INVESTIGATIONS ON THE ENERGY BALANCE OF THE ATMOSPHERE

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РЕЗЮМЕ

В работе проведено исследование энергетических условий ограниченного пространства атмосферы, пригодного для исследования синоптических процессов. Были оценены польная потенциальная и кинетическая энергия исследуемого диапазона а также и та потенциальная энергия которой владеет кинетическая энергия и которая может преобразоваться в нее. Были определены соотношения отдельных видов энергии к кинетической и эти соотношения сравнивались с теми, которые характеризуют атмосферу в глобальном масштабе. Высшеупомянутые соотношения оказались больше соответствующих глобальных значений, и это объясняется тем, что в исследуемом отрезке времени в данном диапазоне происходила интенсивная деятельность циклонов. На это указывают и величины «активности кинетической энергии» и «времени затухания»-параметров, введенных для характеристики интенсивности процессов в атмосфере. Был определен и переход резервированной потенциальной энергии в кинетическую на примере образования и развития одного средиземноморского циклона. Величины, характеризующие процессы перехода, были определены с применением детального вертикального подразделения, но в работе приводим только результаты, характеризующие процессы во всей тольщине данного диапазона. Результаты приведены в виде изображения на картах.

The intensity and stability of the general circulation depends on the equilibrium between the production and dissipation of the kinetic energy. The only source of the kinetic energy is the available potential energy, defined by Lorenz (1955) as the deviation between the total potential energies of the natural state of the atmosphere and of a reference state formed in the course of an adiabatic rearrangement of the air masses, (total potential energy = gravitational potential energy + internal energy + latent energy). By the introduction of this concept Lorenz gave the connection between the driving mechanism and the atmospheric energy cycle. In viscous fluids part of the mechanical energy dissipates into heat and this process leads to a gradual loss of the kinetic energy. Thus there must be a continuous energy production, if we want that the kinetic energy should be maintained. The mean order of magnitude of energy transformation is known, but we have very few knowledge of the extent of connection between the parameters of friction and macrosynoptical flow.

According the estimation of Lorenz the ration of the average available potential energy of the Earth and of the total potential energy is 1/200, that of the kinetic energy and of the available potential energy is 1/10. But because the total potential energy of the atmosphere exceeds well the kinetic energy of it — the order of which is 1/2000 —, when investigating the ration between production and dissipation of the kinetic energy it is practical to compare the kinetic energy with the available potential energy. If we represent the summed up values of the potential, internal and latent energy for a given atmospheric domain, we know only the energy store of the domain. Such a representation has no significance in itself, but it plays an accentuated role in case of an investigation of the general circulation processes, when we want to know, which regions of the Earth possess a big energy store and where can we find the deficient domains. In this sense, namely, the unevenly distributed energy content may be handled as a katalitic effect producing primarily available energy and stimulating the atmosphere towards movements in order to solve the contradiction being inherent is the differences of non-adiabatic warmings up. The mobility represented by the total energy store of a domain can be estimated only by a comparison with other domains. According to the computations of Dutton and Johnson (1969) the total potential energy can be estimated in the summer months to $2.58 \cdot 10^{12}$ ergcm^{-2}, while in the winter months we have an estimated amount of $2.51 \cdot 10^{12}$ ergcm^{-2}. At the same time the available potential energy in the winter months was estimated to $4.46 \cdot 10^{9}$ ergcm^{-2}, while in the summer monthy it amounted only to $1.57 \cdot 10^{9}$ ergcm^{-2}. Though we have the total potential energy at our disposal, owing to the above considerations we will pay attention only to the connection between the available potential energy and the production and dissipation of the kinetic energy.

In a previous study we investigated the role of the efficiency factor and the non-adiabatic heating between 00 GMT on the 19th October 1970 and 12 GMT on the 21th, when in the course of a slow eastwards shifting of a large North-Europian cyclone and its filling up a cyclone of smaller dimension appeared over the Mediterranean and later over the Europian territory of the Soviet Union. Our energy-calculations were made also on the basis of the said time interval, but owing to the largeness of the material we will show the detailed results only in the characteristical phases of development of the Mediterranean cyclone.

The kinetic energy of the domain of x area S lying between the pressure levels p_1 and p_2 can be given by the formula

$$K = \frac{1}{g} \int\limits_S \int\limits_{p_2}^{p_1} \frac{u^2 + v^2}{2} \, dp \, dS, \tag{1}$$

its potential energy by the expression

$$\Phi = \frac{1}{g} \int\limits_S \left[\int\limits_{p_2}^{p_1} RT \, dp + p_1 z_1 - p_2 z_2 \right] dS, \tag{2}$$

its internal energy is

$$I = \frac{1}{g} \int_S \int_{p_2}^{p_1} c_v T \, dp \, dS , \tag{3}$$

its latent energy reads as

$$L = \frac{1}{g} \int_S \int_{p_2}^{p_1} Hq \, dp \, dS , \tag{4}$$

and finally the available potential energy can be given, as

$$A = \int_S \frac{1}{g} \int_{p_2}^{p_1} c_p \Theta \frac{p^{\varkappa} - p_r^{\varkappa}}{p_{00}^{\varkappa}} dp \, dS , \tag{5}$$

where u and v are the horizontal components of the wind velocity V, g is the gravity acceleration, T is the temperature, Θ the potential temperature, c_v the specific heat at a constant volume, q is the specific humidity, H is heat of condensation, p is the pressure, $p_{00} = 1000$ mb, p_r is the so called reference pressure belonging to the potential temperature assumed by the isentropic surfaces after the rearrangement, $k = R/c_p$, R is the gas constant and c_p is the specific heat at constant pressure.

