A computational study of the energetics of a limited region of the atmosphere

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(Manuscript received April 22, 1968, revised version October 25, 1968)

ABSTRACT

Utilizing Smith's (1969) equations, which describe the contribution of a limited region to the global energy budget, numerical estimates were computed for the various terms of his equations for North America, March, 1962. It is shown that realistic results, reflecting the importance of the region in the general circulation, can be obtained using this concept. Important differences between the energetics of the limited region and the entire atmosphere are shown to exist in the available potential energy, generation, boundary flux, and conversion terms. The estimates of the boundary flux and pressure work terms indicate significant interaction between the region and its external environment.

Introduction

Recently Smith (1969) has pointed out that the energetics of a limited region of the atmosphere can be defined in terms of the contribution that the region makes to the global energy budget. This formulation has the property of defining the relation of the energy processes occurring in the region to those associated with the general circulation. The purposes of this paper are: (1) to report on the numerical computations of the terms in the equations cited below using data from North America, March, 1962; and (2) to suggest relationships between the energetics of the region and the global energy budget.

A number of investigators have applied Lorenz's (1955*a*) equations to studies of the global energy budget. See Oort (1964) for a summary of many of these studies. Although Lorenz's equations involve certain limiting assumptions, their application to descriptions of processes on a global scale, where for example quasi-geostrophic equations are applied, has yielded meaningful results. However, in the study of the contribution of a limited region to the total atmospheric energy budget, equations such as formulated by Smith (1969) are advantageous. In addition to containing boundary terms, these equations avoid the quasi-geostrophic assumption and thus may be more effectively used in studying smaller scale synoptic processes with actual wind data.

Equations

The basic equations used in this study were

$$A_j = \frac{c_p}{g}\int_\sigma \int_{p_2}^{p_1} \frac{p^\varkappa - p_r^\varkappa}{p^\varkappa} T\,dp\,d\sigma \qquad (1)$$

$$K_j = \frac{1}{g}\int_\sigma \int_{p_2}^{p_1} \frac{w \cdot w}{2}\,dp\,d\sigma \qquad (2)$$

$$\frac{\partial A_j}{\partial t} = \overbrace{\frac{1}{g}\int_\sigma \int_{p_2}^{p_1} \frac{p^\varkappa - p_r^\varkappa}{p^\varkappa} Q\,dp\,d\sigma}^{G}$$

$$+ \overbrace{\frac{1}{g}\int_\sigma \int_{p_2}^{p_1} \omega\alpha\,dp\,d\sigma}^{C_A}$$

$$- \overbrace{\frac{1}{g}\int_\sigma \int_{p_2}^{p_1} \nabla_p \cdot \left(c_p \frac{p^\varkappa - p_r^\varkappa}{p^\varkappa} T w\right) dp\,d\sigma}^{HF_A}$$

$$\overbrace{-\frac{1}{g}\int_\sigma\int_{p_2}^{p_1}\frac{\partial}{\partial p}\left(c_p\frac{p^\varkappa-p_r^\varkappa}{p^\varkappa}T\omega\right)dp\,d\sigma}^{VF_A}$$

$$\overbrace{+\frac{1}{g}\int_\sigma c_p\frac{p_1^\varkappa-p_{r_1}^\varkappa}{p_1^\varkappa}T_1\frac{\partial p_1}{\partial t}d\sigma}^{X} \quad (3)$$

$$\frac{\partial K_j}{\partial t}=\overbrace{\frac{1}{g}\int_\sigma\int_{p_2}^{p_1}w\cdot F\,dp\,d\sigma}^{D}$$

$$\overbrace{-\frac{1}{g}\int_\sigma\int_{p_2}^{p_1}w\cdot\nabla_p\phi\,dp\,d\sigma}^{C_K}$$

$$\overbrace{-\frac{1}{g}\int_\sigma\int_{p_2}^{p_1}\nabla_p\cdot\left(\frac{w\cdot w}{2}w\right)dp\,d\sigma}^{HF_K}$$

$$\overbrace{-\frac{1}{g}\int_\sigma\int_{p_2}^{p_1}\frac{\partial}{\partial p}\left(\omega\frac{w\cdot w}{2}\right)dp\,d\sigma}^{VF_K} \quad (4)$$

$$C_A+C_K=$$

$$\overbrace{-\frac{1}{g}\int_\sigma\int_{p_2}^{p_1}\nabla_p\cdot\phi w\,dp\,d\sigma-\frac{1}{g}\int_\sigma\int_{p_2}^{p_1}\frac{\partial}{\partial p}\omega\phi\,dp\,d\sigma}^{PW} \quad (5)$$

