Assignment 2 - HYSPLIT Modelling

The Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) developed by the National Oceanic and Atmospheric Administration (NOAA) is a computer model that is used to compute air parcel trajectories and deposition or dispersion of atmospheric pollutants ("HYSPLIT – 2", n.d.). A common application is a trajectory analysis to determine origins of air masses and establish source-receiver relationships. HYSPLIT has been used in a variety of simulations and applications such as tracking or forecasting the release of wildfire smoke, pollutants, dust, radioactive material, volcanic ash, etc ("HYSPLIT – 2", n.d.). The model's calculation method uses a moving frame of reference for the diffusion as trajectories of air particles move from the source location. A fixed three-dimensional grid is also used as a frame of reference to compute pollutant concentrations (Stein et al., 2015). A large variety of meteorological data is used in its calculations from mesoscales to global scales (Stein et al., 2015).

Explosive volcanic eruptions can eject large quantities of particulate matter (tephra), along with other aerosols, trace gases and droplets which are carried upwards into the atmosphere by the buoyant eruption column and are dispersed by winds (Heffter, Stunder & Rolph, 1990). Volcanic ash consists of fragments of pulverized rock, minerals and volcanic glass created during volcanic eruptions. These fragments usually measure less than 2mm in diameter. Plumes of volcanic ash are a flight safety hazard. Volcanic ash is small, abrasive and particles of rock and glass can cause significant wear to propellers and turbines - leading to engine stalls and failure. Ash can also affect cabin air quality as well as damage avionics (Heffter, Stunder & Rolph, 1990). The 2010 Eyjafjallajökull eruption produced an ash cloud that forced the cancellation of roughly 100,000 flights and affected close to 7 million passengers, costing the aviation industry an estimated $2.6 billion ("Safe, Efficient Flight Operations in Regions of Volcanic Activity", n.d.). Volcanic ash can have massive impacts to infrastructure, human health and ecosystem functions. Resulting ash fall can lead to crop failure and livestock death (Heffter, Stunder & Rolph, 1990). If inhaled, volcanic ash can trigger asthma and even suffocation. Large eruptions can cause a reduction in global temperatures by raising the Earth's albedo. Long-term cooling effects are primarily dependent upon injection of sulfuric acid which can nucleate and form aerosols which cool the surface by reflection solar radiation and warm the stratosphere by absorbing terrestrial radiation (Heffter, Stunder & Rolph, 1990).

Mount Redoubt, is an active stratovolcano located in the highly volcanic arc of the Aleutian Islands of Alaska. Located in the Kenai Peninsula, it is around 180 kilometers south-west of Alaska's most populous city - Anchorage (Heffter, Stunder & Rolph, 1990). Active for mellennia, Mount Redoubt has erupted four times since it was first observed: in 1902, 1966, 1989 and 2009 (Heffter, Stunder & Rolph, 1990). According to a new volcano threat assessment which determines the greatest risks based on the potential for eruption and human impacts, Mount Redoubt came in fourth place behind: Kilauea, St.Helens and Rainier respectively (Heffter, Stunder & Rolph, 1990). Located right in between a key flight path between North America and Asia, a potential volcanic event could cause temporary halts to global aviation. In 1989, KLM Flight 867, lost power to all engines after being caught in a plume after Redoubt erupted. On March 8th 2017, the Bogoslof volcano spewed ash with advisory warnings send out to air traffic controllers (Heffter, Stunder & Rolph, 1990). This date was chosen to see what would happen if this was a major volcanic event from Redoubt. Since volcanoes can erupt at any time of year, different synoptic conditions can affect the trajectory and deposition of pollutants - June 30th 2017 was the second date used to aid in comparing and contrasting potential releases in regards to different synoptic situations. The two different dates and synoptic conditions should therefore produce very different trajectories and concentration patterns.

