PICTURE OF THE MONTH

A Topographically Forced Convergence Line in the Lee of the Olympic Mountains

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1. Introduction

During the third week of December 1983 the Pacific Northwest experienced an arctic air outbreak that produced record low temperatures. In western Washington State during this period minimum temperatures dropped to as low as −22°C under the influence of generally easterly, offshore flow forced by high pressure to the northeast over British Columbia. Figure 1, the surface chart for 12 GMT on 22 December is representative of that week's synoptic situation. In contrast to the frigid temperatures over land, the Pacific sea surface temperatures in the immediate offshore waters ranged from 8° to 10°C. Although western Washington, Oregon and British Columbia were virtually cloud free, over the Pacific there was extensive convective cloudiness that formed 20–100 km off the coast as cold, continental air became destabilized and moistened by the warmer water below. Such convection, frequently observed off the east and Gulf coasts of the United States, is unusual in the Pacific Northwest where offshore flow in winter is relatively infrequent and rarely much below freezing.

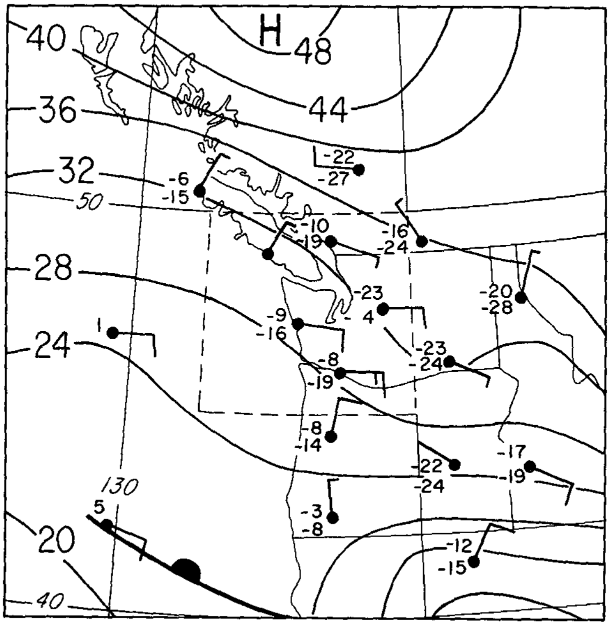

FIG. 1. Pacific Northwest surface synoptic chart at 1200 GMT 22 December 1983. Temperatures are in degrees Celsius (°C) and winds in knots. Sky cover is not indicated in the station model. Solid lines are sea-level isobars in millibars. Dashed lines indicate the domain shown in Figs. 5, 6 and 8.

2. Discussion

The most intriguing feature of the satellite imagery that week was a northeast–southwest stationary band of enhanced convection, which began approximately 20 km off the central Washington coast. This feature

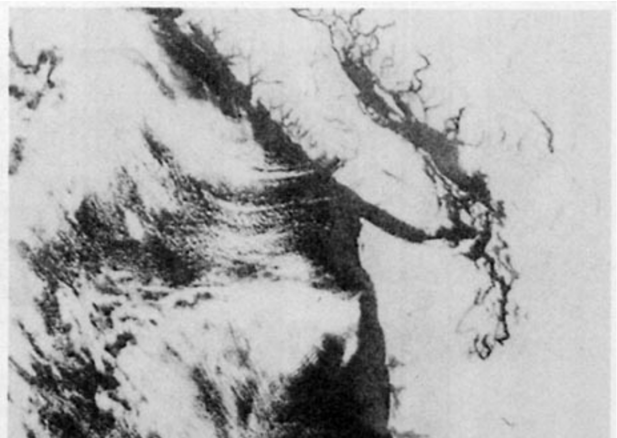

FIG. 2. TIROS-6 infrared imagery at 1200 GMT 22 December 1983.

