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CASE STUDY ANALYSIS REGARDING LOCAL ACCELERATION OF WINDS ALONG THE WASHINGTON COAST

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Introduction

Meteorologists in the Pacific Northwest have long questioned the utility of observations at Tatoosh Island and Destruction Island in issuing High Wind Warnings. Tatoosh Island is located one half mile northwest of Cape Flattery; Destruction Island is 3 1/2 miles off the northern Washington coast, 19 miles southwest of Quillayute. This study was undertaken to determine if the wind speeds at Tatoosh and Destruction Islands are anomalously high and, therefore, unrepresentative of winds along the coast.

Data Collection

Storm Data and High Wind Warnings were studied to find events when winds at Tatoosh and/or Destruction Islands met the High Wind Warning criteria of 35 knots sustained and/or gusts of 50 knots. Nine events met these criteria in a 15 month period between August 1991 and November 1992. Wind speed data for all stations along the coast, as well as winds from 850 mb and surface analyses, were collected for the events.

One challenging aspect of the study is that there are few sites where observations are consistently taken along the Washington coastline. Two coastal stations, Quillayute and Ocean Shores, were used in the study but are located in sheltered areas and, therefore, tend to report anomalously low wind speeds. Astoria (a reporting station in extreme northwest Oregon) and buoy data provided less contaminated values.

Analysis

A number of interesting findings became apparent while studying the data. Six events had very similar surface patterns with strong southerly winds preceding a warm front. This is reasonable since the flow ahead of a warm front is usually stable. This stability causes blocking of airflow by orographic barriers, which leads to acceleration around the barriers. Figure 1 shows a typical surface analysis; 1200 UTC, November 16, 1991. In the other three events, winds were strongest as a cold front approached, with a warm front not clearly defined.

Although the winds at Tatoosh and Destruction Islands were higher, the wind observations at buoy locations and/or at Astoria also reached High Wind Warning criteria in four of the nine events. To provide further insight, the highest sustained wind speed and gust for each station were identified for each (high wind) event. These winds were then averaged for seven of the events in an effort to make comparisons of the coastal sites (data were insufficient for two of the events.)

The results (Fig. 2) confirmed that Tatoosh and Destruction Islands averaged quite a bit higher for both sustained wind speed and highest gust. The results further revealed that the sustained wind speeds of 43 and 42 knots at the two sites were similar to gusts reported at Astoria and the buoys. The Tatoosh and Destruction anemometers are located on lighthouses rising 80 to 100 feet above the site elevations (which are 101 ft and 70 ft, respectively). The sustained wind speed would arguably be higher due to elevation differences (Fig. 3). The power law, as discussed below, was used to assess this variation in wind speed.

The power law expression:

$$\frac{u(z)}{V_G} = \left(\frac{z}{z_G}\right)^n$$

where

z	=	given height
z_G	=	height of gradient level
$u(z)$	=	wind speed at height z
V_G	=	wind speed at gradient level
n	=	exponent dependent on surface roughness

relates boundary-layer wind speeds at various heights to the gradient speed for different surfaces as determined by their roughness lengths. From this expression, a power law profile was plotted (Fig. 4). The profile is a curve of computed wind speeds from the surface to gradient level; with gradient level being the height at which the wind attains equilibrium flow with the pressure field. One profile was produced for rough seas using accepted values for z_G (820 feet) and n (.11), (Plate, 1982). Because of differing surface roughness, a second profile was necessary for the land stations. Astoria was believed to be the most representative of the land stations so the profile was adjusted to fit Astoria's values. This was done by using 984 feet for z_G and then adjusting n. This gave a value for n of .21, which falls between the empirically derived values of .16 for the plains and .28 for forests (Plate, 1982).

Actual wind speeds at the buoys correlated well with the rough seas profile. As expected, Quillayute and Ocean Shores had wind speeds considerably less than the derived profile for land stations because these sites are protected. Actual winds at Tatoosh and Destruction Islands were 8 and 7 knots higher, respectively, than the land profile but did fit in the domain of the rough seas profile. However, since Tatoosh and Destruction Islands are in the zone of coastal influence, it is felt the increased winds at these two sites are not solely due to elevation differences.