Trajectory Runs:

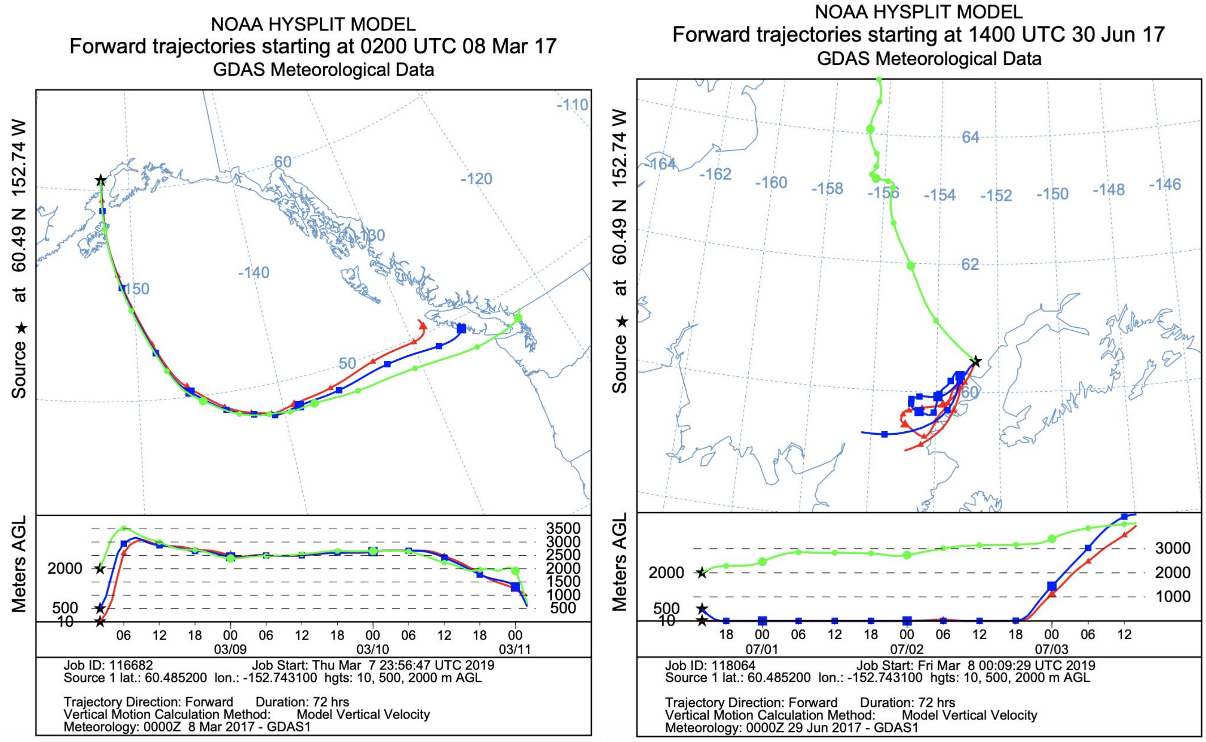

Figure 1 a - Trajectory for 8 March 2017. b - Trajectory for 30 June 2019

Currently, the HYSPLIT model can produce four types of air parcel trajectories: trajectory normal, trajectory matrix, trajectory ensemble and trajectory frequency. For the purpose of this paper, the trajectory normal was used. In this simpler plot, up to three sources can be selected at a user selected starting heights. Stein highlights the many research studies that have used HYSPLIT trajectories to assess and determine possible source region contributions to selected pollutants or to determine air masses that may affect the location under study.