These equations are identical to those developed by Smith (1969) except for simplified terms describing the time rate of change of the vertical boundaries. The simplifications are made possible by fixing the upper boundary at 250 mb and by assuming the wind at the surface to be zero.

Table of symbols

A_j	Contribution of the limited region to the global available potential energy.
K_j	Contribution of the limited region to global kinetic energy.
G	Diabatic generation.
C_A, C_K	A-Conversion and K-conversion, respectively, as suggested by Smith (1969).
HF_A, HF_K	Horizontal flux of A_j and K_j, respectively.
VF_A, VF_K	Vertical flux of A_j and K_j, respectively.
X	Weighted mass change in the region.
D	Dissipation
PW	Pressure work
α	Specific volume
p	Pressure
p_1, p_2	Pressure levels defining vertical limits of the limited region.
p_r	Reference pressure (global mean pressure on a potential temperature surface).
T	Temperature
Z	Height in geopotential units.
ϕ	gZ
w	Horizontal wind vector.
ω	dp/dt (referred to as vertical motion in this paper).
Q	Diabatic heating rate per unit mass.
t	Time
ε_A	Available potential energy error.
ε_C	Conversion error
E	Efficiency factor
g	980 cm $\sec^{-2}$
c_p	Specific heat of dry air at constant pressure.
R	Gas constant for dry air.
$\varkappa$	R/c_p
σ	Area of limited region.
∇_p	Del operator on constant pressure surface.
$(\bar{\bar{\ }})$	Limited area average on a potential temperature surface.
$(\bar{\ })$	Limited area average on a pressure surface.
$(')$	Deviation from $(\bar{\ })$

Data and computational methods

Data for this study consisted of March, 1962, daily radiosonde data (50 mb intervals for 00 and 12Z) from the network of North American stations shown in Fig. 1. These data provide coverage for a budget area containing 65 stations (outlined in Fig. 1 by the heavier line) and an additional 28 stations required for computations on the boundary of the budget area. The data for these stations were obtained from the MIT General Circulation Data Library[1] and the National Weather Records Center.

Although the original data extended as high as 7 mb, because of incomplete coverage at high levels this study utilized only data obtained at or below the 250 mb level. Of course, missing data levels were still present below 250 mb at some stations. Where possible, the missing data were estimated by linear interpolation; however, when interpolation could not be performed, the appropriate energy terms were not computed. There were never more than 22 stations with missing data at any level. With the exception of the linear interpolation the temperature and height data were used directly, while the wind data were filtered using a five-point "least squares" approximating polynomial to suppress the effects of random errors (Bullock *et al.*, 1966).

After the data modifications were performed, the integrands of equations 1 through 5 were computed. Nearly all of the terms of equations (3), (4), (5), depend either directly or indirectly on computations involving the del operator (Smith *et al.*, 1967). The vertical motion (ω) was estimated at each level by the kinematic method using the estimates of horizontal divergence

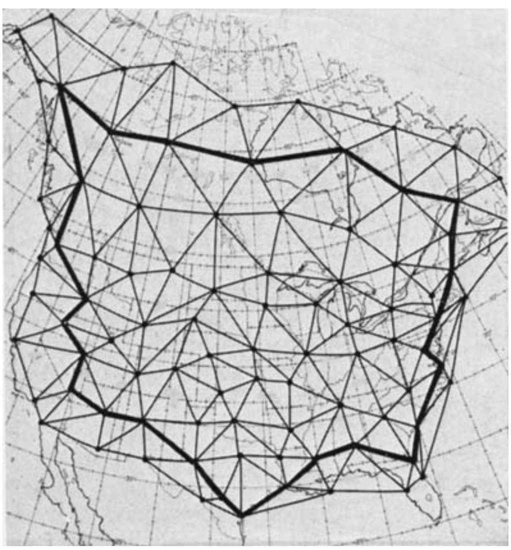

Fig. 1. Stations and triangular grid used in computing energy budgets. Heavy line defines budget region.

