On the Coupling between Upper Waves and Surface Pressure Centers

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Abstract

Taking into account the adiabatic pressure change due to the density change, the tendency equation is rewritten into a form where temperature advection is easily seen. As the temperature field is determined by the pressure and temperature field of two given levels, the surface pressure change and therefore moving velocity of pressure system may be calculated from this tendency equation.

J. G. Charney succeeded in preparing the 500 mb chart based on numerical calculation with remarkable accuracy and very simple assumptions. This encorages us in the hope for the perfection for upper wave prediction in near future. His method is a sort of coupling of upper and lower layers, but has no connection with the surface layer predictions. In this paper, the translation of surface pressure centers is dealt with by the kinematic method, assuming that upper waves have already been predicted. The tendency equation which is the most suitable to this problem will be improved by the consideration of adiabatic pressure change due to the density change. Temperatue field will be assumed as the form $T(x, y, z, t) = T(x, y, o, t) + \alpha(x, y, t) Z(z)$. Adiabatic change and geostrophic approximation will be adopted. A formula will be obtained which expresses the moving velocity of surface pressure center by known pressure and temperature field of upper and lower layers.

1. Improved tendency equation

There is a well-known tendency equation which expresses the surface pressure change $\frac{\partial p_0}{\partial t}$ as the summation of density change $\frac{\partial \rho}{\partial t}$ in the air column over it, and we measure this by wind divergence $\mathrm{div} V$ and density advection $V \cdot \nabla \rho$ with the aid of the equation of continuity. Although tendency equation explains physically the mechanism of pressure change, it is difficult to calculate numerically pressure change because estimation of divergence from practical wind data is difficult, and moreover geostrophic approximation gives no pressure change.

Now we discuss it from a different point of view. The density changes must be accompanied by the pressure changes in every level's particles due to the relation of adiabatic change $\frac{1}{\rho}\frac{d\rho}{dt}=\frac{c_v}{c_p}\frac{1}{p}\frac{dp}{dt}$,

namely,

$$(1)\qquad \frac{\partial\rho}{\partial t}=\frac{c_v}{c_p}\frac{\rho}{p}\frac{\partial p}{\partial t}+\frac{c_v}{c_p}\frac{\rho}{p}V\cdot\nabla p-V\cdot\nabla\rho,$$

where c_v, c_p is specific heat under constant volume or constant pressure. Using potential temperature $\theta=T\left(\frac{p_0}{p}\right)^{\frac{R}{c_p}}$, (1) may be written as

$$(1)'\qquad \frac{\partial\rho}{\partial t}=\frac{c_v}{c_p}\frac{1}{RT}\frac{\partial p}{\partial t}+\frac{\rho}{\theta}V\cdot\nabla\theta.$$

Substituting (1)′ into the relation $\frac{\partial^2 p}{\partial z\partial t}=-g\frac{\partial\rho}{\partial t}$ which is obtained by differentiating the static equilibrium equation with respect to time we obtain the differential equation to determine the pressure change

$$(2)\qquad \frac{\partial}{\partial z}\left(\frac{\partial p}{\partial t}\right)+\frac{g}{R}\frac{c_v}{c_p}\frac{1}{T}\frac{\partial p}{\partial t}+g\frac{\rho}{\theta}V\cdot\nabla\theta=0.$$

The integration of eq. (2) with respect to z from 0 to H is

$$\frac{\partial p_H}{\partial t}-\frac{\partial p_s}{\partial t}=-ge^{-\frac{g}{R}\frac{c_v}{c_p}\int_0^H\frac{dz}{T}}\int_0^H\frac{\rho}{\theta}V\cdot\nabla\theta\, e^{\frac{g}{R}\frac{c_v}{c_p}\int_0^z\frac{dz}{T}}dz$$

$$=g\left(\frac{p_H}{p_s}\right)^{\frac{c_v}{c_p}}\int_0^H\left(\frac{p}{p_s}\right)^{-\frac{c_v}{c_p}}\rho\theta V\cdot\nabla\left(\frac{1}{\theta}\right)dz.$$

This is written by the aid of relation $\rho=\frac{p}{RT}=\frac{p_0^{\frac{R}{c_p}}}{R}p^{1-\frac{R}{c_p}}\theta^{-1}$ as

$$(3)\qquad \frac{\partial p_s}{\partial t}=\frac{\partial p_H}{\partial t}-\frac{g}{R}p_0^{\frac{R}{c_p}}p_H^{\frac{c_v}{c_p}}\left\{\int_0^H V_2\cdot\nabla_2\left(\frac{1}{\theta}\right)dz+\int_0^H w\frac{\partial}{\partial z}\left(\frac{1}{\theta}\right)dz\right\},$$

where suffixes s, H respectively denote the surface and level H value and 2 denotes horizontal component. The improved tendency eq. (3) expresses that surface pressure change is given by upper level pressure change and the velocity and temperature field between these two levels, and geostrophic approximation gives some pressure change.