Figure 1 shows the trajectory runs for 8th March 2017 at 0200 UTC and 30th June 2017 at 1400 UTC. For both trajectories, meteorological data was taken from the Global Data Assimilation System (GDAS) where pressure is the vertical coordinate. It has a spatial resolution of 1 degree and a temporal resolution of 3 hours. Both dates are set to have a forward trajectory direction and model vertical velocity for vertical motion with a total run time of 72 hours. 3 heights of release were chosen to mimic different scenarios, 10 meters - a ground level leak, 500 meters - a small explosion and 2000 meters - a large explosion. Looking at two separate dates, 8th March and 30th June 2017, we can start to identify patterns of trajectories in pollutants from the source region. Figure 1a plots the trajectories in March, the trajectory here moves south before veering east with Vancouver Island and the Lower Mainland of British Columbia as a sink. This will have major implications to air quality and visibility. The graph shows an initial peak at the start of the eruption, with all release heights reaching 2500 - 3500 meters AGL within the first 6 hours. For the next 30 hours, all release heights travel together across the pacific at around 2500 m AGL. The 10 m height trajectory veers off by the tip of Vancouver Island (around Cape Scott Provincial Park), both the 500m and 2000m make landfall (500m AGL), with the 500m ending up slightly above Tofino and 2000m ending up by the U.S border/Delta. The plot for June on the other hand (Fig.1b) shows much more localized trajectories. The 2000m trajectory gradually climbs through the initial 72 hours peaking at around 4000+ m AGL. This particular trajectory moves north towards the pole, travelling much further than the 10m and 500m. The 10m and 500m stays below 500m AGL for the next 48 hours before rapidly increasing, surpassing 4000m AGL. Looking at the plot (Fig. 1b), both the 10m and 500m initially move west, before looping and ‘backtracking’ making it almost all the way back to the source and then looping back again west not making it past the Katmai National Park in this particular run.

Concentration Runs:
A single trajectory cannot properly represent the growth of a pollutant cloud when wind field varies in space and height and hence simulations must be conducted using multiple pollutant particles. A plume is created as wind speed and direction can vary with height in the boundary layer. A forward trajectory is the line that is at the ‘centre’ of a plume, while horizontal and vertical dispersion occurs around this centre line. The HYSPLIT model allows for dispersion models to be run with the same forecast and archived meteorological data as the trajectory model for durations up to 84 hours forward or backwards (Stein et al., 2015). The user enters information on the release location, height, quantity and duration as well as the output concentration. Users can choose between give types of releases: unknown material (<24 hours), unknown material (long duration), prescribed burn, volcanic ash, and volcanic ash (24 hour, 5 levels). For the purpose of this paper, since volcanic ash was looked at, the parameter chosen was volcanic ash. Release duration of 6 hours was set with a total run time of again 72 hours. Release quantity to was set to 1000 mass and height set between 10 m and 2000m.

March Concentration Runs:

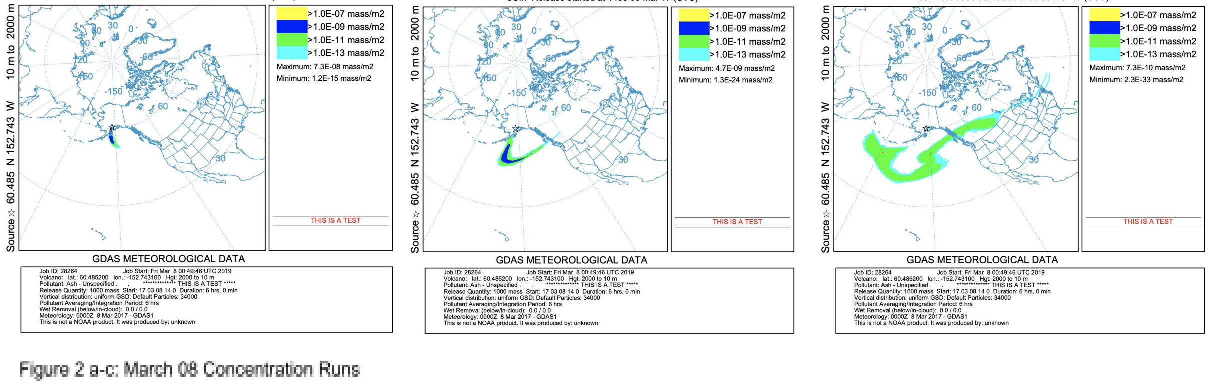

Figure 2 a-c: March 08 Concentration Runs

Figure 2 shows the 72 hour concentration run for 8th March. The ash plume follows the trajectory (Fig 1a), starting south and sharply veering towards the east onto the mainland. The plume (Fig. 2c) wraps around the Aleutian arc, ending slightly before the Kamchatka Peninsula, Russia and travelling across most of Canada and the Great Lakes before ending up in the Atlantic off the coast of New York city. Figure 3 shows the plume arrival (in hours) from the initial time. Within 60 hours, the plume has travelled around 6,000 km east and around 2,000 km west (as the crow flies).