In addition, if the assumption is made that momentum above the friction layer is occasionally brought down to the surface in the form of gusts by mixing within the frictional layer, then the gusts at all the sites should be comparable. Since the gusts at Tatoosh and Destruction Islands are much higher than other sites, either the winds at Tatoosh and Destruction Islands are not representative of the coastal winds or there is some local process acting at these two sites.

Local Terrain Influences

Frictional effects are one possible cause of the higher winds (Roeloffzen et al. 1985; Overland and Bond 1993). The discontinuity in surface roughness at the coast will slow onshore flow. With a southwest geostrophic flow, there will be decreasing wind speed over land and backing of winds inland causing convergence. This frictional convergence will cause air to "pile up" along the coast, which in turn will force stronger southerly winds in the headlands.

A similar situation exists due to the Olympic Mountains. This is explained by Mass and Ferber (1990) in their studies on pressure perturbations produced by an isolated mesoscale barrier. With south-southwest winds at 850 mb, as the flow impinges the barrier (the Olympics), a windward ridge will develop to the southwest and a lee trough will be clearly evident to the northeast (Fig. 5). As the ridge develops, inland winds will accelerate coastward and north of the pressure anomaly. This will produce increasing ageostrophic downgradient winds, particularly evident at Destruction Island. (This is produced by the enhanced pressure gradient on the west side of the Olympics.)

A mechanism that will affect both Tatoosh and Destruction Islands because of their location on high bluffs is the Bernoulli Effect (Hunt 1980). Winds will increase as the airflow is forced over a hill or escarpment (Fig. 6). Pressure increases as the airflow stagnates at the foot of the hill. Over the top of the hill, the pressure falls and flow accelerates. An important feature of a wind profile over a hill is that it increases with height much more rapidly than the profile over nearby level ground.

Other local effects include high frequency phenomena that interact with the terrain to produce high winds (Dorman 1985). An example is a Kelvin wave, which is a gravity wave trapped by the terrain. Internal Kelvin waves will propagate northward along the Washington coast in symmetrical troughs and crests. As the corresponding pressure perturbations advance up the coast, they cause winds to increase and decrease locally.

Conclusions

The study verifies the suspicion that Tatoosh Island and Destruction Island report consistently higher winds when compared to buoys and all other coastal observing points. Further analysis suggests this enhancement results from a combination of factors: favorable station elevation, exposure, and local terrain influences. Thus, it has been concluded that wind observations at these two stations are not representative of the coast as a whole and result in overwarning for the coast.

It was noted that the sustained winds at Tatoosh and Destruction Islands were similar to the gusts at more representative coastal stations. However, the basis for this correlation is not easily explained. It could be argued that the winds at Tatoosh and Destruction Islands represent the maximum low-level wind speeds over the coast and, thus, are an upper threshold for gusts at the surface. Winds at elevations higher than these sites may not mix down to the surface because of dissipation through turbulence.

Based on this reasoning, a new policy has been implemented at the Seattle Weather Service Forecast Office concerning only Tatoosh and Destruction Islands. It has been agreed that the sustained winds at these two sites will be treated as representative of gusts over the coastal plain. Thus, the sustained winds at these sites will need to reach 50 knots to verify a High Wind Warning for the coast. Gusts at Tatoosh and Destruction Islands will continue to be reported but will not be used to verify warnings. Ongoing analysis will further validate and refine this policy.