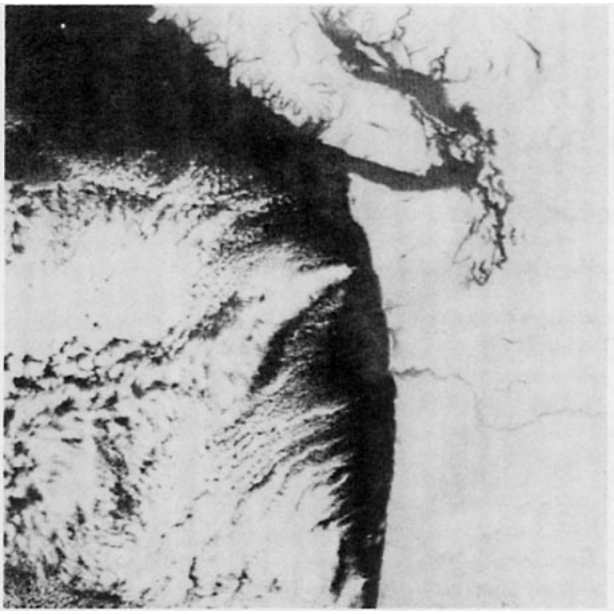

FIG. 3. TIROS-6 infrared imagery at 0300 GMT 23 December 1983.

is clearly evident in the TIROS-6 infrared imagery for 1200 GMT 22 December and 0300 GMT 23 December (Figs. 2 and 3) as well as the GOES-West visible picture for 18 GMT December 23 on (Fig. 4). For the first part of 22 December the band was relatively wide (Fig. 2) but by 0300 GMT on 23 December it had narrowed and become quite well-defined (Fig. 3). Narrower convective lines and some cloud patches are also evident; however, these features were quite variable in position, intensity and configuration. By 18 GMT on 23 December (Fig. 4) the convective cloudiness surrounding the band had attenuated, leaving it dramatically isolated (Fig. 4).

To understand the origin of this band it is important to know it's position with respect to the topography of the region (Fig. 5). The most significant topographic features include the north-south oriented Cascade Mountains, which reach heights exceeding 2000 m, the somewhat lower mountains of Vancouver Island, and the nearly circular Olympic Range. Between the Cascades and the Olympics are the lowlands of western Washington, which include Puget Sound. There are two low-level passages to the Pacific around the Olympic Range: the Strait of Juan de Fuca to the north and the Chehalis Gap to the south. A careful comparison of Figs. 5a and b and the satellite pictures indicates that the enhanced convective band stretched westward from the southern flank of the Olympics and remained in that position for several days.

We believe that there is strong evidence to suggest that the cloud band was a manifestation of a line of convergence created by the deflection of low-level flow around the Olympic Mountains. Surface wind observations (Fig. 6) suggest a confluent pattern in the lee of the Olympics, with northeasterly winds on the northern Washington coast veering to easterly and southeasterly to the south. Further evidence of convergence (or at least confluence) in the low-level winds is found in the satellite pictures. For example, in Fig. 2 cloud streets indicate easterly to northeasterly flow off the northern Washington coast, while to the south, wave-like variations in the low-level clouds suggest southeasterly winds. These waves are probably

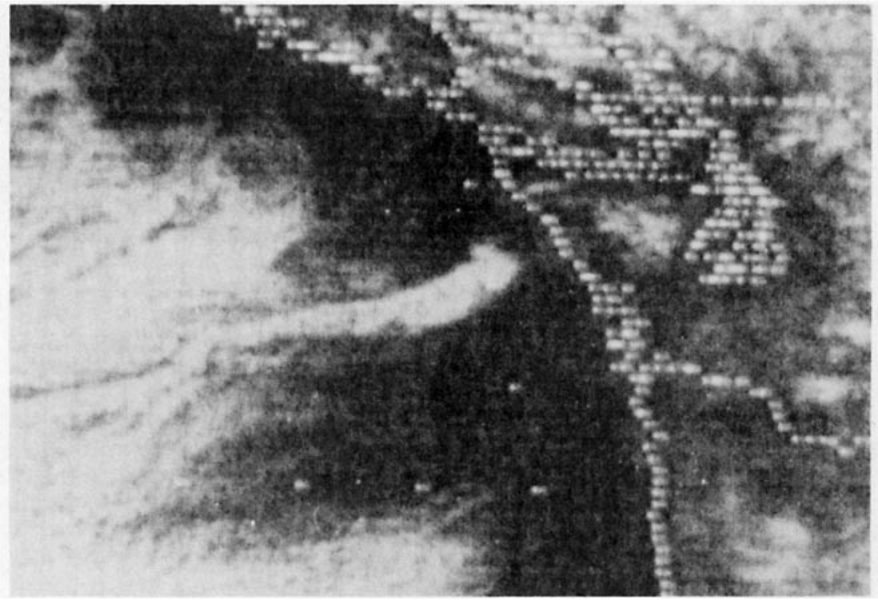

FIG. 4. GOES-W visible picture at 1800 GMT 23 December 1983.