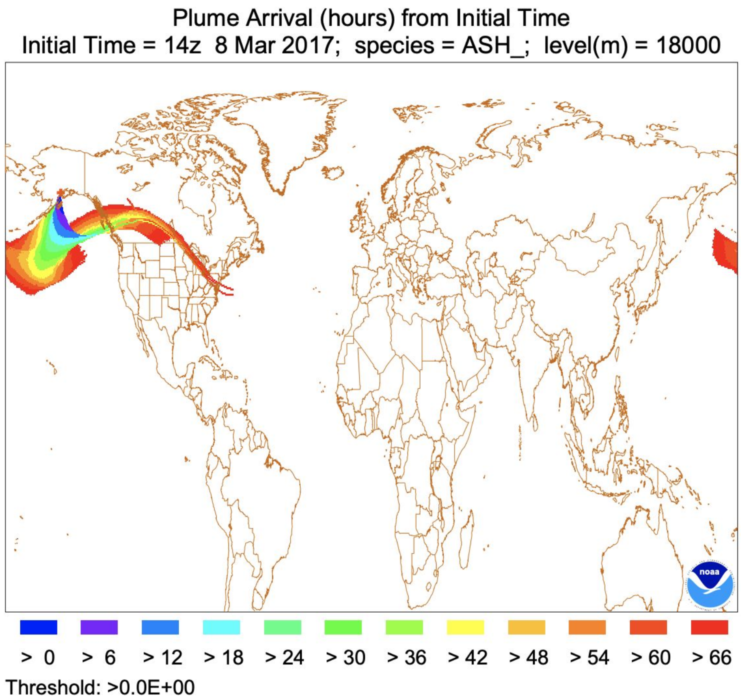

Figure 3: Plume arrival for March 08 2017

June Concentration Runs:

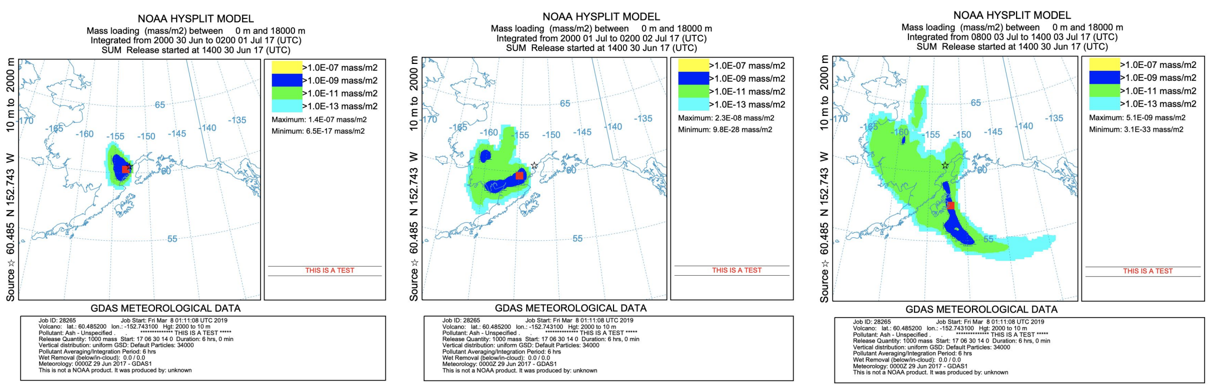

Figure 4 a-c: Concentrations Runs for June 30 2017

Figure 4 shows the 72 hour concentration runs for June 30th. The ash plume somewhat follows the trajectory (Fig. 1b), but shows slight deviations, for example, at 72 hours, the plume is see by the Gulf of Alaska, heading towards the Alaskan Panhandle. The plume is seen over Anchorage and the northern extent goes up to the Yukon Delta National Refuge.

