Evidence of Post-frontal Mountain Wave Enhanced Wind Shear in Juneau Alaska

Carl F. Dierking
NOAA/National Weather Service, Juneau, Alaska

Frederick C. Fritsch
NOAA/National Weather Service, Juneau, Alaska

Abstract
Around 0315 UTC, 30 January 1993, a commercial jet aircraft departing the Juneau International Airport encountered severe wind shear that resulted in a temporary departure from controlled flight and a near accident. While on a climbing, right turn departure, off runway 08 at a 30 degree bank, the crew reported extreme crosswinds when the aircraft was opposite the Fish Creek valley on Douglas Island. The timing of the incident closely corresponded with the passage of a strong cold front, which was supported by airport surface observations of rapidly rising pressure and an abrupt wind shift. A high resolution WRF simulation of this event using North American Regional Reanalysis (NARR) data suggests that wind shear in the affected area was enhanced by a topographically induced gravity wave. This short-lived mountain wave developed in the low-level stable layer immediately behind the front, accelerating lee-side winds with a downward component northward from the west side of the Fish Creek valley across the departure path of the aircraft.

As a result of the January 1993 event, as well as other wind shear and turbulence problems, development of an alert system called Juneau Airport Wind System (JAWS) was initiated by the Federal Aviation Administration (FAA) and National Center for Atmospheric Research (NCAR) in 1995. The sensor network for this system includes three boundary layer wind profilers and an array of anemometers at both sea level and mountain top locations. One of the JAWS wind profilers, near the northwestern mouth of the Fish Creek valley, is in an ideal location for detecting other occurrences of post-frontal topographically enhanced wind shear, and an examination of historical data has found evidence of similar events. An example is presented.

Based on the WRF case study and historical observational evidence, a set of criteria has been identified that would favor the development of this type of wave enhanced wind shear: (1) A deep low making landfall in the northeast Gulf of Alaska; (2) pressure rising rapidly at the Juneau airport following passage of a strong front; (3) low level winds shifting to south or southwest after frontal passage; (4) low level cooling behind the front. The forecast of these criteria should be an important consideration when evaluating wind shear potential in the vicinity of the Juneau airport.

1. Introduction
The steep terrain surrounding Juneau, Alaska can present challenges, at times, for aircraft arriving and departing from the Juneau International Airport. The airport is located at the northwest end of the narrow Gastineau channel with a single runway oriented at 080 and 260 degrees magnetic. Since the predominant wind direction with approaching weather is from the southeast, the vast majority of instrument departures is to the east southeast using runway 08. Prior to 1996, departing aircraft on instruments using runway 08, would use turning departures known as FOX and LEMON CREEK (Figure 1) in order to avoid terrain. Both departure routes employed 180 degree climbing right turns. While maneuvering through these routes under strong wind conditions aircraft would often encounter turbulence or wind shear that at times would be severe.

The most serious wind shear event on a departure from the Juneau airport occurred in January of 1993, when a Boeing 727 aircraft at a 30 degree bank experienced extreme crosswinds that resulted in an overturn and departure from controlled flight. Miraculously, the crew was able to regain control of the aircraft within 150 feet of the ground. As a result of the January 1993 event and other severe turbulence and wind shear problems, the Federal Aviation Administration (FAA) contracted with the National Center for Atmospheric Research (NCAR) to conduct a comprehensive wind shear study of the Juneau Airport beginning in 1995. The end result of that study was the development of a wind hazard alert system called the Juneau Area Wind System, or JAWS.   The JAWS alert system receives input from a local mesonet of sensors that include three boundary layer wind profilers, and seven anemometers at both sea level and mountain top sites. The location of these instruments (Figure 1) was based on air traffic routes and known wind hazard areas. Algorithms were developed correlating observed wind parameters with the location and severity of wind shear and turbulence. These correlations were developed from previous airport studies and data gathered during three extensive field studies involving research aircraft.

