 0.4 to 0.7 μm *(Painter et al., 2012).*

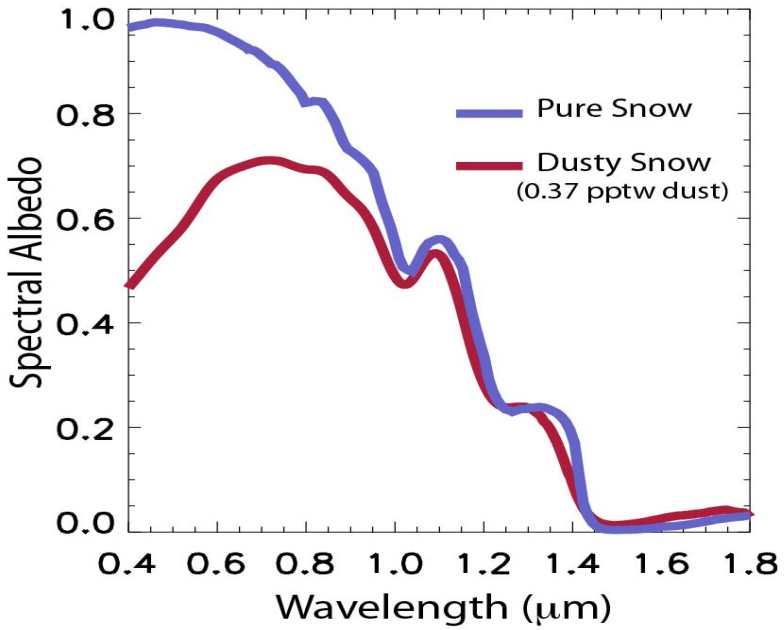


Figure 2. *Graph displaying the spectral albedo of pure (clean) snow and snow with a very high dust concentration of 0.37 parts per thousand by weight (pptw) or milligram of dust per gram of snow sample (mg g^{-1})* (Source: Painter el al., 2012. Figure 1).

Sources of Dust and Black Carbon on Snow

Aerosols such as black carbon and dust do occur naturally in the atmosphere. Wind can easily loft dust from soils into the atmosphere and black carbon aerosols can be generated, for example, by wildfires. However, atmospheric dust concentrations can be increased by anthropogenic activities such as agriculture, mining and heavy vehicle traffic on dirt roads. For example, studies have shown a doubling of desert dust in the atmosphere during the 20th century over most of the globe *(Mahowald et al., 2010).*

Black carbon in the atmosphere is most commonly derived from man-made sources. Soot particles and black carbon are anthropogenically generated primarily from incomplete combustion in diesel engines and burning of coal, agricultural fires and residential wood burning *(Grenfell et al., 2011).* In the first deployment of the HIAPER Pole-to-Pole Observations campaign (HIPPO1), black carbon concentration measurements in the atmosphere were made using a Single-Particle Soot Photometer (SP2) on board the NSF/NCAR GV aircraft *(Schwarz et al., 2010).* These measurements, made from January 9-23, 2009, covered the troposphere in the latitudes from 80°N to 67°S *(Schwarz et al., 2010).* The results of HIPPO1, shown in Figure 3, show the highest levels of black carbon concentrations in the very high northern latitudes and the lowest concentrations in the southern hemisphere. It is noticeable that many of the cleanest conditions were observed in the southern tropics at altitudes between 3,000 and 6,000 meters. This could imply that any black carbon deposits found in the Cordillera Blanca do not originate from long range, large-scale global transport, but instead come from local anthropogenic sources.

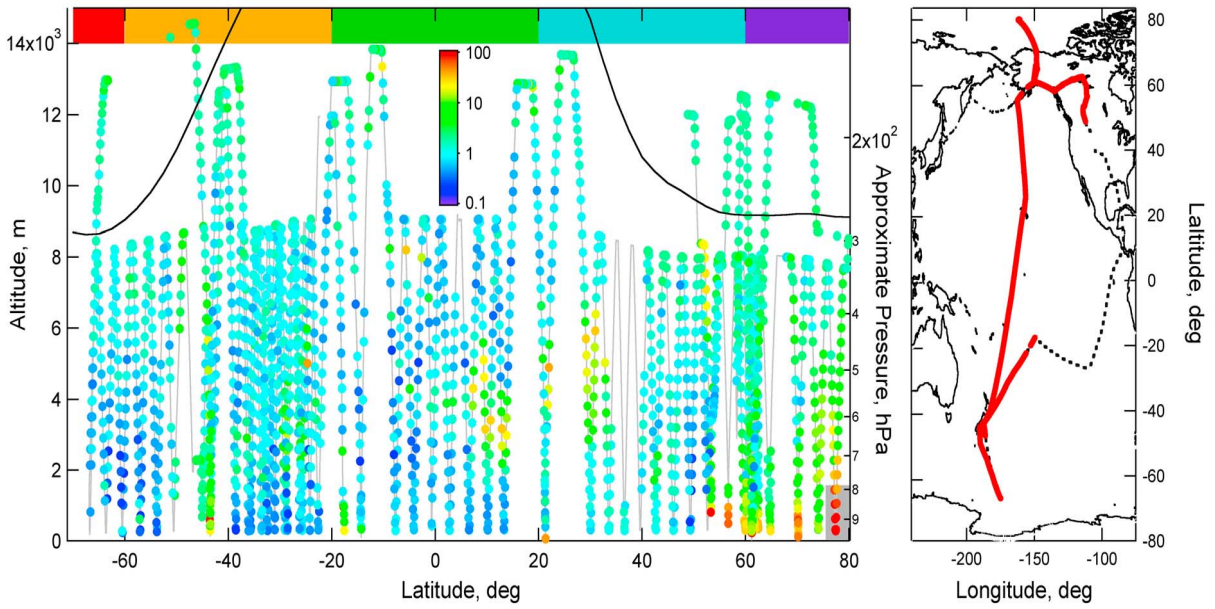


Figure 3. *Atmospheric cross section of black carbon concentration in January 2009. The black carbon mass loadings are color-coded along the flight tracks, with the red showing the highest pollution levels (e.g. urban environments) and purple representing the cleanest conditions observed* (Source: Schwarz et al., 2010. Figure 1).