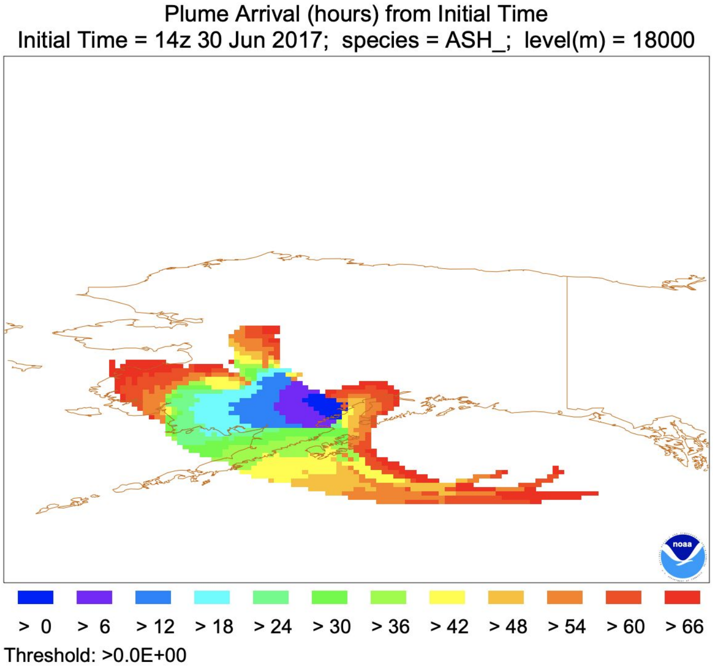

Figure 5: Plume Arrival (hours) for June 30 2017

Unlike the March plume arrival, the June plume arrival is much slower moving, travelling around 750 km south-east in around 60 hours (Fig. 5). This can potentially be due to the 'backtracking' as seen in the trajectory (Fig. 1b).

Synoptic Conditions

Geopotential height and vector winds were mapped out to see the effects of these meteorological conditions on ash trajectory and plume dispersion for 8th March and 30th June. The geopotential height approximates the actual height of a pressure surface above mean sea-level ("ATMO336 - Spring 2014", n.d.). A line drawn on a weather map connecting points of equal height (in meters) is called a height contour which means that at every point along a given contour, the value of geopotential height are the same. 500mb and 200mb levels were used. The 500 mb level is very near the level of non-divergence, it represents the level where about half of the atmosphere's mass is below it and half above it ("ATMO336 - Spring 2014", n.d.). 850mb represents the top of the planetary boundary layer (PBL) (for low elevation regions) ("ATMO336 - Spring 2014", n.d.). This is near the boundary between the troposphere and the free atmosphere, since 850 mb level is best to asses low elevation regions, it is not included in this study as the coast mountains affect elevation. The 200 mb level was chosen as it can be used to assess the jet stream. Jet streams are extremely important to the aviation industry as flight time can be dramatically affected by the flow of the jet stream, often aircrafts work to fly 'with' the jet stream. The jet stream is also an area most likely to be affected by a volcanic eruption ("ATMO336 - Spring 2014", n.d.). According to a paper by Marcus Bursik "In the research we did, we found that the jet stream essentially stops the plume from rising higher into the atmosphere, because the jet stream causes the density of the plume to drop so fast, the plume's ability to rise above the jet stream is halted: the jet stream caps the plume at a certain atmospheric level." ("ATMO336 - Spring 2014", n.d.). Wind vectors are represented through arrows which shows wind speed and direction.

Arrows point in the direction the wind is blowing and the longer the wind vector, the stronger the wind.