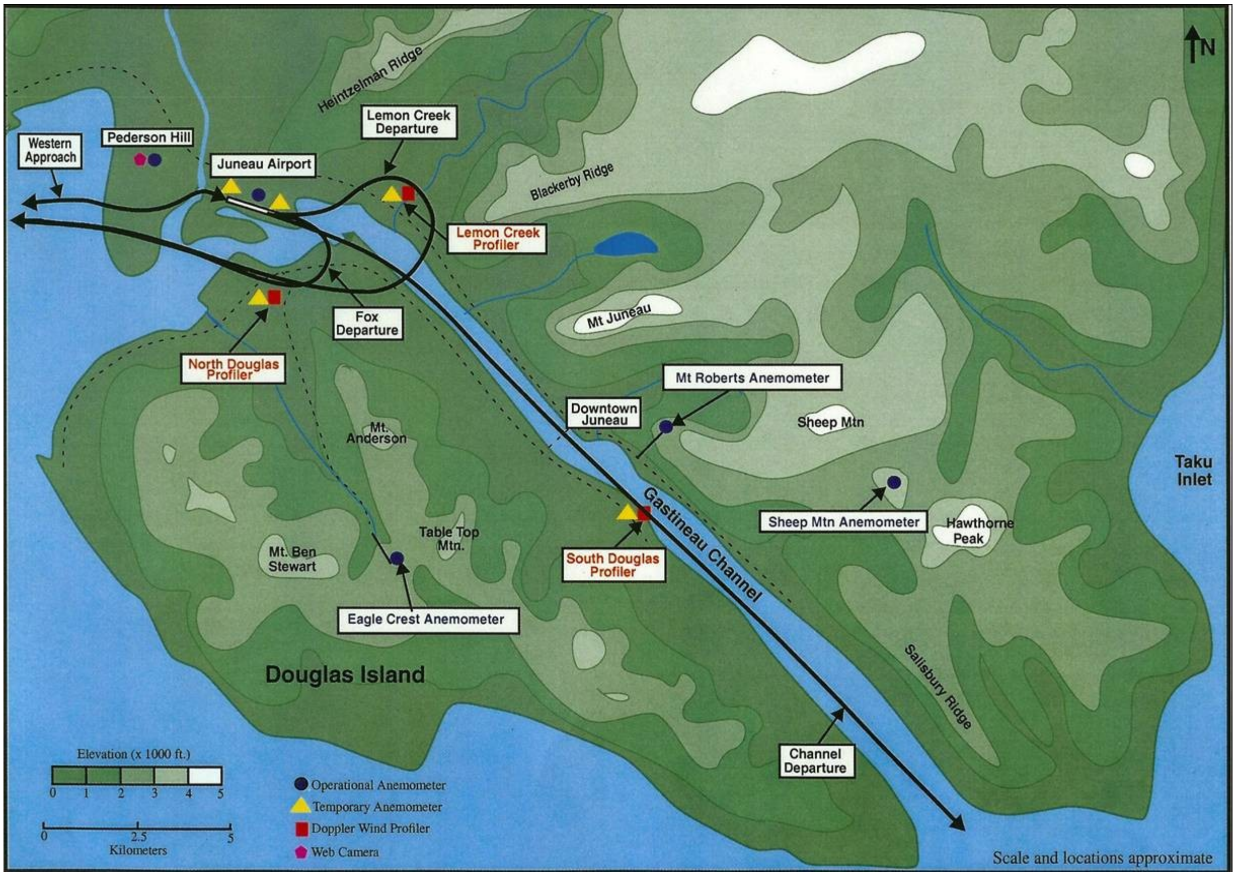

Figure 1. Topography in the vicinity of the Juneau Internation airport. Also shown are approach and departure routes and observational resouces in the local area.

In addition to development of the JAWS alert system, the FAA partnered with the commercial carrier, Alaska Airlines, to implement GPS based arrival and departure routes from the Juneau airport that would allow aircraft to avoid the hazards associated with turning departures. This “Required Navigational Performance” (RNP) departure allows properly equipped aircraft to fly straight down Gastineau Channel while on instruments to avoid many of the problem areas encountered with FOX and LEMON CREEK departures.

There has been much speculation about the exact circumstances that led to the near accident on 30 January 1993. Nothing approaching the severity of this event was detected during the three field studies, but it is assumed that the hazard algorithms would extend to more extreme events. In order to determine if this assumption is true, and to better understand this type of wind shear which had the potential for such disastrous consequences, a high resolution model simulation of the 1993 event was conducted using North American Regional Reanalysis (NARR) data. The results of the model study suggest that crosswinds in a section of the FOX departure corridor were enhanced by a short-lived mountain wave that developed after passage of a strong front. In addition, meteorological characteristics are identified that are conducive to the formation of a wave in this region. Finally, more recent events are identified and compared with the 1993 event to determine what the JAWS observation network is able to detect with an event of this type.

2. Description of the 30 January 1993 event

Table 1. Time sequence of wind and pressure tendency observations at the Juneau International Airport (PAJN) along with time and description of the aircraft incident.

Time UTC	Lowest Ceiling	Vis/Wx	Pres	Temp	Wind	Remarks
2300	030BKN	20SM -RA	854	45	11016G27KT	
0000	030BKN	30SM -RA	854	46	12024KT	
0100	050BKN	20SM -RA	871	45	13020KT	
0200	050BKN	20SM	898	45	14015KT	PRESRR
0300	050BKN	7SM	919	43	12015KT	INTMNT R- / PRESRR
0315						PIREP: Over Fish Creek after curved, right turn departure...at 900 ft, 30 deg right bank, aircraft suddenly rolled to 60-90 deg, lost control, regained at 150 ft AGL.
0400	050BKN	7SM	959	46	17019G34KT	PRESRR
0500	065BKN	7SM -RA	990	44	19019G30KT	PRESRR

As the sequence of observations in Table 1 shows, the initial pressure trough had passed through Juneau around 0000 UTC, and pressures had begun rising rapidly after that. The winds remained southeasterly until 0300 UTC and then switched to southerly with gusts over 30 knots.
It was around that same time when the commercial aircraft lifted off runway 08 and shortly thereafter encountered the severe crosswinds that produced the near catastrophic roll over. Pilots later estimated the speed of the cross wind at over 100 knots.

