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IMPACT OF PLANETARY BOUNDARY LAYER PROCESSES ON FRONTOGENESIS

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1. INTRODUCTION

Several analytical and numerical studies of the processes by which frontogenesis occurs have been performed (a brief review appears in Gill (1982)). However, some important questions regarding frontogenesis remain unanswered. One of the most fundamental of these concerns the impact of planetary boundary layer (PBL) physics on the evolution of fronts.

In g[illegible]ral, one can envision that surface s[illegible]s, static stability, and turbulent diffusion must be important in the formation of zones of large horizontal gradients in the atmosphere. In particular, the formation of discontinuities does not take place in numerical modeling studies incorporating turbulent diffusion since turbulent mixing reduces the magnitude of gradients in temperature and wind speed. Hoskins and Bretherton (1972) note that the existence of a large Richardson number in the vicinity of modeled fronts implies that turbulent mixing would be important. Steady-state fronts were produced by Williams (1974) using simple parameterizations of horizontal and vertical diffusion of heat and momentum. In a two-dimensional modeling study, Keyser and Anthes (1982) found that adding PBL physics to an adiabatic and inviscid simulation resulted in much more realistic frontal structure and circulation.

In the present study, three dimensional aspects of the problem are investigated. In order to isolate boundary layer processes important in frontogenesis, several different PBL parameterizations are used . Frontogenesis is forced by an unstable baroclinic wave. A series of 5 day integrations using a three dimensional, hydrostatic, primitive equation model is discussed. In each case, warm and cold fronts of approximately equivalent strength are produced as the wave amplitude increases.

2. RESULTS

The simulations are initialized with a baroclinically unstable state on which a 3,000 km perturbation is super-imposed. Given these initial conditions, linear baroclinic instability theory predicts an exponential doubling time of 43 hours and the time of "frontal collapse" is 91 hours. Fig. 1 shows a time series of minimum surface pressure for 3 different simulations. The curve labeled "1" is for a high vertical resolution adiabatic and inviscid (AIHR) simulation. The curve labeled "2" is for a high vertical resolution simulation employing a K-theory parameterization similar to that used by the European Center for Medium Range Weather Forecasting (Louis, 1979). The curve labeled "3" is for a low vertical resolution simulation employing a bulk PBL parameterization developed by Deardorff (1972).

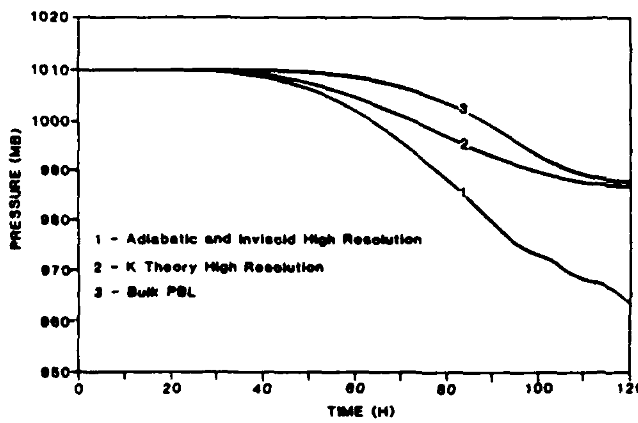

Figure 1. Time series of minimum surface pressure (mb) for three simulations

Fig. 2 shows a cross section of cold frontal structure for the AIHR simulation at day 4. Note that, without PBL physics, the model produces an intense cold front and a thermally direct vertical circulation (not shown). The cross-front temperature gradient is nearly independent of elevation. The boundary layer behind the front is slightly stable, however, and the ascending branch of the vertical circulation is weak and not based at the surface. Fig. 3 shows the cold frontal structure for the bulk PBL simulation at day 5. Note that the PBL in the cold air is well mixed and that the vertical motion field (not shown) exhibits a very compact

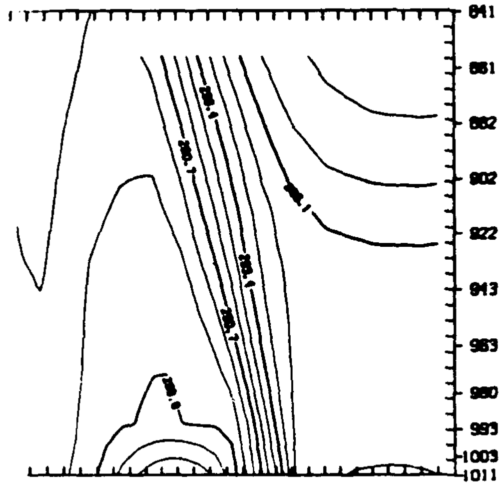

Figure 2. Cross section of potential temperature (K) for AIHR simulation

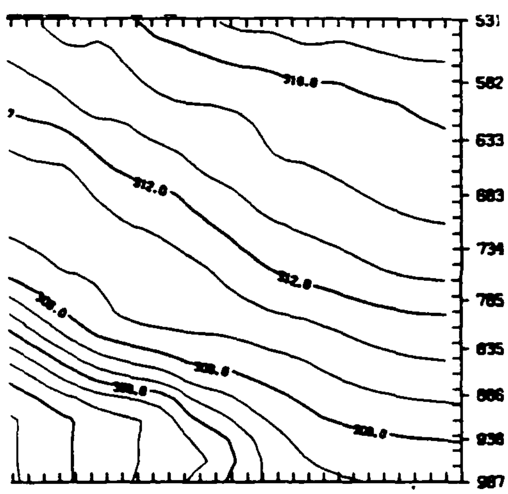

Figure 3. As in Fig. 2 for bulk PBL simulation

thermally direct circulation near the surface. The cross front temperature gradient in much smaller than in the AIHR simulation at the surface but differs only slightly above 900 mb. The front has a slightly larger slope in this case as well (note that the vertical scales are not the same in Figures 1 and 2).

Particular emphasis is placed on investigation of the importance of surface heat flux induced by thermal advection over a surface having initially uniform temperature in the E-W direction. Results using the bulk parameterization indicate that the cold front is much stronger when surface heat flux is not included. The boundary layer in the cold air behind the front is neutral when surface heat flux is active, as shown in Fig. 3. With no surface heat flux, mechanical mixing maintains the neutral structure only to day 4. The PBL is stable thereafter.

3. DISCUSSION

The results indicate that inclusion of even a simple PBL parameterization in a simulation of frontogenesis produces a far more realistic depiction of frontal features than does an adiabatic and inviscid simulation. With the additional sophistication of the K-theory parameterization, the ascending branch of the direct vertical circulation (not shown) has the appearance of an ascending jet. A similar feature has been observed in advance of cold fronts by Sanders (1955) and Shapiro (1984) and simulated by Keyser and Anthes 1982) and Reeder (1986).

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