Synoptic Conditions in March:

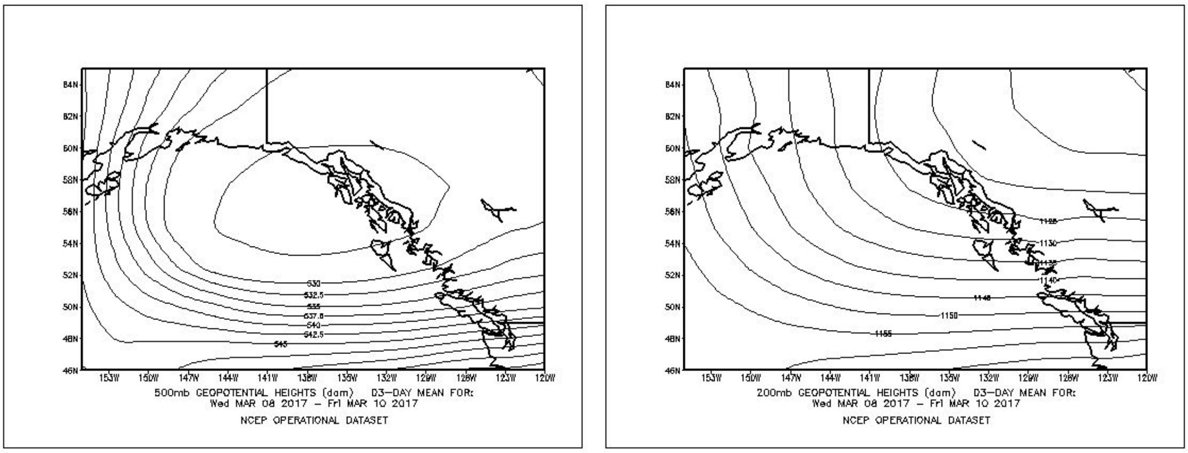

Figure 6 a-b: Geopotential height for March 08, 500 mb and 200 mb respectively

In the case of Fig. 6, geopotential height is averaged over 3 days (72 hours). In Figure. 6a, there is a closed low by Haida Gwaii which indicates a pool of colder air surrounded by warmer air. Fig. 6a shows regions of relative high pressure to the south (52^{o}N - 48^{o}N), from this we would expect cyclonic flow producing easterly-winds over coastal British Columbia. Figure. 6b also shows similar patterns in the jet stream, with contour lines moving in from the north and veering towards the east. The trajectory (Fig. 1a) also follows these patterns closely. Figure 7, is the wind vector averaged over 3 days (500 mb and 200 mb respectively). Again, the trajectory (Fig 1a) follows the wind patterns of figure 7. All these results support the HYSPLIT model's trajectory and dispersion results. It's interesting to note that in this particulate based based on the trajectory model (Fig. 1a) all three heights (10m, 500m and 2000m) travel together at relatively the same speed and distance.