Observational evidence was limited in 1993, however there are some important things to note in the surface observations taken at the time. First, pressures were rising rapidly for several hours after the frontal passage indicating the presence of a very strong isallobaric ridge following the front (Figure 2). Second, wind observations at the airport recorded a wind shift from southeast to south at the time of the incident with stronger winds and gusts. This may not seem unusual for a post-frontal situation, but at the Juneau airport it is actually fairly rare. As can be seen in Figure 1, there is steep topography surrounding the airport and nearby Gastineau Channel, which constrains winds to a southeasterly direction. As a result, typically the only significant change in wind at the airport after passage of a front, is in

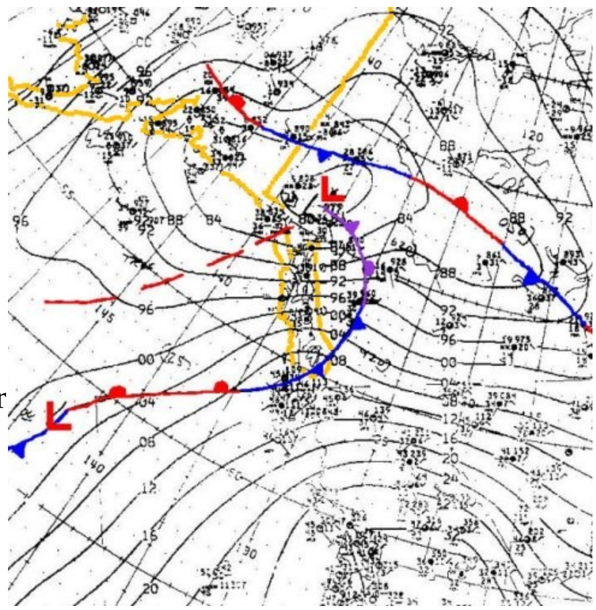

Figure 2. 0300 UTC 30 Jan 1993 surface analysis

the magnitude.

3. Model simulation of 30 January 1993 event

In order to construct a conceptual model about factors that may have contributed to strong wind shear in the affected area, a high resolution WRF simulation of the 1993 event was conducted using North American Regional Reanalysis data (NARR) for initialization. The model was configured with 3 nests at 9 km, 3 km, and 1 km, to downscale from the course NARR grid.

a. Synoptic environment evolution

In the larger scale features, the WRF simulation matched the analysis fairly well (not shown), although it is unclear how significant subtle differences might be for this type of mesoscale, short duration event. At 0000 UTC 30 January, a 972 mb surface low was analyzed directly over Yakutat, Alaska, which is located on the coast adjacent to the northeast Gulf of Alaska. At the same time a 973 mb low was already starting to developing inland, a little north of Yakutat. An occluded front extended southeastward from the low near Yakutat to near Juneau while a trailing cold trough was close behind along the southeast Alaska outer coast. The delay in the wind shift a few hours after pressures began to rise (Table 1) supports the existence of this trailing trough.

At 0300 UTC, the center of the low was analyzed at 979mb near Whitehorse, Canada while the WRF deepened the low to 970 mb with the center located a little further west, near the Alaska-Canada border. The occluded front was aloft east of Juneau, however the cold air trough was now moving though northern southeast Alaska. At the same time pressures were rising to the south which resulted in a tightening of the pressure gradient in the vicinity of Juneau. This trend was also represented in the WRF simulation.

By 0600 UTC 30 January, the low had filled to 980 mb and moved well inland into northwest Canada. The WRF simulation follows a similar synoptic progression, but keeps a weak low in Canada north of the Coastal Mountains near the the Alaska-Canada border.