Particulates such as dust or black carbon end up in the snowpack in one of two ways: wet deposition (from actual snowfall events) or dry deposition (from wind or other non-precipitation events) *(DeWalle et al., 2008).* These aerosol particles, in a wet deposition scenario, act as condensation nuclei for the initial formation of the ice crystal. After ice crystals are formed in clouds and gain sufficient mass, gravity takes over and these crystals fall toward the earth's surface *(McClung et al., 1993).* Additional aerosols can be scavenged out of the atmosphere by the falling snowflakes. Due to their much higher surface area to mass ratio and slower falling velocities, snowflakes are much more efficient than raindrops at scrubbing particulates out of the atmosphere *(DeWalle et al., 2008).* Thus, under similar atmospheric conditions, snowpacks typically have higher concentrations of aerosols than does rainwater *(DeWalle et al., 2008).*

Dry deposition of light-absorbing particulates on snow occurs primarily because of air-mass movements. This can result from large-scale wind events, weather patterns, or smaller, more local thermal and orographically driven wind events *(Wang et al., 2013).* Most of the large-scale major weather systems tend to arrive in the Cordillera Blanca from the southeast, originating in the Amazon River Basin *(Racoviteanu et al., 2008).* Shown in Figure 4 is the 12-hour trajectory for an air mass originating in the city of Huaraz on July 29, 2013. However, because the Cordillera Blanca is situated in the tropics and has tremendous local vertical relief of more than 4,200 meters, this mountain range experiences extremely wide daily temperature swings *(Shoobridge, 2005*). This is particularly noticeable at high-altitudes where the air temperature plummets rapidly after sunset. It is not uncommon for temperatures to drop below -20°C at night over 5,000 meters, while rising up to over 25°C in the day in the valley bottoms at 4,200 meters *(Johnson, 2003).* These large diurnal temperature swings, in turn, can cause very strong local thermally induced mountain winds that can originate from the western valleys despite the prevailing wind pattern *(Sevink, 2009).*

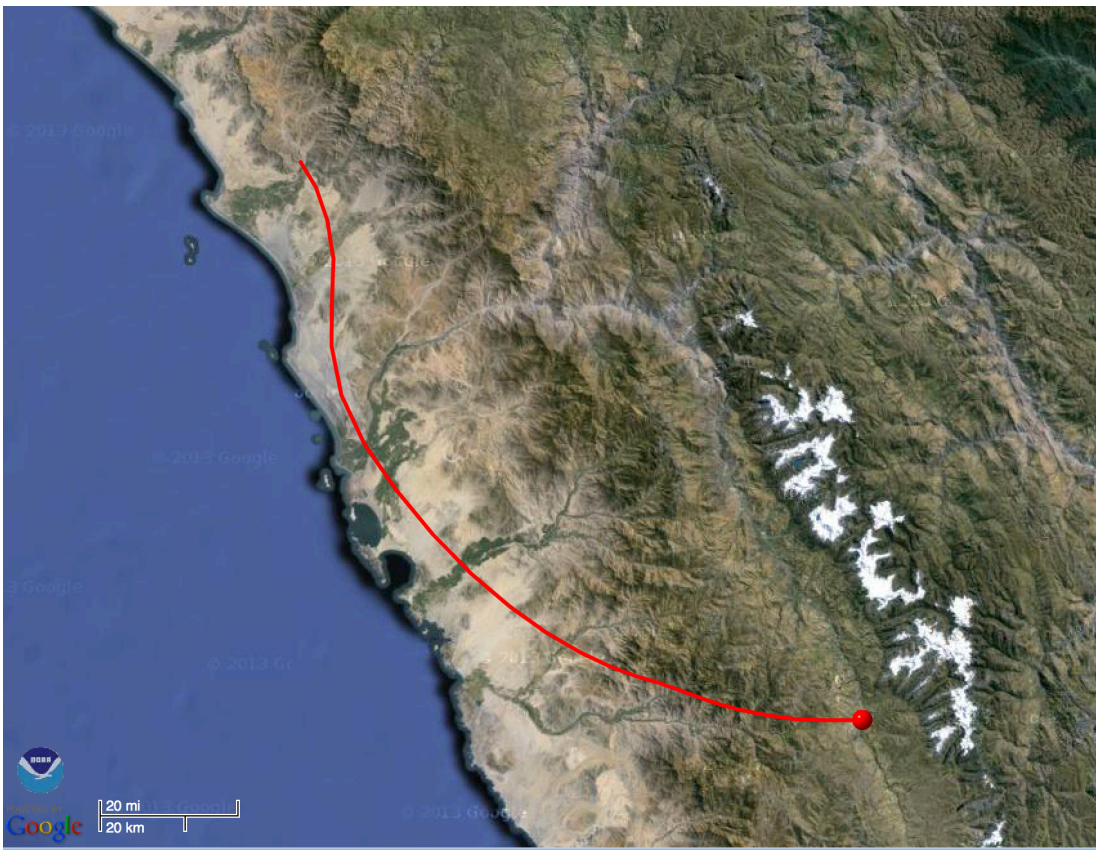


Figure 4. *This figure shows an atmospheric projection model during late-July, 2013 for an air mass originating from the city of Huaraz (77.53333°W , 9.533333°S) at an altitude of 3,000 m a.s.l.*
(Source: http://ready.arl.noaa.gov/HYSPLIT_proj.php).

The southern end of the Cordillera Blanca is home to the most likely sources of anthropogenically produced dust and black carbon. Huaraz, the capital of the District of Ancash, is by far the largest city in the area with a population of about 100,000 *(Johnson, 2003).* Huaraz is dense, growing and developing city packed into the bottom of the southern-end of the Callejón de Huaylas. Surrounding Huaraz, there is an intense, albeit mostly small-scale, year-round agricultural industry *(McKinney, 2011).* In addition to the dust and soil disturbances created by this agricultural industry, it also generates soot and black carbon associated with the burning of fields.

In addition, there are several mines in and around the Cordillera Blanca *(Sevink, 2009).* Many of these are small-scale coal mines operated by only a small number of workers *(Sevink, 2009).* There are, however, two huge modern open-pit mines near the

southern part of the range: the Antamina Mine which produces copper, zinc and molybdenum on the eastern side, and the Pierina Mine producing gold on the western side *(Sevink, 2009)*. Figure 5 is a HYSPLIT particle dispersion/deposition model for a twelve-hour period on August 1, 2013 for an air mass originating from near the Antamina Mine on the eastern side of the range (77.050464°W, 9.542594°S).