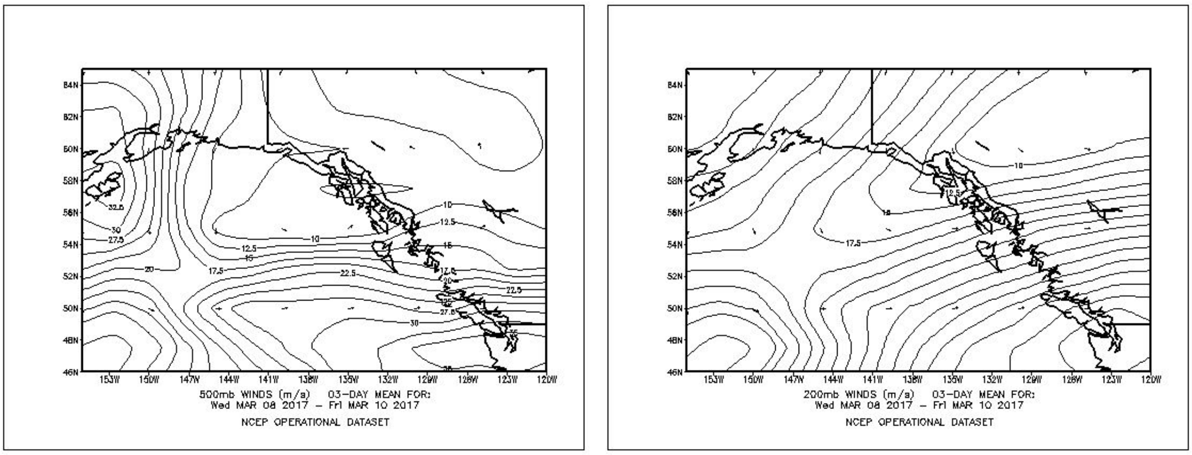

Figure 7 a-b: Wind vectors for March 08, 500 mb and 200 mb respectively

Synoptic Conditions in June:

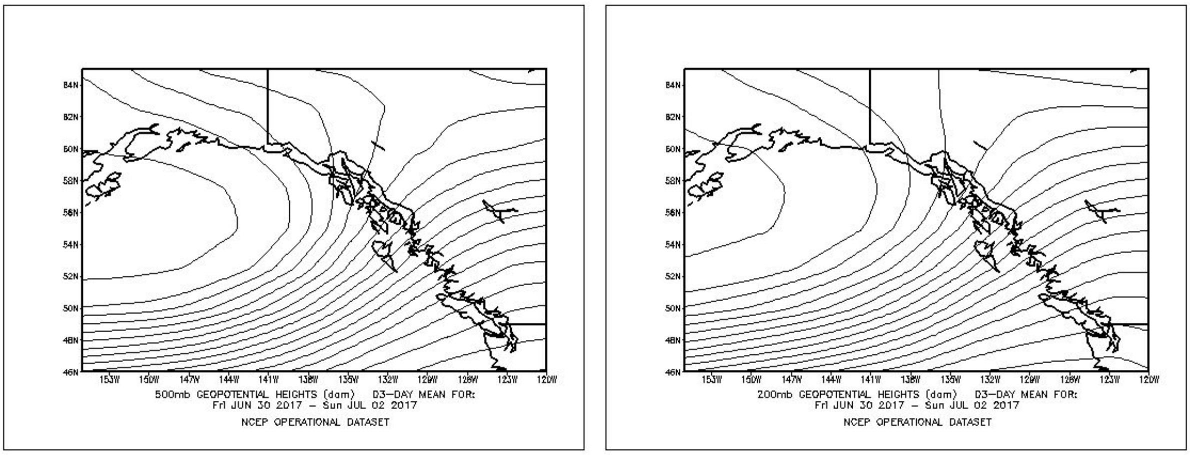

Figure 8 a-b: Geopotential height for June 30 2017. 500 mb and 200 mb respectively

Geopotential heights for both 500 and 200 mb are very similar for June 30 - July 2 (Fig. 8). A low pressure system is present by the Aleutian range as well as a stationary front (Fig. 10b) which could explain why the HYSPLIT trajectory model's result did not show the trajectory move past the coastline. A stationary front could explain why little dispersion occured as stationary fronts are often associated with light winds and no mass transfer as neither of the two air masses are strong enough to replace the other. Wind vectors (Fig. 9) show a wind direction moving north-east could explain the 2000m's trajectory towards the pole. The HYSPLIT dispersion model also shows similar results. A low pressure system by Kodiak island could explain the 'backtracking' trajectory the 10m and 500m experienced as ash moved within that low pressure system.