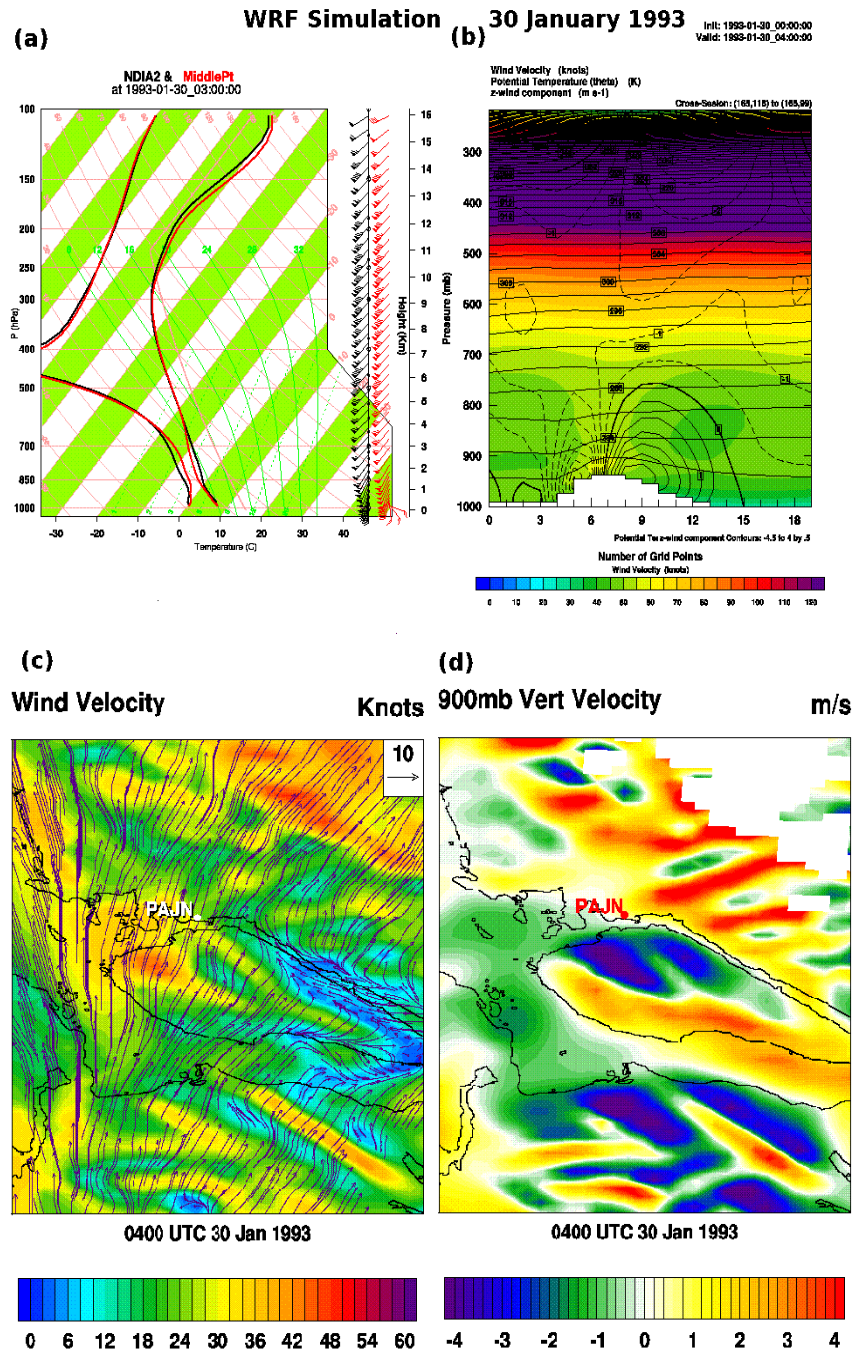

Figure 3. Results of the WRF simulation. (a) WRF skewt for points on windward (red) and lee (black) side of the mountain. (b) Model cross-section of theta, vertical velocity, and wind speed (color). (c) surface wind velocity and streamlines. (d) 900mb vertical velocity.

b. Mesocale changes in the vertical

Close examination of the WRF results for the inner 1 km nest in the vicinity of the Juneau airport provides clues about the type of feature that might have produced this extreme event. Prior to the time of the incident, the model shows that an influx of cold air in the lower level behind the trough. This produces a temporary stable layer above mountains on Douglas Island south of the Juneau airport

(Figure 3a). Concurrently, low level wind flow becomes south to southwest which is perpendicular to the same mountain range (Figure 3c). The isallobaric ridge produced enough momentum to generate strong cross-barrier flow while a stable layer at was present at mountain-top. A short-lived mountain wave developed, causing enhanced downslope winds the lee side. The vertical cross-section of model winds and potential temperature shows that the wave had developed by 0400 UTC with a maximum of negative vertical velocity on the lee side and positive vertical velocity on the windward side (Figure 3b). A few hours later the wave had nearly dissipated (not shown). WRF surface winds at 0400 UTC show a maximum on the lee side of the mountains of west Douglas Island and WRF vertical velocities develop strong negative vertical velocities in the same area (Figures 3c and 3d). This is the region that the aircraft would pass while heading west on departure.

These pieces of evidence help to clarify what was observed on that day. The mountain wave aloft helped to enhance winds on lee side of the the mountains near the west side of the mouth of Fish Creek. As the aircraft was climbing through the area in a banked attitude, it was particularly vulnerable to enhanced cross winds and downward accelerations which could certainly have lead to the overturn and near accident. While the mountain wave itself was not long-lasting or particularly severe, it occurred at a time and a place that very easily could have had serious consequences.

4. Recent case studies and model simulations

In order to determine whether there were more recent cases that exhibited characteristics similar to the 1993 event, a search of ASOS data at the Juneau airport was conducted for frontal passages with strong south or southwesterly wind shifts accompanied by rapid rises in pressure. Recent cases would have the benefit of additional profiler and surface observations from the JAWS network, adding much greater detail about the intensity and extent of the event. Particularly well situated are the North Douglas profiler, located near the mouth of the Fish Creek valley on Douglas Island, and the Eaglecrest anemometer, located in the saddle between two mountain ranges on Douglas Island.