[1] Processed by Travelers Research Center, Inc., under National Science Foundation grants GP 820 and GP 3657.

$\nabla_p \cdot w$ and the assumption that at the ground $\omega = \partial p/\partial t$. This is consistent with the previous assumption that the wind at the surface is zero. Of course immediately above the ground w is no longer zero and $\nabla_p \cdot w$ might be quite significant. If a detailed profile of the convergence close to the ground were available, a more sophisticated integration scheme could be adopted yielding improved estimates of ω in the boundary layer. However, synoptic data does not allow this resolution. Hence, the integration over 50 mb increments will no doubt result in the neglect of some convergence near the lower boundary.

The net diabatic heating (Q) was estimated by the thermodynamic method; i.e., by evaluating the right-hand side of the first law of thermodynamics in the form

$$Q = c_p \frac{\partial T}{\partial t} + c_p w \cdot \nabla_p T + \left(c_p \frac{\partial T}{\partial p} - \alpha \right) \omega \qquad (6)$$

where $\partial T/\partial p$ was estimated by finite difference and $\nabla_p T$ by the del operator method. This del operator method was also used to estimate the horizontal boundary flux and pressure work terms. The only remaining parameter required is the global reference pressure for each isentropic surface. The estimates used in this study were determined by averaging the monthly mean reference pressures computed by Dutton & Johnson (1967) from data along the 75° W meridian. Table 1 lists the mean annual reference pressures corresponding to particular potential temperature surfaces. Reference pressures for other potential temperature surfaces were obtained by linear interpolation between the values in this table.

The vertical integrals were estimated by the trapezoidal method using 50 mb increments and divided into three separate layers (Layer 1 = surface to 750 mb; Layer 2 = 750 to 500 mb; Layer 3 = 500 to 250 mb). These integrals were then averaged over the budget area by multiplying the integral value at each station by an area weight for that station, summing over all stations, and dividing by the total area. To compute the area weights a triangular grid (see Fig. 1) with the data stations as vertices was constructed over the budget area. The area weight for each station was then computed as one-third of the sum of the areas of the triangles for which the station was a vertex. When mis-

Table 1. *Potential temperatures and corresponding reference pressures*

θ, °K	p_r, mb
240	998.4
250	996.3
260	990.4
270	975.7
280	940.7
290	866.3
300	751.0
310	597.6
320	453.2
330	342.2
340	253.3
350	187.8
360	155.7
370	136.3

sing data occurred, the station at which the data was missing was not considered in the area average. The local time derivatives of A_f, K_f, T, and surface pressure were estimated by a centered 24 hour finite difference. Finally, the monthly means reported in this paper were computed from the daily area averages.

Results

The data and computational procedures were used to compute monthly mean estimates of the terms of equations 1 through 5. When considering these values it should be realized that many energy terms are dependent on several parameters and could be the result of a number of physical processes. Because of this lack of uniqueness the discussion will sometimes seem speculative, reflecting the authors' attempt to specify the particular process which most likely accounts for the computed energy value. In addition recall that the values computed here represent "contributions" made by the limited region to the corresponding term in the global energy budget.

Before examining the energy estimates, consider the monthly mean vertical motion and diabatic heating profiles, depicted in Fig. 2. The vertical motion profile shows subsidence in the layer between the surface and 300 mb and rising motion in the 300–250 mb layer. The diabatic heating profile indicates warming in the surface to 850 mb and 300–250 mb layers and cooling in the 850–300 mb layer. The integrated value of -2.3 ly day^{-1} compares with -1.3 ly day^{-1} estimated by Davis (1963) for April for a zonal ring extending from 30 to 60°N and from the surface to 200 mb. The heating below 850 mb can be attributed to eddy conduction and direct solar heating (Hanson *et al.*, 1967) during this spring period, while the estimates above 850 mb are probably due to infrared processes, the 250 mb value obtained in this study agreeing well with Kuhn's (1967) infrared warming estimates of between 0 and 1