The total energy content of the domain can be seen is Table I. The comparison with the global energy store directs our attention to a few important facts. According to the data of the Table the greatest variability is represented by the latent energy. The average kinetic energy is $21{,}1 \cdot 10^5$ joule m^{-2}, somewhat greater, than the global yearly mean. Holcpainen (1963) obtained for the mean kinetic energy of the layer below 200 mb the value: $23{,}6 \cdot 10^5$ joule m^{-2}, Smith (1969) got: $11.75 \cdot 10^5$ joule m^{-2}, Oort (1964) gave: $15 \cdot 10^5$ joul m^{-2}. Taking into account the fact that during the time interval under investigation an intensive cyclonic activity took place in our domain, the obtained value of $21.1 \cdot 10^5$ joule m^{-2} does not seem as an exaggerated one. The date of the above authors refer only to average time conditions, in the actual daily values we have to calculate with great and significant oscillations. E.g. Danard (1964) obtained for the value of the kinetic energy of an intensive cyclone $33.4 \cdot 10^5$ joule m^{-2}. He carried out his computations for a domain of area $10.5 \cdot 10^{12}$ m^2, which is comparable with the conditions of the domain of area $15.41 \cdot 10^{12}$ m^2 studied by us.

The variation of the potential energy oscillated between $4.5 \cdot 10^{10}$ and $155 \cdot 10^{10}$ kwatt, while for the latent energy the limits were: $292 \cdot 10^{10}$ resp. $2180 \cdot 10^{10}$ kwatt. It is worth while to cast a look at the ratio of the kinetic energy and of the available potential energies as compared with the other kind of energy (Table I., columns 7., 8., 9.). Although the latent energy is

Results of energetical calculations of the demain of

1	2	3	4	5	6	7	8	9
Date	K 10^{14}	Φ 10^{17}	I 10^{17}	L 10^{17}	A 10^{15}	$\frac{K}{I+\Phi+L}$ 10^{-4}	$\frac{K}{I+\Phi}$ 10^{-4}	$\frac{K}{A}$ 10^{-2}
	K joule							
19^{00}	307,16	105,82	339,05	66,28	349,8	6,12	6,9	8,8
19^{12}	313,64	105,15	338,88	56,83	341,6	6,26	7,1	9,1
20^{00}	322,30	104,80	337,71	52,92	338,2	6,51	7,3	9,5
20^{12}	324,18	104,82	337,72	51,65	328,1	6,65	7,3	9,9
21^{00}	356,55	104,48	337,01	53,14	333,6	7,20	8,1	106
21^{12}	333,65	105,04	336,68	50,79	318,8	6,80	7,6	104
Mean value for an area of 1 m^2	21,1 10^5	68,1 10^7	219,2 10^7	37 10^7	216 10^5	6,5 10^{-4}	7,1 10^{-4}	9,7 10^{-2}
	joule m^{-2}							

about the tenth part only of the potential as well as of the internal energies, after all it plays an important role concerning the mobility of atmospheric processes. In this form we are able to characterize in order of magnitude that released energy, which from thermodynamical point of view represents a potential energy influencing drastically – in case of its release – the kinetic energy, and thus the weather too.

The mean distribution of the individual energies in joule m^{-2} units is to be seen on Fig. 1. (the value of the kinetic energy is reduced by 10^3); for the distribution of the potential energy – according to its definition – we got values increasing with height. The latent and internal energies show their highest values in the lower third part of the troposphere. The sharp decrease of the latent energy with height could be expected owing to the vertical gradient of temperature and humidity. The kinetic energy reaches its highest value on the average in the layers between 400 and 200 mb, the highest concentration, however, can be found in the layers between 350 and 250 mb.

On the Fig. 2. we find the mean variability of the individual energies. (Unit for the internal, potential and latent energies is watt m^{-2}, that for the kinetic energy: 10^{-2} watt m^{-2}). The latent energy showed its strongest variation in the near surface layer, but it had a secondary maximum in the level of cloud development (corresponding to the autumn season in

Table I.

$15{,}4 \cdot 10^{12}$ m^2 area reaching from the ground up to the 100 mb level.

