EFFECTS OF ABNORMAL WIND TORQUE ON THE CIRCULATION OF A BAROTROPIC MODEL OF THE NORTH PACIFIC OCEAN

W. S. von ARX
(Read by Fritz Fuglister)

In running experimental models of the wind driven ocean circulations of the Northern and Southern Hemispheres it was always difficult to adjust conditions so that the zonal wind profiles acting on the models resembled those in nature. Often the wind torques would be too strong or too weak at first or have the subtropical inflection point at something other than the correct latitude. In the course of adjusting these variables toward the normal mean, it was noted that the patterns of water motion in the main sub-tropical gyres changed systematically with the wind speed and distribution to the extent that the correct wind profile could be approximated by a simple inspection of the pattern of motions. It remained then to make the finer adjustments by measuring the winds at a number of latitudes and adjusting the wind speeds so that the Rossby number of the water motion, particularly in the zone of westward intensification, was the same as that in nature.

Unfortunately these preliminary adjustments were not recorded photographically and my impression of the changes of circulation with aberrant winds is drawn almost entirely from memory. But insofar as this fallible faculty may serve to support them, these are the facts:

When the Rossby number of the water motion was too high by a factor near 1.5 or 2 the circulation not only increased but crowded westward in an unrealistic way, particularly in the Pacific compartment of the Northern Hemisphere models. Under these conditions the meandering of the Kuroshio became more congested, the Kuroshio extension migrated southward a few degrees, the West Wind Drift broadened and turned equatorward earlier than normal, following a path parallel to the North American coast but situated about midway between the coast and the Hawaiian Islands. In a sense, this is the same as the California Current having broadened and moved away from the coast (Fig. 102).

In the former place of the California Current, the coastal water between the latitudes of the Gulf of Tehuantepec and the Queen Charlotte Islands moved slowly poleward. Due to the sheltering effects of the model continents in the trade wind zone a poleward component of wind developed and caused some coastal sinking to occur in these latitudes. Where the westerlies struck the rubber model of North America and were deflected southward some upwelling developed. The result of this was to produce a slow cyclonic motion in an elongated triangular path between the coast and the flow in the displaced California Current.

This event caused the normally cyclonic circulation in the Gulf of Alaska to become more rounded and to extend a few degrees farther south. However, the circulation in the Gulf of Panama was practically unchanged, presumably because the Equatorial Countercurrent feeding water into the Gulf of Panama made up the water lost to the reversed flow in the former path of the California Current, and was itself resupplied by a branch of the southerly flow taking place in the displaced California Current.

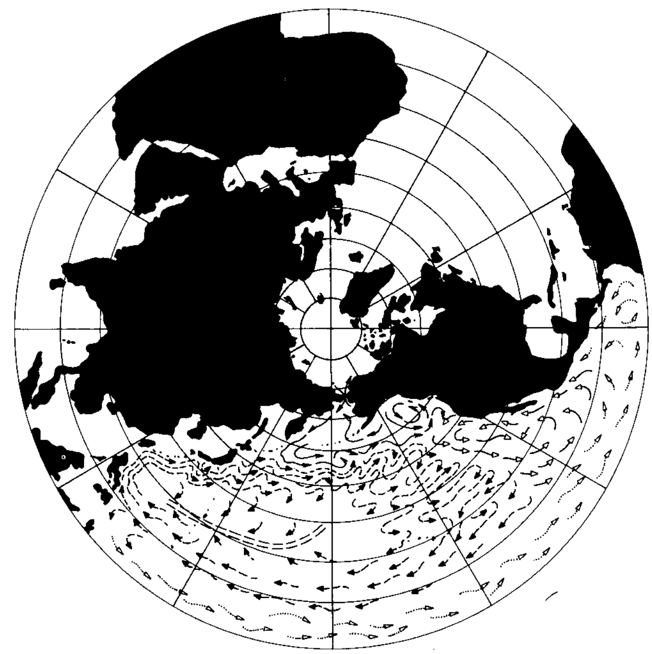

FIGURE 102. A vision of the barotropic motions accompanying high wind torques over a rotating model of the North Pacific.

These changes in the circulation of the North Pacific compartment are peculiar to an abnormally high Rossby number. Reduction of the Rossby number below normal broadens the Kuroshio, reduces its tendency to meander and causes it to turn eastward somewhat farther north than usual, but does not cause a conspicuous change of the circulation in the Gulf of Alaska or along the West Coast of North America.

In considering these experimental effects it should be remembered that they are purely barotropic processes in an Ekman-type ocean. In rotating models of this kind, the time of reorganization of the circulation to an abrupt change of the pattern of wind stresses is about 12 model days. Quite grotesque circulations can result in this short time if the wind pattern is sufficiently garbled by plan or accident. The barotropic readjustment of the model to seasonal changes is so rapid in comparison with a season's duration that unenlightening confusion soon reigns in the pattern of dyes in each of the major water masses. For this reason the experimental winds have been applied without seasonal variations.