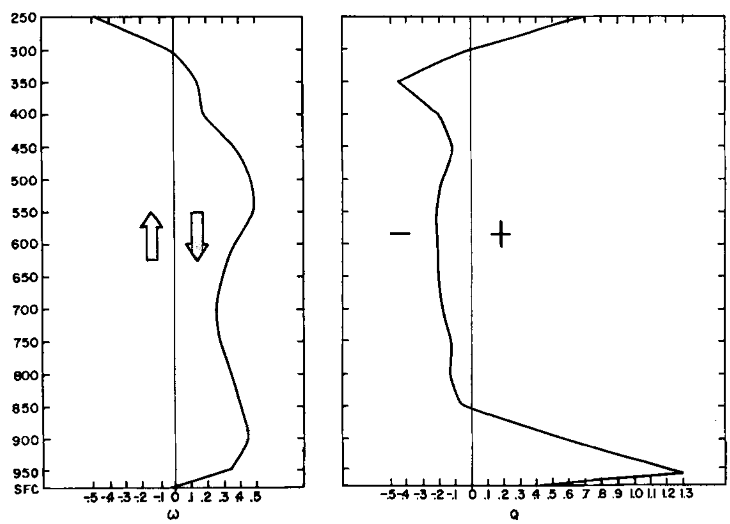

Fig. 2. Monthly mean vertical motion (ω) and diabatic heating (Q) profiles for North America, March, 1962. Units. $\omega = 10^{-4}$ mb sec^{-1}; Q = deg day^{-1}.

deg day^{-1} at tropopause altitudes for the spring season.

The monthly mean energy budget estimates are summarized by layers in Table 2. The kinetic energy K_j for the total layer (11.70×10^5 joules m^{-2}) is somewhat less than the global annual estimate of 15×10^5 joules m^{-2} made by Oort (1964) and Kung's (1966*a*) estimate of 18.96×10^5 joules m^{-2} for the same period and area of this study. Kung's value is probably larger because his study included the atmosphere to 50 mb.

In contrast, the negative value obtained for the available potential energy A_j (-1525×10^5 joules m^{-2}) is not comparable with earlier studies, all of which have yielded positive quantities. The negative value obtained here is the result of defining A_j as the contribution to the global available potential energy. In a region containing air which is colder than the global mean one finds $p < p_r$ and $A_j < 0$. The properties of A_j can be examined further by rewriting (1) as

$$A_j = \frac{c_p}{g}\int_\sigma\int_{p_2}^{p_1}\frac{p^\varkappa - \bar{p}^\varkappa}{p^\varkappa}T\,dp\,d\sigma + \frac{c_p}{g}\int_\sigma\int_{p_2}^{p_1}\frac{\bar{p}^\varkappa - p_r^\varkappa}{p^\varkappa}T\,dp\,d\sigma \quad (7)$$

Table 2. *Monthly mean energy budget by layers for North America, March, 1962*

1, 2, 3, T indicate layers as defined in Section 2. Units: A, $K = 10^5$ joules m^{-2}; energy transformations and fluxes = watts m^{-2}.

	1	2	3	T
A_j	−103	−495	−927	−1525
K_j	.95	2.83	7.92	11.70
$\frac{\partial A_j}{\partial t}$	3.53	5.58	7.97	17.08
G	−0.06	0.68	−0.77	−0.15
C_A	6.55	6.23	−23.53	−10.75
HF_A	8.88	8.88	−0.71	17.05
VF_A	−14.59	−15.37	43.40	13.44
X	−0.33			−0.33
ε_A	3.08	5.16	−10.42	−2.18
$\frac{\partial K_j}{\partial t}$	0.00	−0.05	−0.14	−0.19
D	−0.64	−0.14	−0.30	−1.08
C_K	0.69	−0.09	−0.32	0.28
HF_K	0.01	−0.25	0.59	0.35
VF_K	−0.06	0.43	−0.11	0.26
PW	8.40	8.89	−27.14	−9.85
ε_C	−1.16	−2.75	3.29	−0.62
$\overline{\omega'\alpha'}$	0.08	−4.37	−24.46	−28.75
$\bar{\omega}\bar{\alpha}$	6.47	10.60	0.93	18.00

The first term on the right of (7) is the available potential energy that the region would possess if in passing to the local minimum state the local system were not allowed to interchange mass with its environment, leaving the second term to represent the contribution to the global available potential energy due to the departure of the local reference state from that of the total atmosphere. As in the case when σ is the entire globe, the first term is always positive. Hence, negative A_j values occur when the departure term is negative and its absolute value is greater than the first term. Evidently the cold air in this region leads to values of $\bar{p}$ which are considerably less than p_r, resulting in a very large negative value for A_j.