10	11	12	13	14	15	16	17	18	19
C_k 10^8	$\frac{\partial K}{\partial t}$ 10^8	$\frac{\partial \Phi}{\partial t}$ 10^8	$\frac{\partial I}{\partial t}$ 10^{10}	$\frac{\partial L}{\partial t}$ 10^{10}	$\frac{\partial A}{\partial t}$ 10^{10}	C_{ks} 10^8	D_s 10^8	K_s 10^{13}	Depletion time in the friction layer in hours
kwatt									
1390						+406,0	−333	93,1	7,8
	+149,9	−155,0	− 38,8	−2180	−18,9				
+ 589						+477,1	−303	84,2	7,4
	+200,0	− 79,0	−273,1	− 907	− 7,8				
+1060						− 95,7	−384	89,5	8,7
	+ 43,5	− 4,5	+ 2,4	− 292	−23,5				
+ 582						+359,0	−348	106,0	6,3
	+749,0	− 76,5	−162,0	+ 346	+12,7				
− 233						+466,1	−275	74,9	7,5
	−530,0	+141,0	−767,0	− 544	−34,3				
−1020						−419,1	−257	74,3	8,0
+2,5	+0,78	−22,6	−160,8	−259,2	−9,3	+1,2	−2,1	5,6 10^4 joule m^{-2}	7,6
watt m^{-2}									

the layer between 850 and 750 mb.). It is somewhat surprising that we have a similar march for the variability of the potential as well as kinetic energy in the upper part of the troposphere. When looking at the curve it seems that the troposphere obtains the kinetic energies of movements taking place in its lower part from the changes going on in the internal energy, and more precisely in the lantent energy, while the kinetic energy of the movements setting in the upper levels is due to the changes of the value of the potential energy. The kinetic energy reached its strongest variation in the vicinity of the 250 mb level, but we could observe a secondary maximum too between the layers of 850 and 750 mb. On the Fig. 2. we can well see that the change of the internal energy is of a lower order of magnitude when compared to that of the other energies, while the change of the latent energy surpasses the added values of variation taking place in the potential and internal energies. For the mean variability of the individual energies Boriszenkov (1960) has obtained similar values with the exception that he did not calculate separately the latent energy, but he took it into account in the value of the internal energy, using virtual temperature instead of the common one. As regards the detailed energy values of the domain the contribution of the latent energy to the potential energy being at the disposal of the kinetic energy represents a significant value, even in the development of the northern cyclone. It seemed that it had its part in

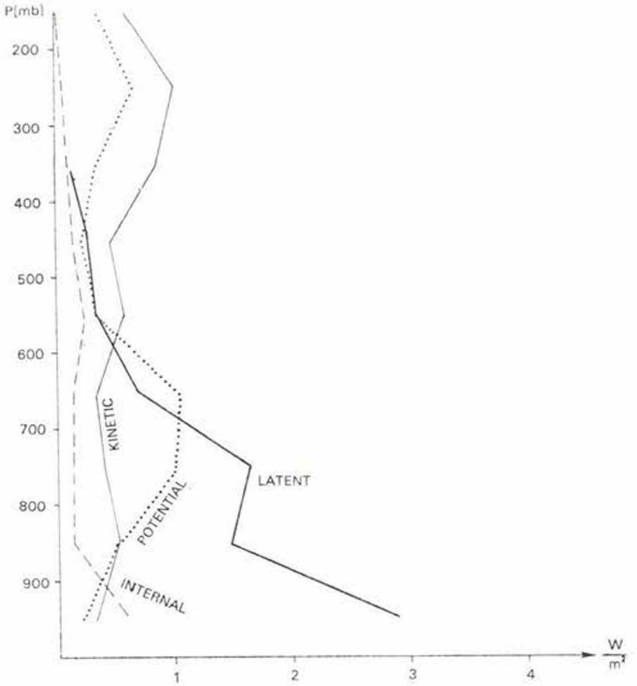


Fig. 1. Vertical distribution of the mean values of various energies: the value of the potential, internal and latent energy is given in 10^6 joule m^{-2}, that of the kinetic energy in 10^3 joulem^{-2} units.

the stability of the large cyclone, and as regards its activity, the latent energy can be taken as the primary energy source of the Mediterranean cyclone.

This supports the previous conclusion that the latent heat release can lead to a significant intensification of cyclones of middle latitudes. The first attempts for taking into account the effect of condensation on the development of cyclones have been made by Smagorinsky (1956), who found that the computed vertical velocity can be increased by an order of magnitude partly by taking into account the horizontal change of the statical stability, partly because in those domains, where latent heat release occurs, vertical velocity will be induced. The non-adiabatic contribution of the released latent heat may – in some cases – surpass the order of magnitude of the absorbed solar radiation by one or two orders of magnitude. Supposedly, the increased amount of available potential energy in the domain of the Mediterranean may be attributed also to the effect of non-adiabatic contributions connected to the latent heat variations. On the series of Figures 3. we see the changes of areal distribution of available potential and kinetic energies at 12^h on the 19th, at 00 as well as 12^h on the