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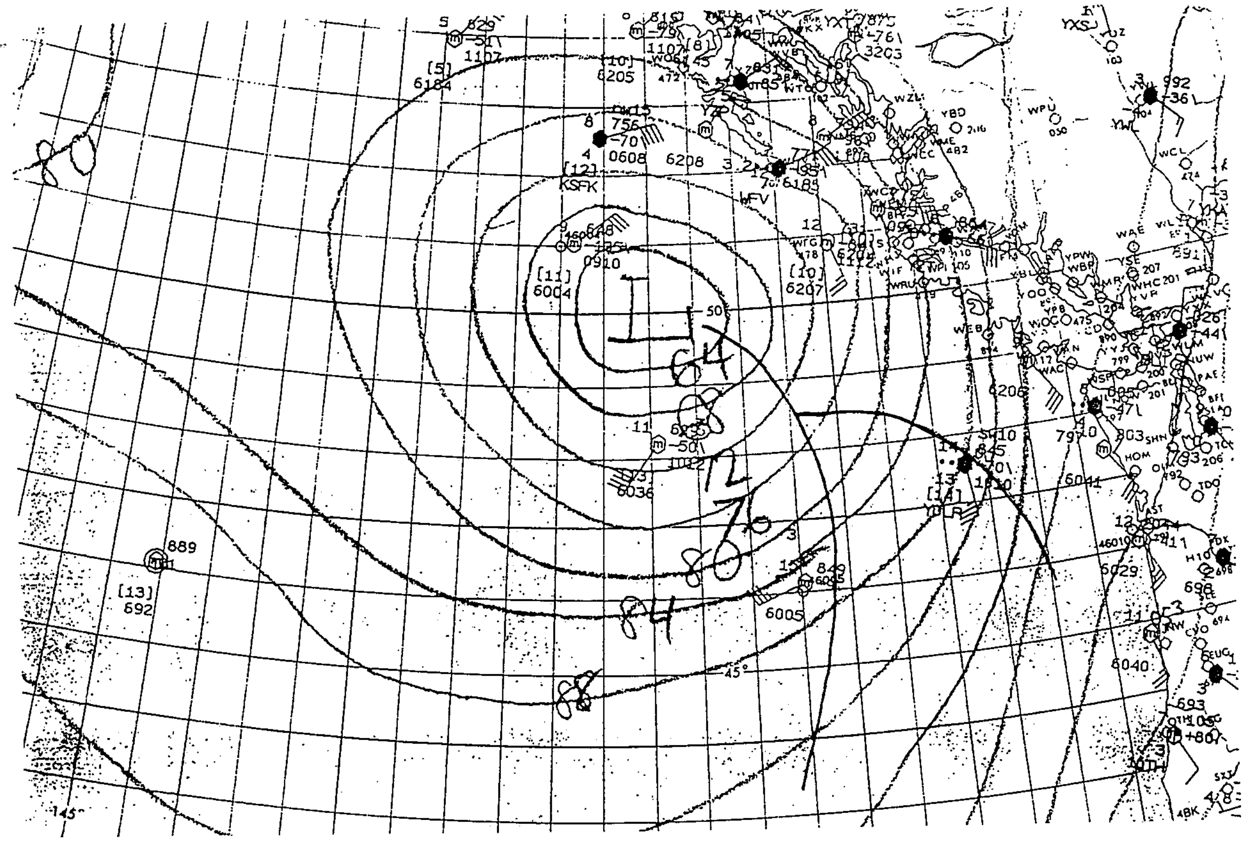

Figure 1. Surface pressure analysis for 1200 UTC 16 November 1991.

HIGHEST WIND GUST

EVENT NO.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*AVG*
TTI	52	50	63	59	48	53	43	53
DES	57	38	54	57	36	43	55	49
029		31	51	45	41	42	42	42
041	39	27	45	43		38	40	39
206	31	33	52	39	33	32	46	38
UIL	42	29	40	40	28	30		35
OCS	25	20	40	35	39	30	31	32
AST	38	35	50	51	48	45	44	44

HIGHEST SUSTAINED WIND SPEED

EVENT NO.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*AVG*
TTI	44	43	47	49	38	45	38	43
DES	51	33	47	50	33	37	46	42
029		23	37	35	29	38	34	33
041	31	21	37	35		30	32	31
206	27	25	39	29	20	26	36	29
UIL	22	14	18	23	15	18		18
OCS	15	10	20	22	34	18	20	20
AST	26	21	29	26	28	24	27	26

Figure 2. Individual and composite wind speeds in knots for seven events between August 1991 and November 1992.