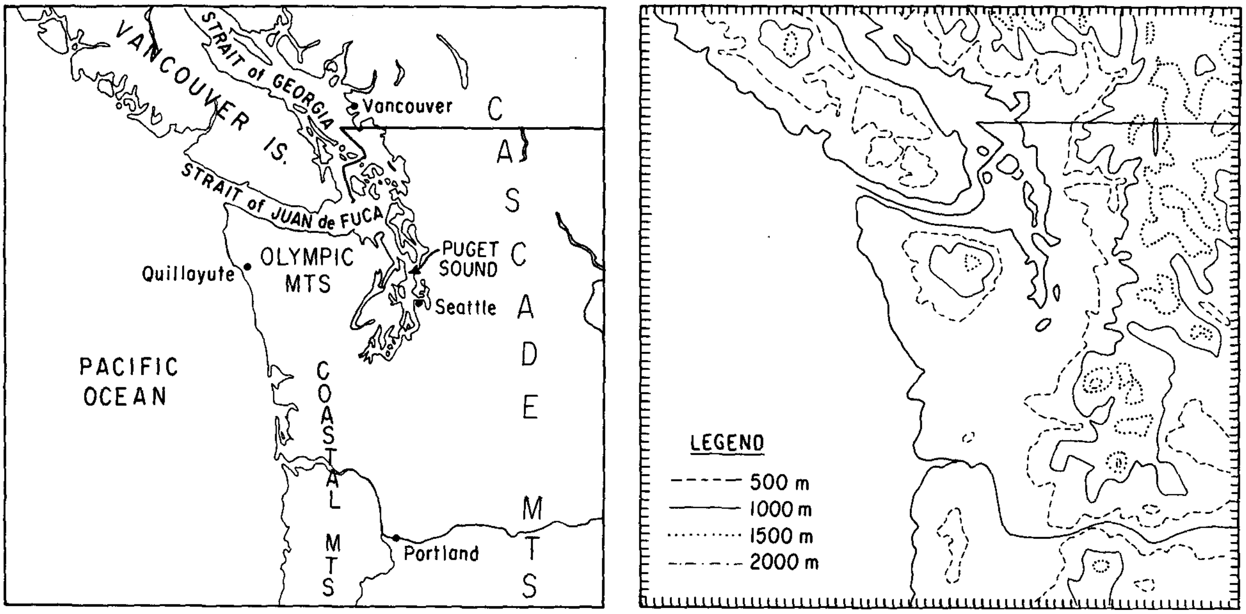

FIG. 5. Major geographic features (a) and terrain heights (b) of the adjacent area of the Pacific Northwest.

evidence of Kelvin–Helmholtz instability between strong southeasterly flow at low-levels and more quiescent flow aloft. Evidence of such a shear layer on the northern flank of the Olympics is shown in Fig. 7, which displays the upper air sounding at 1200 GMT 22 December 1983 at Quillayute, close to the Washington coast. In Fig. 7, there is a wind maximum of 15 m s^{-1} at 910 mb and a rapid weakening to 6 m s^{-1} at 850 mb. In the layer of strong winds the sounding is close to dry adiabatic with a more stable zone above in the layer of strong shear. Over the warmer water, the boundary layer undoubtedly became unstable and well mixed, reducing the wind shear below the jet maximum.