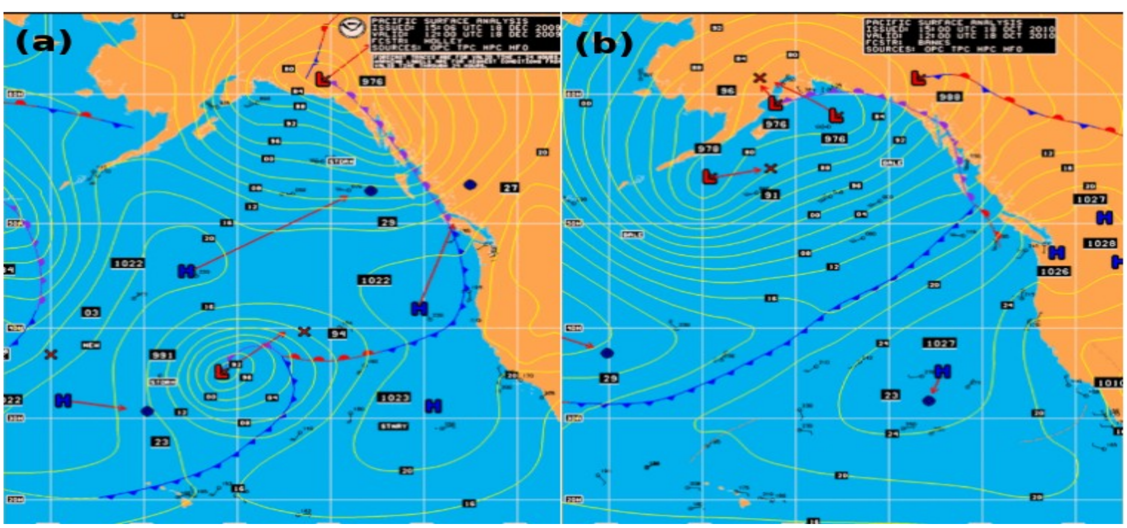

Figure 4. Surface analysis for both case studies: (a) 18 Dec 2009 and (b) 18 Oct 2010.

The two most recent significant events occurred around 1200 UTC 18 October 2010, and 1550 UTC 18 Dec 2009. Although the surface analysis for the 18 December case 2009 case (Figure 4a) is the most similar, in general, the synoptic pattern in both cases evolved in a similar way to that of the 1993 event. A deep low pressure center in the northeast Gulf of Alaska in the process of redeveloping in northwest Canada around the time that a front moves through Juneau. This scenario appears to be the most favorable for producing the identified mesoscale changes that lead to a post-frontal wave response. Figure 5 shows plots of surface observations for the two case studies. NDIA2 is an automated surface instrument located at the North Douglas profiler site. The 2009 case had a stronger and longer lasting pressure rise behind the front than the 2010 case (Figures 5a and 5e). Also, in the 2010 case the gusty southwest winds behind the front diminished more quickly (Figures 5b and 5f) and the wind directions were more variable (Figures 5c and 5g). In the 2010 case while the primary low was in the process of redeveloping in northwest Canada and the front was moving through southeast Alaska, a weak residual low remained in the Gulf of Alaska (Figure 4b). This difference likely contributed to a weaker ridge behind the frontal trough and a shorter duration event.