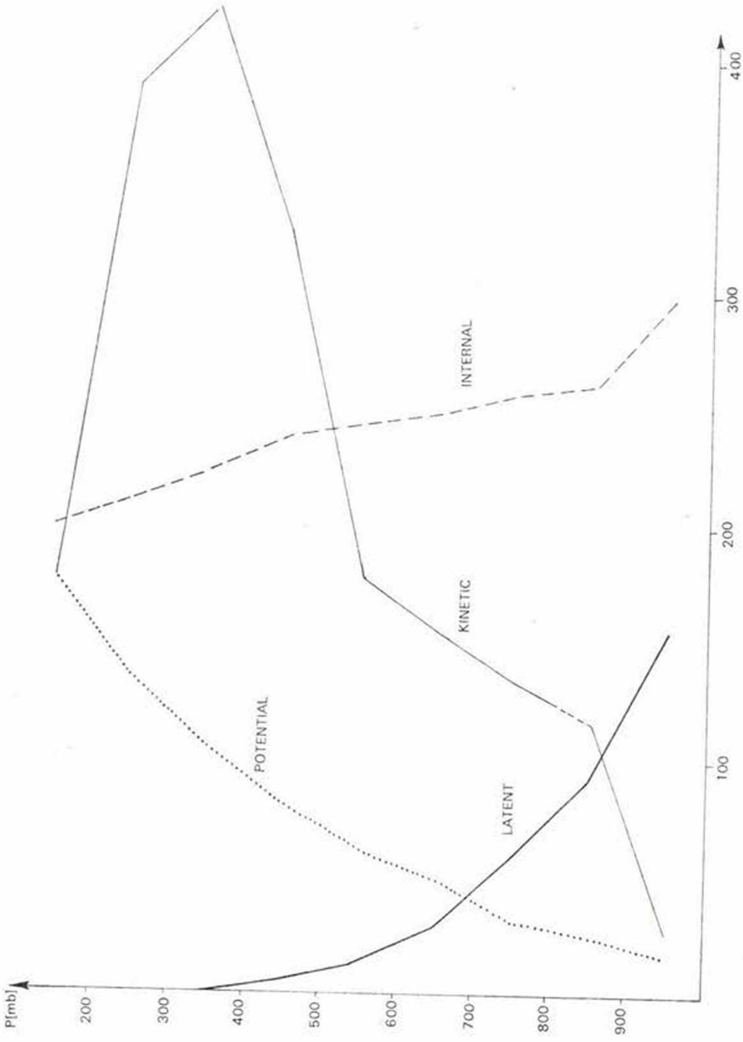


Fig. 2. Vertical distribution of mean variability of various energies: the changes of the potential, internal and latent energy in 10^2 watt m^{-2}, that of the kinetic energy in 10^{-1} watt m^{-2} units.

20 th, while on Figs 4. and 5. we show the variations taking place in the potential, internal and latent energies. The variations of the latent heat show the maximum concentration in the Mediterranen, but we can find significant values also on the area of the North-Europian cyclone too. In the indicated domains the latent heat plays a double role. On the one part it increases the non-adiabatic contribution of the available potential energy in the domains of a positive efficiency factor, while on the other part the induced rising currents within the relatively warmer air supported the conversion into kinetic energy. One can not neglect – owing to the presence of the Mediterranean-sea the contribution of the observable heat supply in

