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SECONDARY CIRCULATIONS AS THE RESULT OF FRICTIONAL CONVERGENCE ALONG A COASTLINE

[Editor's Note: This technical attachment is a condensation of an article which recently appeared in TELLUS. Although the original research was applied to coastal areas of western Europe, the results also have application to the western coast of North America.]

Thermally-driven land and sea breezes, and their relationships to precipitation patterns and zones of discontinuity have been studied extensively. However, the ageostrophic secondary circulations which are mechanically forced by the frictional convergence of the wind component normal to the coastline are not as well known and may be underestimated. Due to their abrupt change in surface roughness, coastlines represent a distinct discontinuity. A natural assumption is that for a given wind speed, the vertical motion pattern inland will be more intense and widespread as the onshore wind direction becomes more normal to the coastline. This is not necessarily the case.

As detailed in the referenced paper, a special mesoscale model was developed to examine secondary circulations resulting from a geostrophic wind flow interacting with a coastline. This was basically a simple 2-dimensional model with the following assumptions.

1. The atmosphere over the sea and coastline is homogeneous and neutrally stratified.

2. Thermodynamics are not included.

3. Straight coastline.

4. Geostrophic wind speed and direction and surface roughness are the only variables.

5. Computation continues until a steady-state is reached.

The size of the model domain was 3000m in the vertical and from -1000km to +1000km in the horizontal (coastline=Ø). Roughness parameters of 10^{-4}m and 10^{-1}m were used over the ocean and land, respectively.

Steady state solutions for a geostrophic wind speed of 20 m/s are given in Figure 1. The resulting flow patterns in the rectangles are shown in terms of streamline projections on a vertical plane perpendicular to the coastline. The density of the streamlines is not a measure of flow intensity. The shaded and non-shaded areas represent qualitatively different solutions. For example, solution 3 is representative of geostrophic wind directions from northeasterly ($\sim 30^{o}$) to easterly ($\sim 90^{o}$). However, a rather narrow range of wind direction values, south ($\sim 180^{o}$) to south-southwesterly ($\sim 210^{o}$), yield 4 different solutions, 5 through 6b. What is significant is that even though solutions 5 through 6b are different, each yields a better developed upward vertical motion pattern near the coastline than solutions from any of the other wind directions. The solutions representing flow more normal to the coastline (4a, 1) do depict vertical motion but not as sharply as in the solutions with south-southwesterly flow.

An expanded view of a few selected solutions is given in Figure 2. Again, note the narrow zone of sharp upward vertical motion resulting from the south-southwesterly flow in 2a-2c, and how quickly it diminishes with just a slight westward shift in the flow in 2d. Also, compare the solution in 2e and 2f, representing southwesterly and northwesterly flow with equal components normal to the coastline. Both yield weak upward vertical motion inland through the first 50km, however, the vertical motion with the 330^{o} wind direction becomes downward further inland.

The reason for these two different vertical motion patterns is further illustrated in Figure 3. The single-shafted arrows represent wind vectors. In the top portions of the diagrams, the side view shows equal components of the southwest and northwest flow normal to the coastline, and the resulting vertical motion patterns inland. The bottom portions of the diagrams show a top view of the wind vectors and how they change inland. In both cases, there is a backing of the wind vectors over land. This is due to the imbalance of forces normal to the flow over land. The flow over the sea is in near geostrophic balance, as there is minimal frictional effect. As the flow moves inland, frictional drag increases, causing deceleration (convergence) and an immediate vertical component. As the flow continues inland, there is further deceleration due to frictional effects and a corresponding decrease in the Coriolis Force. However, the pressure gradient force remains constant, which results in a "backing" or cross-isobaric flow towards lower pressure. In the case of the initial southwesterly flow (3a), the backing of the flow results in directional convergence inland and a broad area of upward vertical motion. However, in the case of northwesterly flow (3b), the backing further inland results in directional divergence and downward vertical motion.

In another series of experiments with this model, the speed of the geostrophic wind and the roughness parameter were varied. As expected, the size of the frictionally-induced secondary circulations increased with increasing speed. As it turned out, the depth of the vertical motion field increased more with the south-southwesterly flow, while the horizontal extent of the vertical motion field increased most with these winds more normal to the coastline. As the inland roughness pattern was increased, more vigorous and deeper secondary circulation developed.