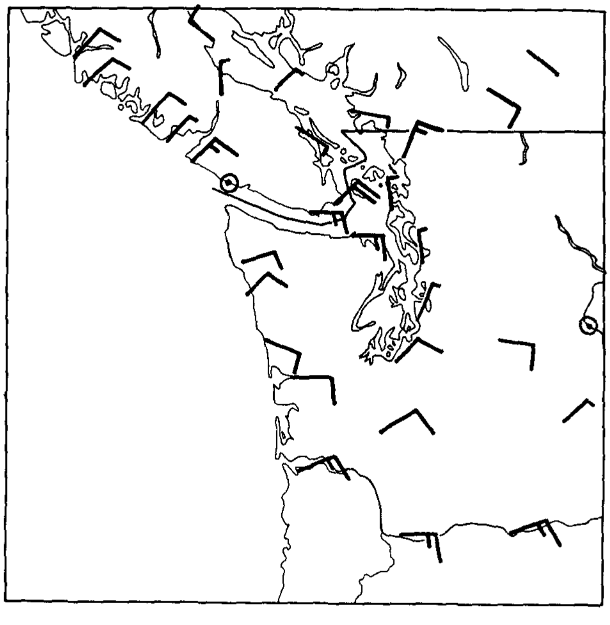

FIG. 6. Surface wind observations at 0000 GMT 23 December 1983. Winds are in knots.

In an attempt to explain better the convergence zone's origin we have applied a one-level model (Mass and Dempsey, 1985) that has been shown to be capable of diagnosing surface winds forced by complex terrain. As described in Mass and Dempsey, this model requires 850 mb geopotential heights and temperatures, a representative sounding for the domain, and the appropriate diabatic forcing. It assumes that the effects of topography and surface diabatic forcing are limited to a 2 km layer adjacent to the surface. Model-produced surface winds using data from 0000 GMT on 23 December and a maximum surface heating rate over land of 0.3°C h^{-1} (see Mass and Dempsey for model details) are shown in Fig. 8. Note how the model has produced a convergence line that extends southwestward from the southwest flank of the Olympic Range. A comparison with the polar orbiter imagery three hours later (Fig. 2) indicates that the model convergence line is close but not exactly coincident with the band of enhanced convective cloudiness. A second zone of convergence in the upper left corner of the model domain was produced by high terrain on Vancouver Island. The polar orbiter imagery at 12 GMT on 23 December does suggest an area of enhanced convection in the region of the second convergence zone. Subsequent images (Figs. 3 and 4) do not.

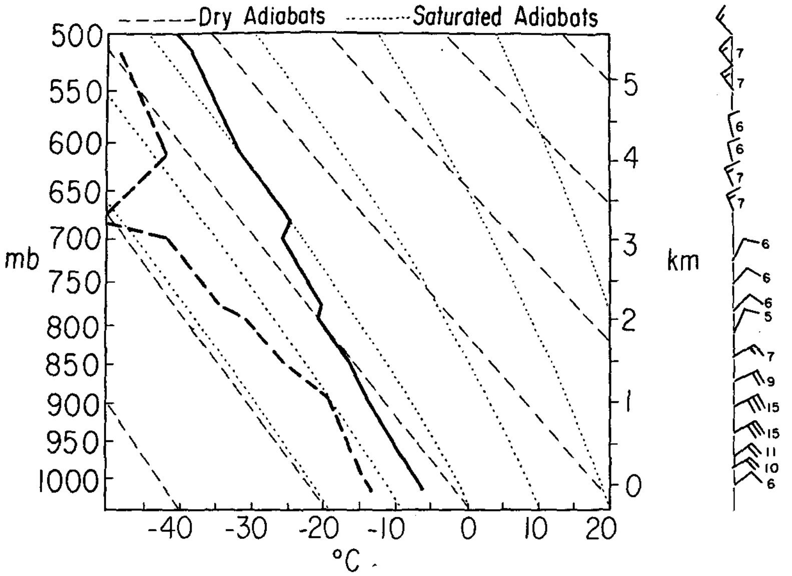

FIG. 7. Upper air sounding at Quillayute, Washington at 1200 GMT 22 December 1983. Numbers next to wind barbs are speeds in meters per second.