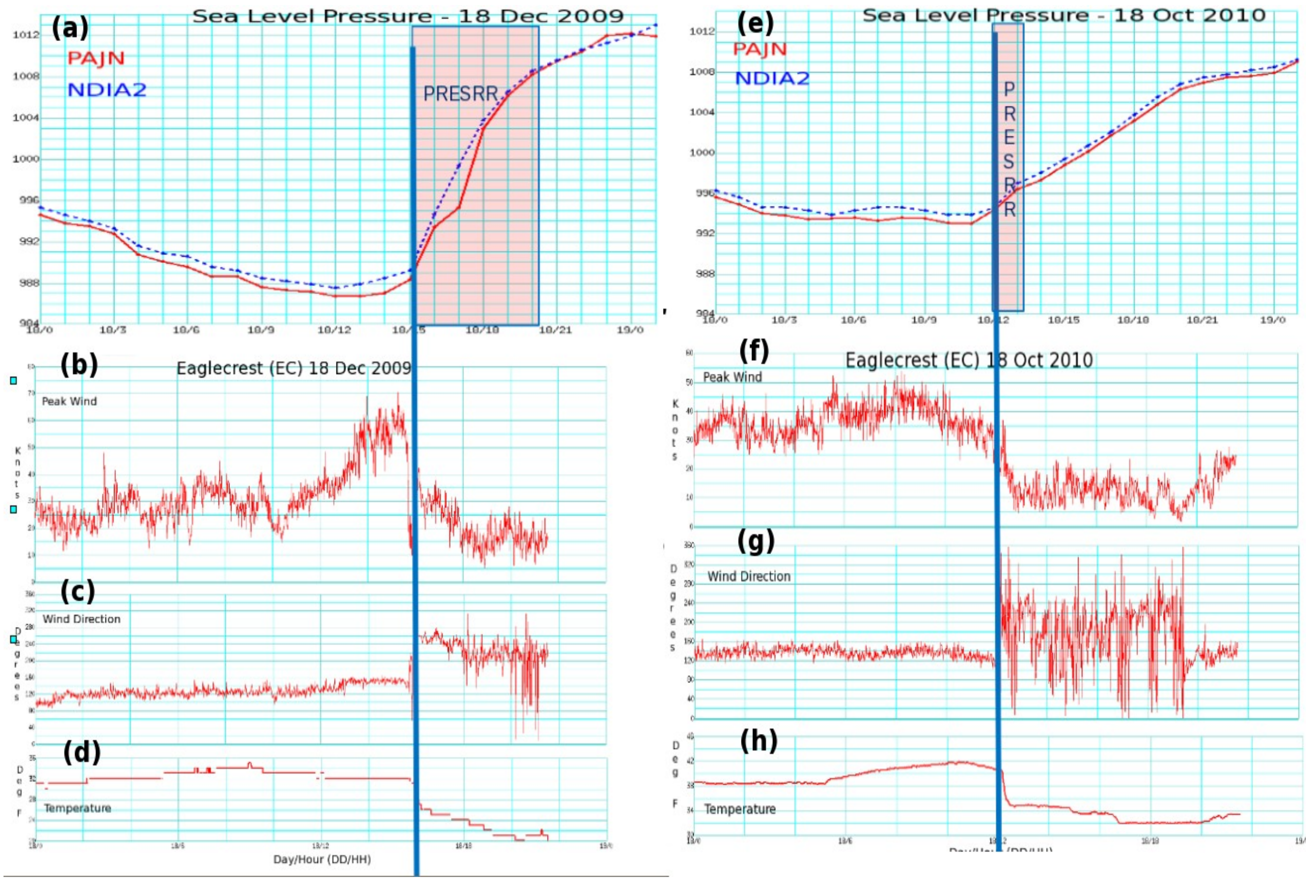

Figure 5. Surface observation timeseries plots for the two case studies: 18 Dec 2009 and 18 Oct 2010. (a) and (e) are pressures from the Juneau airport ASOS (PAJN) and the automated station near the North Douglas profiler (NDIA2). The remainder are from the JAWS Eaglecrest site: (b) and (f) are wind speed; (c) and (g) are wind direction; (d) and (h) are temperature. The vertical line highlights the frontal passage.

The North Douglas profiler data for the two cases is shown in Figure 6. Figures 6a and 6c are radial velocities at 225 degrees. Both cases have vertical shear aloft with negative velocities (northeasterly component) in the low level and positive velocities (southwesterly component) above. At the time of frontal passage, the strong positive velocities descend quickly down to the surface corresponding to the gusty southerly wind shift. Figures 5b and 5d show vertical velocities where negative values are downward. Prior to frontal passage the faster velocity of falling rain drops obscures the lower level atmospheric motion, but even after the rain diminished behind the front, velocities are still downward.