Within the set of estimates involving the time rate of change of the energy parameters perhaps the most surprising feature is the very small size of the generation (G) for the total layer (-0.15 watts m^{-2}) compared to the other terms in the A_j budget. However, this value is not greatly different from the -0.8 watts m^{-2} obtained by Oort (1964) and the 0.8 watts m^{-2} obtained by Dutton and Johnson (1967) for the eddy generation. This suggests that in this study the generation is dominated by eddy heating processes and that the role of zonal generation is limited, probably because of the absence of data from tropical and polar latitudes.

The generation is also relatively small in each of the three layers. A better insight into the physical processes affecting G can be gained by writing the generation expression, after Lorenz (1955*b*), as

$$G = \frac{1}{g}\int_{p_2}^{p_1}\bar{E}\bar{Q}\,dp + \frac{1}{g}\int_{p_2}^{p_1}\overline{E'Q'}\,dp \quad (8)$$

The first term represents the effect of the mean heating field, while the second term, which is nearly the same as Lorenz's (1955*a*) approximate expression, describes the influence of differential heating.

In layer 1 both the mean efficiency factors and mean diabatic heating tend to have predominantly the same sign within the layer and, therefore, would be expected to produce positive generation. However, since the observed value is near zero (-0.06 watts m^{-2}), it appears that the effect of mean heating is offset by a horizontal distribution (described by the second term of 8) which produces heating of relatively cold air and cooling of relatively warm air. In the middle layer the positive generation (0.68 watts m^{-2}) corresponds to the diabatic cooling and negative efficiency factors normally found there. In addition, while the release of latent heat is not dominant in the monthly mean, it does tend to occur in regions of positive efficiency and would, therefore, also contribute to this positive result. In the upper layer the correlation of mean cooling and negative efficiency factors would yield a positive generation. Therefore, the observed negative value (-0.77 watts m^{-2}) would indicate that again there is heating of relatively cold air and cooling of relatively warm air.

The A-conversion (C_A) for the total layer (-10.75 watts m^{-2}) compares with Dutton and Johnson's global annual value (-6.40 watts m^{-2}), which was partially based on Kung's (1966*b*) global annual estimate of frictional dissipation. Both results are considerably larger than Oort's estimate of -2.3 watts m^{-2}. The studies from which Oort derived his value may have underestimated C_A because they employed the quasi-geostrophic vorticity equation or the adiabatic method to determine the vertical motion. These methods tend to smooth out the smaller synoptic scales. In contrast the authors feel that the vertical motion estimates in this study retain much of the influence of the entire range of synoptic scales. The major problem in the method used here, however, is that the magnitude of the vertical motion, and terms utilizing the vertical motion, are sometimes overestimated at higher pressure levels, a well-known problem associated with the kinematic method (O'Neill, 1966). If one assumes that ω is frequently over-estimated in the third layer, the total A-conversion may be less than computed here.

The role of C_A in the energetics of a limited region is perhaps best seen by comparing it with the K-conversion (C_K) and pressure work (PW) estimates, which are linked through equation (5). In these results PW and C_A are of the same size, with C_K much smaller. This means that although C_A indicates a reduction of A_j in layer 3 and increases in layers 1 and 2, it is not accompanied by corresponding increases or decreases of K_j within any of the layers. Therefore, the region apparently exhibits a major interaction with the remaining atmosphere and C_A does not represent direct conversion of potential to kinetic energy within the region and time period studied here.