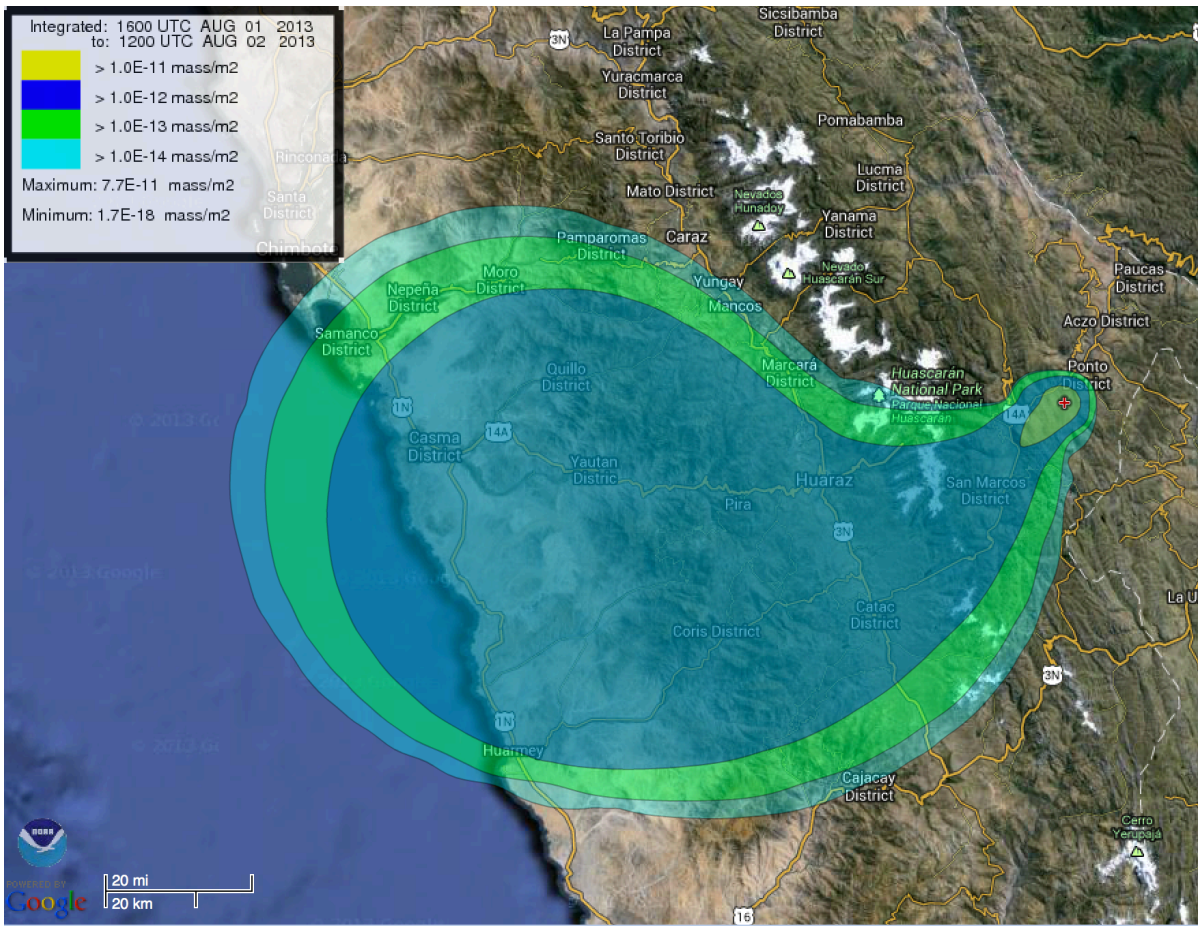
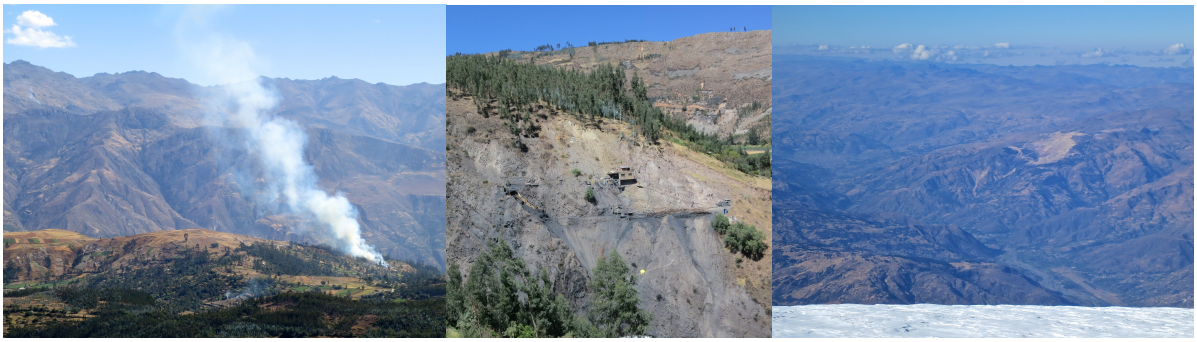


Figure 5. *The extent of particle dry-deposition over the Cordillera Blanca. This is a HYSPLIT atmospheric dispersion/deposition model for a 12-hour period during August 1, 2013 for an air mass originating from near the Antamina Mine at an altitude of 4,100 m a.s.l* (Source: http://ready.arl.noaa.gov/hypub-bin/disp1.pl).

The Antamina mine, in terms of operating volume, is one of the top ten largest mines on the globe, averaging 430,000 tons of material removed per day *(Antamina, 2009)*. Currently, the mine pit measures 3,400 meters long by 1,800 meters wide and is 700 meters deep *(Antamina, 2009)*. The Pierina Gold Mine, owned by the Canadian

Barrick Gold Corporation, is just 10 kilometers northwest of Huaraz at an altitude of 4,100 meters and is the largest open-pit gold mine in Peru *(Barrick, 2013).*



(a) ***(b)*** ***(c)***

Photos 1. ***Potential sources of dust and black carbon aerosols within or near the Cordillera Blanca:*** ***(a).*** *A photo showing common agricultural burning practices within the Callejón de Huaylas.* ***(b).*** *An example of the many small scale coal mining operations near the village of Musho below Huascaran Sur.* ***(c).*** *An image looking south from the summit of Huascaran Sur showing the spatial relationship between the city of Huaraz, the Pierina Gold Mine and the Cordillera Blanca.* (Photos: R. Semborski).

METHODOLOGY

Snow Sampling and Filtering Protocols

Thirty snow samples were collected from five different mountains, representing wide spatial variability throughout the range. The elevation of the sample sites ranged from a low of 4,869 meters on Yannapaccha to a high point of 6,759 meters on Huascaran Sur. The specific location for each of the sample sites was determined using several factors. First, the snow sample sites needed to be located above the equilibrium line altitude (ELA) on each glacier to ensure only the collection of the current season's snow. Second, samples were collected at every 300 to 500 meters of altitude change unless climbing conditions and local topography forced variations to this pattern. Samples were generally collected starting on the summit and continuing on the descent in order to avoid having to carry any snow or extra weight up the mountain. Third, sample sites were selected to be as far away as possible from any potential natural

source of contamination (e.g. bare-rock faces, talus/scree slopes, avalanche paths or moraines). Lastly, sites were chosen, when the specific route conditions permitted, to allow for the collection of samples from different aspects with respect to the Amazonian eastern side versus the drier west side of the range.

At each sample site, two snow samples were collected, one from each of the top two layers in the snowpack. These two samples represented snow from the last two significant snowfall events. Approximately one kilogram of snow was collected in a generic one-gallon Ziploc bag. The specific geographical sample location was determined using a handheld Garmin 62s GPS unit and recorded in a waterproof field notebook. Along with the altitude, longitude and latitude from the GPS, the date, time, wind speed, wind direction, aspect, snow grain type, snow grain size and layer depths were also recorded. Each sample bag was clearly labeled and then double- bagged for careful transport back to camp for processing.