These remarks, being made without knowledge of the facts of observation revealed at this Symposium or the sense of the discussion, may be quite useless. But if there is any resemblance between the abnormal circulations I have described from the model experiments and the present pattern of motions in the North Pacific measured by dynamic sections, I think these must result from a prolonged change of climate and winds in order to have time enough to produce a baroclinic reorganization of the water structure in depth. If the resemblance is limited to superficial changes in the water motion and structure the barotropic mode seems more probable.

DISCUSSION

Question: What is a Rossby number?

Stommel: I think it is the ratio of the characteristic water velocity to the velocity of a point on the Equator due to the Earth's rotation.

Sette: Is the baroclinic ocean essentially a two-layer ocean and how does its motion differ from that of a barotropic ocean?

Stommel: There are two kinds of motion. Even though the real ocean is stratified density-wise, you can conceivably set up a motion, like a tidal current, that has a velocity independent of depth. We call this a barotropic motion. Rossby, a long time ago, pointed out that for most short period changes in wind-stress, of the order of a week or a month, the ocean should respond barotropically, and very little change should be observed in the density structure deep in the ocean. Therefore, von Arx's model may be expected to exhibit some features of the real ocean's response to short period transients in applied wind stress. The theories so far, deal with periodic changes. But I do not think von Arx has made any experiments with periodic wind field yet.

Revelle: I was most struck by the fact (maybe I did not understand it), that von Arx actually gets a situation with an intensification of the wind such as we think we have had this last year, with a slackening of the wind. Increased wind torque shoves the California Current offshore, which we would expect, but the countercurrent looks as though it were a phenomena of low winds rather than high winds.

Sette: I think there is a difficulty that arises here of keeping the parallelism between the model and the ocean, because according to my idea of what has been happening, there was a general decrease of current offshore.

Revelle: That is right, and that is why I said that I did not quite understand. In his model he has a wind that is uniform with longitude.

Stommel: von Arx would probably have given quite a different talk if he had been here. Evidently he had the impression that a large part of this meeting might be taken up with the dynamic topography of a large section of the ocean, a mean picture of the circulation on a large scale. So I think his paper was intended as a contribution to that kind of discussion, and it actually turned out that we did not really discuss dynamic topography on such a scale. One of the interesting differences between the circulation revealed in the model, and that according to the Sverdrup theoretical model is that in the latter, the north-south transport, southward in this case, should be distributed evenly along any latitude circle over the entire ocean. However there are considerable indications that most of the north-south transport in the model occurs on the eastern side of the Pacific, and there is a large region to the west in the gyre where there does not seem to be any north-south transport at all. von Arx's model looks more like a chart of the actual Pacific, but rather different from that Sverdrup would have predicted from his model.

Revelle: It is my impression from working at different levels with drogues off the Baja California Coast, that the thermocline is something like a surface of separation. Above it the top layer sloshes around under the actual wind, just the way one would expect water to behave in a bathtub, but once you get beneath the thermocline, there is no immediate effect; everything in and below the thermocline is more stable and conservative. A long time would be required to set up a circulation beneath the thermocline.

Hubbs: von Arx has the main current near the coast going north as the countercurrent. This would be just wonderful from the standpoint of distribution of some tropical animals of which we have obtained only adults in the north. The model would be much more consistent with our observed distribution of fish than is the conventional one, in which the California Current coming south swings to the right and partly constitutes the North Equatorial Current. Instead of swinging westward into the Equatorial Current, the current in von Arx's model swings eastward into Middle America and then back northward. I do not know of any measurements which would show the countercurrent acting quite as beautifully as that, except possibly a deep current. The Davidson Current as recognized, does not cover the area I mention. It is not located in the tropics where we get the young stages of the fishes that are found up north as adults.

Revelle: Do you know if von Arx's system models the longitudinal dependence of the wind system?

Stommel: There is a rather puzzling discrepancy between von Arx's model, the real Pacific, and the explanation by Sverdrup's method, which I would like to mention. In both von Arx's model and in the Pacific, the southward flow is stronger in the eastern half of the North Pacific subtropical gyre than in the western half. In von Arx's model the wind stress is essentially zonal, whereas over the Pacific there is a marked intensification of curl of wind-stress over the eastern half of the ocean. Thus Sverdrup's method does not lead to the circulation that von Arx obtains, whereas it does lead to the observed circulation of the Pacific. One supposes that this means simply that the model of von Arx's does not behave according to Sverdrup's rules as closely as the real Pacific does.