In an effort to provide an alternate representation of the conversion process many authors have used $\overline{\omega'\alpha'}$ rather than C_A, e.g., White and Saltzman (1956), Winston & Krueger (1961), Oort (1964), and Danard (1966). The term $\overline{\omega'\alpha'}$ has been described as the conversion of available potential to kinetic energy by vertical overturnings within atmospheric waves. Under this formulation a decrease of available potential energy occurs when relatively warm air rises and cold air sinks. C_A, $\overline{\omega'\alpha'}$, and $\bar{\omega}\bar{\alpha}$ are related according to

$$C_A = \frac{1}{g}\int_{p_2}^{p_1} \overline{\omega'\alpha'}\, dp + \frac{1}{g}\int_{p_2}^{p_1} \bar{\omega}\bar{\alpha}\, dp \qquad (9)$$

When the entire atmosphere is considered, the last term is zero and $C_A = (1/g)\int_{p_2}^{p_1} \overline{\omega'\alpha'}\, dp$; however, this relation is in general not valid in limited regions. One can interpret $\overline{\omega'\alpha'}$ as that portion of C_A which can be attributed to scales of vertical motion completely contained in the region, while $\bar{\omega}\bar{\alpha}$ is associated with scales which are only partially sampled in the region.

The values of $\bar{\omega}\bar{\alpha}$ agree well with the mean vertical motion profile (Fig. 1). The subsidence in layers 1 and 2 produces positive values (6.47 and 10.60 watts m^{-2}), while the reversal in the mean vertical motion profile in layer 3 results in a near zero value (0.93 watts m^{-2}). On the other hand $\overline{\omega'\alpha'}$ is very small in layer 1, a somewhat surprising result in view of the fact that to a large extent it reflects the influence of synoptic scale phenomena. A small value in this layer can be partially accounted for by the presumably small values of ω. In addition, however, the negative $\overline{\omega'\alpha'}$ normally associated with developing synoptic scale motions is apparently balanced by a near equal positive value resulting from rising cold air and sinking warm air, as might occur in an occluded storm. In layers 2 and 3 the horizontal variations in vertical motion associated with developing synoptic processes are evidently large enough to yield large values of $\overline{\omega'\alpha'}$. The vertical distribution obtained here agrees qualitatively with the distribution obtained by Eddy (1965) during a three day storm period (January 21–23, 1959) for the portion of $\overline{\omega'\alpha'}$ associated with 1600 and 3500 m mi scales. A significant feature of $\overline{\omega'\alpha'}$ is that it seems to bear no direct relation to C_K.

It would appear, therefore, that over the period and limited region of this study $\overline{\omega'\alpha'}$, like C_A, does not represent direct conversion of potential to kinetic energy.

Considering again the values contained in the energy budgets, it is interesting to note that in spite of the size of the region and the length of the time period the horizontal and vertical fluxes are still very significant. The flux of A_j is accomplished by a net transport which changes the contribution that a limited region makes to the available potential energy of the entire atmosphere. In particular a positive flux can occur with an inflow (outflow) of air warmer (colder) than the global mean. The dominance of the horizontal flux of A_j (HF_A) in layers 1 and 2 indicates that this term may be largely influenced by major synoptic features. Low pressure centers which tend to form or deepen east of the Rocky Mountains and inject warm Gulf air into the budget region probably provide an important source of positive A_j flux. In addition increases of A_j may be noted when cold Canadian air exits the budget region. The net effect of this process would depend on whether the cold air was replaced by warmer air from perhaps the Pacific or Gulf area or colder Arctic air. The vertical flux of A_j (VF_A), agrees qualitatively with the mean vertical motions in Fig. 1. The remaining term (X) indicates that the mean surface pressure, and hence the mass within the region, decreased during March, 1962.

The net change in A_j during the month was 17.08 watts m^{-2}, which is of course considerably different from the zero value one would expect for a global annual mean. The local change of K_j (-0.19 watts m^{-2}) is almost identical to Kung's (1966*a*) estimate of -0.20 watts m^{-2}.