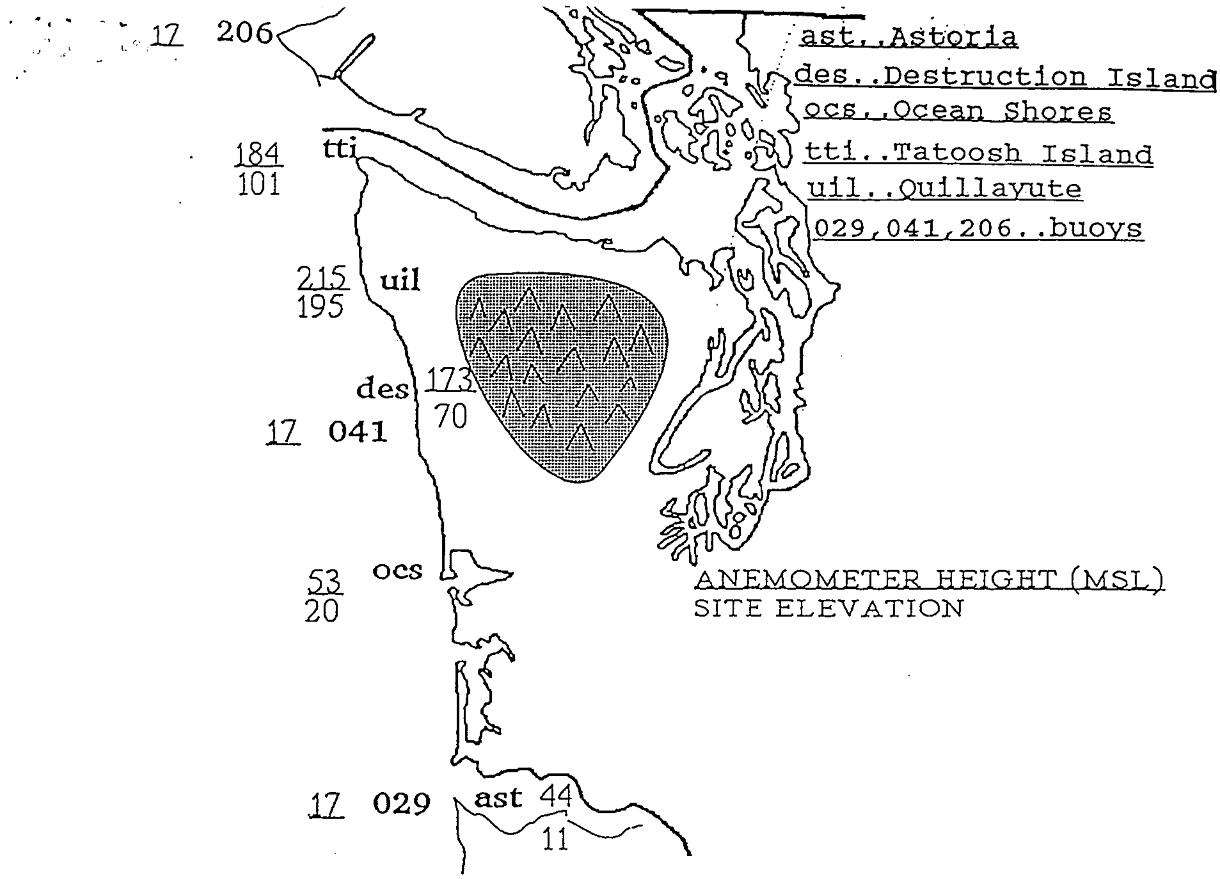

Figure 3. Topographical map displaying the location and elevation in feet of observing stations in the study area.