This paper has potential application to the west coast areas in the Western Region. In addition to the obvious orographic lifting of the flow as winds track onshore (especially in coastal mountainous areas), the results above clearly show that frictional effects at coastlines can lead to important mesoscale secondary circulations. The southwesterly case is particularly interesting because it favors frontogenesis and has a narrow zone with strong upward motion. It should be remembered that most of the above results were obtained with a coastal roughness parameter of only 10^{-1}m. This corresponds to a surface of tall grass, such as a wheat field. Therefore, in coastal areas with sharply rising terrain, the orographic effects can be significantly enhanced by the ageostrophic secondary circulations forced by frictional convergence. The effects of these secondary circulations would be most pronounced with a steady-state, vertically stacked low pressure center off the west coast.

Reference:

Roeloffzen, J.C, Van Denberg, W.D., and Oerlemans, J., 1986: Frictional Convergence at Coastlines. TELLUS, 38A, 397-411.

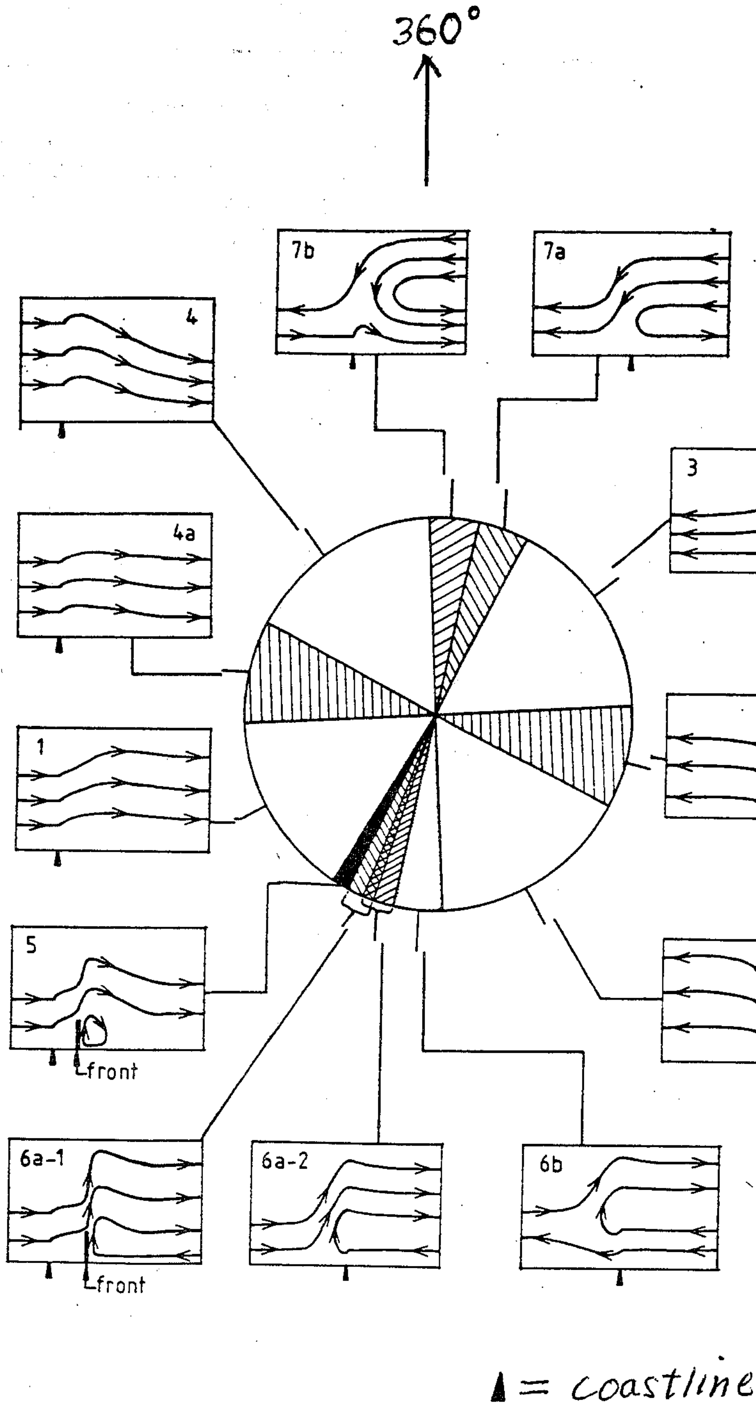


FIGURE 1.