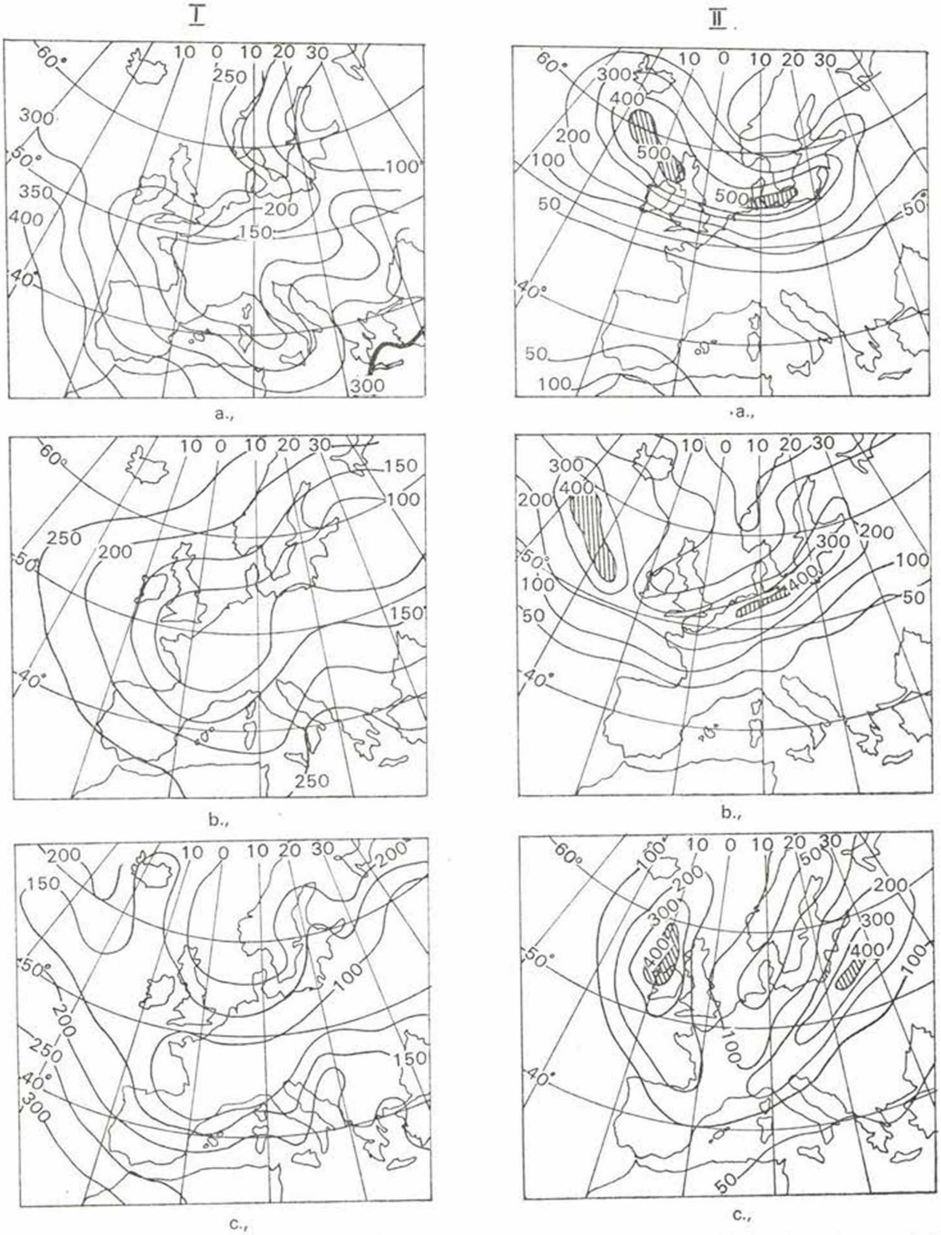
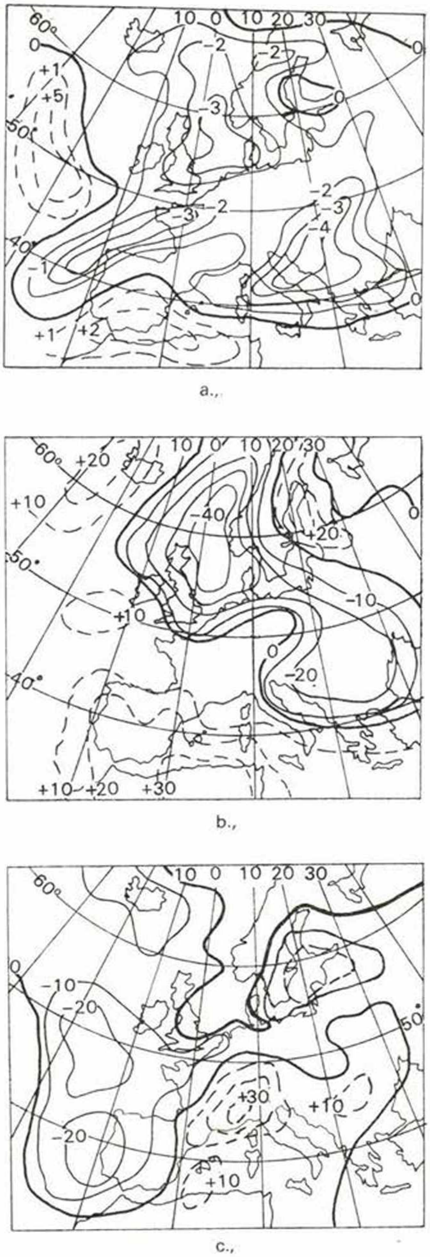


Fig. 3. Areal distribution of the I: available potential energy in 10^{13} kjoule units; and II kinetic energy in 10^{12} kjoule units. Values refer to the volume from the ground up to th 100 mb surface level over areas of 2.5 degrees of width and 2.5 degrees of length each

a) for 19th October 1970, 12 GMT,

b) for 20th October 1970, 00 GMT and

c) for 20th October 1970, 12 GMT.