In the kinetic energy budget the dominant term for the total layer is the frictional dissipation (D), -1.08 watts m^{-2}. This estimate is less than the global, annual estimates of Oort, -2.3 watts m^{-2}. In addition it is also smaller than the value of -4.87 watts m^{-2} given by Kung (1966*a*) for the month and area of this study. However, it should be noted that Kung's March, 1962, result includes a dissipation of about -1.0 watts m^{-2} in the 250–50 mb layer, a layer which was not used in this study. Kung (1967) has found that the inclusion of $12Z$ data with the $00Z$ data used in his earlier studies and use of a more extensive data period resulted in a 36% reduction of his original annual dissipation estimate. Applying this reduction to the surface to 250 mb value of -3.87 watts m^{-2} for March, 1962, yields a revised figure of -2.46 watts m^{-2}. Therefore, depending on which estimate is accepted the result obtained in this study is smaller by a factor of 2 or 3. It is interesting to note that Kung (1966*a*) and Julian & Labitzke (1965) obtained values of -0.28 watts m^{-2} and -0.30 watts m^{-2} for HF_K and VF_K, respectively. Although of opposite sign to the values obtained here and representative of different data samples, their results indicate that the small values obtained in this study are reasonable. If the value of D is in error, it quite likely results primarily from underestimates of the production of K by cross-isobaric flow (C_K).

Finally, an indication of the reliability of the budget estimates can be obtained by considering the discrepancies between the calculated local changes and the sum of the processes which produce the changes. These discrepancies, referred to as ε_A (available potential energy error) and ε_C (conversion error), are

$$\varepsilon_A = \frac{\partial A_j}{\partial t} - (G + C_A + HF_A + VF_A + X) \quad (9)$$

and

$$\varepsilon_C = (C_A + C_K) - PW \quad (10)$$

Table 2 shows that ε_A and ε_C are in general smaller than the more important budget terms. Since the signs of ε_A and ε_C in layers 1 and 2 are opposite to the signs in layer 3, the errors tend to cancel, leaving $\varepsilon_A = -2.18$ watts m^{-2} and $\varepsilon_C = -0.62$ watts m^{-2} for the total layer.

Summary

The equations used in this paper are based on the concept of defining the energetics of limited regions in terms of the contribution the region makes to the global energy budget (Smith, 1969). The results obtained here indicate that realistic results, reflecting the importance of the region in the general circulation, can be obtained using this concept. Some of the more important results are as follows:

(1) Since the region of the atmosphere for the period studied here was in general colder than the global mean, the use of a global refer-

ence state leads to monthly mean values of the contribution to the global available potential energy which are negative.

(2) The generation obtained here is much smaller than any global estimates. However, it does not differ greatly from previous estimates of eddy generation, probably reflecting the reduced influence of zonal effects in the limited region.

(3) The boundary fluxes and pressure work terms, which are zero in the global budget, apparently play an important role in the energetics of this region. The size of these terms demonstrates the significant interaction between the region and its external environment.

(4) The large values of A-conversion (C_A) and $\overline{\omega'\alpha'}$ compared with K-conversion (C_K) indicate that neither C_K nor $\overline{\omega'\alpha'}$, which have been used as conversion terms in other studies, represent direct production of kinetic energy here. Apparently much of the potential energy released in this region is utilized in other portions of the atmosphere.

Collectively these results suggest that similar studies of individual circulation systems might provide insight into the extent to which these systems are self-generating or dependent on the other motions comprising the general circulation.

Acknowledgements

The authors are indebted to Professor Donald R. Johnson for his discussions and critical comments. This research was supported by the National Environmental Satellite Center of ESSA under grant WBG-52. In addition supplemental computer funds were provided by the University of Wisconsin Alumni Research Foundation.

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ЧИСЛЕННОЕ ИССЛЕДОВАНИЕ ЭНЕРГЕТИКИ ОГРАНИЧЕННОЙ ОБЛАСТИ АТМОСФЕРЫ

Используя уравнения Смита (1968), которые описывают вклад, ограниченной области в глобальный баланс энергии, производятся численные оценки для различных членов его уравнений применительно к северному полушарию для марта 1962 года. Показывается, что согласующиеся с наблюдениями результаты, отражающие важность вклада подобной области в общую циркуляцию, могут быть получены, используя такую концепцию. Показывается, что существует важное различие между энергетикой ограниченной области и всей атмосферой в доступной потенциальной энергии, генерации, потоке на границе и преобразовании энергии. Оценки величины потока на границе и работа сил давления указывают на значительное взаимодействие между областью и ее внешним окружением.