ALPEX: SOME CURRENT ISSUES

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1. INTRODUCTION

The ALPEX program in 1982 has brought considerable attention to the influence of orography on the atmosphere. It is impossible in a short discussion to review the field phase of ALPEX, the voluminous ALPEX data sets, the diagnostic analysis on this data, or the stream of theoretical work which followed the experiment. The report of the 1985 ALPEX meeting in Venice published by the World Meteorological Organization contains the most recent summary of this kind. A review of the US effort is given by Smith 1986.

The intention of this note is to mention three particular problems in atmospheric dynamics on which theoretical progress has been made during ALPEX. These are: 1) airflow blocking and frontal deformation by mountains; 2) lee cyclogenesis; and 3) the severe wind Bora. This choice is somewhat personal as the writer has been active in each of these areas. It is true, however, that these subjects have attracted the attention of many other ALPEX scientists. In fact, each of these three topics are treated from other perspectives by other writers in this volume.

Each of the three subjects discussed here are covered in more detail in journal articles. The intention here is to acquaint the reader with the issues in each area and indicate the appropriate reference for further study.

2. AIRFLOW BLOCKING AND FRONTAL DEFORMATION

2.1 Two-dimensional airflow

The influence of a mountain on an approaching airstream should first be studied in two-dimensions to simplify the dynamics. The earliest work on this problem was the linear theory of Queney 1948. Queney showed that the tendency for upstream blocking depends on the Rossby number $R = U/fL$ and the non-dimensional mountain height $\hat{h} = hN/U$. The flow upstream of the mountain is strongly retarded if $\hat{h} > 1$ for large R, but not for small R. This work has been extended to account for finite mountain height by Pierrehumbert and Wyman 1985. They find that the blocking region forming upstream is confined to a dimension $L = Nh/f$. This agrees qualitatively with the Queney result as the effective mountain containing the actual mountain and the blocked region will then have $R = U/Nh$. The condition $\hat{h} > 1$ thus insures $R < 1$ and further blocking should not occur.

The modification of an incoming front by a ridge has been considered by Bannon (1984). For small Rossby number flow using semi-geostrophic theory, an upstream retardation of the front was found caused by ageostrophic advection.

2.2 Three-dimensional airflow

The observations from ALPEX suggest that much of the incoming airstream splits and flows around the Alps. This suggests that airflow blocking and frontal deformation are really three-dimensional processes. Observational studies by Steinacker (1981) indicate that the incoming surface front will wrap around the Alps. Isentropic trajectories (Buzzi and Tibaldi 1978) and low level trajectories (Chen and Smith 1986) indicate that the post frontal air splitting is associated with ageostrophic flow.

The theory of three-dimensional airflow has not progressed as far as the two-dimensional theories. An analytical theory for large Rossby number 3-D flow was presented by Smith (1980, 1982). There seems to be some qualitative similarity between theoretical predictions and the Alpex observations, but there are differences also. One problem is that the observed flows are often quite unsteady. The direction of the incoming flow and the point of flow splitting change with time. Furthermore, no frontal temperature gradients or wind shear were included in the theory. The 3-D frontal deformation process is currently being modeled by C. Schar and H. Davies in Zurich. The most complete observational study of the mid troposphere frontal deformation is that of McGinley 1982.

3. LEE CYCLOGENESIS

The primary focus of ALPEX research has been the formation of cyclones in the lee of the Alps. Recent reviews of this work are Pierrehumbert 1985, Buzzi and Tosi 1982, and the WMO report of the Venice ALPEX Workshop 1986. Amid the current controversy about the mechanism of lee cyclogenesis very few facts are undisputed. One of these is that cyclogenesis always follows the approach and impingement of a surface front and tropospheric baroclinic zone on the Alps. Second, the resulting lee cyclone has a structure which is very similar to cyclones forming far away from mountains. Most of the theories being discussed actively today at least partially account for these two facts.

A theory proposed by the writer (Smith 1984, 1986) holds that when a baroclinic zone moves over the mountain a baroclinic lee wave will begin to form. This lee wave is analogous to a small scale buoyancy lee wave except that the scale is much greater and the restoring force for the wave is the horizontal temperature gradient. Calculations show that the formation of the first trough of this wave is similar in many ways to observed lee cyclone formation.

4. SEVERE WINDS AND THE BORA

During the ALPEX field phase, five research missions were flown into the Yugoslavian Bora near Senj on the Adriatic Coast. These flights provided the first aerial observations of Bora structure (Smith 1986). These data together with theory and numerical simulation have led to new understanding of the severe downslope wind phenomena.

Some common features from the five Bora cases include:

- only a shallow layer is accelerated
- the acceleration begins upstream of the ridge crest
- the region between the descending accelerating bora layer and the less disturbed flow aloft is filled with a slow-moving turbulent layer of variable depth
- the upstream stable layer is usually split with only the lower part descending as part of the Bora layer.

Two other points are worth noting:

- the structure of the bora (noted above) is similar in many ways to the much deeper Boulder windstorm phenomena in Colorado.
- four of the five observed bora wind cases had reversed or turning winds above the Bora, unlike the Boulder storms, but one Bora case (25 March 1982) had constant wind direction with height, like the Boulder storms. Furthermore, this Bora case had a structure similar to the other four.

It seems possible then that the Boulder and Bora storms, which had previously been considered to be unrelated because of their different depth and wind turning characterisitcs, might be closely related phenomena. The challenge is to understand the dynamics of this class of flow.

It has been suggested for many years that cold air spilling over a ridge might have the "hydraulic" character of a layer of water spilling over a dam. The problem has been to find a meaning for the "top" of the spilling layer in the atmosphere. Upstream of the ridge there might be no feature in the temperature and wind profile which would suggest where the top of the layer would be as it later spilled over the ridge. Even if an inversion was present, the fluid might decide to split the inversion when descent begins. In 1985 it was proposed by the writer that the non-linear equations of internal hydraulics might be used to predict the layer depth. This theory is currently being tested in several ways. The layer depth predictions seem to agree with the numerical experiments of unidirectional flow over a ridge by Clark and Peltier 1984. Recent unpublished numerical experiments at other institutions seem to be yielding similar results. Recent tow tank experiments (Rottman and Smith 1986) yielded similar agreement. Predicted values for the Boulder storm and the March 25th Bora seem reasonable as well.

Applying the hydraulic theory to environments with strong wind turning requires an additional assumption: that the layer top will nearly coincide to the zero normal wind line above the ridge. Apparently (Clark and Peltier 1984, Smith 1985) severe wind flow with a hydraulic character can only form when the zero wind height nearly agrees with the prediction of internal hydraulic theory. This prediction has been checked in flow-through laboratory experiments (unpublished) and gives reasonable values for the four Bora cases with reversed flow.

The exciting prospect here is that we might be nearing a unified theory of severe downslope winds. It should be quickly added, however, that the above interpretation is extremely controversial as this is written. Other authors, including some in this volume, have different perspectives on this problem. Furthermore, the internal hydraulic theory is a steady state theory with no real predictive power. Thus it may be quite some time before we can forecast the occurence of a severe downslope wind.

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