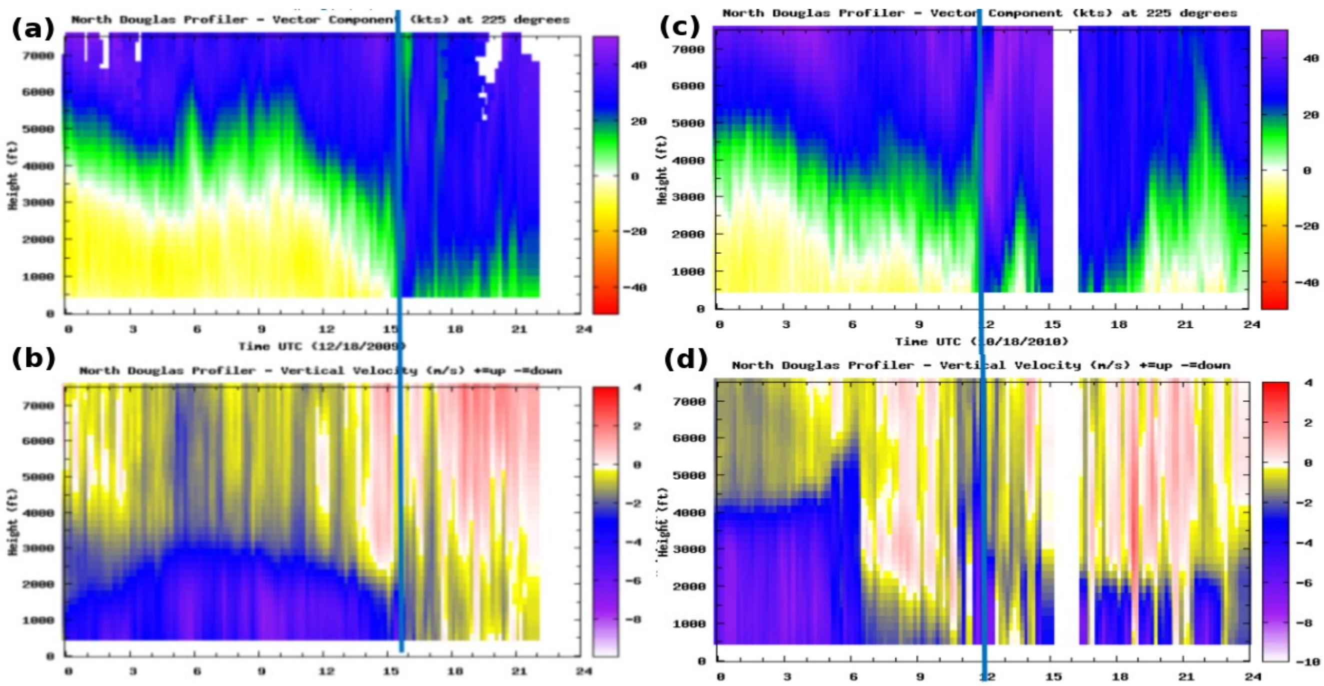

Figure 6. Profiler plots for the two case studies: 18 Dec 2009 and 18 Oct 2010. (a) and (c) are radial velocities for 225 degrees (positive from southwest); (b) and (d) are vertical velocities. The vertical line highlights the frontal passage.

WRF simulations were done for both case studies to see if they also showed evidence of mountain wave development. Figures 7 and 8 show the results of those model runs with the same panels that were shown for the 1993 simulation. Both case studies show evidence of the mountain wave in the vertical cross-sections, and both show enhanced surface flow and downward vertical velocities in the same area of North Douglas as the 1993 case. Although the Dec 2010 WRF simulation was a little slow in bringing the winds around to the southwest, the wave signature was apparent once cross-barrier winds materialized. Although not as strong as the 1993 case, especially in Dec 2010, these simulations display remarkably similar characteristics and are likely the same type of event.

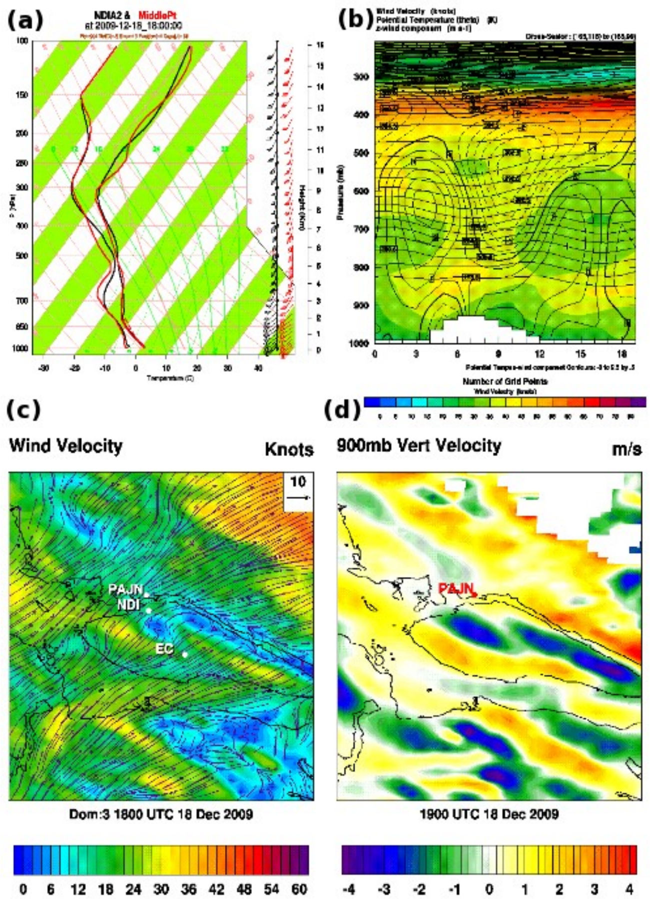

Figure 7. WRF output for the 18 Dec 2009 case study valid at 1800 UTC. (a) model sounding on windward and leeward side of mountain. (b) model cross-section; (c) surface wind velocity; (d) vertical velocity

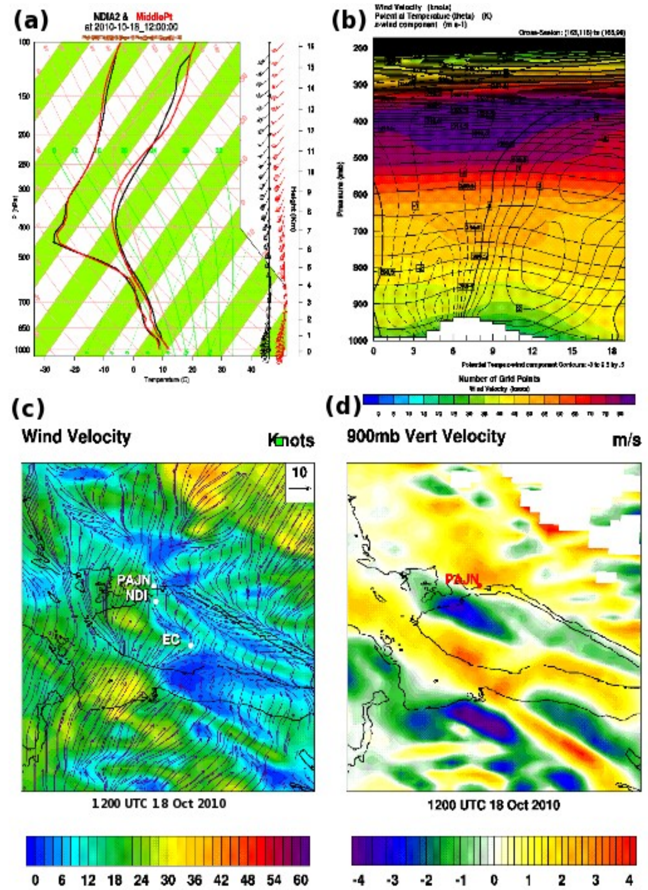

Figure 8. WRF output for the 18 Oct 2010 case study valid at 1200 UTC. (a) model sounding on windward and leeward side of mountain. (b) model cross-section; (c) surface wind velocity; (d) vertical velocity.