The snow samples were processed in camp the same day they were collected, unless the return to camp was extremely late and it was cold enough to ensure the sample remained frozen; in that case, it was processed early the next morning. Each double-bagged sample was quickly melted using a six-liter plastic tub and a bath of boiling water melted from nearby snow or from a local stream. Using a 60 mL syringe, 600 mL (10 syringes) of water from the sample was slowly (~30 seconds for each syringe) pushed through a 25 mm quartz fiber filter (Pallflex Tissuquartz, 0.7 μm pore size). Each filter was allowed to air-dry as much as possible while in the field, then stored in an Airtite coin holder case with protective foam donuts for transport back to Huaraz. Upon return to Huaraz, the filters were completely dried and stored in a freezer, thereby preventing any biological contamination or activity.

(a) ***(b)***

Photos 2. ***(a).*** *Collecting snow samples and recording data on the summit of Huascaran Sur (6,768 m), August 2, 2013* (Photo: M. Lurie). ***(b).*** *Equipment used for the melting of collected snow samples and filtering at Vallunaraju Basecamp (4,900 m), July 6, 2013* (Photos: R. Semborski).

Concentration Analysis

Each filter was analyzed to determine the bulk mass of solid particulates per unit volume of snow water equivalent (SWE), or rather, the concentration of dust in the snow. This was accomplished by weighing the filters in their respective pre-labeled cases before filtering and again afterwards, then simply subtracting the difference. The filters, with their cases, were weighed at the Kiowa Water Lab located at the Institute of Arctic and Alpine Research (INSTAAR) in Boulder, CO, using a Mettler AE50. In order to convert the mass accumulated in the 600 mL samples confidently to a more convenient milligram per liter (mg L^{-1}) or milligram/gram (mg g^{-1}) format, the correlation between the mass gained versus the number of syringes used needed to be established.

To test if the dust concentration levels remained consistent with different volumes of filtered water, snow was collected in the foothills above Boulder, CO, using the same method as described above. The snow samples were then filtered using

different numbers of syringes: 1, 2, 4 and 8. The results of this initial experiment are shown in Figure 6. There was an R^2 value of 0.97, implying that over 97% of the mass added is explained by the increase in volume of water sampled, thus justifying the normalization to mg L^{-1} or mg g^{-1}.

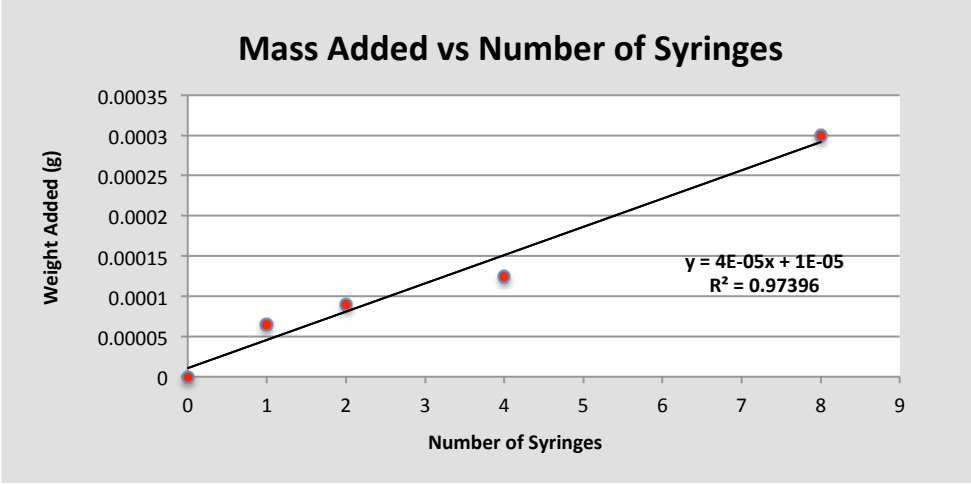


Figure 6. *The results from the initial experiment showing mass gained from snow samples with using different number of syringes. It was used to establish correlation between mass of sediment on filter vs. volume of water filtered.*

Loss on Ignition Analysis

The twelve filters with the highest concentrations of dust were further analyzed using the Loss on Ignition (LOI) method at the Sedimentology Lab located at the Institute of Arctic and Alpine Research (INSTAAR) in Boulder, CO. This method allows accurate measurement of organic material (carbons) in the sediment on the filters *(Veres, 2002).* The filters separate the organic materials from the inorganic materials in terms of mass. LOI consists of "igniting" a sample of predetermined mass at a very high temperature, allowing the volatile matter (the organics) to burn off, and then re-determining the mass, thus measuring the total mass of lost matter. The protocol for the LOI analysis is as follows: (1) weigh empty crucibles (tare) using a Mettler AE 100 scale, (2) weigh crucible plus air-dried filter, (3) place in oven at 105 °C overnight, (4) put samples in dessicator and burp at 15 seconds/15 minutes/30 minutes, (5) place

samples in furnace at 550 °C for two hours, (6) place back in oven at 105 degrees C for 10 minutes (to cool sample), (7) place samples back in dessicator and burp at 15 seconds/15 minutes/30 minutes, (8) re-weigh crucibles for ashed weighed plus tare.

RESULTS

Dust Concentrations in Snow

The results of the bulk mass analysis, the concentration of particles per unit volume of SWE (mg g^{-1}), varied widely in the snow for the five different mountains. Figure 7 shows the distribution of dust concentration versus the altitude at which the sample was collected. Dust concentrations increased with increases of altitude, up to ~5,700 m a.s.l. This is most noticeable on Vallunaraju, Yannapaccha and Artesonraju. Dust concentrations then declined above altitudes of ~6,000 m a.s.l.