2. Approximate expression for surface change

We may regard the wind field as geostrophic for the first appoximation, so we get

$$(4)\qquad V_2\simeq\frac{k}{\lambda}\times\theta\nabla_2\pi,$$

where k is vertical unit vector, λ is Coriolis' parameter and $\pi=c_p\left(\frac{p}{p_0}\right)^{\frac{R}{c_p}}$ where

c_p is estimated by work unit. We may use Ekman's spiral instead of geostrophic wind for V_2. or more precisely isallobaric wind under the influence of viscosity.

Putting (4) into (3), we get

$$(5)\qquad \frac{\partial p_s}{\partial t}=\frac{\partial p_H}{\partial t}-\frac{g}{\lambda R}p_0^{\frac{B}{c_p}}\,p_H^{\frac{c_v}{c_p}}\,\boldsymbol{k}\cdot\int_0^H\theta\nabla_2\pi\times\nabla_2\left(\frac{1}{\theta}\right)dz-\frac{g}{R}p_0^{\frac{R}{c_p}}\,p_H^{\frac{c_v}{c_p}}\,\overline{w}\left(\frac{1}{\theta_H}-\frac{1}{\theta_s}\right),$$

where $\overline{w}$ is the average vertical velocity between 0 to H and is of course assumed to stand in the ordinary case.

Now we should remark that the temperature field of intermediate levels is determined by the pressure field of upper and lower levels and temperature field of lower level, so far as the static equilibrium equation may be adopted as a first approximation and the temperature field may be separated by the function of z and the function of x, y. If we take

$$(6)\qquad \frac{1}{\theta(x,y,z)}=\frac{1}{\theta_s(x,y)}\left\{1-\alpha(x,y)\,z\right\},$$

which shows a slowly increasing stability with height as is the actual case, we obtain by integration of the static eq. $\frac{\partial\pi}{\partial z}=-g\frac{1}{\theta}$,

$$(7)\qquad \pi-\pi_s=-\frac{g}{\theta_s}z\left(1-\frac{\alpha z}{2}\right),$$

from which we can understand the above explanation. Further $\nabla_2\pi$ and $\nabla_2\left(\frac{1}{\theta}\right)$ in the integrant of (6) may be also expressed by π_s, π_H, θ_s Namely, taking horizontal gradient of (7) and (6) we obtain

$$(8)\qquad \nabla_2\pi=\nabla_2\pi_s-gz\nabla_2\left(\frac{1}{\theta_s}\right)-\frac{gz}{2}\left(\frac{\nabla_2\theta_s}{\theta_s}-\frac{\nabla_2\alpha}{\alpha}\right)\frac{\alpha z}{\theta_s},$$

$$(9)\qquad \nabla_2\left(\frac{1}{\theta}\right)=\nabla_2\left(\frac{1}{\theta_s}\right)+\left(\frac{\nabla_2\theta_s}{\theta_s}-\frac{\nabla_2\alpha}{\alpha}\right)\frac{\alpha z}{\theta_s},$$

where

$$(10)\qquad \frac{\nabla_2\theta_s}{\theta_s}-\frac{\nabla_2\alpha}{\alpha}=\frac{2\theta_s}{\alpha H}\left[\frac{1}{gH}(\nabla_2\pi_s-\nabla_2\pi_H)-\nabla_2\left(\frac{1}{\theta}\right)\right].$$