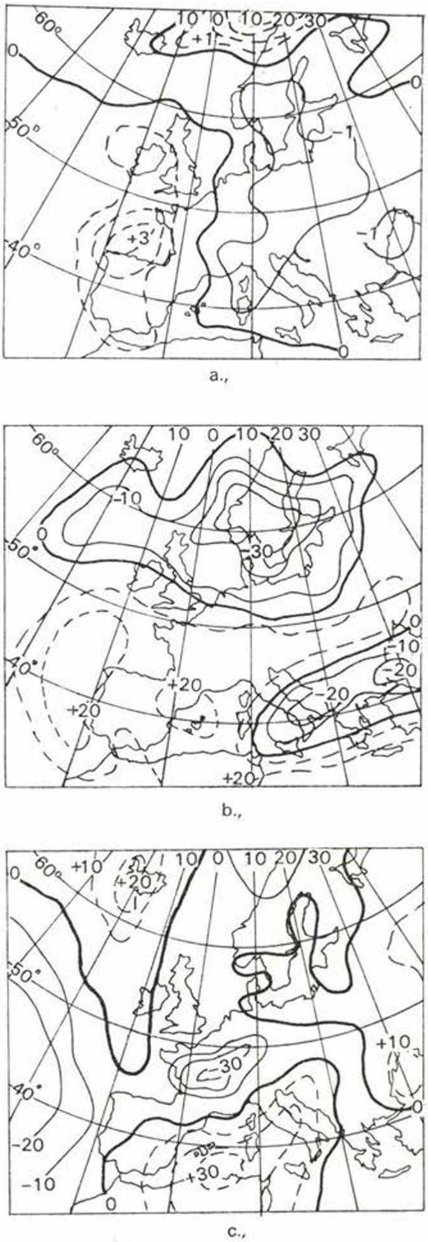


Fig. 4. Areal distribution of the variation of the energies in 10⁹ kwatt, from 19th Oct. 12 GMT and 20th Oct. OOGMT; *a)* potential energy, *b)* internal energy, *c)* latent energy

Fig. 5. Areal distribution of the variation of the energies in 10⁹ kwatt, from 20th, Oct. OOGMT to 20th Oct. 12 GMT.

developing potential energy. Petterssen (1962) made calculations concerning the development of the cyclone of the Atlantic and according to him the contribution of the observable heat of 1 cal cm^{-2} order of magnitude played an accentuated role.

Regarding the development of the Mediterranean cyclone this can be linked first of all with global reasons, it appears in the first phase of its development as a marginal cyclone of a large central one, as a result – according to the maps representing the changes of the individual energies – at first of the contribution of the decrease in potential energy, then setting in motion processes having as a consequence a further development fed first of all on local sources. So, in a later stage the latent energy could be stated as a primary source.

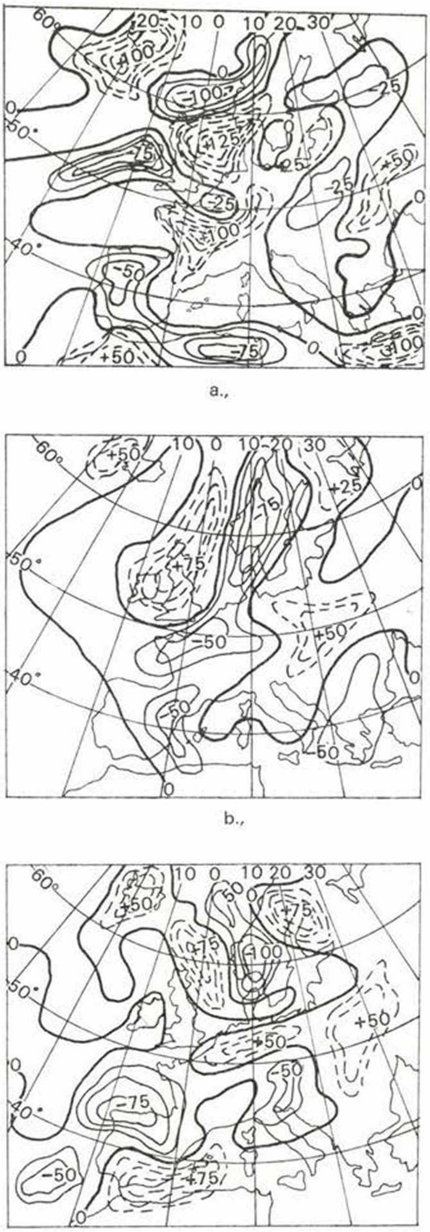
Although the available potential energy might be extremely high at cases, we can not be sure that this transforms partly or completely into kinetic energy. If the flow is purely zonal and the mass, as well as the rotational momentum distribution is in dynamicaly stable equilibrium, then the kinetic energy will not be realized. This appears also immediately, if we consider the figure series 3. We observe extremely high amounts of the available potential energy on the area of the subtropical high pressure belt, while at the same time we encounter in this domain very low values if we follow the distribution of the kinetic energy.

Our foregoing analysis has given answer only to one of the basic problem of the energetics of the atmosphere: how much is the available energy in case of maximum favourable conditions. No answer has been given as yet to the question, which part of this transforms into kinetic energy and this can be given only on the basis of a closer knowledge of the mechanism triggering and determining the process. The answer to this question is made possible only through the use of the whole hydro-thermodynamical equation system, of which we will deal here first of all with the determination of the parameters marking the transformation mechanism as well as with the comparison of the amount of dissipation.