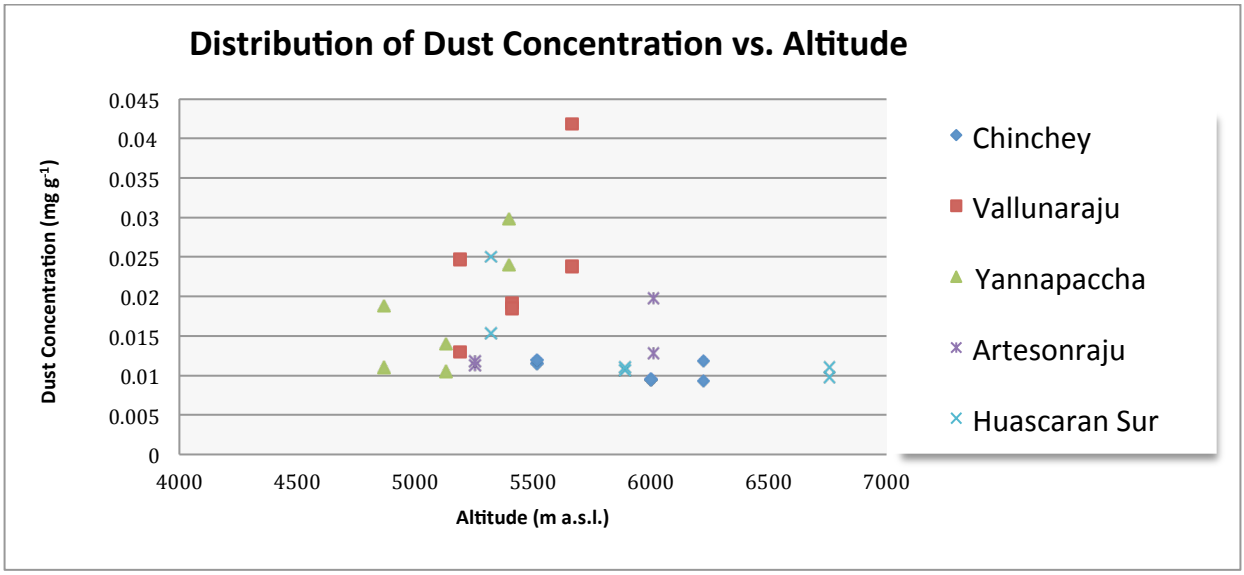


Figure 7. *The concentration of dust particles for all of the filtered snow samples (mg g^{-1}) versus the altitude (m a.s.l.) at which each of the samples was collected for each of the mountains. It shows a general trend, most noticeable on Vallunaraju, Yannapaccha and Artesonraju, towards an increase in dust concentrations which correlates with an increase in altitude up to ~5,700 meters. Above ~6,000 meters, however, there are lower concentrations of dust.*

The snow sample with the lowest dust concentration, 0.0093 mg g^{-1}, was collected from the second-layer on the eastern aspect of the summit cone of Chinchey at 6,224 m a.s.l. The highest dust concentration sampled, 0.0418 mg g^{-1}, came from the surface layer on the summit of Vallunaraju at 5,667 m a.s.l. Both snow layers sampled at 5,399 m a.s.l. on the summit of Yannapaccha had relatively high dust concentrations: 0.024 mg g^{-1} (surface layer) and 0.0298 mg g^{-1} (sub-surface). The only other sample with a similarly high concentration of 0.0250 mg g^{-1} was collected from the sub-surface layer at 5,321 m a.s.l. on the lower western slopes of Huascaran Sur.

The results of dust concentrations were then averaged for each of the five different mountains on which samples were collected, (Figure 8.) Chinchey, located on the remote eastern side of the range, was the "cleanest" mountain with an average dust concentration of 0.0106 mg g^{-1}. The snow on Vallunaraju, located closest to Huaraz on the western side of the range, was the "dirtiest", with dust concentration of 0.0235 mg g^{-1}, approximately twice the level of Chinchey. The other three mountains, Yannapaccha, Artesonraju and Hauscaran Sur, had average dust concentrations of 0.0180 mg g^{-1}, 0.0140 mg g^{-1}, and 0.0138 mg g^{-1}, respectively.

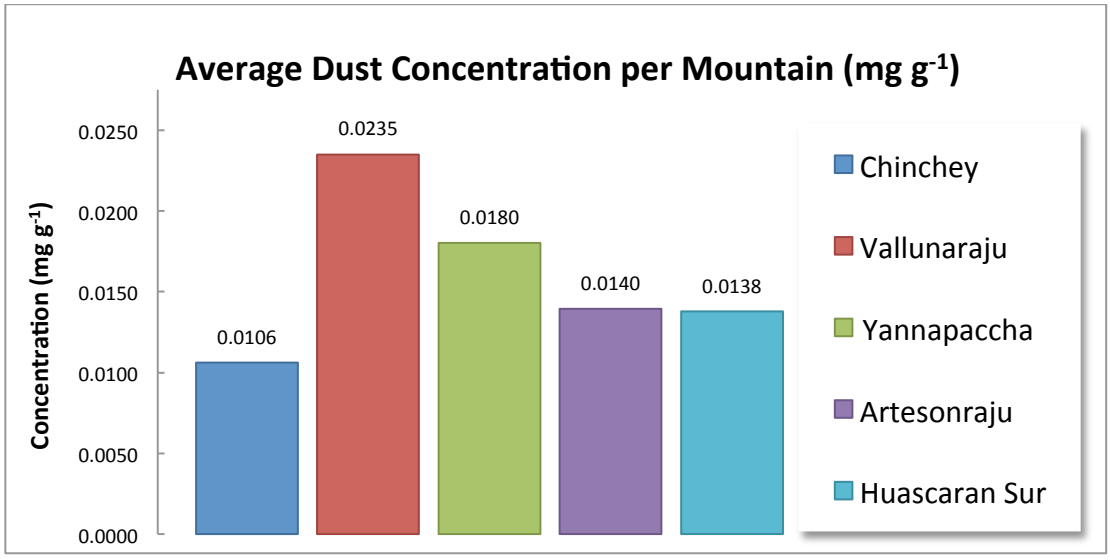


Figure 8. *Average concentration load of particles for all of the filtered snow samples (mg g^{-1}) for each of the mountains. The highest average concentration of dust in the snow reveals the dirtiest snow is on Vallunaraju. The lowest average concentration of dust in the snow reveals the cleanest snow was on Chinchey.*

Minerals vs. Organic Carbon

The Loss on Ignition analysis of the filters resulted in the percentage of minerals versus organic material (carbon), ranging from a low of 9.2% carbon at 6,012 m a.s.l. on Artesonraju to a high of 26.4% carbon at 5,399 m a.s.l. on Yannapaccha. As shown in Table 1, the snow samples from Yannapaccha had the highest overall percentage of carbon matter, including the only two samples with over 20% carbon.

Table 1. *Comparison of dust concentrations and the percent of organic matter (carbon) in the snow samples for each of the mountains.*

Mountain	Altitude of Sample (m a.s.l.)	Dust Concentration (mg g^{-1})	% Organic Carbon
Chinchey	5516	0.0015	11.6
	6224	0.0018	9.9
Vallunaraju	5667	0.0418	12.4
	5667	0.0238	18.9
	5412	0.0192	13.9
	5188	0.0247	14.9
Yannapaccha	5399	0.0240	26.4
	5399	0.0298	20.7
	4869	0.0188	15.9
Artesonraju	6012	0.0198	9.2
Huascaran Sur	5321	0.0153	16.3
	5321	0.0250	15.3

Comparing Results with Past Research

The percentage of organic carbon matter in the surface dust from other glaciers throughout the world fall into the following ranges: 15.7 – 20.1% on the Greenland Ice Cap; 0.3 – 13.8% in the Canadian Arctic; 6.3 – 22.0% in the Himalaya; and a significantly lower 0.6 – 2.7% in Patagonia *(Takeuchi et al., 2001).* The results from the LOI analysis showed that the percentage of organic carbon material in the Cordillera Blanca ranges from 9.2 – 26.4%. The percentages of organic carbon material on the glaciers of the Cordillera Blanca are significantly higher than what was reported in the 2001 Takeuchi

et al. study of the much lower altitude Tyndall Glacier located on the Southern Patagonia Icecap.