Therefore

$$\theta\nabla_2\pi\times\nabla_2\left(\frac{1}{\theta}\right)=\theta_s\nabla_2\pi_s\times\nabla_2\left(\frac{1}{\theta_s}\right)\frac{\left(1-\frac{z}{H}\right)^2}{1-\alpha z}+\theta_s\nabla_2\left(\frac{1}{\theta_s}\right)\times\nabla_2\pi_H\frac{\frac{z^2}{H^2}}{1-\alpha z}$$

$$-\theta_s\frac{\nabla_2\pi_s\times\nabla_2\pi_H}{gH}\frac{2\frac{z}{H}}{1-\alpha z},$$

and integrating from 0 to H we obtain

$$\int_0^H\theta\nabla_2\pi\times\nabla_2\left(\frac{1}{\theta}\right)dz=\theta_s\nabla_2\pi_s\times\nabla_2\left(\frac{1}{\theta_s}\right)HA+\theta_s\nabla_2\left(\frac{1}{\theta_s}\right)\times\nabla_2\pi_H HB$$

$$-\frac{\theta_s}{gH}\nabla_2\pi_s\times\nabla_2\pi_H HC,$$

where

$$
(11) \qquad \begin{cases} A = \frac{1}{3} + \frac{1}{12}\alpha H + \frac{1}{30}\alpha^2 H^2 + \frac{1}{60}\alpha^3 H^3 + \cdots\cdots , \\ B = \frac{1}{3} + \frac{1}{4}\alpha H + \frac{1}{5}\alpha^2 H^2 + \frac{1}{6}\alpha^3 H^3 + \cdots\cdots , \\ C = 1 + \frac{2}{3}\alpha H + \frac{1}{3}\alpha^2 H^2 + \frac{2}{5}\alpha^3 H^3 + \cdots\cdots . \end{cases}
$$

After all, eq. (5) is written as

$$
(12) \qquad \frac{\partial p_s}{\partial t} = \frac{\partial p_H}{\partial t} - \frac{gH}{\lambda R} p_0^{\frac{R}{c_p}} p_H^{\frac{c_v}{c_p}} \left\{ \mathrm{A}k \cdot \theta_s \nabla_2 \pi_s \times \nabla_2\left(\frac{1}{\theta_s}\right) - Bk \cdot \theta_s \nabla_2 \pi_H \times \nabla_2\left(\frac{1}{\theta_s}\right) \right.
$$

$$
\left. - Ck \cdot \theta_s \nabla_2 \pi_s \times \frac{\nabla_2 \pi_H}{gH} \right\} - \frac{g}{R} p_0^{\frac{R}{c_p}} p_H^{\frac{c_v}{c_p}} \overline{w} \left(\frac{1}{\theta_H} - \frac{1}{\theta_s} \right)
$$

or

$$
(12)' \qquad \frac{\partial p_s}{\partial t} = \frac{\partial p_H}{\partial t} - \frac{gH}{R} p_0^{\frac{R}{c_p}} p_H^{\frac{c_v}{c_p}} \left\{ A V_s \cdot \nabla_2\left(\frac{1}{\theta_s}\right) - B \frac{\theta_s}{\theta_H} V_H \cdot \nabla_2\left(\frac{1}{\theta_s}\right) - C V_s \cdot \frac{\nabla_2 \pi_H}{gH} \right\}
$$

$$
+ \frac{gH}{R} p_0^{\frac{R}{c_p}} p_H^{\frac{c_v}{c_p}} \overline{w} \frac{\alpha}{\theta_s} .
$$

Eq. (12) shows that the surface pressure change may be determined for the first approximation by the pressure change of given level and pressure field of surface and given level and surface temperature field which are all observed and calculated. There are five terms to determine the surface pressure change. First, upper pressurefall; second, advection of surface warm air; third, upper wind blowing towards warm area on the surface; fourth, surface wind blowing towards upper low pressure area; fifth, descending current. Each of them may be the cause of the surface pressure fall. If thermal wind blows at level H, the third term vanishes, and if not, it gives correction for second term due to vertical stratification. The fourth term is rewritten as $CV_s \cdot \nabla_2 p_H$ or $C(1-\alpha H) V_H \cdot \nabla_2 p_s$ and has max. value of all the five terms when thermal wind relation stands. If both upper and lower winds blow along surface isotherms, the second, the third and the fourth term vanish and surface pressure change is caused only by upper pressure change and vertical motion and not by vertical stratification.