The local change of the kinetic energy can be written in the following form, obtained by a transformation of the horizontal motion equation:

$$\frac{\partial K}{\partial t} = -\frac{1}{g}\int\limits_S \int\limits_{p_2}^{p_1}\left(\nabla kV + \frac{\partial(k\omega)}{\partial p} + V\nabla\varphi - V\nabla F\right) dp\, dS + \frac{1}{g}\int\limits_S \left(k_1\frac{\partial p_1}{\partial t} - k_2\frac{\partial p_2}{\partial t}\right) dS \tag{6}$$

where $\nabla kV + \frac{\partial(k\omega)}{\partial p}$ is the horizontal and vertical advection of the kinetic energy across the boundaries, $V\nabla\varphi$ is the formation of kinetic energy within the volume due to the effect of horizontal pressing forces, and finally $V\nabla F$ is a simple expression of the frictional loss of kinetic energy.



a.,

b.,

c.,

Fig. 6. Conversion of available potential energy into kinetic one in 10^9 kwatt units,
a) 19 thOct., 1970. 12 GMT
b) 20 th Oct., 1970. OOGMT,
c) 20 th Oct. 1970 12 GMT.

The explicit ness of the expression of $V \nabla \varphi$ is very favourable both of physical sense as well as of the point of view of the analysis of the observed meteorological data. The kinetic energy develops from the potential energy on the expenst of the work exerced by the horizontal pressure force to the air mass, when there is a flow component in the negative direction of the geopotential. If we apply the form of the continuity equation in a p – coordinate-system and the basic equation of the statics, the expression $V \nabla \varphi$ can be written in the following form

$$V \nabla \varphi = \nabla V \varphi + \frac{\partial \omega \varphi}{\partial p} + \alpha \omega \tag{7}$$

Substituting into (6) we get for the local variation of the kinetic energy

$$\frac{\partial K}{\partial t} = -\frac{1}{g} \int_S \int_{p_2}^{p_1} \left[\nabla k V + \frac{\partial \omega k}{\partial p} + \alpha \omega + \nabla V \varphi + \frac{\partial \omega \varphi}{\partial p} - V \nabla F \right] dp dS \tag{8}$$

While the redistribution term $\nabla V \varphi + \frac{\partial \omega \varphi}{\partial p}$ presents itself as the indicator of the effective development of the kinetic energy, the term $\alpha\omega$ can be taken as the indicator of the release of the available potential energy. If the term $\alpha\omega$ is written in the form of the areal average and of the deviation of it we get

$$\alpha \omega = \overline{\alpha \omega} + \alpha' \omega' \tag{9}$$

and in this alternative the conversion is in connection with the space correlation of α' and ω'. On the parts, where the air warmer than its sourroundings rises and the cooler air descends, the positive circulation supports the conversion into kinetic energy, while on areas, where the negative (indirect) circulation takes place – this being connected with a destruction of kinetic energy –, the increase of the available potential energy sets in. This is apparent immediately also form the equation describing the local change of the available potential energy, which can be written – after calculations not given here is detail – and differentiating equation 5. – in the following form:

$$\frac{\partial A}{\partial t} = \frac{1}{g} \int_S \int_{p_2}^{p_1} \left[(\dot{Q} + \delta)\left(1 - \frac{p_r^{\varkappa}}{p^{\varkappa}}\right) + \alpha\omega - \nabla \left(1 - \frac{p_r^{\varkappa}}{p^{\varkappa}}\right) V c_p T - \right.$$
$$\left. - \frac{\partial \left(1 - \frac{p_r^{\varkappa}}{p^{\varkappa}}\right) \omega}{\partial p} \right] dp\, dS +$$
$$+ \int_S \left[c_p \left(\frac{p_1^{\varkappa} - p_{r1}^{\varkappa}}{p_1^{\varkappa}} \right) T_1 \frac{\partial p_1}{\partial t} - \left(\frac{p_2^{\varkappa} - p_{2r}^{\varkappa}}{p_2^{\varkappa}} \right) T_2 \frac{\partial p_2}{\partial t} \right] dS \tag{10}$$

where Q is the heat added to or taken out of the unit mass, the individual forms of which can be: evaporation, condensation, various components of radiation, the sensible heat- contribution etc., σ is the friction heating, this being always positive; the term

$$\nabla \left(1 - \frac{p_r^\varkappa}{p^\varkappa}\right) V c_p T + \frac{\partial \omega \left(1 - \frac{p_r^\varkappa}{p^\varkappa}\right)}{\partial p}$$

is the horizontal and vertical advection of the potential and internal energy across the boundaries, while the last term reflects the change of the vertical boundaries; we find also the term $\alpha\ \omega$ marking the transformation with opposite sign, representing here the transformation of the available potential energy into kinetic one.