In 1993, Lonnie Thompson et al., (1995) drilled two ice-cores to bedrock on the col between the Huascaran Norte and Huascaran Sur (6,048 m a.s.l.). These ice-cores were analyzed for dust concentrations going back to the time period prior to the transition of the Holocene from Late Glacial Stage (LGS), ~15,000 the years before present *(Thompson et al., 1995).* They reported findings for these paleo-dust concentrations as the number of particles with diameters ≥ 0.63 μm and ≤ 16.0 μm per milliliter of sample for the entire Holocene in 100-year averages, [Figure 9: (reproduced from *Thompson et al., 1995)].* According to Thompson et al., the average dust concentration at ~6,000 m on Huascaran for the entire Holocene is 0.16 mg kg^{-1}, or 0.00016 mg g^{-1} and the LGS average dust concentration is 32.2 mg kg^{-1}, or 0.0322 mg g^{-1}. There are six major Holocene dust events (> 30 x 10^3 particles per ml of ice) shown in Figure 9 as well, but the origin of these is currently unknown *(Thompson et al., 1995).*

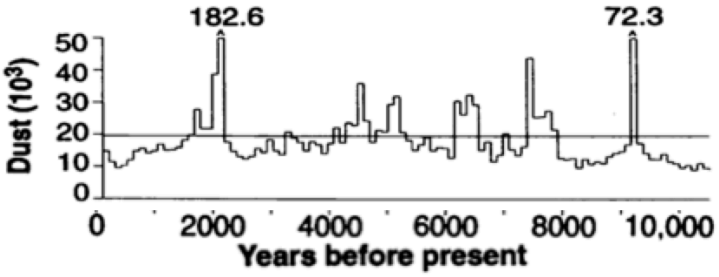


Figure 9. *Dust concentrations versus time (100-year averages) from the 1993 Huascaran Thompson et al. ice cores. This chart represents numbers of particles with diameters* ≥ 0.63 *μm and* ≤ 16.0 *μm per milliliter of ice sample* (Source: Thompson et al., 1995. Figure 7).

In this study, dust concentrations from the two samples collected from ~5,900 m a.s.l. on the col between the two Huascarans yielded 0.0110 mg g^{-1} and 0.0107 mg g^{-1}, respectively. The location of these samples is nearly identical to that of the ice cores collected twenty years earlier.

Summary

Are local anthropogenic activities, such as mining, agriculture and increased emissions due to a dense and growing population, contributing to the retreat of the glaciers in the Cordillera Blanca? An affirmative answer suggests itself based on the following factors: (1) the spatial variability of the dust concentrations throughout the range, (2) the percentage of carbon in the snowpack throughout the range, and (3) the comparison of present-day dust concentrations on the Huascaran col from this current study to paleo-dust concentrations as reported by Thompson et al., (1995).

The aim of this research project was to obtain accurate measurements determining differences in dust concentrations for five separate mountains located in different parts of the Cordillera Blanca. These measurements show that Vallunaraju, the mountain closest to Huaraz that was sampled, has a much higher dust level concentration than does Chinchey, the mountain furthest east from Huaraz. Despite the prevailing winds originating in the Amazon, it appears that the local mountain winds, caused by the dramatic and large diurnal temperature swings within the Cordillera Blanca, are strong enough to transport aerosols originating from the Callejón de Huaylas and the city of Huaraz. Furthermore, it appears these winds are capable of transporting dust and other aerosols to at least an altitude of ~5,700 m a.s.l.

The percentage of organic carbon in the snowpack is more consistent with other mountain ranges and glaciers located in the more populated northern hemisphere than it is with the sparsely populated southern tip of South American at the Patagonian Tyndall Glacier *(Takeuchi et al., 2001).* Moreover, the dust concentrations in the snow sampled from the ~6,000 m a.s.l. col on Huascaran during this research project are approximately 68 times dustier than that of the Holocene average (0.0110 mg g^{-1} vs. 0.00016 mg g^{-1}), from the ice cores. In addition, some of dust concentrations from this research project are approaching and even exceed the high dust concentrations of the LGS. For example, the snow on the summit of Vallunaraju had a measured dust concentration of 0.0418 mg g^{-1}, compared to the LGS average on Huascaran of 0.0322 mg g^{-1} *(Thompson et al., 1995).*

These conclusions suggest that anthropogenic activities are indeed increasing the dust levels found in the snow on the glaciers of the Cordillera Blanca and are likely contributing to the retreat of the glaciers. While not all of the mountains in the Cordillera Blanca are receiving anthropogenic dust from sources located within Callejón de Huaylas, results from this study suggest that, at a minimum, the mountains located on the west side of the range, especially in the southern end near the principal population and industrial centers, do.

FURTHER RESEARCH

This research takes a preliminary peek into the role of light-absorbing particles on the melting snow of the glaciers in the Cordillera Blanca. Recognizing the limitations of the types and costs of the analysis used in this project, more sophisticated analyses that can be employed with the same snow collection and filtration techniques. For example, an integrated sandwich spectral analysis setup could be used to quantify the spectral absorptivity of the particulates on the filters *(Grenfell et al., 2011).* Spectral absorptivity could then be compared to samples created using fullerene soot in known quantities *(Schwarz et al., 2012).* This could aid in the quantification of absorptivity from black carbon versus dust. Data could then be analyzed for its particulate composition and spatial relationship to population centers, mines and other industrial activities with respect to prevailing weather patterns in an effort to determine the source of these particulates.