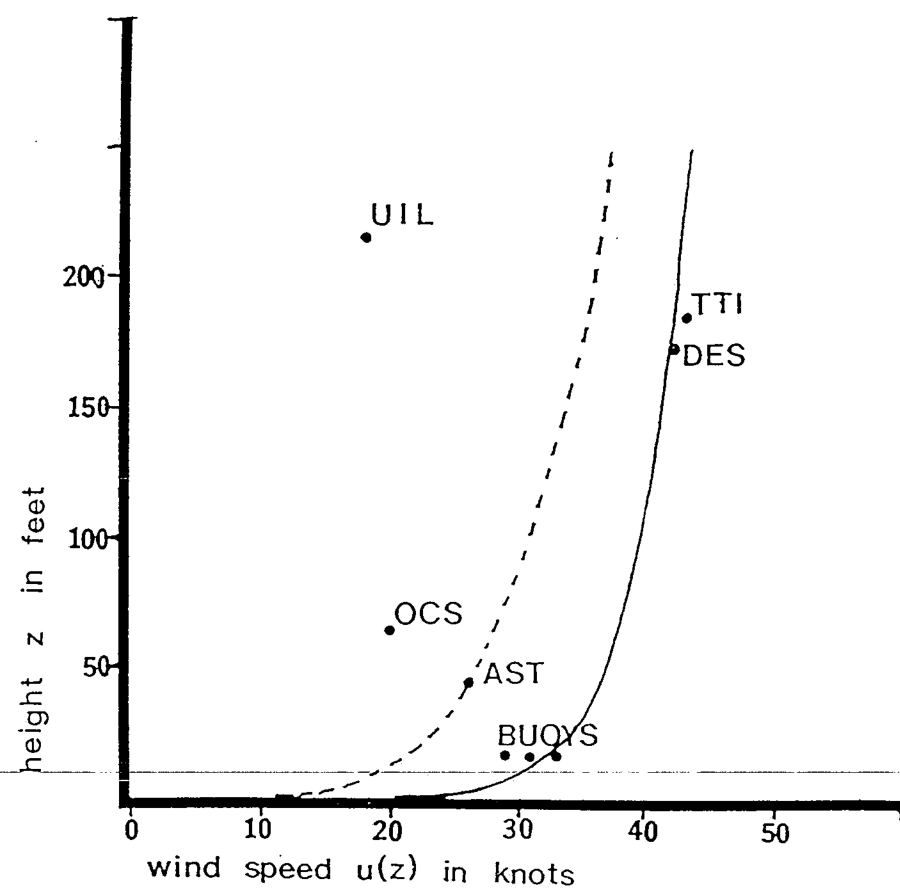

Figure 4. Profiles of sustained wind speeds over varying terrain. Dashed curve represents the power law profile for coastal plains ($n=.21$, $z_G=984$ feet). Solid line represents the profile for rough seas ($n=.11$, $z_G=820$ feet). [Note: both profiles projected to V_G would reach 50 knots.]

Figure 5. Deviation (from the daily mean) sea level pressure composite. Pressures are in tenths of a millibar (Mass and Ferber, 1990).

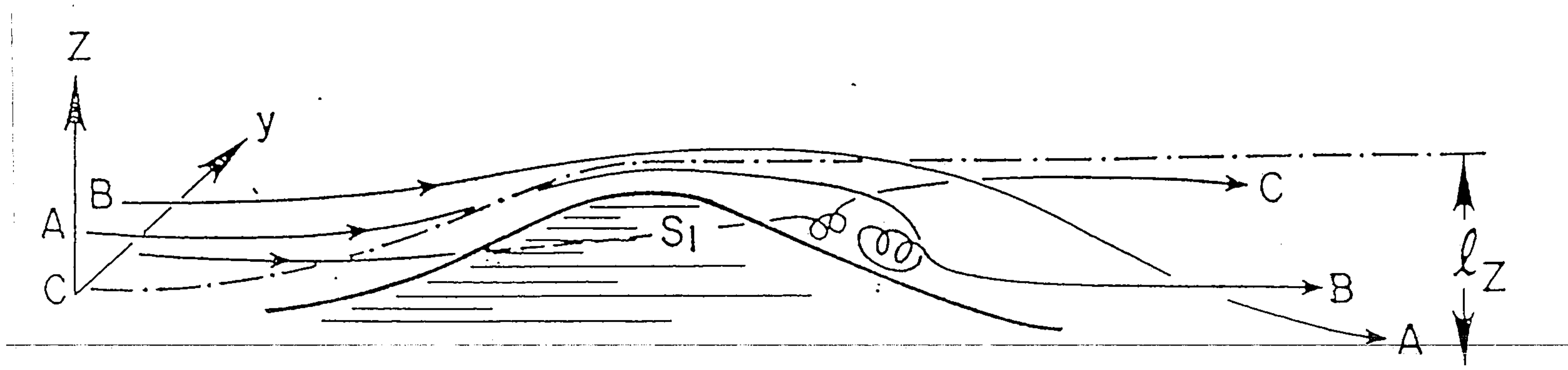

Figure 6. Neutral flow over 3-dimensional hills. Sketch of streamline pattern (Plate, 1982).