3. Moving velocity of surface pressure centers

As many authors intended to explain the movement of pressure center, the formula which expresses moving velocity of surface centers by upper and lower field of temperature and pressure or wind can be obtained by applying kinematic method for eq. (12)'. Surface pressure center is defined by $\frac{\partial p_s}{\partial x} = \frac{\partial p_s}{\partial y} = \frac{\partial^2 p_s}{\partial x \partial y} = 0$. Besides we assume linear surface temperature field, and take into accunt $\frac{\partial^2 p_H}{\partial x^2}$ only among second order differentials of upper field p_H. That is to say,

$$\frac{\partial^2 T_s}{\partial x^2}=\frac{\partial^2 T_s}{\partial x\partial y}=\frac{\partial^2 T_s}{\partial y^2}=\frac{\partial^2 p_H}{\partial x\partial y}=\frac{\partial^2 p_H}{\partial y^2}=0.$$

In the first place we calculate the gradient of $A(x.\ y)$, $B(x,y)$, $C(x,y)$.

$$(13)\quad\left\{\begin{aligned}
&\nabla_2 A=H\nabla_2\alpha\left(\frac{1}{12}+\frac{1}{15}\alpha H+\frac{1}{20}\alpha^2H^2+\cdots\cdots\right)=H\nabla_2\alpha\ A',\\
&\nabla_2 B=H\nabla_2\alpha\left(\frac{1}{4}+\frac{2}{5}\alpha H+\frac{1}{2}\alpha^2H^2+\cdots\cdots\right)=H\nabla_2\alpha\ B',\\
&\nabla_2 C=H\nabla_2\alpha\left(\frac{2}{3}+\alpha H+\frac{6}{5}\alpha^2H^2+\cdots\cdots\right)=H\nabla_2\alpha\ C',
\end{aligned}\right.$$

where

$$H\nabla_2\alpha=-(2-\alpha H)\frac{\nabla_2\theta_s}{\theta_s}-\frac{2\theta_s}{gH}(\nabla_2\pi_s-\nabla_2\pi_H).$$

Differentiating (12) or (12)′ with respect to x, y, we obtain by taking account of the above assumption,

$$(14)\quad\left\{\begin{aligned}
&\frac{\partial^2 p_s}{\partial x\partial t}=\frac{\partial^2 p_H}{\partial x\partial t}+\frac{gH}{R}\frac{c_s}{c_p}p_H^{-\frac{R}{c_p}}p_s^{\frac{R}{c_p}}\frac{\partial p_H}{\partial x}B(1-\alpha H)\ V_H\cdot\nabla_2\left(\frac{1}{T_s}\right)\\
&\qquad+\frac{gH}{R}\frac{c_s}{c^p}p_H^{-\frac{R}{c_p}}p_s^{\frac{R}{c_p}}\frac{\partial p_H}{\partial x}\overline{w}\frac{\alpha}{T_s}-\frac{gH}{R}p_H^{-\frac{R}{c_p}}p_s^{\frac{R}{c_p}}\left[A\frac{\partial V_s}{\partial x}\cdot\nabla_2\left(\frac{1}{T_s}\right)\right.\\
&-B(1-\alpha)\frac{\partial V_H}{\partial x}\cdot\nabla_2\left(\frac{1}{T_s}\right)-\left.\left\{\frac{\partial B}{\partial x}(1-\alpha H)-BH\frac{\partial\alpha}{\partial x}\right\}V_H\cdot\nabla_2\left(\frac{1}{T_s}\right)\right]\\
&\qquad+Cp_H^{1-\frac{R}{c_p}}p_s^{\frac{R}{c_p}}\frac{\partial V_s}{\partial x}\cdot\nabla_2 p_H+\frac{gH}{R}p_H^{1-\frac{R}{c_p}}p_s^{\frac{R}{c_p}}\overline{w}\left[\frac{1}{T_s}\frac{\partial\alpha}{\partial x}+\alpha\frac{\partial}{\partial x}\left(\frac{1}{T_s}\right)\right]\\
&\qquad-\frac{gH}{R}p_H^{1-\frac{R}{c_p}}p_s^{\frac{R}{c_p}}B(1-\alpha H)V_H\cdot\nabla_2\left(\frac{1}{T_s}\right)\frac{\partial ln\lambda}{\partial y}.
\end{aligned}\right.$$

where we assume symmetric vertical motion and take account of latitudinal variation of Coriolis' parameter λ. The same relation stands with respect to y. Eq. (13) may be written