5. Summary and Conclusions

The results of the WRF modeling study shows clear evidence of wave enhanced winds that can occur with the passage of a strong front at the Juneau airport, and this is likely what produced the severe wind shear of 30 January 1993. The occurrence of this condition is infrequent however, since very specific conditions are required to generate a significant wave response: 1) There needs to be a large temperature contrast across the front in order to cool the lower level enough to generate a temporary stable layer; 2) The front needs to be followed by an intense isallobaric ridge with large pressure rises in order to provide enough momentum to force low level winds to shift to the southwest and flow over mountainous terrain that would typically constrain it.

The specific nature of the required local conditions eliminate many of the typical frontal passage scenarios that affect the Juneau airport, however one particular synoptic evolution seems to be the most favorable for producing this result. There should be a relatively deep surface low in the Gulf of Alaska that moves northeastward toward the northeast Gulf coast and then redevelops in northwest Canada, while the associated surface front moves through southeast Alaska. Usually this is supported aloft by a sharp progressive trough that is followed by a minor ridge.

Although infrequent and short-lived, the impacts of this type of event can be significant due to its proximity to take-off and departure corridors at the Juneau airport. In the Fish Creek valley, on the lee side of a mountain range, horizontal accelerations are accompanied by downward vertical velocities can be particularly dangerous for aircraft in a crossing trajectory, especially if trying to gain altitude while in a banked attitude. Fortunately, at the Juneau airport, the implementation of a GPS based RNP departure has significantly reduced the need for the curved type departure that was used in 1993.

The JAWS observation network has proven to be a vital resource for improved understanding of mesoscale meteorological processes in the Juneau area. While not a focus in this study, it was encouraging to discover that the that the JAWS sensors are well placed to monitor turbulence and wind shear from this type of event.

For airports in the vicinity of complex topography it is likely there are other localized, terrain-enhanced, wind conditions that in the right circumstances be hazardous to aircraft. High resolution modeling studies of this type can be helpful in identifying many of these potential problem areas and the antecedent conditions which lead to their onset. This is essential to help aviation forecasters to anticipate these events.

References

Braid, J. T., 2004: Turbulence PIREPs in Juneau – an analysis. Preprints, 11th Conference on Aviation, Range, and Aerospace Meteorology, Hyannis, MA

Cohn, S. A., J. T. Braid, C. Dierking, M. K. Politovich and C. G. Wade, 2004: Weather patterns of Juneau Alaska and their relationship to aircraft hazards. Preprints, 11th Conference on Aviation, Range, and Aerospace Meteorology, Hyannis, MA

Cohn, S. A., R. Barron, A. Yates, S. Mueller, A. R.Rodi, P. P. Neilley, A. Praskovsky and L. B. Cornman, 2004: Field programs to investigate hazards to aviation in Juneau, Alaska. Preprints, 11th Conference on Aviation, Range, and Aerospace Meteorology, Hyannis, MA

Colman, B. R., 1986: The winter climate of Juneau: A mean of contrasting regimes, Natl. Wea. Dig., 11, 29-34.

Morse, C. S., S. G. Carson, D. Albo, S. Mueller, S. Gerding, and R. K. Goodrich, 2004: Generation of turbulence and wind shear alerts: Anatomy of a warning system. Preprints, 11th Conference on Aviation, Range, and Aerospace Meteorology, Hyannis, MA

Morse, C. S., R. K. Goodrich and L. B. Cornman, 2002: The NIMA method for improved moment estimation from Doppler spectra. J. Atmos. Oceanic Technol., 19, 274-295

Politovich, M. K., F. W. Wilson, R. K. Goodrich, S. A. Cohn, R. A. Weekley, C. S. Morse and M. Pocernich, 2004: A climatology of predicted turbulence and shear near Juneau, Alaska. Preprints, 11th Conference on Aviation, Range, and Aerospace Meteorology, Hyannis, MA

Weekley, R. A., R. K. Goodrich, A. Praskovsky and L. B. Cornman, 2004: An anemometer data quality control method designed for a turbulence and wind shear prediction algorithm. Preprints, 11th Conference on Aviation, Range, and Aerospace Meteorology, Hyannis, MA

Wilson, F. W., 2004: Aviation impacts of terrain-induced wind shear. Preprints, 11th Conference on Aviation, Range, and Aerospace Meteorology, Hyannis, MA