Since the determination of the $\alpha\omega$ conversion term depends according to (9) strongly on that how can we estimate ω from the operationally smoothed and modified data (obtained by means of adiabatic, quasigeostrophic or kinematic methods) the reliability of the conversion term can be uncertain on areas, where the boundary conditions set by one or another method are not fulfilled

In the course of our investigation we have determined ω in the expression $\alpha\ \omega$ concerning the development of kinetic energy by a kinematic method for the layer between the ground and 100 mb, supposing that this layer incorporates the most part of the influence of processes of synoptic scale, but the value of ω has been certainly underestimated at the places, where the release of latent heat is significant. Also here – as we did earlier – we do not present the whole material owing its largeness, but we show the term $\alpha\ \omega$ only in the dates of the three ascents indicated, (Figs 6. a., b and c.).

The highest values of conversion are found to the left – when looking. with the direction of the flow – from the centres representing the highest values of the kinetic energy. The maximum values of the kinetic energy appear on these areas after the next 12 hours, while in the spots of the previous centers the highest reduction of the kinetic energy, i.e. a negative conversion can be found, and at the same time the available potential energy is significantly increased. When looking back again to the formation period of the Mediterranean cyclone and to the maps showing the variation of potential as well internal energies we find a decreasing march. In reality we have here the strongest withdrawal of air and the highest vertical divergence of the velocity is also formed here in connection with the ascending movement within the cyclone. As a matter of fact, part of the released energy is used up for the expansion work and for the kinetic energy of the vertical movements. In the whole domain, the transformation value computed from data of the six ascents was oscillating – according to the data of Table I. – between $+139 \cdot 10^8$, $+589 \cdot 10^8$ $+106 \cdot 10^8$, $+582 \cdot 10^8$, $-233 \cdot 10^8$, $+102 \cdot 10^8$ kwatt, and this values were strongly influenced by the terms representing the horizontal and vertical advection. While the vertical transport is only of a modificating influence, the horizontal energy transport may be especially singificant at the jet level. This indicates that the local production of the kinetic energy dies not necessarily feed on sources available on the spot.

Regarding the significance of the energy transport across the boundaries we can read in a theoretical study of Van Mieghem (1967). The application of his ideas from the point of view of cyclogenesis has been studied theoretically by Eliassen (1952), while from the diagnostic aspect it was Sechrist who has treated them (1968). The boundary-processes in the variation of the available potential and kinetic energy of an open system play so much an important part, the smaller the domain is, for the conditions of which the processes are treated. To demonstrate this we can apply – among others – also in the case of the Mediterranen cyclone the circomstance that, if we restrict ourselves to the domain marked by Radinovic (1968) in the formation phase of a Mediterranean cyclone, i.e. we write the summed up transformation term for the area between the 0° and East 17.5° meridians, respectively between the latitudes 30° N and 47.5° N, we get the values: $-1{,}06 \cdot 10^{10}$ kwatt at 12^h on the 19 th , $-0.8 \cdot 10^{10}$ kwatt at 00^h and $+3.6 \cdot 10^{10}$ kwatt at 12^h, i.e. in the formation stage of the cyclone the summed up values does not seem to suppert the transformation into kinetic energy. More detailed investigation has shown that the positive values of the transformation into kinetic energy on these days could be found only in the lower third of the troposphere, while in the upper parts we get negative values and this surpassed the lower positive conversion value in the course of summation. Because in the regional domain there was present a very significant amount of released latent heat, by all certainly the computation of the vertical velocity by a kinematical method has led to an underestimation of the real vertical movements, to which the energy transport across the boundary was added as a significant component. In the last column of Table I. we see the dissipation values of a lower, about 1000 m thick layers of the troposphere. According to the data of the six escents the dissipation oscillated between $257 \cdot 10^8$ and $448 \cdot 10^8$ kwatt. If we compare this value with the average kinetic energy (column 18., Table I.) of the lower layer we find that in case the rate of dissipation does not change and if we have no assurance for the replacement of the kinetic energy, this would be taken out of the layer of the tropcsphere indicated above during an average time of 7.8 hours. To similar result came also Boriszenkov, according to the computation of whom the kinetic energy of the lower layer would be dissipated in less than one day, while the total troposphere would give away its complete kinetic energy in 3–4 days. Kung (1966) has carried out computations concerning the connection between the kinetic energy of the lower layer and its dissipation. His results show that in case of a rate of the dissipation as high as 2.21 wattm^{-2} the kinetic energy would be dissipated from the lower layer in an average time of 4.3 hours.

According to Kung (1966) about 31% of the complete dissipation takes place in the lower layer of 1 km thickness. If we take into account this ratio, and using the dissipation value obtained we can get the exhaustion time for the entire domain, which can be estimated – according to Kung – to 2.73 days. The average depletation time computed from the data of the single days amounted to 4 days in our case.

The results discucced above attire the attention – among others – of the scientists to the circumstance that models applied to the forecasting of weather can promise reliable results only in case they will be completed by a suitable model of the energy transformation.

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