$$(15)\quad\left\{\begin{aligned}
&\left\{\begin{matrix}\dfrac{\partial^2 p_s}{\partial x\partial t}\\[2ex]\dfrac{\partial^2 p_s}{\partial y\partial t}\end{matrix}\right\}=\left\{\begin{matrix}\dfrac{\partial^2 p_H}{\partial x\partial t}\\[2ex]\dfrac{\partial^2 p_H}{\partial y\partial t}\end{matrix}\right\}-C(1-\alpha H)\left(\frac{\pi_s}{\pi_H}\right)^2\left(\frac{p_H}{p_s}\right)^2\left\{\begin{matrix}\dfrac{\partial^2 p_H}{\partial x^2}U\\[2ex]\dfrac{\partial^2 p_H}{\partial y^2}V\end{matrix}\right\}\\
&\qquad-\left[\frac{c_v}{R}B(1-\alpha H)^2\left(1-\frac{\alpha H}{2}\right)^{-1}\left(\frac{\pi_s}{\pi_H}-1\right)+2\{B'(1-\alpha H)-B\}(1-\alpha H)\right]\\
&\qquad\frac{\lambda}{RH}\frac{\pi_s}{\pi_H}\frac{p_H}{p_s}V_H\cdot\nabla_2\ln T_sH\left\{\begin{matrix}V\\-U\end{matrix}\right\}+\left[\frac{c_v}{R}\alpha H(1-\alpha H)\left(1-\frac{\alpha H}{2}\right)^{-1}\left(\frac{\pi_s}{\pi_H}-1\right)\right.\\
&\qquad\left.+2(1-\alpha H)\right]\frac{\lambda}{RH}\frac{\pi_s}{\pi_H}\frac{p_H}{T_s}\overline{w}\left\{\begin{matrix}V\\[2ex]-U\end{matrix}\right\}
\end{aligned}\right.$$

$$+\left\{\begin{array}{l} +\left\{A\frac{p_H}{p_s}\frac{\partial^2 p_s}{\partial x^2}-B(1-\alpha H)\frac{\partial^2 p_H}{\partial x^2}\right\}\frac{gH}{\lambda}\frac{\pi_s}{\pi_H}\frac{\partial lnT_s}{\partial x} \\ -A\frac{p_H}{p_s}\frac{\partial^2 p_s}{\partial y^2}\frac{gH}{\lambda}\frac{\pi_s}{\pi_H}\frac{\partial lnT_s}{\partial y} \end{array}\right\}$$

$$+2\left[\{B'(1-\alpha H)-B\}\left(1-\frac{\alpha H}{2}\right)V_H\cdot\nabla_2 lnT_sH-\overline{w}\right]\frac{g}{R}\frac{\pi_s}{\pi_H}\frac{p_H}{T_s}\left\{\begin{array}{l}\frac{\partial lnT_s}{\partial x}\\ \frac{\partial lnT_s}{\partial y}\end{array}\right\}$$

$$+\left\{\begin{array}{l} 0 \\ +B(1-\alpha H)\frac{g}{R}\frac{\pi_s}{\pi_H}\frac{p_H}{T_s}V_H\cdot\nabla_2 lnT_sH\frac{\partial ln\lambda}{\partial y}\end{array}\right\}.$$

Two equations, $\frac{\partial^2 p_s}{\partial x\partial t}$ and $\frac{\partial^2 p_s}{\partial y\partial t}$, are expressed in one form, where if we select the above in the symbol $\{\ \}$ we obtain the expression for $\frac{\partial^2 p_s}{\partial x\partial t}$ and the below for $\frac{\partial^2 p_s}{\partial y\partial t}$. The second, the third and the fourth term show steering of upper level the magnitude of which depends on field quantity, temperature advection and vertical motion. The fifth and the sixth term show the effect of temperature field the magnitude of which depends on kinematic condition and temperature field and vertical motion. The seventh term shows the effect of the variation of Coriolis' parameter. The field quantities which decide the magnitude of each effect may be approximately taken as the avarage condition in the considering interval.

For example we take

$$H=5\text{ km},$$
$$\theta_H=27.3\ ^\circ\text{C},$$
$$\theta_s=6.8\ ^\circ\text{C},$$
$$\frac{p_H}{p_s}=\frac{1}{2},$$
$$T_H=-13.0\ ^\circ\text{C},$$

which is average condition of November in central Japan. We get

$$\alpha=1.8\times10^{-7},$$
$$\frac{\pi_s}{\pi_H}=1.2,$$
$$\frac{\lambda}{RH}\frac{\pi_s}{\pi_H}\frac{p_H}{T_s}=1.6\times10^{-13},$$
$$\frac{gH}{\lambda}\frac{\pi_s}{\pi_H}=6\times10^{12},$$
$$\frac{g}{R}\frac{\pi_s}{\pi_H}\frac{p_H}{T_s}=0.8.$$