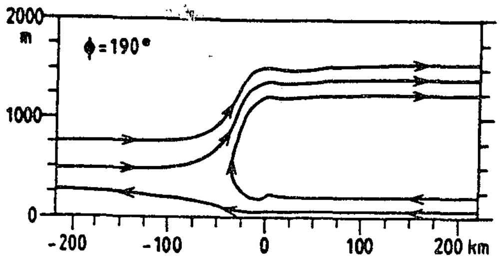


FIGURE 2a.

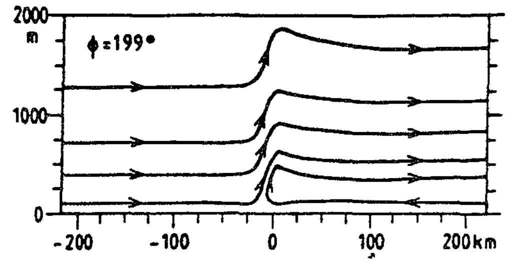


FIGURE 2b.

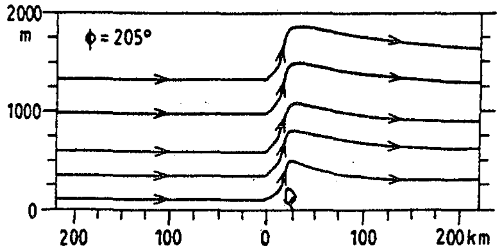
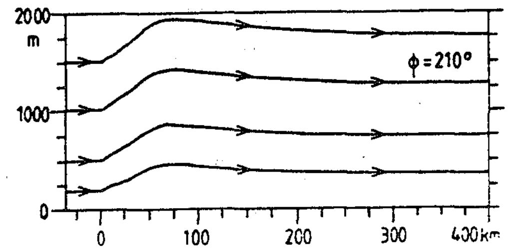


FIGURE 2c.



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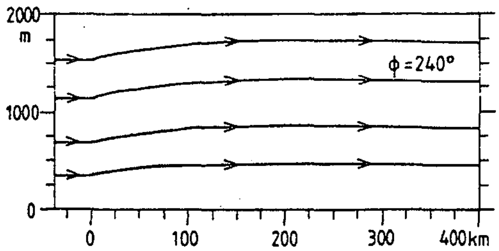

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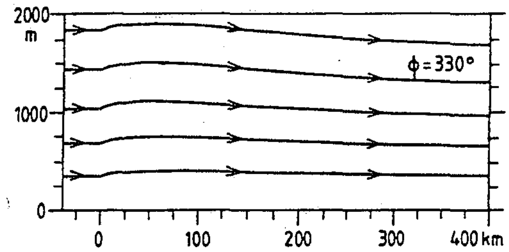

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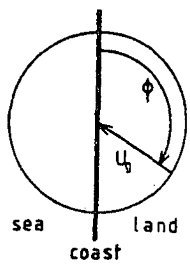

FIGURE 2.

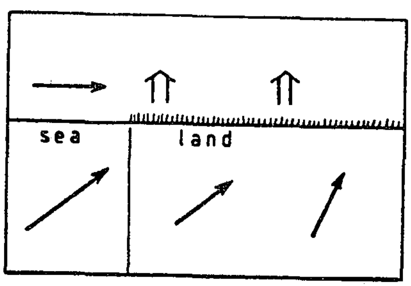

FIGURE 3a.
SOUTHWEST FLOW

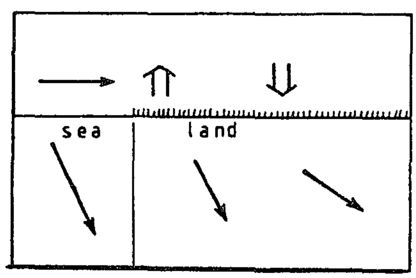

FIGURE 3b.
NORTHWEST FLOW

FIGURE 3.