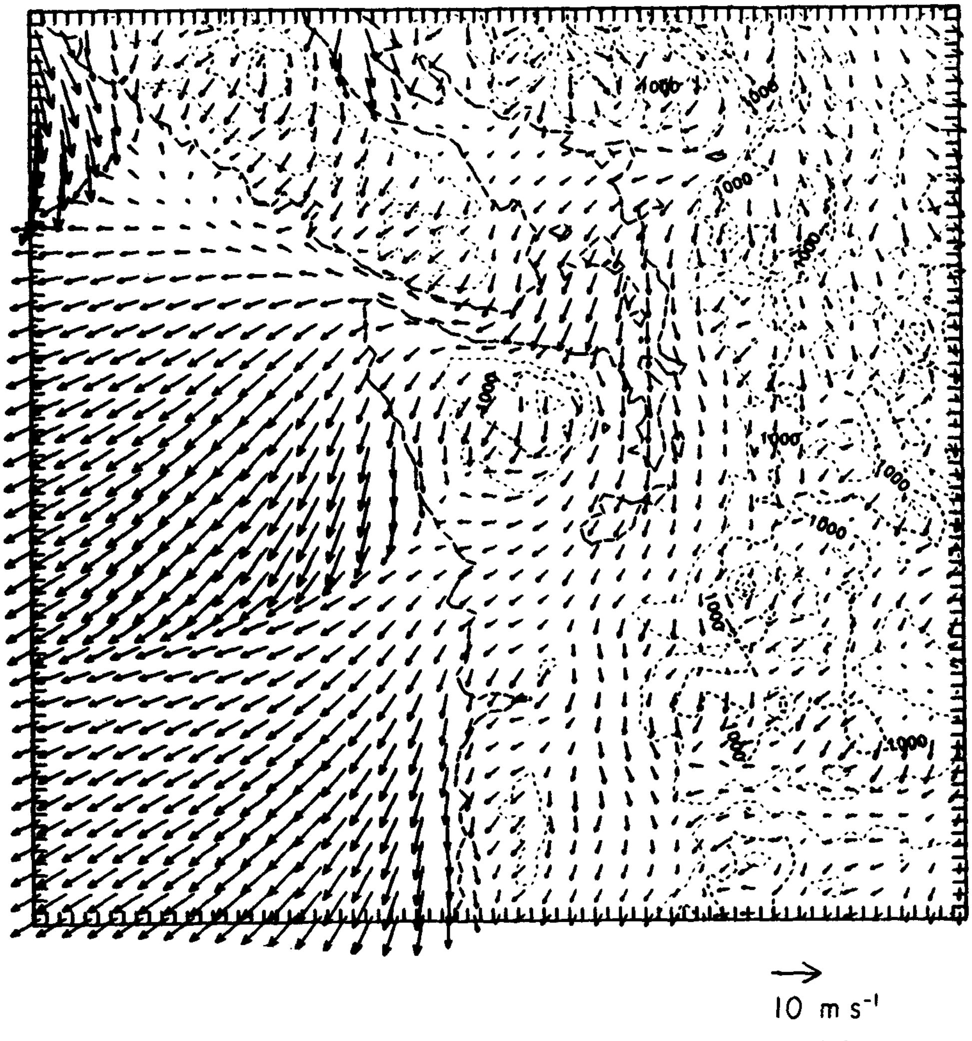

FIG. 8. Model surface winds based on data from 0000 GMT 23 December 1983.

We believe that a comparison of the model and observed wind fields gives confidence in the model's winds and thus the realism of the convergence line. Note that both model and observed winds are northerly in northern Puget Sound and veer to northeasterly in the southern Sound and to easterly near the coast. Similarly, both wind fields display northeasterlies on the coasts of Vancouver Island and Washington State, as well as a confluent zone in the lee of the Olympics.

The origin of the convergence line is suggested by the model's surface pressure field (not shown) which indicates a lee trough (in the surface pressure field) extending downwind of the Olympics. The modeled winds react to this pressure field by converging into the trough. A similar situation has been shown to occur east of the Olympics (Mass, 1981; Mass and Dempsey, 1985) under west to northwesterly flow at low-levels. Under these circumstances a zone of convergence forms over Puget Sound; it is usually associated with enhanced cloudiness and precipitation. Although previous studies have not discussed the convergent nature of the surface wind field behind an isolated mesoscale barrier, several (e.g., Smith 1979, 1982; Walter and Overland, 1982) have examined the creation of lee troughs behind such obstacles.

3. Conclusion

It appears that the nearly stationary cloud band observed off the Washington coast on 22 and 23 December 1983 was the result of topographically forced convergence in the lee of the Olympic mountains. This convergence line is suggested by coastal observations, satellite imagery and the wind field calculated by a one-layer mesoscale model.

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