ACKNOWLEDGEMENTS

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APPENDIX

Data

Filter Number	Date	Mountain	Time	Site Description	Altitude (m)
1	6/21/13	Chinchey	3:45pm	Camp 2:Flat Glacier	5122
2	6/21/13	Chinchey	3:45pm	Camp 2:Flat Glacier	5122
Orange 1	6/24/13	Chinchey	10:15am	High Camp: Flat Glacier	5516
Orange 2	6/24/13	Chinchey	10:15am	High Camp: Flat Glacier	5516
Orange 3	6/25/13	Chinchey	1:20pm	Summit: East Aspect	6224
Orange 4	6/25/13	Chinchey	1:20pm	Summit: East Aspect	6224
Orange 5	6/25/13	Chinchey	3:30pm	Descent: West Aspect	6000
Orange 6	6/25/13	Chinchey	3:30pm	Descent: West Aspect	6000
Orange 7	7/6/13	Vallunaraju	2:15pm	Summit: Flat	5667
Orange 8	7/6/13	Vallunaraju	2:15pm	Summit: Flat	5667
Orange 9	7/6/13	Vallunaraju	3:05pm	Descent: West Aspect	5412
Orange 10	7/6/13	Vallunaraju	3:05pm	Descent: West Aspect	5412
Orange 11	7/6/13	Vallunaraju	3:30pm	Descent: Southwest Aspect	5188
Orange 12	7/6/13	Vallunaraju	3:30pm	Descent: Southwest Aspect	5188
Orange 13	7/18/13	Yannapaccha	3:00pm	Summit: West Aspect	5399
Orange 14	7/18/13	Yannapaccha	3:00pm	Summit: West Aspect	5399
Orange 15	7/18/13	Yannapaccha	5:10pm	Descent: West Aspect	5133
Orange 16	7/18/13	Yannapaccha	5:10pm	Descent: West Aspect	5133
Orange 17	7/18/13	Yannapaccha	5:50pm	Descent: West Aspect	4869
Orange 18	7/18/13	Yannapaccha	5:50pm	Descent: West Aspect	4869
Orange 19	7/24/13	Artesonraju	2:30pm	Summit: North Aspect	6012
Orange 20	7/24/13	Artesonraju	2:30pm	Summit: North Aspect	6012
Orange 21	7/24/13	Artesonraju	8:45pm	Descent: South Aspect	5253
Orange 22	7/24/13	Artesonraju	8:45pm	Descent: South Aspect	5253
Orange 23	7/30/13	Huascaran Sur	1:45pm	Camp 2: West Aspect	5321
Orange 24	7/30/13	Huascaran Sur	1:45pm	Camp 2: West Aspect	5321
Orange 25	7/31/13	Huascaran Sur	10:30am	Col Camp: West Aspect	5892
Orange 26	7/31/13	Huascaran Sur	10:30am	Col Camp: West Aspect	5892
Orange 27	8/2/13	Huascaran Sur	8:35am	Summit: Flat	6759
Orange 28	8/2/13	Huascaran Sur	8:35am	Summit: Flat	6759

Filter Number	GPS Waypoint	Longitude	Latitude
1	151	077°20.389' W	09°23.836' S
2	151	077°20.389' W	09°23.836' S
Orange 1	154	077°20.617' W	09°23.137 S
Orange 2	154	077°20.617' W	09°23.137 S
Orange 3	155	077°19.863' W	09°22.877' S
Orange 4	155	077°19.863' W	09°22.877' S
Orange 5	156	077°19.920' W	09°22.966' S
Orange 6	156	077°19.920' W	09°22.966' S
Orange 7	157	077°27.387' W	09°25.274' S
Orange 8	157	077°27.387' W	09°25.274' S
Orange 9	158	077°27.523' W	09°25.670' S
Orange 10	158	077°27.523' W	09°25.670' S
Orange 11	159	077°27.703' W	09°26.084' S
Orange 12	159	077°27.703' W	09°26.084' S
Orange 13	160	077°34.596' W	09°01.621' S
Orange 14	160	077°34.596' W	09°01.621' S
Orange 15	161	077°34.750' W	09°01.630' S
Orange 16	161	077°34.750' W	09°01.630' S
Orange 17	162	077°35.044' W	09°01.948' S
Orange 18	162	077°35.044' W	09°01.948' S
Orange 19	163	077°37.916' W	08°57.104' S
Orange 20	163	077°37.916' W	08°57.104' S
Orange 21	164	077°37.832' W	08°57.454' S
Orange 22	164	077°37.832' W	08°57.454' S
Orange 23	165	077°37.314' W	09°07.699' S
Orange 24	165	077°37.314' W	09°07.699' S
Orange 25	166	077°37.054' W	09°06.943' S
Orange 26	166	077°37.054' W	09°06.943' S
Orange 27	167	077°36.245' W	09°07.266' S
Orange 28	167	077°36.245' W	09°07.266' S

Filter Number	Fliter Weight: Clean (g)	Filter Weight: Dirty (g)	Mass Gained (g)	Concentration (mg/g)
1	N/A	N/A	N/A	
2	N/A	N/A	N/A	
Orange 1	4.2182	4.2251	0.0069	0.0115
Orange 2	4.2909	4.2981	0.0072	0.0120
Orange 3	4.2848	4.2919	0.0071	0.0118
Orange 4	4.2511	4.2567	0.0056	0.0093
Orange 5	4.2664	4.2721	0.0057	0.0095
Orange 6	4.2463	4.2520	0.0057	0.0095
Orange 7	4.2406	4.2657	0.0251	0.0418
Orange 8	4.2619	4.2762	0.0143	0.0238
Orange 9	4.2191	4.2306	0.0115	0.0192
Orange 10	4.2898	4.3009	0.0111	0.0185
Orange 11	4.2584	4.2732	0.0148	0.0247
Orange 12	4.2628	4.2706	0.0078	0.0130
Orange 13	4.2851	4.2995	0.0144	0.0240
Orange 14	4.2753	4.2932	0.0179	0.0298
Orange 15	4.2907	4.2970	0.0063	0.0105
Orange 16	4.2702	4.2786	0.0084	0.0140
Orange 17	4.2436	4.2502	0.0066	0.0110
Orange 18	4.2575	4.2688	0.0113	0.0188
Orange 19	4.2471	4.2590	0.0119	0.0198
Orange 20	4.2531	4.2608	0.0077	0.0128
Orange 21	4.2665	4.2733	0.0068	0.0113
Orange 22	4.3013	4.3084	0.0071	0.0118
Orange 23	4.2630	4.2722	0.0092	0.0153
Orange 24	4.2390	4.2540	0.0150	0.0250
Orange 25	4.2585	4.2649	0.0064	0.0107
Orange 26	4.2647	4.2713	0.0066	0.0110
Orange 27	4.2555	4.2613	0.0058	0.0097
Orange 28	4.2695	4.2761	0.0066	0.0110

Filter Number	Tare + Oven Dry	Tare + Ashed	Total Mass (g)	Mass of Carbon (g)	% Carbon
1					
2					
Orange 1	**7.624**	**7.6232**	**0.0069**	**0.0008**	**11.6**
Orange 2					
Orange 3	**12.986**	**12.9853**	**0.0071**	**0.0007**	**9.9**
Orange 4					
Orange 5					
Orange 6					
Orange 7	**9.9308**	**9.9277**	**0.0251**	**0.0031**	**12.4**
Orange 8	**9.6471**	**9.6444**	**0.0143**	**0.0027**	**18.9**
Orange 9	**9.9136**	**9.912**		**0.0016**	**13.9**
Orange 10					
Orange 11	**7.4054**	**7.4032**	**0.0148**	**0.0022**	**14.9**
Orange 12					
Orange 13	**11.7278**	**11.724**	**0.0144**	**0.0038**	**26.4**
Orange 14	**12.7128**	**12.7091**	**0.0179**	**0.0037**	**20.7**
Orange 15					
Orange 16					
Orange 17					
Orange 18	**12.8485**	**12.8467**	**0.0113**	**0.0018**	**15.9**
Orange 19	**10.7853**	**10.7842**	**0.0119**	**0.0011**	**9.2**
Orange 20					
Orange 21					
Orange 22					
Orange 23	**12.9726**	**12.9711**	**0.0092**	**0.0015**	**16.3**
Orange 24	**12.5388**	**12.5365**	**0.015**	**0.0023**	**15.3**
Orange 25					
Orange 26					
Orange 27					
Orange 28					

Huascaran National Park Research Permit

REPUBLICA DEL PERU

RESOLUCIÓN JEFATURAL N° 016-2013-SERNANP-PNH

Huaraz, 12 de Julio de 2013.