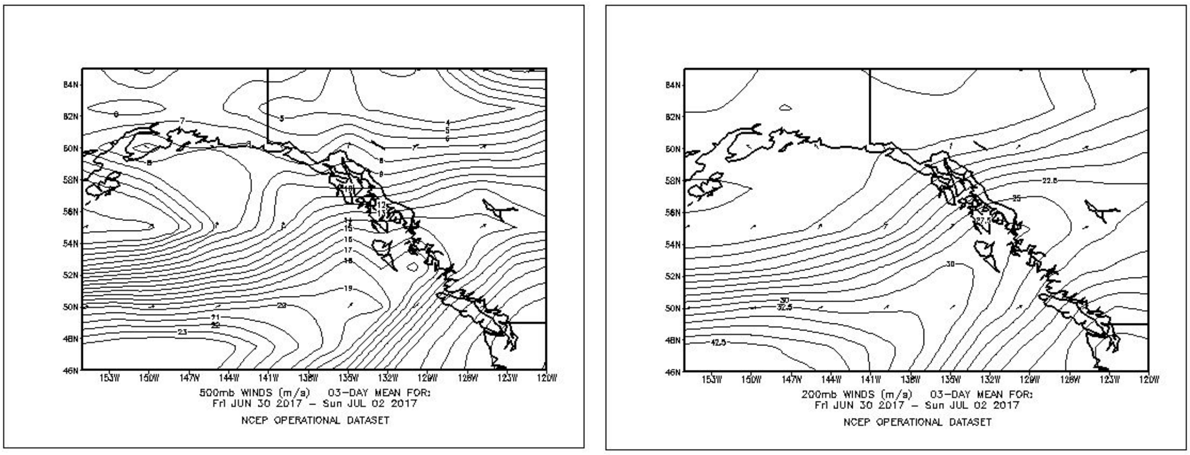

Figure 9 a-b: Vector Winds for June 30. 500 mb and 200 mb respectively

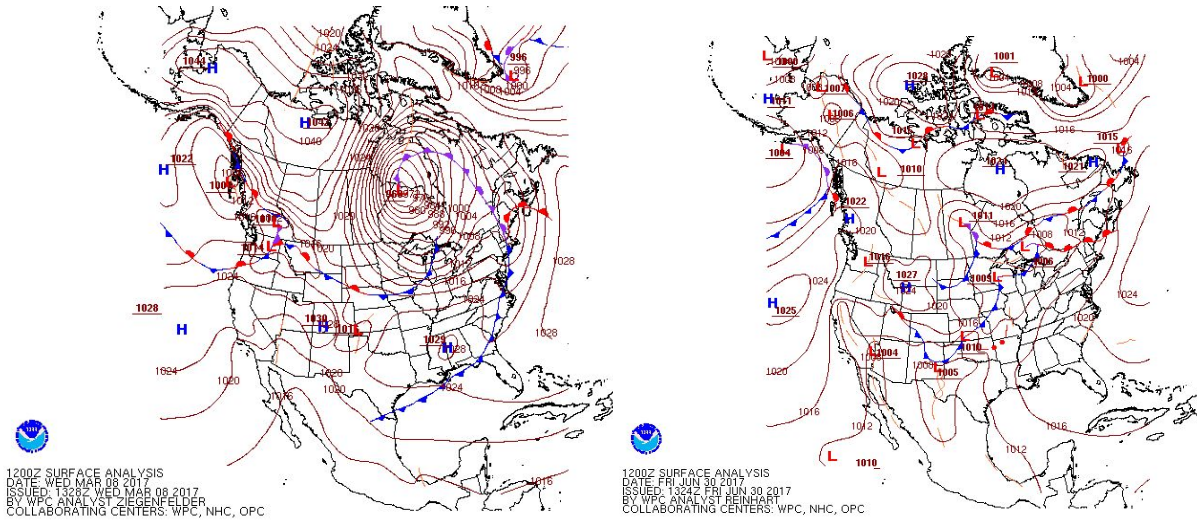

Figure 10 a-b: Archival weather maps. March 08 and June 30 respectively

Limitations of HYSPLIT:

According to the website, the HYSPLIT interface does not incorporate the effects gases that are not neutrally buoyant or complex terrain. This could be a potential issue for looking at Alaska due to the multiple mountain ranges that surround the peninsula. Since meteorological data is used for HYSPLIT is at a relatively coarse resolution, there are limitations that affect the model's ability to accurately forecast. Spatial scales of phenomenon that may affect dispersion are sea-breezes, land breeze and mountain-valley circulations.

References

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