12.804
Project 3
Fronts and the thermal wind equation-atmospheric data

October 2005

1 The thermal wind relation

Because the large-scale pressure field is in hydrostatic balance, the variation of the geostrophic wind with height is closely related to the variation of temperature in the horizontal - the so-called "thermal wind equation":

$$f\frac{\partial \mathbf{V}_g}{\partial p} = -\frac{R}{p}\mathbf{k} \times \nabla T_{\mathrm{p=const}} \tag{1}$$

This relation tells us that the vertical shear of the geostrophic wind should be related to the horizontal variation of temperature in precisely the same way as the geostrophic wind on a constant pressure surface is related to the horizontal variation in the height of the pressure surface:

$$\mathbf{V}_g = \frac{g}{f}\mathbf{k} \times \nabla z_{\mathrm{p=const}} \tag{2}$$

The thermal wind gives an immediate connection between the dynamics and the thermodynamics of large-scale motion. In this assignment we will use the thermal wind relation to study the structure of fronts.

1.1 Sections through fronts

Use GEMPAK program gdcross to construct vertical cross-sections trough the following fronts:

1.1.1 The polar front

Plot the 500mb temperature field using current synoptic data. Identify the region of strong temperature gradient, separating the colder polar air from the warmer tropical air - the so-called "polar front".

Construct a north-south section of winds and temperature through the front:

(a) Identify the tropopause and the position of the upper level jet

(b) Identify the frontal zone between cold and warm air

(c) How is vertical wind shear related to the horizontal temperature gradient both in the troposphere and stratosphere?

Estimate the vertical wind shear using the thermal wind equation and check if it is consistent with the observed wind shear?

Plot the corresponding section with ϑ instead of T and compare them. Under adiabatic conditions air motion is along isentropic surfaces.

1.1.2 A cold front

A marked cold front affected the Boston area on September 30^{th}. Fig.a shows the IR satellite picture on the day, when the cold front reached the Boston area. Fig.b shows the analyzed mean sea level pressure together with the surface obs and the position of the cold fronts for the same time.

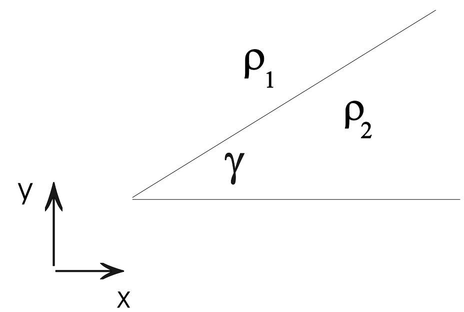
Plot a section of temperature and wind across the cold front:

(a) Identify the frontal zone between cold and warm air and estimate the slope of the frontal surface.

(b) Look for regions of strong vertical wind shear. Are they consistent with the thermal wind equation?

1.1.3 A warm front

Repeat the same as above but for a warm front. At this time of the year, warm fronts are not so easily identifiable. Look for an example in recent analyses. If you don't find a suitable case, you could use an example from few years ago winter. A marked warm front affected the Boston area on 14th



February 2000 - the so called "Valentine's Day warm front". Fig.c shows the IR satellite picture on the 14th February 2000, when the warm front reached the Boston area. Fig.d shows the analyzed mean sea level pressure together with the surface obs and the position of the warm and cold fronts for the same time.

Plot a section of temperature and wind across the warm front:

(a) Identify the frontal zone between cold and warm air and estimate the slope of the frontal surface. Compare the slope of the warm front with the slope of the cold front in.

(b) How is vertical wind shear related to the horizontal temperature gradient?

2 Slope of a frontal surface - Margules formula

A simple and instructive model of a front can be constructed as follows, following Margules (1906). Suppose that at some height z the density is ρ_2 on one side of the front and then changes discontinuously to ρ_1 on the other [see fig(2)]. Let x be a horizontal axis normal to the discontinuity and let γ be the angle that the surface of discontinuity makes with the horizontal.

Since the pressure must be the same on both sides of the discontinuity it is easy to show, making use of the hydrostatic equation, that:

$$\tan\gamma = \frac{dz}{dx} = \frac{\frac{\partial p_2}{\partial x} - \frac{\partial p_1}{\partial x}}{g\left(\rho_2 - \rho_1\right)}$$

Using the geostrophic approximation to the wind, show that:

$$\frac{v_2}{T_2} - \frac{v_1}{T_1} = \frac{g \tan \gamma}{f} \left(\frac{1}{T_2} - \frac{1}{T_1} \right) \tag{3}$$

where v is the component of the wind parallel to the front.

We can use (3) to estimate the frontal slope from observations of the changes in temperature and tangent-velocity across the front - for this purpose the following slightly more approximate form can be used:

$$\tan \gamma = \frac{f\,(v_2 - v_1)}{g\,(T_1 - T_2)\,/T}$$