VISTA:

La Solicitud de Autorización para realizar investigación científica sin extracción de especímenes silvestres en el Área Natural Protegida, ingresada al Servicio Nacional de Áreas Naturales Protegidas por el Estado – SERNANP – Parque Nacional Huascarán, con registro TUPA N° PNH-005-2013, el Plan de Investigación correspondiente, la ficha de datos del responsable, así como la carta de acreditación de la entidad académica de procedencia, el depósito en cuenta corriente M.N Nº 57960756, así como el Informe Nº 030-2013-SERNANP-PNH/MSP.

PARQUE NACIONAL HUASCARAN V° B° JEFATURA - SERNANP -

PARQUE NACIONAL HUASCARAN V° B° Asesoría Jurídica - SERNANP -

CONSIDERANDO:

Que, el artículo 29° de la Ley N° 26834, Ley de Áreas Naturales Protegidas, el Estado reconoce la importancia de las Áreas Naturales Protegidas para el desarrollo de las actividades de investigación científica básica y aplicada, las mismas que sólo serán utilizadas si su desarrollo no afecta los objetivos primarios de conservación del área en la cual se lleven a cabo y se respete la zonificación y condiciones establecidas en el Plan Maestro del área;

Que, mediante el numeral 2 de la Segunda Disposición Complementaria Final del Decreto Legislativo N°1013, Ley de Creación del Ministerio del Ambiente, se crea el Servicio Nacional de Áreas Nacional de Áreas Naturales Protegidas por el Estado – SERNANP, constituyéndose como ente rector del Sistema Nacional de Áreas Naturales Protegidas por el Estado – SINANPE, y en su autoridad técnico normativa.

Que, asimismo, el numeral 2 de la Tercera Disposición Complementaria Final del Decreto Legislativo señalado en el considerando que antecede, dispone la fusión de la Intendencia de Áreas Naturales Protegidas – IANP del Instituto Nacional de Recursos Naturales – INRENA con el SERNANP, constituyendo éste último el ente incorporante, y así mismo establece que toda referencia hecha al INRENA, y a la IANP, o a las competencias, funciones y atribuciones respecto a las Áreas Naturales Protegidas, se entenderá efectuada al SERNANP.

Que, el numeral 163.1 del artículo 163 del Reglamento de la Ley de Áreas Naturales Protegidas, aprobado mediante Decreto Supremo N°038-2001-AG, dispone que se requiere de autorización del SERNANP, para el desarrollo de investigaciones básicas y aplicadas al interior de un Área Natural Protegida cumpliendo con un conjunto de requisitos de carácter obligatorio.

Que, el inciso h) del artículo 27° del Decreto Supremo N°006-2008-MINAM, el mismo que aprueba el Reglamento de Organización y Funciones del SERNANP, establece que es función de las Jefaturas de las Áreas Naturales Protegidas, autorizar el ingreso para realizar investigación científica en el Área Natural Protegida a su cargo.

Que, en virtud al Decreto Supremo N° 0622-75-AG del 1° de julio de 1975 se creó el Parque Nacional Huascarán (PNH), donde se deja expresamente señalado que los variados ecosistemas de la Cordillera Blanca deben ser conservados por el Estado ya que constituyen patrimonio natural, científico y cultural de la Nación.

Que, mediante solicitud señalada en el visto, el investigador Robert James Semborski, solicita al SERNANP – Parque Nacional Huascarán una autorización para realizar una investigación científica sin extracción de especímenes, en el Área Natural Protegida - Parque Nacional Huascarán a fin de ejecutar el proyecto de investigación "Polvo y Depósitos de Carbono Negro de Fuentes Antropogénicos en la Capa de Nieve de los Glaciares en la Cordillera Blanca, Perú", por el período comprendido entre el 04 de julio hasta el 04 de agosto del 2013.

Que, luego de la evaluación técnica y legal efectuada respecto a los documentos que obran en el expediente señalados en el visto, se concluye que el solicitante ha cumplido con presentar los requisitos estipulados en el Reglamento de la Ley General de Áreas Naturales Protegidas, así con el vigente Texto Único de Procedimientos Administrativos – TUPA del Servicio Nacional de Áreas Naturales Protegidas por el Estado - SERNANP, aprobado mediante Decreto Supremo N° 002-2012-MINAM, por lo que resulta pertinente otorgar la autorización de investigación científica solicitada.

En uso de las atribuciones conferidas en el inciso h) del artículo 27° del Reglamento de Organización y Funciones del SERNANP, aprobado mediante Decreto Supremo N°006-2008-MINAM.

SE RESUELVE:

Artículo 1°.- Otorgar la autorización de ingreso para realizar investigación científica en el Parque Nacional Huascarán a través del proyecto de investigación denominado "Polvo y Depósitos de Carbono Negro de Fuentes Antropogénicos en la Capa de Nieve de los Glaciares en la Cordillera Blanca, Perú", requerida mediante

solicitud con registro TUPA N° PNH-005-2013, del Sistema de Gestión de Documentos del SERNANP por un período comprendido entre el 04 de julio hasta el 04 de agosto del 2013.

Artículo 2°.- Autorizar el ingreso al Parque Nacional Huascarán de conformidad con lo señalado en el artículo precedente, a las siguientes personas:

- Robert James Semborski, Usa, con Pasaporte N° 216919662, Estudiante de Glaciología, Universidad de Colorado, departamento de geografía, Responsable.
- Max Cassady Lurie, Usa, con Pasaporte Nº 425816941, Glaciología y Cambio Climático, Universidad de Maine, El Instituto de Cambio Climático, Colaborador.

Artículo 3°.- La autorización a que se refiere el artículo primero de la presente resolución, caducará automáticamente al vencer el plazo concedido para la misma, así como por el incumplimiento de los compromisos adquiridos o de la normatividad de la materia, específicamente la Ley de Áreas Naturales Protegidas y su Reglamento, sin perjuicio de las responsabilidades administrativas, civiles o penales que pudieran originarse.

Artículo 4°.- Las Instituciones Científicas que respaldan a las personas antes señaladas, según el acuerdo de cooperación científica que obra en el expediente, serán responsables por los compromisos adquiridos, y estarán sujetas a sanción por incumplimiento de los mismos.

Artículo 5°.- El responsable del mencionado proyecto de investigación, se compromete a entregar al SERNANP – Parque Nacional Huascarán, un informe referente al avance del proyecto y posteriormente al concluir con la investigación entregará un ejemplar del estudio final.

Artículo 6°.- Regístrese la presente Resolución en el archivo de autorizaciones del Parque Nacional Huascarán.

Regístrese y comuníquese.

Ing. Ricardo Jesús Gómez López
Jefe del Parque Nacional Huascarán
SERNANP-MINAM

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