Denoting the east and the north component of moving velocity of surface pressure center by c_x and c_y respecively, the velocity of upper trough by C, the following relations stand

$$
(16)\quad \begin{cases}
\dfrac{\partial^2 p_s}{\partial x \partial t} + c_x \dfrac{\partial^2 p_s}{\partial x^2} = 0, \\[2mm]
\dfrac{\partial^2 p_s}{\partial y \partial t} + c_y \dfrac{\partial^2 p_s}{\partial y^2} = 0, \\[2mm]
\dfrac{\partial^2 p_H}{\partial x \partial t} + C \dfrac{\partial^2 p_H}{\partial x^2} = 0.
\end{cases}
$$

Therefore we get the formula which expresses the moving velocity of pressure center

$$
(17)\quad \begin{cases}
c_x = 0.36U \\
\quad -0.30\times 10^{-12} \dfrac{\overline{w}}{\dfrac{\partial^2 p_s}{\partial x^2}} V \\[2mm]
\quad -\left(0.96\times 10^{12} - 1.98\times 10^{12} \dfrac{\dfrac{\partial^2 p_H}{\partial x^2}}{\dfrac{\partial^2 p_s}{\partial x^2}}\right) \dfrac{1}{T_s}\dfrac{\partial T_s}{\partial y} \\[2mm]
\quad + \dfrac{0.14 \dfrac{H}{T_s}\left(U \dfrac{\partial T_s}{\partial x} + V \dfrac{\partial T_s}{\partial y}\right) + 1.6\,\overline{w}}{\dfrac{\partial^2 p_s}{\partial x^2}} \dfrac{1}{T_s}\dfrac{\partial T_s}{\partial x} \\[2mm]
\quad + C \dfrac{\dfrac{\partial^2 p_H}{\partial x^2}}{\dfrac{\partial^2 p_s}{\partial x^2}},
\end{cases}
\qquad
\begin{aligned}
c_y &= 0.36V \\
&\quad +0.30\times 10^{-12} \dfrac{\overline{w}}{\dfrac{\partial^2 p_s}{\partial y^2}} U \\[2mm]
&\quad +0.96\times 10^{12} \dfrac{1}{T_s}\dfrac{\partial T_s}{\partial x} \\[2mm]
&\quad + \dfrac{0.14 \dfrac{H}{T_s}\left(U \dfrac{\partial T_s}{\partial x} + V \dfrac{\partial T_s}{\partial y}\right) + 1.6\,\overline{w}}{\dfrac{\partial^2 p_s}{\partial y^2}} \dfrac{1}{T_s}\dfrac{\partial T_s}{\partial y} \\[2mm]
&\quad -0.42\times 10^{-9} \dfrac{\dfrac{H}{T_s}\left(U \dfrac{\partial T_s}{\partial x} + V \dfrac{\partial T_s}{\partial y}\right)}{\dfrac{\partial^2 p_s}{\partial y^2}}.
\end{aligned}
$$

In eq. (17), the first term gives the greatest velocity and the other terms give the correction. The steering effect of upper wind on the moving velocity of surface pressure center is 0.36 $\left[=\dfrac{C}{V}\right]$ for Nov. in Japan. For anti-cyclone $\dfrac{\partial^2 p_s}{\partial x^2}$ and $\dfrac{\partial^2 p_s}{\partial y^2}$ are small and the terms after the second give considerable amounts, and the tendency of southward displacement of anti-cyclone.

4. Conclusion

We assume the static equilibrium equation for vertical equation of motion and geostrophic approximation and derive the moving velocity of surface pressure center. We consider that the movement of surface pressure system is caused by the asymmetric field above the pressure system, and calculate the change in the weight of the air column above it. Deviation from geostrophic approximation may be considered symmetric around the pressure center, so any serious error would not arise from geostrophic approximation. The study of the asymmetric field of moisture content should be our next step. In this computation, we assume adiabatic change and use potential temprature. By using polytropic potential temperature for polytropic change, the formula of the same form and different coefficients will be obtained.

References

J. G. Charney & A. Eliassen : A Numerical Method for Predicting the Perturbations of the Middle Latitude Westerlies., Tellus **1**, No. 2, pp. 38-54, (1949).

J. G. Charney : On a Physical Basis for Numerical Predicion of Large-Scale Motions in the Atmospoere., Journ. Met. **6**, pp. 371-385, (1949).

S. Petterssen : Contribution to the Theory of Pressure Variation. Q. J. R. M. S. **71**, pp. 307-308, (1945).

D. R. Eliatt : Note on Advective Pressure Changes., Mon. Weath. Rov. **72** (1944).